MODULE 1

INTRODUCTION TO METROLOGY AND LINEAR MEASUREMENT AND ANGULAR MEASUREMENTS

OBJECTIVES

Students will be able to

1. Understand the basic principles of metrology its advancements & measuring instruments
2. Acquire knowledge on different standards of length, calibration of End Bars, linear and angular measurements,
3. Analyses the various types of measuring instruments and applications, and
4. Know the fundamental of the standards

1. Introduction to Metrology

1.1 Definition of Metrology

Metrology [from Ancient Greek metron (measure) and logos (study of)] is the science of measurement. Metrology includes all theoretical and practical aspects of measurement.

Metrology is concerned with the establishment, reproduction, conservation and transfer of units of measurement & their standards.

For engineering purposes, metrology is restricted to measurements of length and angle & quantities which are expressed in linear or angular terms. Measurement is a process of comparing quantitatively an unknown magnitude with a predefined standard.

1.2 Objectives of Metrology

The basic objectives of metrology are;

1. To provide accuracy at minimum cost.
2. Thorough evaluation of newly developed products, and to ensure that components are within the specified dimensions.
3. To determine the process capabilities.
4. To assess the measuring instrument capabilities and ensure that they are adequate for their specific measurements.
5. To reduce the cost of inspection & rejections and rework.
6. To standardize measuring methods.
7. To maintain the accuracy of measurements through periodical calibration of the instruments.
8. To prepare designs for gauges and special inspection fixtures.

1.3 Need of Inspection

In order to determine the fitness of anything made, man has always used inspection. But industrial inspection is of recent origin and has scientific approach behind it. It came into being because of mass production which involved interchangeability of parts. In old craft, same craftsman used to be producer as well as assembler. Separate inspections were not required. If any component part did not fit properly at the time of assembly, the craftsman would make the necessary adjustments in either of the mating parts so that each assembly functioned properly. So actually speaking, no two parts will be alike/and there was practically no reason why they should be. Now new production techniques have been developed and parts are being manufactured in large scale due to low-cost methods of mass production. So hand-fit methods cannot serve the purpose any more. When large number of components of same part is being produced, then any part would be required to fit properly into any other mating component part. This required specialization of men and machines for the performance of certain operations. It has, therefore, been considered necessary to divorce the worker from all round crafts work and to supplant hand-fit methods with interchangeable manufacture. The modern production techniques require that production of complete article be broken up into various component parts so that the production of each component part becomes an independent process. The various parts to be assembled together in assembly shop come from various shops. Rather some parts are manufactured in other factories also and then assembled at one place. So it is very essential that parts must be so fabricated that the satisfactory mating of any pair chosen at random is possible. In order that this may be possible, the dimensions of the component part must be confined within the prescribed limits which are such as to permit the assembly with a predetermined fit. Thus industrial inspection assumed its importance due to necessity of suitable mating of various components manufactured separately. It may be appreciated that when large quantities of work-pieces are manufactured on the basis of interchangeability, it is not necessary to actually measure the important features and much time could be saved by using gauges which determine whether or not a particular feature is within the prescribed limits. The methods of gauging, therefore, determine the dimensional accuracy of a feature, without reference to its actual size. The purpose of dimensional control is however not to strive for the exact size as it is impossible to produce all the parts of exactly same size due to so many inherent and random sources of errors in machines and men. The principal aim is to control and restrict the variations within the prescribed limits. Since we are interested in producing the parts such that assembly meets the prescribed work standard, we must not aim at accuracy beyond the set limits which, otherwise is likely to lead to wastage of time and uneconomical results. Lastly, inspection led to development of precision inspection instruments which caused the transition from crude machines to better designed and precision machines. It had also led to improvements in metallurgy and raw material manufacturing due to demands of high accuracy and precision. Inspection has also introduced a spirit of competition and led to production of quality products in volume by eliminating tooling bottle-necks and better processing techniques.

Fundamental methods of Measurement

Two basic methods are commonly employed for measurement.

(a) Direct comparison with primary or secondary standard.

(b) Indirect comparison through the use of calibrated system.

Direct comparison

In this method, measurement is made directly by comparing the unknown magnitude with a standard & the result is expressed by a number. The simplest example for this would be, length measurement using a meter scale. Here we compare the bar's length (unknown quantity/ measure and) with a scale (Standard/predefined one). We say that the bar measures so many mms, cms or inches in length.

• Direct comparison methods are quite common for measurement of physical quantities like length, mass, etc.

• It is easy and quick.

Drawbacks of Direct comparison methods

• The main drawback of this method is, the method is not always accurate and reliable.

• Also, human senses are not equipped to make direct comparison of all quantities with equal facility all the times.

• Also measurements by direct methods are not always possible, feasible and practicable.

Example: Measurement of temperature, Measurement of weight.

Indirect comparison

• Most of the measurement systems use indirect method of measurement.

• In this method a chain of devices which is together called as measuring system is employed.

• The chain of devices transform the sensed signal into a more convenient form & indicate this transformed signal either on an indicator or a recorder or fed to a controller.

• i.e. it makes use of a transducing device/element which convert the basic form of input into an analogous form, which it then processes and presents as a known function of input.

• For example, to measure strain in a machine member, a component senses the strain, another component transforms the sensed signal into an electrical quantity which is then processed suitably before being fed to a meter or recorder.

• Further, human senses are not equipped to detect quantities like pressure, force or strain.

• But can feel or sense and cannot predict the exact magnitude of such quantities.

• Hence, we require a system that detects/sense, converts and finally presents the output in the form of a displacement of a pointer over a scale a , a change in resistance or raise in liquid level with respect to a graduated stem.

DIRECT COMPARISON	INDIRECT COMPARISON
1)Unknown quantity is measured comparing directly with primary or secondary standards	1)unknown magnitude is measured by comparing with a standard indirectly through the use of a calibrated system
2)human senses are very much necessary for measurement	2)Consists of a chain of devices which form a measuring system
3)Results obtained from direct comparison are not that dependable	3)this consists of a detector element to detect ,a transducer to transducer and a unit to indicate or record the processed signal
4)Not always accurate	4)Fairly accurate .

1.4 Classification of measuring instruments and system

Measurements are generally made by indirect comparison method through calibration. They usually make use of one or more transducing device. Based upon the complexity of measurement system, three basic categories of measurements have been developed.

They are;

1. Primary measurement
2. Secondary measurement
3. Tertiary measurement

Primary measurement

In primary mode, the sought value of a physical parameter is determined by comparing it directly with reference standards. The requisite information is obtainable through senses of sight and touch.

Example: matching of two lengths when determining the length of an object with a ruler.

Secondary measurement

The indirect measurements involving one translation are called secondary measurements. Example: the conversion of pressure into displacement by bellows.

Tertiary measurement

The indirect measurements involving two conversions are called tertiary measurements. Example: the measurement of the speed of a rotating shaft by means of an electric tachometer.

Accuracy

The accuracy of an instrument indicates the deviation of the reading from a known input. In other words, accuracy is the closeness with which the readings of an instrument approaches the true values of the quantity measured. It is the maximum amount by which the result differs from the true value.

Accuracy is expressed as a percentage based on the actual scale reading / full scale reading.

Percentage accuracy based on reading = [Vr(max or min) –Va]*100/Va

Percentage accuracy (based on full scale reading) = $(Vr(\text{max or min}) - Va) * 100/Vfs$

Va =Actual value

Vr = max or min result value.

Vfs = full scale reading

Example: 100 bar pressure gauge having an accuracy of 1% would be accurate within +/-1 bar over the entire range of gauge.

Precision

The precision of an instrument indicates its ability to reproduce a certain reading with a given accuracy. In other words, it is the degree of agreement between repeated results.

Sl no	Accuracy	Precision
1	It is the closeness with the true value of the quantity being measured	It is a measure of reproducibility of the measurements
2	The accuracy of measurement means conformity to truth	The term precise means clearly or sharply defined
3	Accuracy can be improved	Precision cannot be improved
4	Accuracy depends upon simple techniques of analysis	Precision depends upon many factors and requires many sophisticated techniques of

1.5 Errors in Measurements

Error may be defined as the difference between the measured value and the true value.

Error classification

Classified in different ways

- Systematic error
- Random errors
- Illegitimate errors

Systematic errors

• Generally the will be constant / similar form /recur consistently every time measurement is measured.

• May result from improper condition or procedures employed.

Calibration errors

Calibration procedure-is employed in a number of instruments-act of checking or adjusting the accuracy of a measuring instrument.

Human errors

• The term “human error” is often used very loosely.

• We assume that when we use it, everyone will understand what it means.

• But that understanding may not be same as what the person meant in using the term.

• For this reason, without a universally accepted definition, use of such terms is subject to
misinterpretation.

(1) Systematic or fixed errors:

(a) Calibration errors

(b) Certain types of consistently recurring human errors

(c) Errors of technique

(d) Uncorrected loading errors

(e) Limits of system resolution Systematic errors are repetitive & of fixed value. They have a definite magnitude & direction

(2) Random or Accidental errors:

(a) Errors stemming from environmental variations

(b) Certain types of human errors

(c) Due to Variations in definition

(d) Due to Insufficient sensitivity of measuring system.

Random errors are distinguishable by their lack of consistency. An observer may not be consistent in taking readings. Also the process involved may include certain poorly controlled variables causing changing conditions. The variations in temperature, vibrations of external medium, etc. cause errors in the instrument. Errors of this type are normally of limited duration & are inherent to specific environment.

(3) Illegitimate errors:

(a) Blunders or Mistakes

(b) Computational errors

(c) Chaotic errors

1.6 Definition of Standards

A standard is defined as “something that is set up and established by an authority as rule of the measure of quantity, weight, extent, value or quality”.

For example: a meter is a standard established by an international organization for measurement of length. Industry, commerce, international trade in modern civilization would be impossible without a good system of standards.

Role of Standards

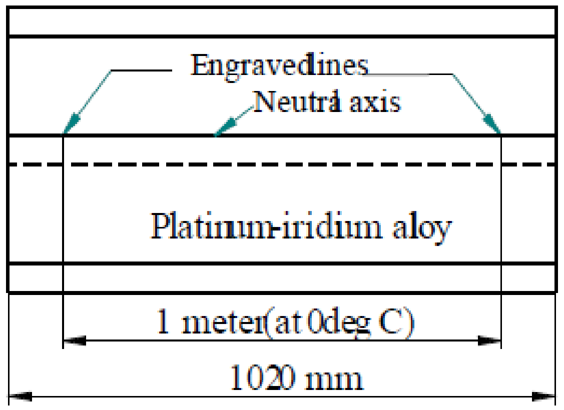
The role of standards is to achieve uniform, consistent and repeatable measurements throughout the world. Today our entire industrial economy is based on the interchangeability of parts the method of manufacture. To achieve this, a measuring system adequate to define the features to the accuracy required & the standards of sufficient accuracy to support the measuring system are necessary.

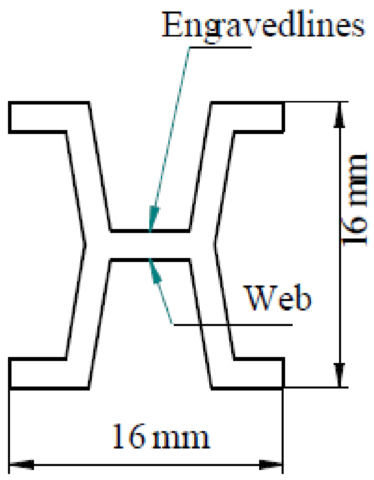
STANDARDS OF LENGTH

In practice, the accurate measurement must be made by comparison with a standard of known dimension and such a standard is called “Primary Standard”. The first accurate standard was made in England and was known as “Imperial Standard yard” which was followed by International Prototype meter” made in France. Since these two standards of length were made of metal alloys they are called ‘material length standards’.

International Prototype meter

It is defined as the straight line distance, at 0°C, between the engraved lines of pure platinum-iridium alloy (90% platinum & 10% iridium) of 1020 mm total length and having a ‘tresca’ cross section as shown in fig. The graduations are on the upper surface of the web which coincides with the neutral axis of the section.





The tresca cross section gives greater rigidity for the amount of material involved and is therefore economic in the use of an expensive metal. The platinum-iridium alloy is used because it is non oxidizable and retains good polished surface required for engraving good quality lines.

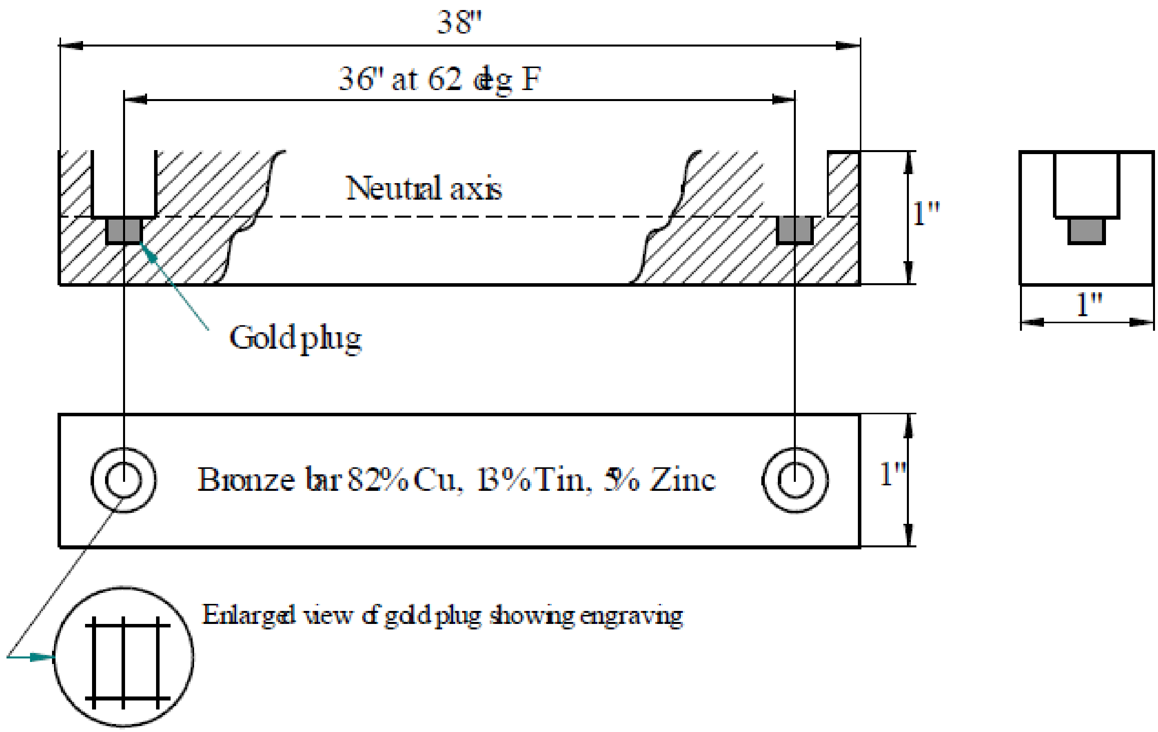
Imperial Standard yard

An imperial standard yard, shown in fig, is a bronze (82% Cu, 13% tin, 5% Zinc) bar of 1 inch square section and 38 inches long. A round recess, 1 inch away from the two ends is cut at both ends upto the central or ‘neutral plane’ of the bar.

Further, a small round recess of (1/10) inch in diameter is made below the center. Two gold plugs of (1/10) inch diameter having engravings are inserted into these holes so that the lines (engravings) are in neutral plane.

Yard is defined as the distance between the two central transverse lines of the gold plug
at 620F.

The purpose of keeping the gold plugs in line with the neutral axis is to ensure that the neutral axis remains unaffected due to bending, and to protect the gold plugs from accidental damage.



Bronze Yard was the official standard of length for the United States between 1855 and 1892, when the US went to metric standards. 1 yard = 0.9144 meter. The yard is used as the standard unit of field-length measurement in American, Canadian and Association football, cricket pitch dimensions, swimming pools, and in some countries, golf fairway measurements.

Disadvantages of Material length standards

1. Material length standards vary in length over the years owing to molecular changes in the alloy.

2. The exact replicas of material length standards were not available for use somewhere else.

3. If these standards are accidentally damaged or destroyed then exact copies could not be made.

4. Conversion factors have to be used for changing over to metric system.

Light (Optical) wave Length Standard

Because of the problems of variation in length of material length standards, the possibility of using light as a basic unit to define primary standard has been considered. The wavelength of a selected radiation of light and is used as the basic unit of length. Since the wavelength is not a physical one, it need not be preserved & can be easily reproducible without considerable error.

A krypton-filled discharge tube in the shape of the element's atomic symbol. A colorless, odorless, tasteless noble gas, krypton occurs in trace amounts in the atmosphere, is isolated by fractionally distilling liquefied air. The high power and relative ease of operation of krypton discharge tubes caused (from 1960 to 1983) the official meter to be defined in terms of one orange-red spectral line of krypton-86.

Advantages of using wave length standards

1. Length does not change.
2. It can be easily reproduced easily if destroyed.
3. This primary unit is easily accessible to any physical laboratories.
4. It can be used for making measurements with much higher accuracy than material standards.
5. Wavelength standard can be reproduced consistently at any time and at any place.

1.7 Subdivision of standards

The imperial standard yard and the international prototype meter are master standards & cannot be used for ordinary purposes. Thus based upon the accuracy required, the standards are subdivided into four grades namely;

1. Primary Standards
2. Secondary standards
3. Teritiary standards
4. Working standards

Primary standards

They are material standard preserved under most careful conditions. These are not used for directly for measurements but are used once in 10 or 20 years for calibrating secondary standards. **Ex:** International Prototype meter, Imperial Standard yard.

Secondary standards

These are close copies of primary standards w.r.t design, material & length. Any error existing in these standards is recorded by comparison with primary standards after long intervals. They are kept at a number of places under great supervision and serve as reference for tertiary standards. This also acts as safeguard against the loss or destruction of primary standards.

Teritiary standards

The primary or secondary standards exist as the ultimate controls for reference at rare intervals. Tertiary standards are the reference standards employed by National Physical laboratory (N.P.L) and are the first standards to be used for reference in laboratories & workshops. They are made as close copies of secondary standards & are kept as reference for comparison with working standards.

Working standards

These standards are similar in design to primary, secondary & tertiary standards. But being less in cost and are made of low grade materials, they are used for general applications in metrology laboratories.

Sometimes, standards are also classified as;

• Reference standards (used as reference purposes)

• Calibration standards (used for calibration of inspection & working standards)

• Inspection standards (used by inspectors)

• Working standards (used by operators)

1.8 LINE STANDARDS

When the length being measured is expressed as the distance between two lines, then it is called "Line Standard".

Examples: Measuring scales, Imperial standard yard, International prototype meter, etc.

Characteristics of Line Standards

1. Scales can be accurately engraved but it is difficult to take the full advantage of this accuracy. ***Ex:*** A steel rule can be read to about ± 0.2 mm of true dimension.
2. A scale is quick and easy to use over a wide range of measurements.
3. The wear on the leading ends results in ***'under sizing'***
4. A scale does not possess a 'built in' datum which would allow easy scale alignment with the axis of measurement, this again results in 'under sizing'.

5. Scales are subjected to parallax effect, which is a source of both positive & negative reading errors

6. Scales are not convenient for close tolerance length measurements except in conjunction with microscopes.

END STANDARDS

When the length being measured is expressed as the distance between two parallel faces, then it is called ***'End standard'.*** End standards can be made to a very high degree of accuracy.

Ex: Slip gauges, Gap gauges, Ends of micrometer anvils, etc.

Characteristics of End Standards

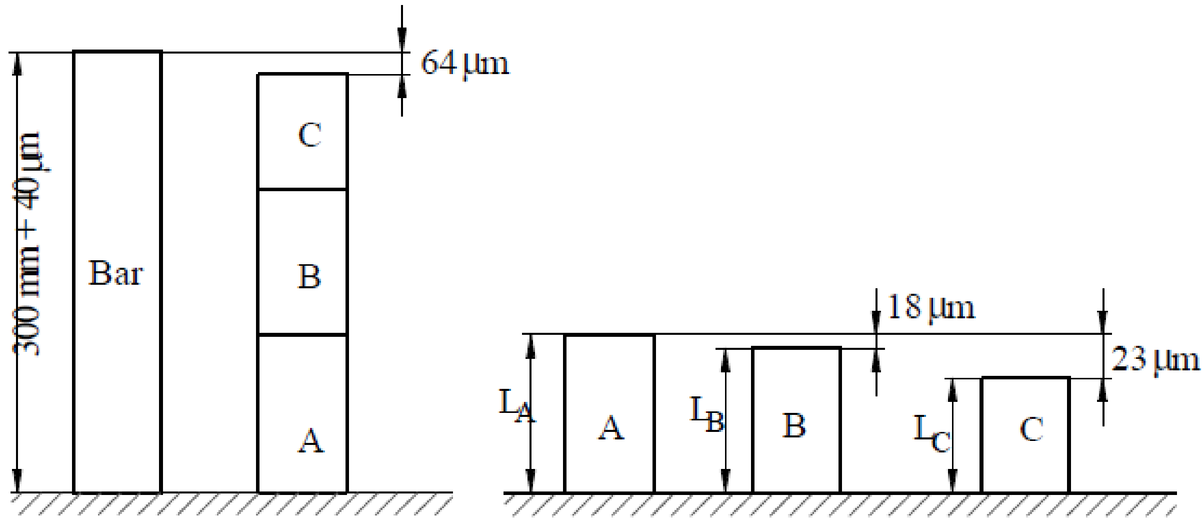
1. End standards are highly accurate and are well suited for measurements of close tolerances as small as 0.0005 mm.
2. They are time consuming in use and prove only one dimension at a time.
3. End standards are subjected to wear on their measuring faces.
4. End standards have a 'built in' datum, because their measuring faces are flat & parallel and can be positively located on a datum surface.
5. They are not subjected to the parallax effect since their use depends on ***"feel".***
6. Groups of blocks may be ***"wrung"*** together to build up any length. But faulty wringing leads to damage.
7. The accuracy of both end & line standards are affected by temperature change.

1.9 CALIBRATION OF END BARS

The actual lengths of end bars can be found by wringing them together and comparing them with a calibrated standard using a level comparator and also individually comparing among themselves. This helps to set up a system of linear equations which can be solved to find the actual lengths of individual bars. The procedure is clearly explained in the forthcoming numerical problems.

Numerical problem-1

Three 100 mm end bars are measured on a level comparator by first wringing them together and comparing with a calibrated 300 mm bar which has a known error of +40mm. The three end bars together measure 64 m m less than the 300 mm bar. Bar A is 18 mm longer than bar B and 23mm longer than bar C. Find the actual length of each bar.



Numerical problem-2

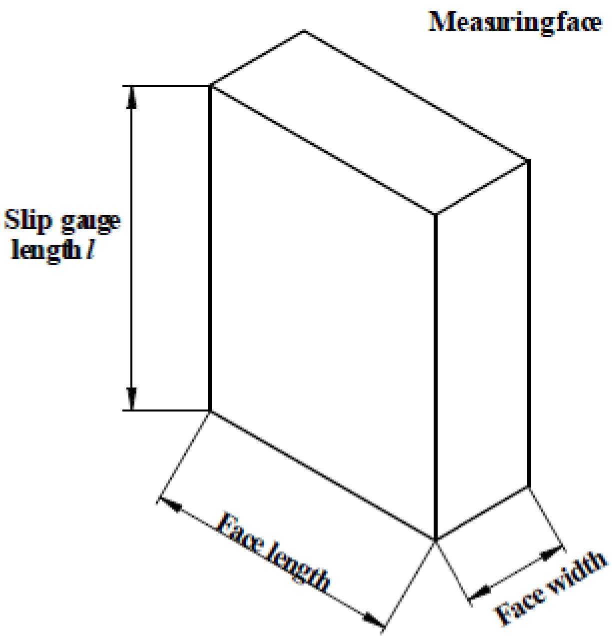
Four end bars of basic length 100 mm are to be calibrated using a standard bar of 400 mm whose actual length is 399.9992 mm. It was also found that lengths of bars B,C & D in comparison with A are +0.0002 mm, +0.0004 mm and -0.0001 mm respectively and the length of all the four bars put together in comparison with the standard bar is +0.0003mm longer. Determine the actual lengths of each end bars.

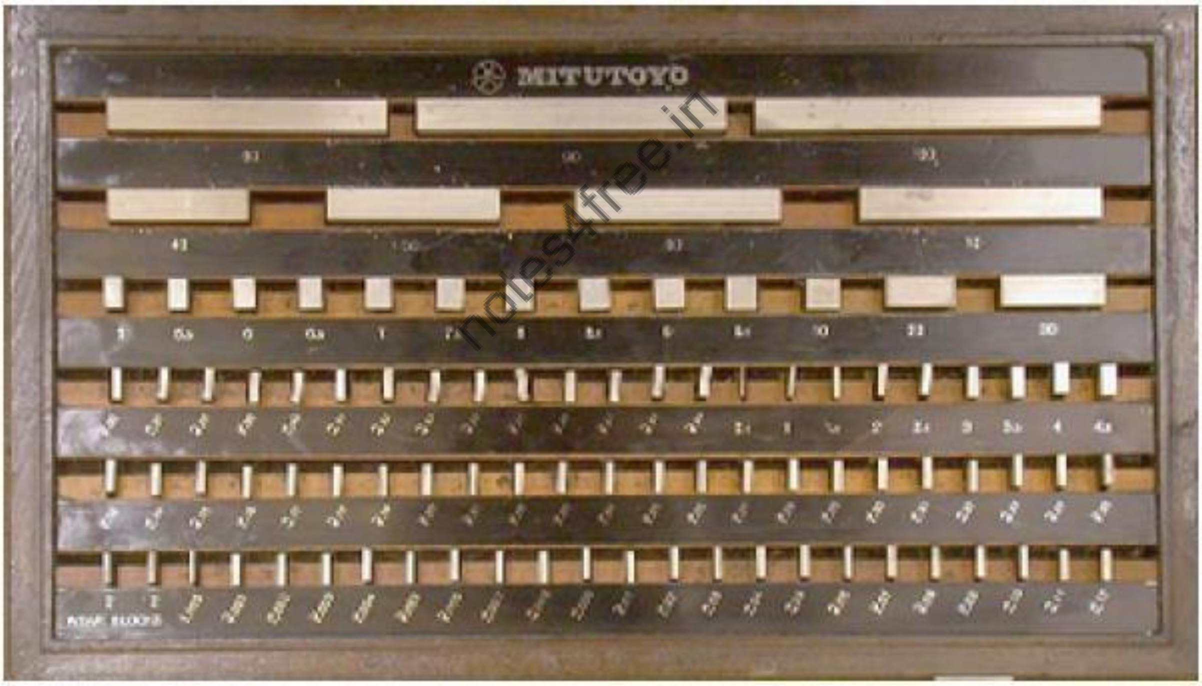
LINEAR MEASUREMENT AND ANGULAR MEASUREMENTS

LINEAR MEASUREMENT

SLIP GAUGES OR GAUGE BLOCKS (JOHANSSON GAUGES)

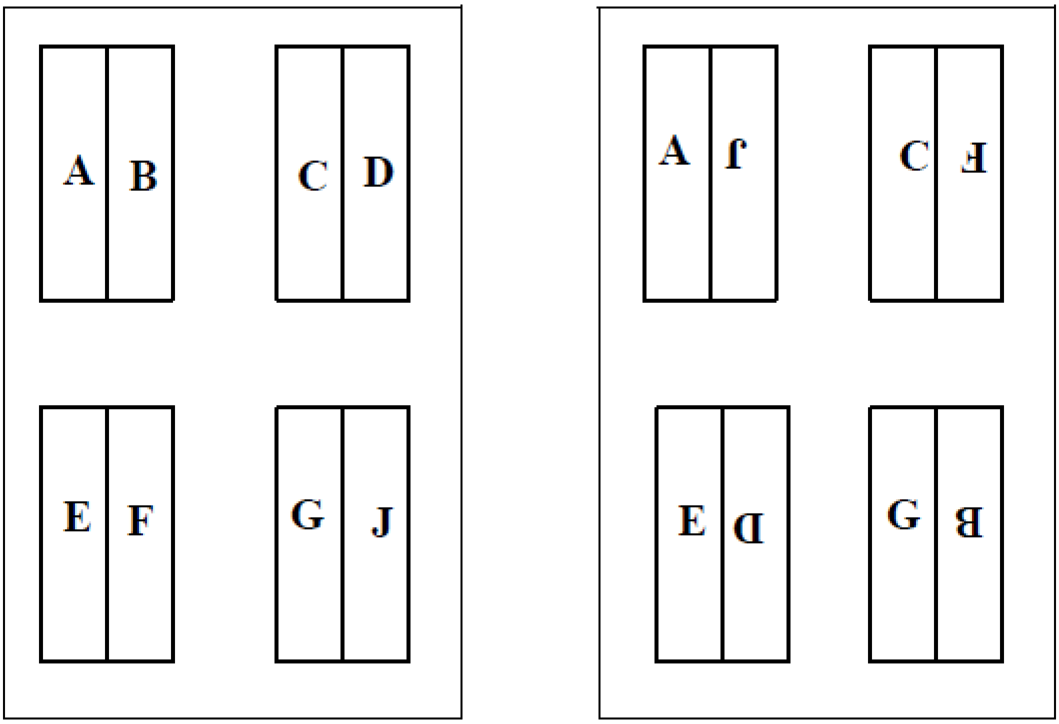
Slip gauges are rectangular blocks of steel having cross section of 30 mm face length & 10 mm face width as shown in fig.





Slip gauges are blocks of steel that have been hardened and stabilized by heat treatment. They are ground and lapped to size to very high standards of accuracy and surface finish. A gauge block (also known Johansson gauge, slip gauge, or Jo block) is a precision length measuring standard consisting of a ground and lapped metal or ceramic block. Slip gauges were invented in 1896 by Swedish machinist Carl Edward Johansson.

Manufacture of Slip Gauges



When correctly cleaned and wrung together, the individual slip gauges adhere to each other by molecular attraction and, if left like this for too long, a partial cold weld will take place. If this is allowed to occur, the gauging surface will be irreparable after use, hence the gauges should be separated carefully by sliding them apart. They should then be cleaned, smeared with petroleum jelly (Vaseline) and returned to their case.

Protector Slips

In addition, some sets also contain protector slips that are 2.50mm thick and are made from a hard, wear resistant material such as tungsten carbide. These are added to the ends of the slip gauge stack to protect the other gauge blocks from wear. Allowance must be made of the thickness of the protector slips when they are used.

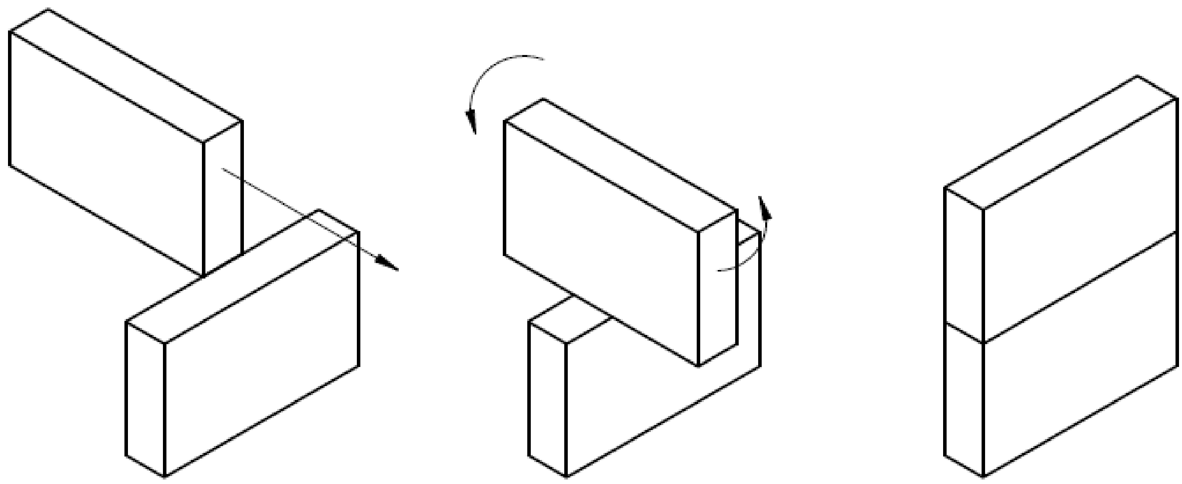
Wringing of Slip Gauges

Slip gauges are wrung together to give a stack of the required dimension. In order to achieve the maximum accuracy the following precautions must be taken

• Use the minimum number of blocks.

• Wipe the measuring faces clean using soft clean chamois leather.

• Wring the individual blocks together by first pressing at right angles, sliding & then twisting.



Wringing of Slip Gauges

INDIAN STANDARD ON SLIP GAUGES (IS 2984-1966)

Slip gauges are graded according to their accuracy as Grade 0, Grade I & Grade II. Grade II is intended for use in workshops during actual production of components, tools & gauges.

Grade I is of higher accuracy for use in inspection departments.

Grade 0 is used in laboratories and standard rooms for periodic calibration of Grade I & Grade II gauges.

M-87 set of slip gauges

Range (mm)	Steps (mm)	No. of pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
1.0005	---	1
	Total	87

M-112 set of slip gauges

Range (mm)	Steps (mm)	No. of pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 24.5	0.5	49
25,50,75,100	25	4
1.0005	---	1
	Total	112

Important notes on building of Slip Gauges

- Always start with the last decimal place.
- Then take the subsequent decimal places.
- Minimum number of slip gauges should be used by selecting the largest possible block in each step.
- If in case protector slips are used, first deduct their thickness from the required dimension then proceed as per above order.

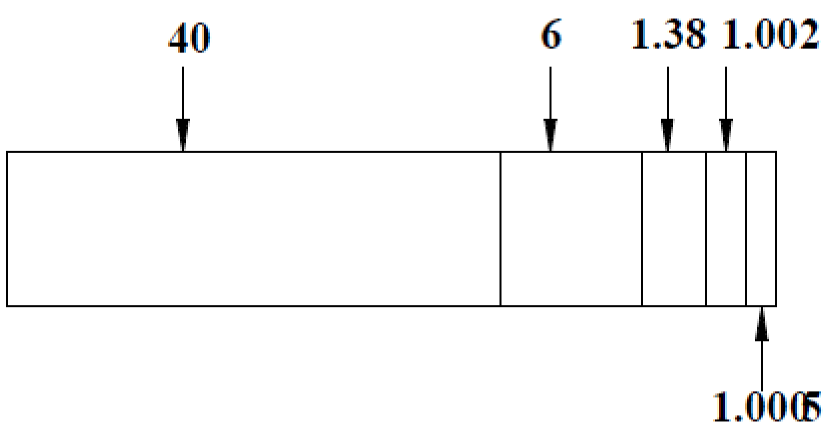
Numerical problem-1

Build the following dimensions using M-87 set. (i) 49.3825 mm (ii) 87.3215 mm

Solution

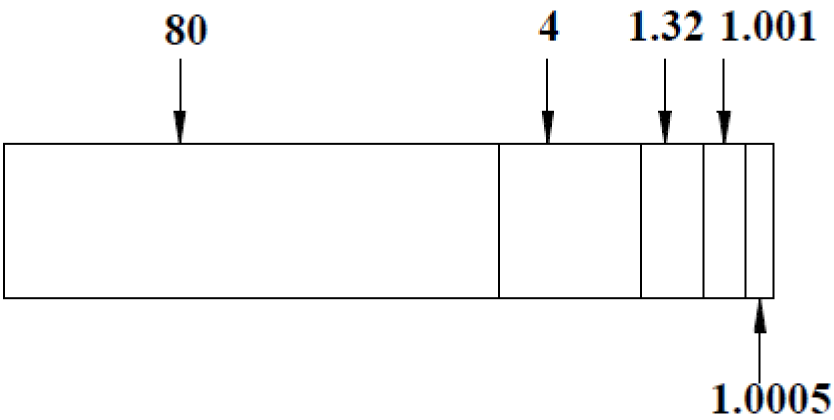
(i) To build 49.3825 mm

Combination of slips; 40+6+1.38+1.002+1.0005 = 49.3825 mm



(ii) To build 87.3215 mm

Combination of slips; 80+4+1.32+1.001+1.0005 = 87.3215 mm

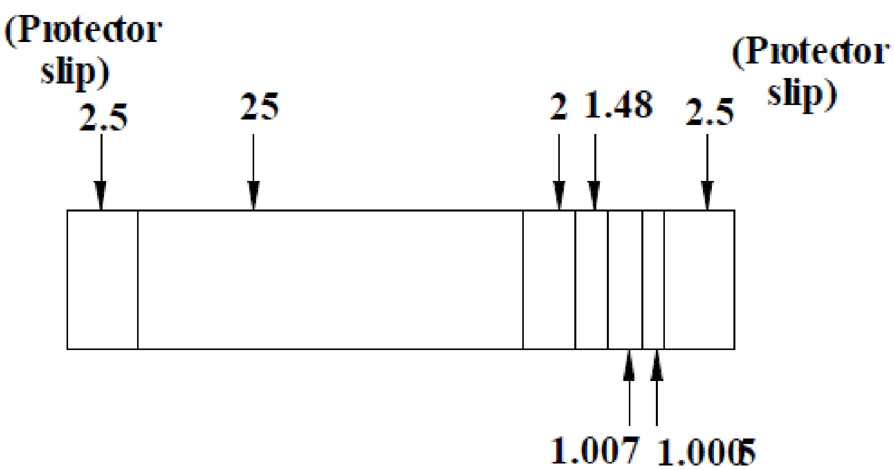


Numerical problem-2

Build up a length of 35.4875 mm using M112 set. Use two protector slips of 2.5 mm each.

Solution:

Combination of slips; 2.5+25+2+1.48+1.007+1.0005+2.5 = 35.4875 mm



1.10 Angular Measurements

Introduction

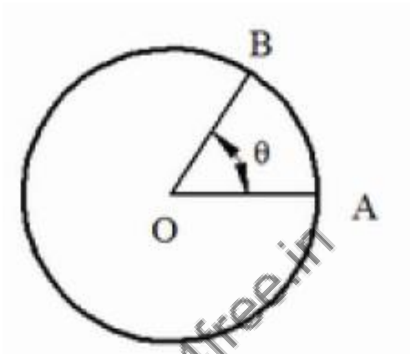
Definition of Angle

• Angle is defined as the opening between two lines which meet at a point.

• If a circle is divided into 360 parts, then each part is called a degree (o).

• Each degree is subdivided into 60 parts called minutes ('), and each minute is further subdivided into 60 parts called seconds (").

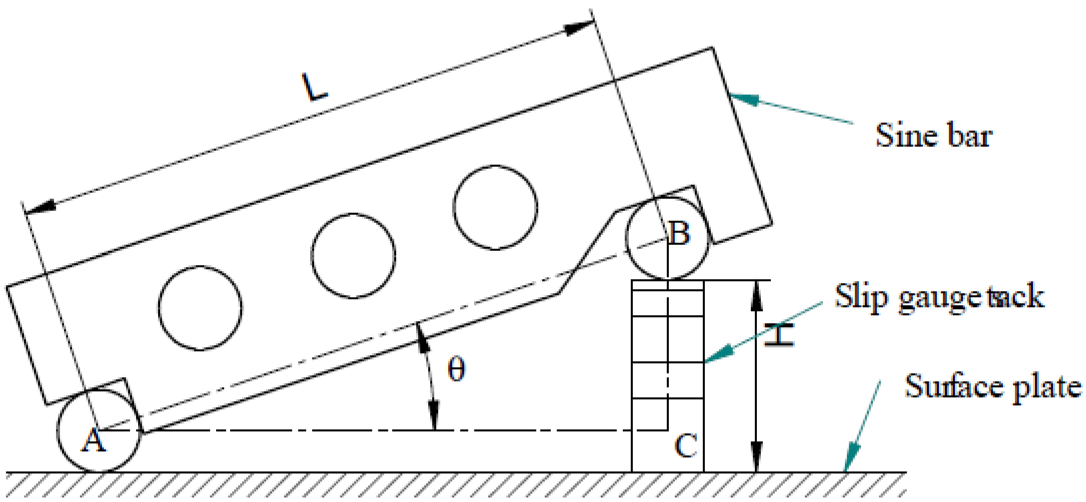
The unit 'Radian' is defined as the angle subtended by an arc of a circle of length equal to
radius. If arc AB = radius OA, then the angle q = 1 radian.



Sine bar

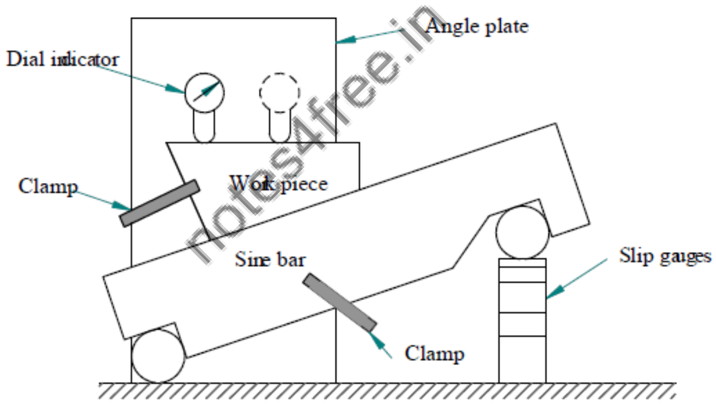
Sine bars are made from high carbon, high chromium, corrosion resistant steel which can be hardened, ground & stabilized. Two cylinders of equal diameters are attached at the ends as shown in fig. The distance between the axes can be 100, 200 & 300 mm. The Sine bar is designated basically for the precise setting out of angles and is generally used in conjunction with slip gauges & surface plate. The principle of operation relies upon the application of Trigonometry.

In the below fig, the standard length AB (L) can be used & by varying the slip gauge stack (H), any desired angle q can be obtained as, q=sin-1(H/L).

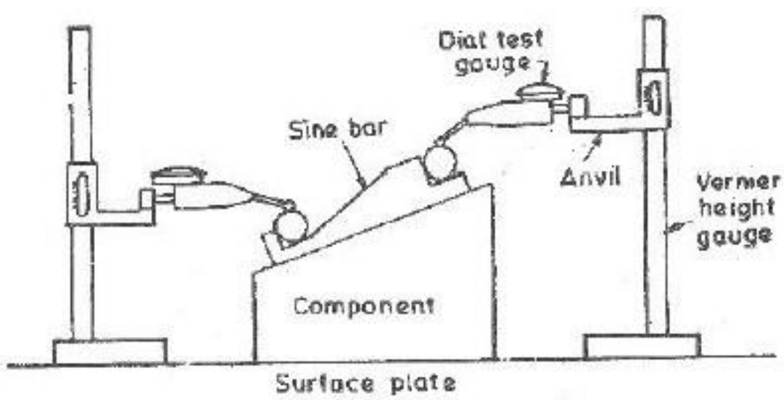


(1) For checking unknown angles of a component

A dial indicator is moved along the surface of work and any deviation is noted. The slip gauges are then adjusted such that the dial reads zero as it moves from one end to the other.



(2) Checking of unknown angles of heavy component



In such cases where components are heavy and can't be mounted on the sine bar, then sine bar is mounted on the component as shown in Fig. The height over the rollers can then be measured by a vernier height gauge ; using a dial test gauge mounted on the anvil of height gauge as the fiducial indicator to ensure constant measuring pressure. The anvil on height gauge is adjusted with probe of dial test gauge showing same reading for the topmost position of rollers of sine bar. Fig. 8.18 shows the use of height gauge for obtaining two readings for either of the roller of sine bar. The difference of the two readings of height gauge divided by the centre distance of sine bar gives the sine of the angle of the component to be measured. Where greater accuracy is required, the position of dial test gauge probe can be sensed by adjusting a pile of slip gauges till dial indicator indicates same- reading over roller of sine bar and the slip gauges.

Advantages of sine bar

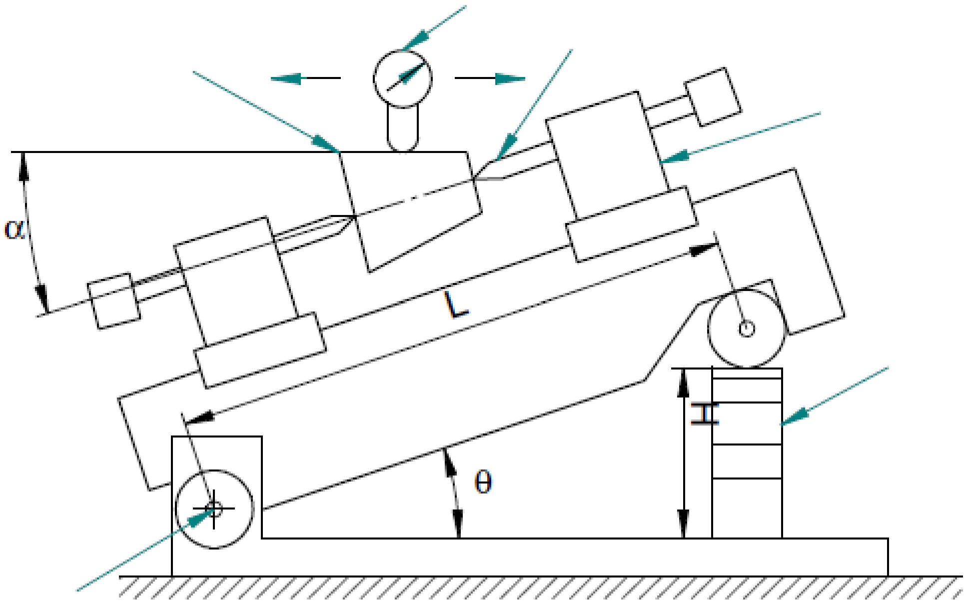
1. It is used for accurate and precise angular measurement.
2. It is available easily.
3. It is cheap.

Disadvantages

1. The application is limited for a fixed center distance between two plugs or rollers.
2. It is difficult to handle and position the slip gauges.
3. If the angle exceeds 45°, sine bars are impracticable and inaccurate.
4. Large angular error may results due to slight error in sine bar.

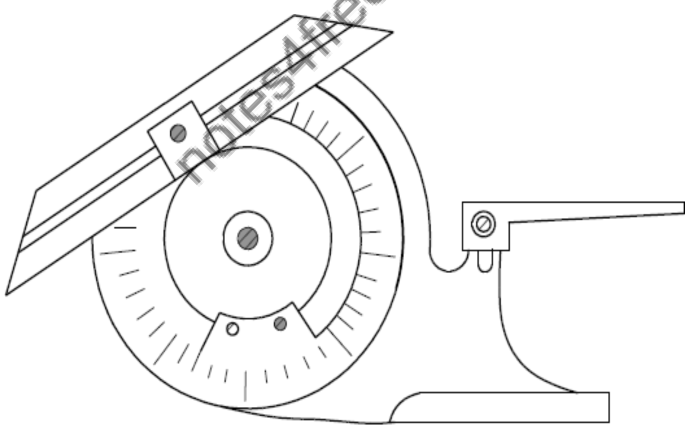
Sine Centers

It is the extension of sine bars where two ends are provided on which centers can be clamped, as shown in Figure. These are useful for testing of conical work centered at each end, up to 60°. The centers ensure correct alignment of the work piece. The procedure of setting is the same as for sine bar. The dial indicator is moved on to the job till the reading is same at the extreme position. The necessary arrangement is made in the slip gauge height and the angle is calculated as $\theta = \text{Sin-1} (h/L)$.



Vernier Bevel Protractor (Universal Bevel Protractor)

It is a simplest instrument for measuring the angle between two faces of a component. It consists of a base plate attached to a main body and an adjustable blade which is attached to a circular plate containing vernier scale.



The adjustable blade is capable of sliding freely along the groove provided on it and can be clamped at any convenient length. The adjustable blade along with the circular plate containing the vernier can rotate freely about the center of the main scale engraved on the body of the instrument and can be locked in any position with the help of a clamping knob.

The adjustable blade along with the circular plate containing the vernier can rotate freely about the center of the main scale engraved on the body of the instrument and can be locked in any position with the help of a clamping knob.

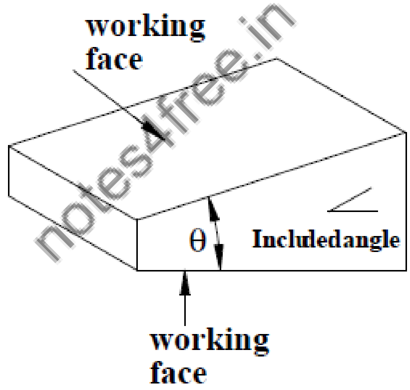
The main scale is graduated in degrees. The vernier scale has 12 divisions on either side of the center zero. They are marked 0-60 minutes of arc, so that each division is $1/12^{th}$ of

60 minutes, i.e. 5 minutes. These 12 divisions occupy same arc space as 23 degrees on the main scale, such that each division of the vernier = (1/12)*23 = 1(11/12) degrees.

Angle Gauges

These were developed by Dr. Tomlinson in 1939. The angle gauges are hardened steel blocks of 75 mm length and 16 mm wide which has lapped surfaces lying at a very precise angle.

In this method, the auto collimator used in conjunction with the angle gauges. It compares the angle to be measured of the given component with the angle gauges. Angles gauges are wedge shaped block and can be used as standard for angle measurement. They reduce the set uptime and minimize the error. These are 13 pieces, divided into three types such as degrees, minutes and seconds. The first series angle are 1°, 3°, 9°, 27° and 41 ° and the second series angle are 1', 3', 9' and27' And the third series angle are 3", 6", 18" and 30". These gauges can be used for large number of combinations by adding or subtracting these gauges, from each other.



The engraved symbol '<' indicates the direction of the included angle. Angle gauges are available in a 13 piece set.

Nominal angles of combination angle gauges

Degrees	1	3	9	27	41
Minutes	1	3	9	27	-
Fraction of minute	0.05	0.1	0.3	0.5	-
(or seconds)	3	6	18	30	-

These gauges together with a square block enable any angle between 0°& 360° to be built within an accuracy of 1.5 seconds of the nominal value. The wringing is similar to that of slip gauges.

1.11 Numericals on building of angles

The required angle may built by wringing suitable combination of angle gauges similar to that of slip gauges. Each angle is a wedge and thus two gauges with narrow ends together provide an angle which is equal to the sum of angles of individual gauges. Two gauges when wrung together with opposing narrow ends give subtraction of the two angles.

Numerical 1:

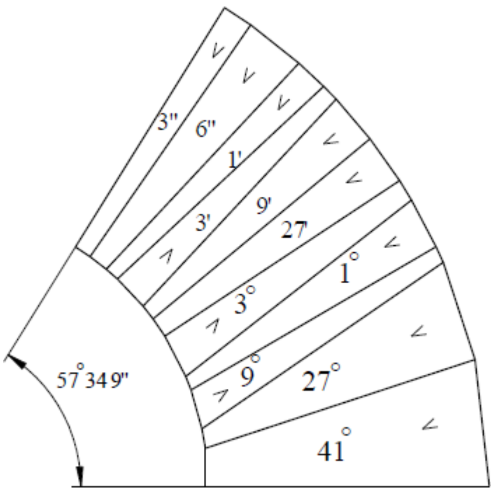
Build an angle of 57°34' 9"

Solution:

Degree = 41° +27° -9°+1°-3°=57°

Minutes = 27'+9'-3'+1' = 34'

Seconds = 6"+ 3" =9"



Numerical 2:

Give the combination of angle gauges required to build 102°8' 42"

Solution:

Degree: 90°+9° +3° =102°

Minutes: 9’-1’ = 8’

Seconds 30”+ 18”- 6” =42”

Clinometer

A clinometer is a special case of the application of spirit level. In clinometer, the spirit level is mounted on a rotary member carried in housing. One face of the housing forms the base of the instrument. On the housing, there is a circular scale. The angle of inclination of the rotary member carrying the level relative to its base can be measured by this circular scale. The clinometer mainly used to determine the included angle of two adjacent faces of workpiece. Thus for this purpose, the instrument base is placed on one face and the rotary body adjusted till zero reading of the bubble is obtained. The angle of rotation is then noted on the circular scale against the index. A second reading is then taken in the similar manner on the second face of workpiece. The included angle between the faces is then the difference between the two readings.

Clinometers are also used for checking angular faces, and relief angles on large cutting tools and milling cutter inserts.

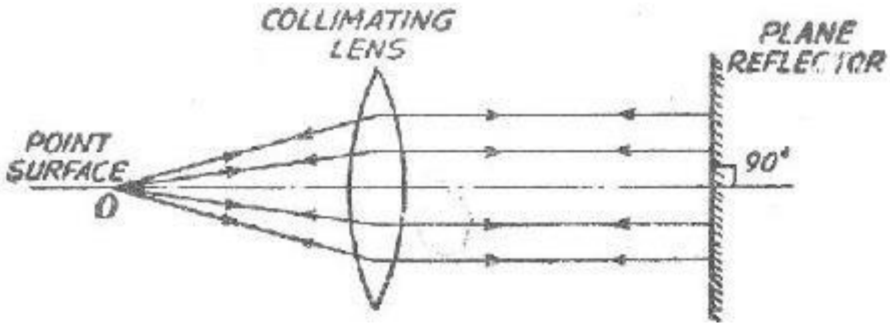
These can also be used for setting inclinable table on jig boring; machines and angular work on grinding machines etc.

The most commonly used clinometer is of the Hilger and Watts type. The circular glass scale is totally enclosed and is divided from 0° to 360° at 10′ intervals. Sub-division of 10′ is possible by the use of an optical micrometer. A coarse scale figured every 10 degrees is provided outside the body for coarse work and approximate angular reading. In some instruments worm and quadrant arrangement is provided so that reading upto 1′ is possible.

In some clinometers, there is no bubble but a graduated circle is supported on accurate ball bearings and it is so designed that when released, it always takes up the position relative to the true vertical. The reading is taken against the circle to an accuracy of 1 second with the aid of vernier.

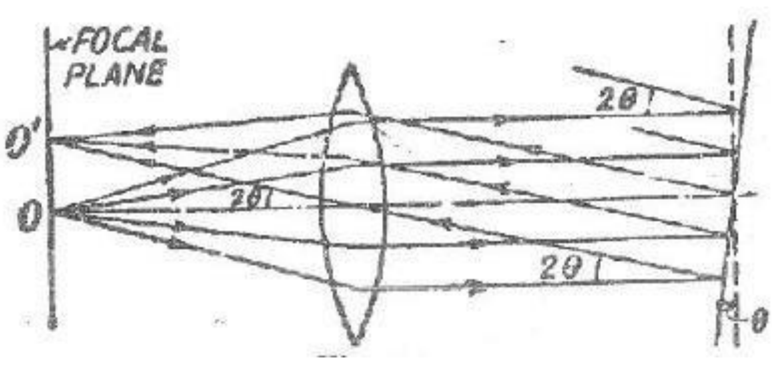
1.12 Autocollimators

This is an optical instrument used for the measurement of small angular differences. For small angular measurements, autocollimator provides a very sensitive and accurate approach. Auto-collimator is essentially an infinity telescope and a collimator combined into one instrument. The principle on which this instrument works is given below. O is a point source of light placed at the principal focus of a collimating lens in Fig. 8.30. The rays of light from O incident on the lens will now travel as a parallel beam of light. If this beam now strikes a plane reflector which is normal to the optical axis, it will be reflected back along its own path and refocused at the same point O. If the plane reflector be now tilted through a small angle 0, [Refer Fig] then parallel beam will be deflected through twice this angle and will be brought to focus at O' in the same plane at a distance x from O. Obviously OO'=x=2θ.f, where *f* is the focal length of the lens.



There are certain important points to appreciate here:

The position of the final image does not depend upon the distance of reflector from the lens, i.e. separation x is independent of the position of reflector from the lens. But if reflector is moved too much back then reflected rays will completely miss the lens and no image will be formed. Thus for full range of readings of instrument to be used, the maximum remoteness of the reflector is limited.



For high sensitivity, i.e., for large value of x for a small angular deviation θ, a long focal length is required.

Principle of the Autocollimator

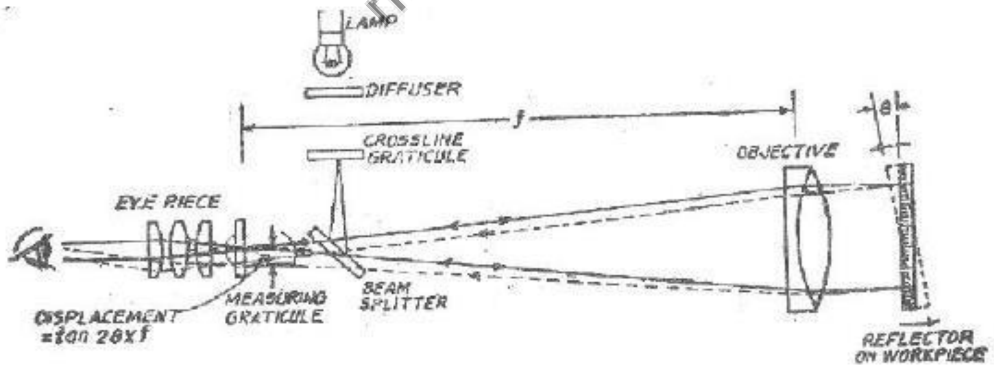
A crossline "target" graticule is positioned at the focal plane of a telescope objective system with the intersection of the crossline on the optical axis, i.e. at the principal focus.

When the target graticule is illuminated, rays of light diverging from the intersection point reach the objective via a beam splitter and are projected-from the objective as parallel pencils of light. In this mode, the optical system is operating as a “collimator”

A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel pencils of light back along their original paths. They are then brought to focus in the plane of the target graticule and exactor coincident with its intersection. A proportion of the returned light passes straight through the beam splitter and the return image of the target crossline is therefore visible through the eyepiece. In this mode, the optical system is operating as a telescope focused at infinity.

If the reflector is tilted through a small angle the reflected pencils of light will be deflected by twice the angle of tilt (principle of reflection) and will be brought to focus in the plane of the target graticule but linearly displaced from the actual target crosslines by an amount $2\theta * f$.

Linear displacement of the graticule image in the plane of the eyepiece is therefore directly proportional to reflector tilt and can be measured by an eyepiece graticule, optical micrometer no electronic detector system, scaled directly in angular units. The autocollimator is set permanently at infinity focus and no device for focusing adjustment for distance is provided or desirable. It responds only to reflector tilt (not lateral displacement of the reflector).



This is independent of separation between the reflector and the autocollimator, assuming no atmospheric disturbance and the use of a perfectly flat reflector. Many factors govern the specification of an autocollimator, in particular its focal length and its effective aperture. The focal length determines basic sensitivity and angular measuring range. The longer the focal length the larger is the linear displacement for a given reflector tilt, but the maximum reflector tilt which can be accommodated is consequently reduced. Sensitivity is therefore traded against measuring range. The maximum separation between reflector and autocollimator, or “working distance”, is governed by the effective aperture of the objective and the angular measuring range of the instrument becomes reduced at long working distances. Increasing the maximum working distance by increasing the effective aperture then demands a larger reflector for satisfactory image contrast. Autocollimator design thus involves many conflicting criteria and for this reason a range of instruments is required to optimally cover every application.

Air currents in the optical path between the autocollimator and the target mirror cause fluctuations in the readings obtained. This effect is more pronounced as distance from autocollimator to target mirror increases. Further errors may also occur due to errors in flatness and reflectivity of the target mirror which should be of high quality.

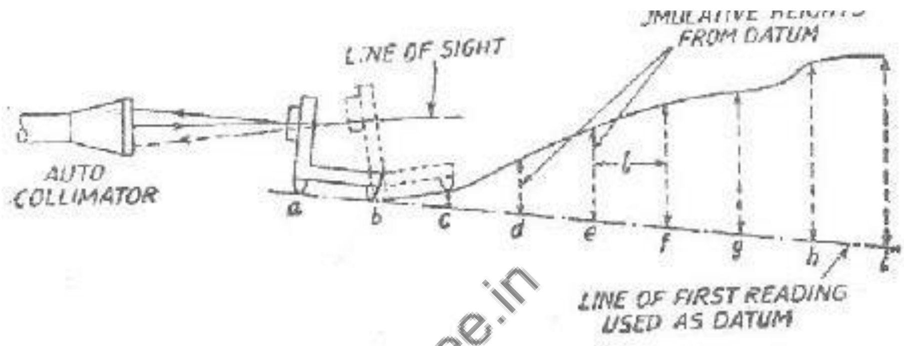
When both the autocollimator and the target mirror gauge can remain fixed, extremely close readings may be taken and repeatability is excellent. When any of these has to be moved, great care is required.

Tests for straightness

It can be carried out by using spirit level or auto-collimator. The straightness of any surface could be determined by either of these instruments by measuring the relative angular positions of number of adjacent sections of the surface to be tested. So first a straight line is drawn on the surface whose straightness is to be tested. Then it is divided into a number of sections, the length of each section being equal to the length of spirit level base or the plane reflector’s base in case of auto-collimator. Generally the bases of the spirit level block or reflector are fitted with two feet so that only feet have line contact with the surface and whole of the surface of base does not touch the surface to be tested. This ensures that angular deviation obtained is between the specified two points. In this case length of each section must be equal to distance between the centre lines of two feet. The spirit level can be used only for the measurement of straightness of horizontal surfaces while auto-collimator method can be used on surfaces in any plane. In case of spirit level, the block is moved along the line on the surface to be tested in steps equal to the pitch distance between the centre lines of the feet and the angular variations of the direction of block are measured by the sensitive level on it. Angular variation can be correlated in terms of the difference of height between two points by knowing the least count of level and length of the base.

In case of measurement by auto-collimator, the instrument is placed at a distance of 0.5 to 0.75 metre from the surface to be tested on any rigid support which is independent of the surface to be tested. The parallel beam from the instrument is projected along the length of the surface to be tested. A block fixed on two feet and fitted with a plane vertical reflector is placed on the surface and the reflector face is facing the instrument. The reflector and the instrument are set such that the image of the cross wires of the collimator appears nearer the centre of the field and for the complete movement of reflect or along the surface straight line, the image of cross-wires will appear in the field of eyepiece. The reflector is then moved to the other end of the surface in steps equal to the centre distance between the feet and the tilt of the reflector is noted down in seconds from the eyepiece.

Therefore, 1 sec. of arc will correspond to a rise or fall of 0.000006* l mm, where I is the distance between centers of feet in mm. The condition for initial and subsequent readings is shown in Fig. 7.2 in which the rise and fall of the surface is shown too much exaggerated.



With the reflector set at a-b (1st reading), the micrometer reading is noted and this line is treated as datum line. Successive readings at b-c, c-d, d-e etc. are taken till the length of the surface to be tested has been stepped along. In other to eliminate any error in previous set of readings, the second set of readings could be taken by stepping the reflector in the reverse direction and mean of two taken. This mean reading represents the angular position of the reflector in seconds relative to the optical axis or auto-collimator.

Column 1 gives the position of plane reflector at various places at intervals of *'l'* e.g. a-b, b-c, c-d etc., column 2 gives the mean reading of auto-collimator or spirit level in seconds. In column 3, difference of each reading from the first is given in order to treat first reading as datum. These differences are then converted into the corresponding linear rise or fall in column 4 by multiplying column 3 by *'l'*. Column 5 gives the cumulative rise or fall, i.e., the heights of the support feet of the reflector above the datum line drawn through their first position. It should be noted that the values in column 4 indicate the inclinations only and are not errors from the true datum. For this the values are added cumulatively with due regard for sign. Thus it leaves a final displacement equal to L at the end of the run which of course does not represent the magnitude of error of the surface, but is merely the deviation from a straight line produced from the plane of the first reading. In column 5 each figure represents a point, therefore, an additional zero is put at the top representing the height of point *a*.

The errors of any surfaced may be required relative to any mean plane. If it be assumed that mean plane is one joining the end points then whole of graph must be swung round until the end point is on the axis. This is achieved by subtracting the length L proportionately from the readings in column 5. Thus if n readings be taken, then column 6 gives the adjustments— L/n, —2L/n… etc., to bring both ends to zero. Column 7 gives the difference of columns 5 and 6 and represents errors in the surface from a straight line joining the end points. This is as if a straight edge were laid along the surface profile to be tested and touching the end points of the surface when they are in a horizontal plane and the various readings in column 7 indicate the rise and fall relative to this straight edge.

OUTCOMES

Students will be able to

1. Understand the objectives of metrology, methods of measurement, selection of measuring instruments, standards of measurement and calibration of end bars.
2. Slip gauges, wringing of slip gauges and building of slip gauges, angle measurement using sine bar, sine center, angle gauges, optical instruments and straightness measurement using Autocollimator Analysis types of fits and gauges.

Questions

1. Define metrology
2. Classi fie standards
3. Distinguish between line and end standards
4. How to calibrate slip gauges
5. explain angle gauges
6. explain working principle of sine bar
7. explain applications of sine bar
8. with sketch explain autocollimator

MODULE 2

SYSTEM OF LIMITS, FITS, TOLERANCE AND GAUGING

CONTENTS

OBJECTIVES

Students will be able to

1 Understand the basic principles of fits and tolerances,
2 Explain various types of fits and their applications,
3 Analyses the various types of tolerances and applications, and
4 Know the fundamental of the systems of fits.

2.1 Definition:

Limits

The maximum and minimum permissible sizes within which the actual size of a component lies are called Limits.

Tolerance:

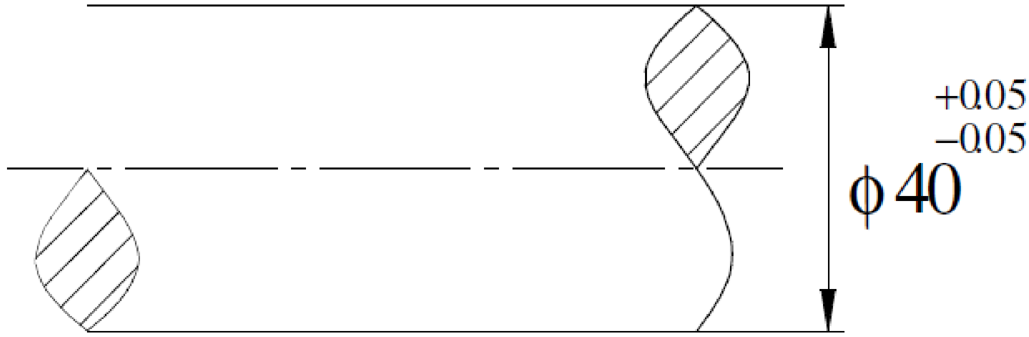
It is impossible to make anything to an exact size, therefore it is essential to allow a definite tolerance or permissible variation on every specified dimension.

Why Tolerances are specified?

· Variations in properties of the material being machined introduce errors.

· The production machines themselves may have some inherent inaccuracies.

· It is impossible for an operator to make perfect settings. While setting up the tools and workpiece on the machine, some errors are likely to creep in.



Consider the dimension shown in fig. When trying to achieve a diameter of 40 mm (Basicor Nominal diameter), a variation of 0.05 mm on either side may result.If the shaft is satisfactory even if its diameter lies between 40.05 mm & 39.95 mm, thedimension 40.05 mm is known as Upper limit and the dimension 39.95 mm is known asLower limit of size. Tolerance in the above example is (40.05-39.95) =0.10 mmTolerance is always a positive quantitative number.

Unilateral Tolerance:

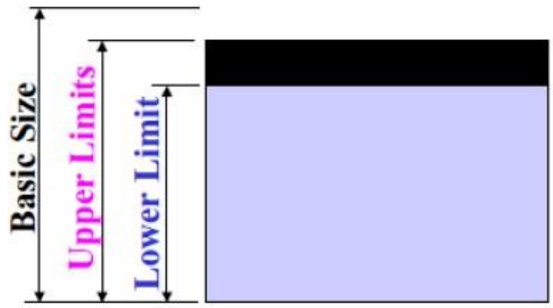
· Tolerances on a dimension may either be unilateral or bilateral.

· When the two limit dimensions are only on one side of the nominal size, (either aboveor below) the tolerances are said to be unilateral.

· For unilateral tolerances, a case may occur when one of the limits coincide with thebasic size.

e.g. Ø25 $^{+0.18}_{+0.10}$

Basic Size = 25.00 mm
Upper Limit = 25.18 mm
Lower Limit = 25.10 mm
Tolerance = **0.08 mm**

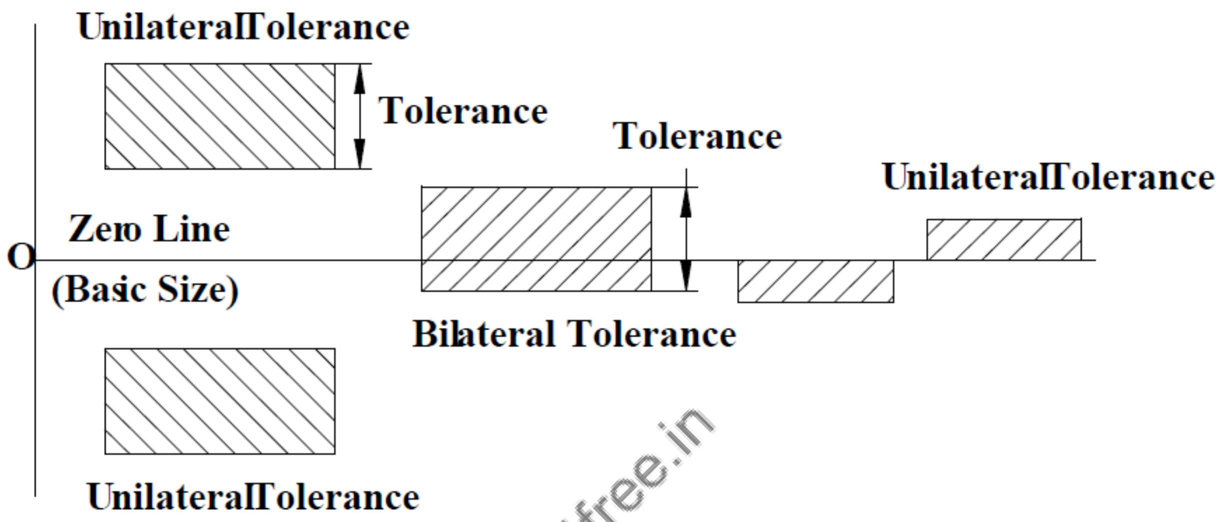


e.g. Ø25 $^{-0.10}_{-0.20}$

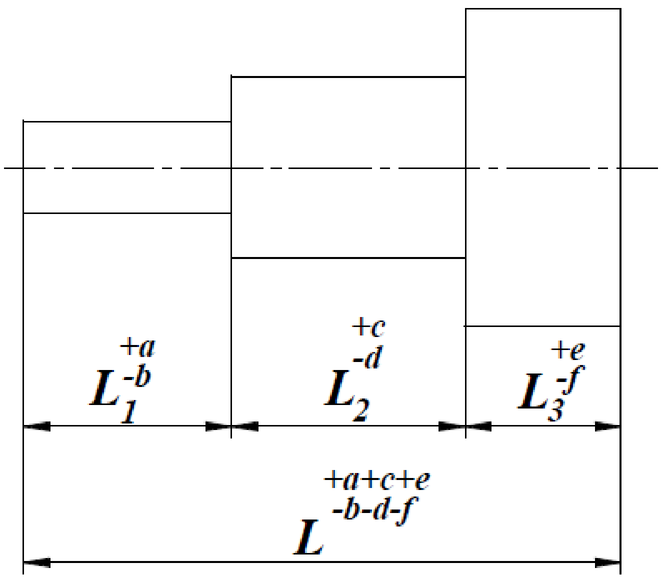
Basic Size = 25.00 mm
Upper Limit = 24.90 mm
Lower Limit = 24.80 mm
Tolerance = **0.10 mm**

Bilateral Tolerance: When the two limit dimensions are above and below nominal size,(i.e. on either side of the nominal size) the tolerances are said to be bilateral.Unilateral tolerances, are preferred over bilateral because the operator can machine to theupper limit of the shaft (or lower limit of a hole) still having the whole tolerance left formachining to avoid rejection of parts.

Schematic representation of tolerances:



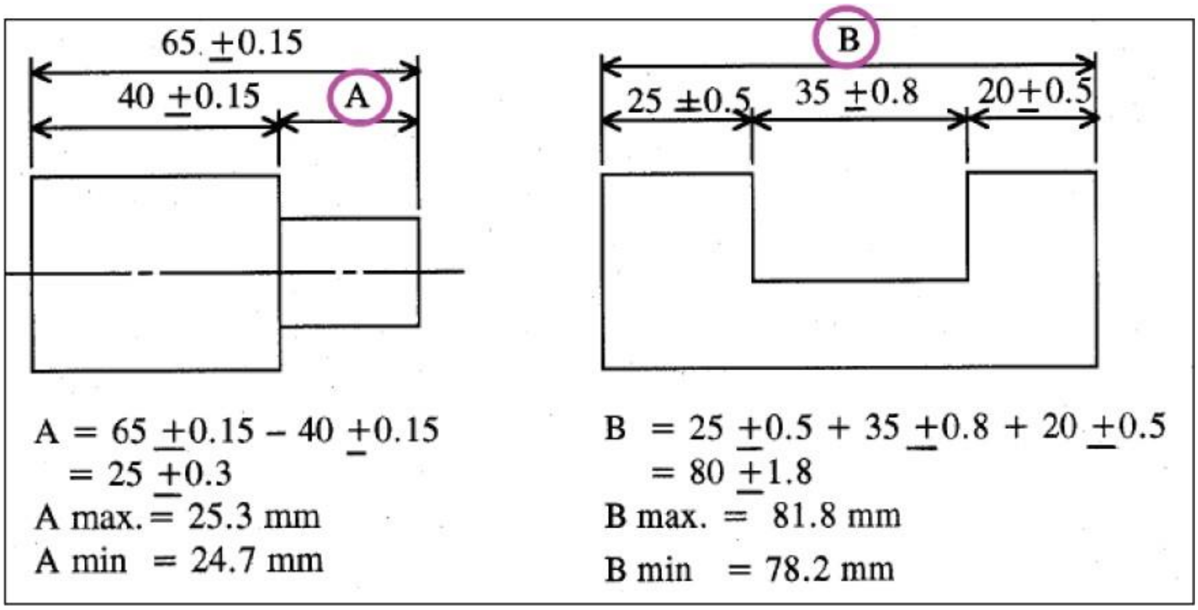
Tolerance Accumulation (or) Tolerance Build up:



If a part comprises of several steps, each step having some tolerance specified over itslength, then the overall tolerance on the complete length will be the sum of tolerances on individual lengths.

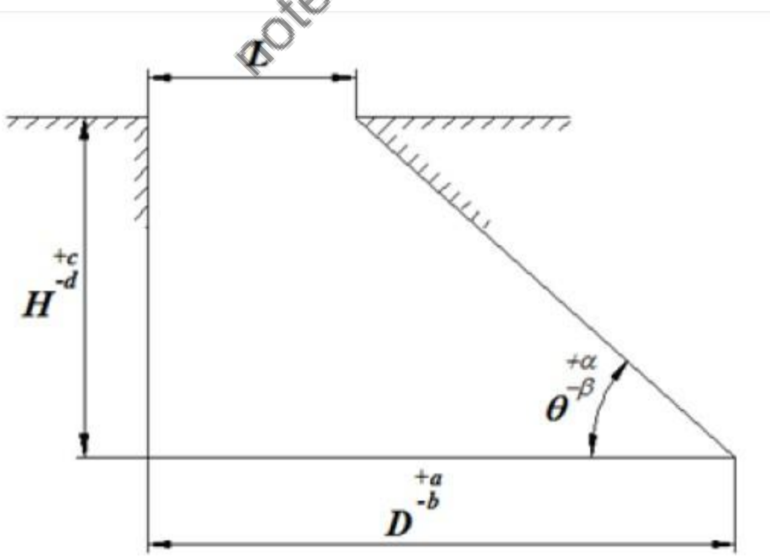
The effect of accumulation of tolerances can be minimized by adopting progressive dimensioning from a common datum.

Another example of tolerance build up is shown below.



Compound Tolerances:

A compound tolerance is one which is derived by consideringthe effect of tolerances on more than one dimension.



For ex, the tolerance on the dimension L is dependent on the tolerances on D, H & q.

The dimension L will be maximum when the base dimension is (D+a), the angle is (q+a),and the vertical dimension is (H-d).

The dimension L will be minimum when the base dimension is (D-b), the angle is (q-b),and the vertical dimension is (H+c).

2.2 LIMITS OF SIZE & TOLERANCE

Terminology of limit systems:

Limits of size: The two extreme permissible sizes of a component between which the actual size should lie including the maximum and minimum sizes of the component.

Nominal size: It is the size of the component by which it is referred to as a matter of convenience.

Basic size: It is the size of a part in relation to which all limits of variation are determined.

Zero Line: It is the line w.r.t which the positions of tolerance zones are shown**.**

Deviation: It is the algebraic difference between a limit of size and the corresponding basic size.

Upper Deviation: It is the algebraic difference between the maximum limit of size and the corresponding basic size. It is denoted by letters ***'ES'*** for a hole and ***'es'*** for a shaft.

Lower Deviation: It is the algebraic difference between the minimum limit of size and the corresponding basic size. It is denoted by letters ***'EI'*** for a hole and ***'ei'*** for a shaft.

Fundamental Deviation: It is the deviation, either upper or lower deviation, which is nearest to the zero line for either a hole or a shaft. It fixes the position of the tolerance zone in relation to the zero line.

Allowance: It is the intentional difference between the hole dimensions and shaft dimension for any type of fit.

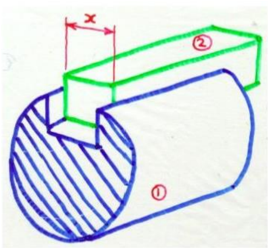
Size of tolerance: It is the difference between the maximum and minimum limits of size.

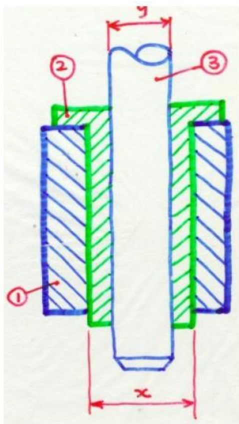
2.3 SYSTEM OF FITS

Fit is an assembly condition between 'Hole' & 'Shaft'

Hole: A feature engulfing a component.

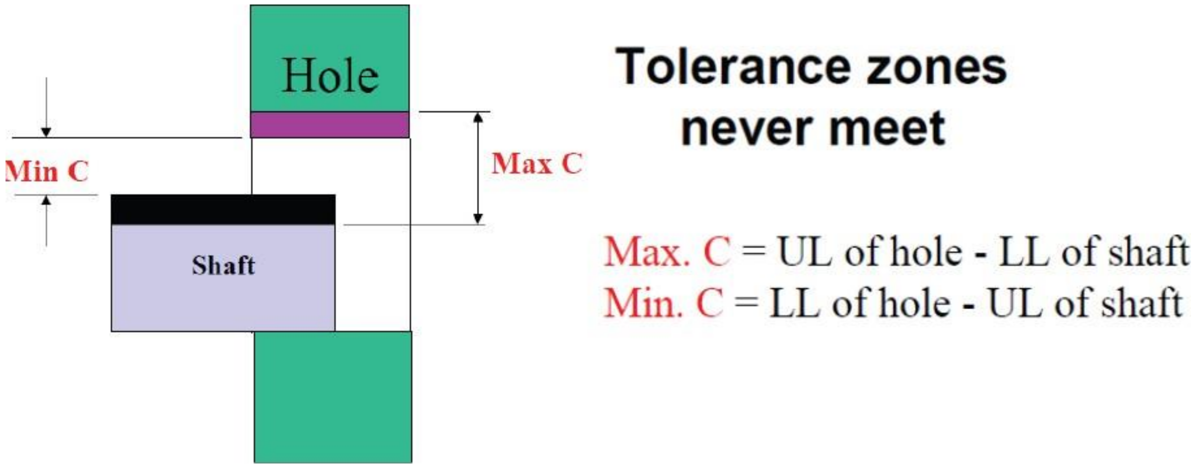
Shaft: A feature being engulfed by a component.





Clearance fit:

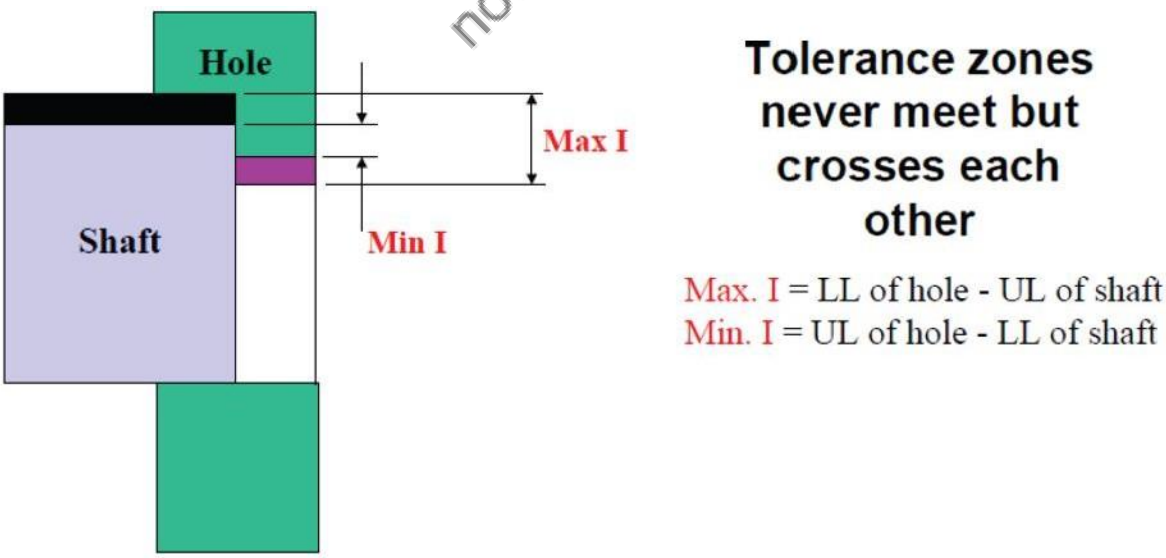
In this type of fit, the largest permitted shaft diameter is less than the smallest hole diameter so that the shaft can rotate or slide according to the purpose of the assembly.



Interference Fit:

It is defined as the fit established when a negative clearance exists between the sizes of holes and the shaft. In this type of fit, the minimum permitted diameter of the shaft is larger than the maximum allowable diameter of the hole. In case of this type of fit, the members are intended to be permanently attached.

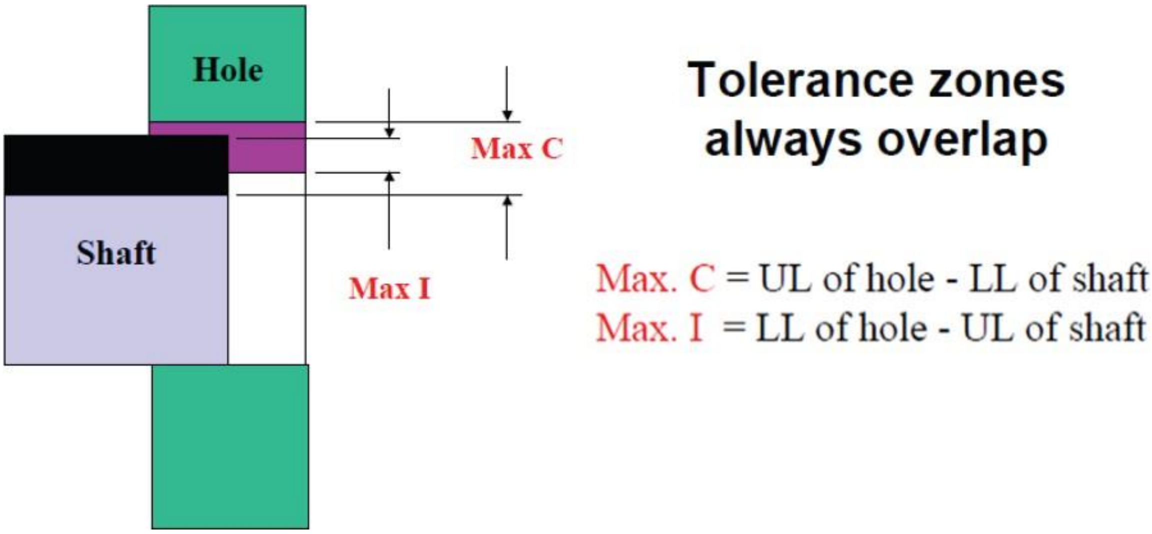
Ex: Bearing bushes, Keys & key ways



Transition Fit:

In this type of fit, the diameter of the largest allowable hole is greater than the smallest shaft, but the smallest hole is smaller than the largest shaft, such that a small positive or negative clearance exists between the shaft & hole.

Ex: Coupling rings, Spigot in mating holes, etc.



Interchangeability:

Interchangeability occurs when one part in an assembly can be substituted for a similar part which has been made to the same drawing. Interchangeability is possible only when certain standards are strictly followed.

Universal interchangeability means the parts to be assembled are from two different manufacturing sources.

Local interchangeability means all the parts to be assembled are made in the same manufacturing unit.

Selective Assembly:

In selective assembly, the parts are graded according to the size and only matched gradesof mating parts are assembled. This technique is most suitable where close fit of twocomponents assembled is required.

Selective assembly provides complete protection against non-conforming assemblies and reduces machining costs as close tolerances can be maintained.

Suppose some parts (shafts & holes) are manufactured to a tolerance of 0.01 mm, then an automatic gauge can separate them into ten different groups of 0.001 mm limit for selective assembly of the individual parts. Thus high quality and low cost can be achieved.

Selective assembly is used in aircraft, automobile industries where tolerances are very narrow and not possible to manufacture at reasonable costs.

2.4 Geometrical Tolerances:

It is necessary to specify and control the geometric features of a component, such as straightness, flatness, roundness, etc. in addition to linear dimensions. Geometric tolerance is concerned with the accuracy of relationship of one component to another and should be specified separately.

Geometrical tolerance may be defined as the maximum possible variation of **form** or **position of form** or **position of a feature.**

Geometric tolerances define the shape of a feature as opposed to its size. There are three basic types of geometric tolerances:

Form tolerances:

Straightness, flatness, roundness, cylindricity

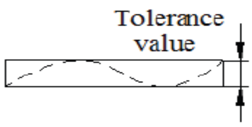
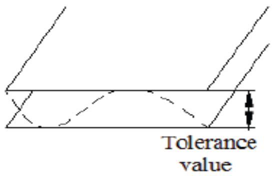
Orientation tolerances:

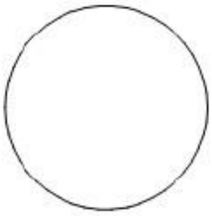
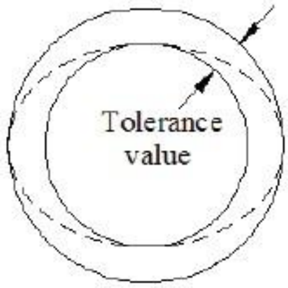
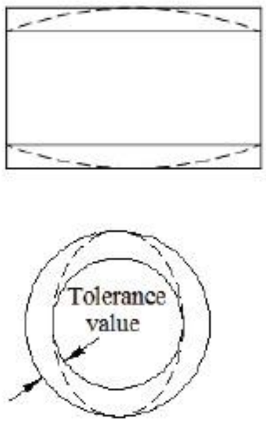
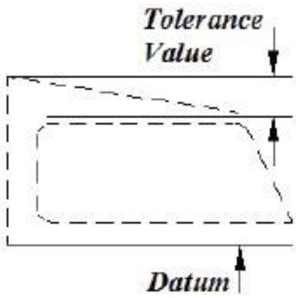
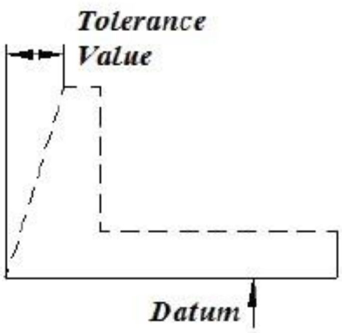
Perpendicularity, parallelism, angularity

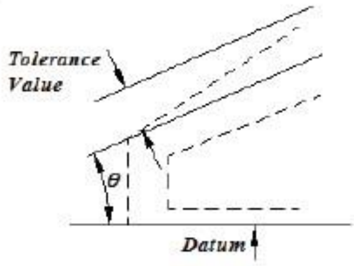
Position tolerances:

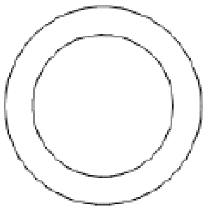
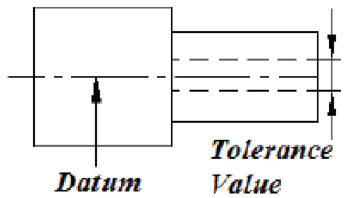
Position, symmetry, concentricity

FORM TOLERANCES

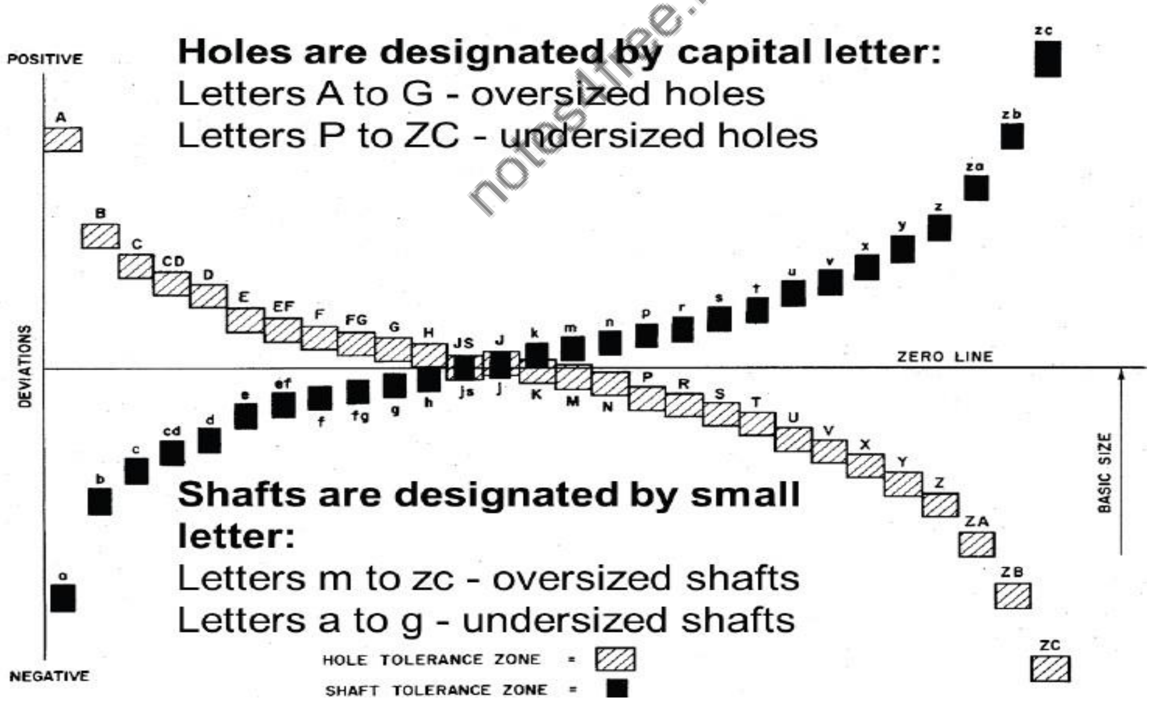
Characteristic or symbol	Function of geometric tolerance	Tolerance zone	Typical example
Straightness	To control the straightness of the line on a surface.	Area between two parallel straight lines in the plane containing the considered line or axis, Tolerance value is the distance between them.	
Flatness 	To control the flatness of a surface.	Area between two planes. Tolerance value is the distance between them.	

Roundness 	To control the errors of roundness of a circle in the plane in which it lies.	Area between two concentric circles. Tolerance value is the radial distance between them.	
Cylindricity 	To control combination of roundness, straightness, and parallelism of a cylindrical surface.	Annular space between two cylinders that are co axial. Tolerance value is the radial distance between them.	
ORIENTATION TOLERANCES			
Parallelism 	To control the parallelism of a line or surface w.r.t some datum.	Area between two parallel lines or space between two parallel lines which are parallel to the datum	
Squareness 	To control the perpendicularity of a line or surface w.r.t a datum.	Area between two parallel lines or space between two parallel lines which are perpendicular to the datum.	

Angularity 	To control the inclination of a line or surface w.r.t a datum.	Area between two parallel lines or space between two parallel lines which are inclined at a specified angle to the datum.	

POSITIONAL TOLERANCES			
Concentricity 	To control the deviation of the position of the position of the center or axis of the toleranced circles or cylinders.	Center or axis to lie within the circle or cylinder. Tolerance value is the diameter of such a circle or cylinder.	

2.5 SYSTEM OF TOLERANCES



'H' is used for holes and 'h'is used for shafts whose fundamental deviation is zero.

Basic shaft: It is a shaft whose upper deviation is zero. i.e. the maximum limit of shaftcoincides with the nominal size.(zero line). Eg: shaft 'h'

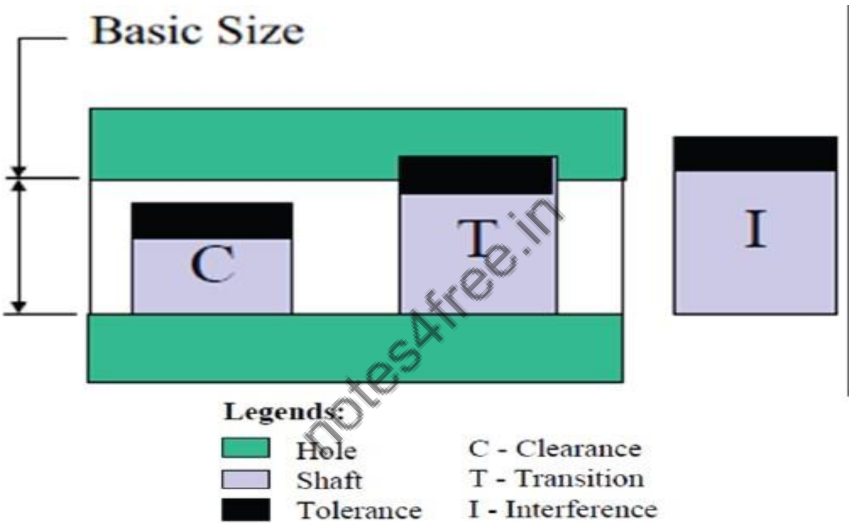
Basic hole: It is a hole whose lower deviation is zero. i.e. the minimum limit of holecoincides with the nominal size.(zero line). Eg: shaft 'H'

Hole Basis: In this system, the basic diameter of the hole is constant while the shaft sizeis varied according to the type of fit.

Significance of Hole basis system: The bureau of Indian Standards (BIS) recommendsboth hole basis and shaft basis systems, but their selection depends on the productionmethods. Generally, holes are produced by drilling, boring, reaming, broaching, etc.whereas shafts are either turned or ground.

If the shaft basis system is used to specify the limit dimensions to obtain various typesof fits, number of holes of different sizes are required, which in turn requires tools ofdifferent sizes.

Hole basis system:



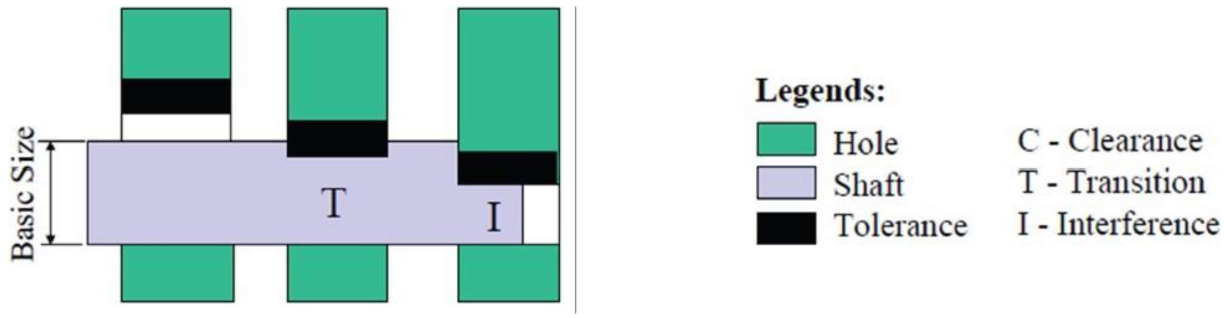
If the hole basis system is used, there will be reduction in production costs as only onetool is required to produce the ole and the shaft can be easily machined to any desiredsize. Hence hole basis system is preferred over shaft basis system.

Shaft Basis system:

In this system, the basic diameter of the shaft is constant while the hole size is varied according to the type of fit.

It may, however, be necessary to use shaft basis system where different fits are required along a long shaft.

For example, in the case of driving shafts where a single shaft may have to accommodate to a variety of accessories such as couplings, bearings, collars, etc., it is preferable to maintain a constant diameter for the permanent member, which is the shaft, and vary the bore of the accessories.



GRADES OF TOLERANCES

Grade is a measure of the magnitude of the tolerance. Lower the grade the finer thetolerance. There are total of 18 grades which are allocated the numbers IT01, IT0, IT1,IT2 T16.

Fine grades are referred to by the first few numbers. As the numbers get larger, so the tolerance zone becomes progressively wider. Selection of grade should depend on the circumstances. As the grades get finer, the cost of production increases at a sharper rate.

TOLERANCE GRADE

The tolerance grades may be numerically determined in terms of the standard tolerance unit '***i***' where ***i***in microns is given by (for basic size up to and including 500 mm) and(for basic size above 500 mm upto and including 3150 mm), where D is in mm and it is the geometric mean of the lower and upper diameters of a particular step in which the component lies.

The above formula is empirical and is based on the fact that the tolerance varies more or less parabolic ally in terms of diameter for the same manufacturing conditions. This is so because manufacture and measurement of higher sizes are relatively difficult.

The various diameter steps specified by ISI are:1-3, 3-6, 6-10, 10-18, 18-30, 30-50, 50-80, 80-120,180-250, 250-315, 315-400, and 400-500 mm. The value of 'D' is taken as the geometric mean for a particular range of size to avoid continuous variation of tolerance with size.

The fundamental deviation of type d,e,f,g shafts are respectively $-16D^{0.44}$, $-11D^{0.41}$, $-5.5D^{0.41}$ & $-2.5D^{0.34}$

The fundamental deviation of type D,E,F,G shafts are respectively $+16D^{0.44}$, $+11D^{0.41}$,$+5.5D^{0.41}$& $+2.5D^{0.34}$.

The relative magnitude of each grade is shown in the table below;

Tol. Grade	IT 5	IT 6	IT 7	IT 8	IT 9	IT 10	IT 11	IT 12	IT 13	IT 14	IT 15	IT 16
	7i	*10i*	*16i*	*25 i*	*40 i*	*64 i*	*100 i*	*160 i*	*250 i*	*400 i*	*640 i*	*1000 i*

It may be noted that from IT 6 onwards, every 5th step is 10 times the respective grade.i.e. IT 11=10xIT6=10x10i=100 i, IT12=10xIT7=10x16i=160 i, etc.

Numerical Problem 1:

Calculate the limits of tolerance and allowance for a 25 mm shaft and hole pair designated by H_8d_9. Take the fundamental deviation for 'd' shaft is $-16D^{0.44}$.

Numerical Problem 2

Determine the tolerances on the hole and the shaft for a precision running fit designated by 50 H_7g_6, given;

50 mm lies between 30-50 mm

i (in microns)=$0.45(D)^{1/3}+0.001D$

Fundamental deviation for 'H' hole=0

Fundamental deviation for g shaft =$-2.5D^{0.34}$

IT7=16i and IT6=10i

State the actual maximum and minimum sizes of the hole and shaft and maximum and minimum clearances.

Numerical Problem 3:

Calculate all the relevant dimensions of $35H_7/f_8$ fit, dimension 35 mm falls in the step of 30-50 mm. The fundamental deviation for f shaft is – $5.5D^{0.41}$. i (in microns)=$0.45(D)^{1/3}+0.001D$, IT7=16i and IT8=25i.

LIMIT GAUGES

A ***Go-No GO*** gauge refers to an inspection tool used to check a workpiece against itsallowed tolerances. It derives its name from its use: the gauge has two tests; the checkinvolves the workpiece having to pass one test (Go) and fail the other (No Go).

It is an integral part of the quality process that is used in the manufacturing industryto ensure interchangeability of parts between processes, or even between different manufacturers.

A Go - No Go gauge is a measuring tool that does not return a size in the conventional sense, but instead returns a state. The state is either acceptable (the part is withintolerance and may be used) or it is unacceptable (and must be rejected).

They are well suited for use in the production area of the factory as they require little skill or interpretation to use effectively and have few, if any, moving parts to be damaged in the often hostile production environment.

PLAIN GAUGES

Gauges are inspection tools which serve to check the dimensions of the manufactured parts. Limit gauges ensure the size of the component lies within the specified limits. They are non-recording and do not determine the size of the part. Plain gauges are used for checking plain (Unthreaded) holes and shafts.

Plain gauges may be classified as follows;

According to their type:

(a) Standard gauges are made to the nominal size of the part to be tested and have the measuring member equal in size to the mean permissible dimension of the part to be checked. A standard gauge should mate with some snugness.

(b) Limit Gauges These are also called **'go'** and **'no go'** gauges. These are made to the limit sizes of the work to be measured. One of the sides or ends of the gauge is made to correspond to maximum and the other end to the minimum permissible size. The function of limit gauges is to determine whether the actual dimensions of the work are within or outside the specified limits.

According to their purpose:

(a) Work shop gauges: Working gauges are those used at the bench or machine in gauging the work as it being made.

(b) Inspection gauges: These gauges are used by the inspection personnel to inspect manufactured parts when finished.

(c) Reference or Master Gauges: These are used only for checking the size or condition of other gauges.

According to the form of tested surface:

Plug gauges: They check the dimensions of a hole

Snap & Ring gauges: They check the dimensions of a shaft.

According to their design:

Single limit & double limit gauges

Single ended and double ended gauges

Fixed & adjustable gauges

LIMIT GAUGING

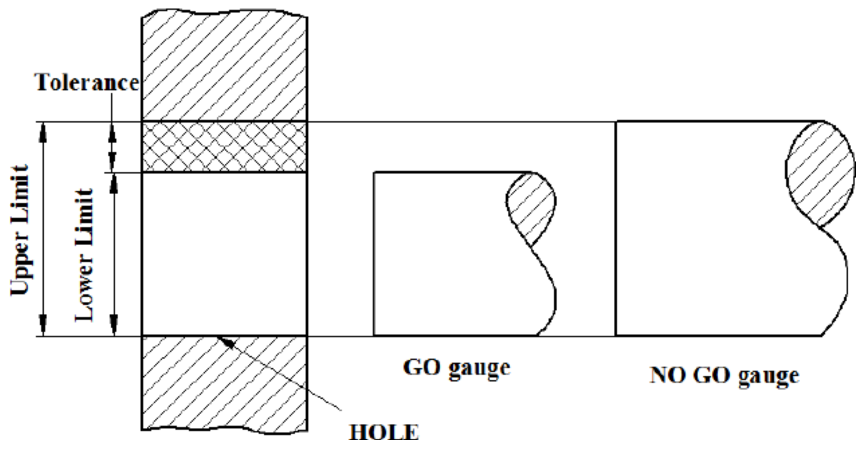
Limit gauging is adopted for checking parts produced by mass production. It has the advantage that they can be used by unskilled persons.

Instead of measuring actual dimensions, the conformance of product with tolerance specifications can be checked by a 'GO' and 'NO GO' gauges.

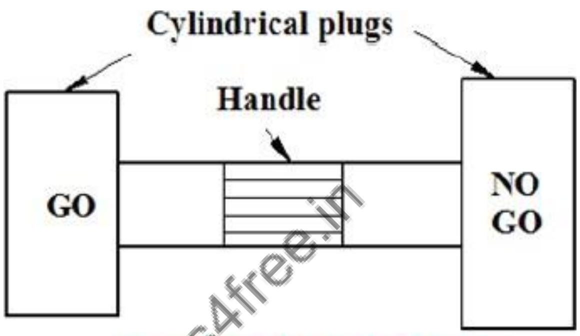
A 'GO' gauge represents the maximum material condition of the product (i.e. minimum hole size or maximum shaft size) and conversely a 'NO GO' represents the minimum material condition (i.e. maximum hole size or minimum shaft size).

Plug gauges:

Plug gauges are the limit gauges used for checking holes and consist of two cylindrical wear resistant plugs. The plug made to the lower limit of the hole is known as 'GO' end and this will enter any hole which is not smaller than the lower limit allowed. The plug made to the upper limit of the hole is known as 'NO GO' end and this will not enter any hole which is smaller than the upper limit allowed. The plugs are arranged on either ends of a common handle.



Plug gauges are normally double ended for sizes upto 63 mm and for sizes above 63 mm they are single ended type.

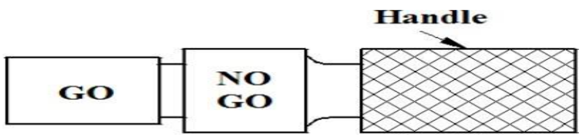


Double ended Plug Gauge

The handles of heavy plug gauges are made of light metal alloys while the handles of small plug gauges can be made of some nonmetallic materials.

Progressive plug gauges:

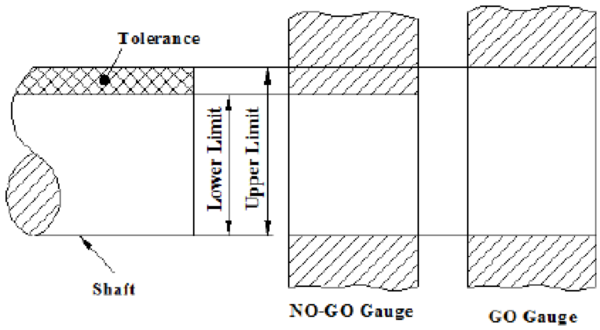
For smaller through holes, both GO & NO GO gauges are on the same side separatedby a small distance. After the full length of GO portion enters the hole, further entry isobstructed by the NO GO portion if the hole is within the tolerance limits.



Progressive Plug Gauge

Ring gauges:

Ring gauges are used for gauging shafts. They are used in a similar manner to that of GO & NO GO plug gauges. A ring gauge consists of a piece of metal in which a hole of required size is bored.



SNAP (or) GAP GAUGES:

A snap gauge usually consists of a plate or frame with a parallel faced gap of the required dimension. Snap gauges can be used for both cylindrical as well as non cylindrical work as compared to ring gauges which are conveniently used only for cylindrical work.

Double ended snap gauges can be used for sizes ranging from 3 to 100 mm.For sizes above 100 mm upto 250 mm a single ended progressive gauge may be used.

Desirable properties of Gauge Materials:

The essential considerations in the selection of material of gauges are;

1 Hardness to resist wear.

2 Stability to preserve size and shape

3 Corrosion resistance

4 Machinability for obtaining the required degree of accuracy.

5 Low coefficient of friction of expansion to avoid temperature effects.

Materials used for gauges:

High carbon steel: Heat treated Cast steel (0.8-1% carbon) is commonly used for most gauges.

Mild Steel: Case hardened on the working surface. It is stable and easily machinable.

Case hardened steel: Used for small & medium sized gauges.

Chromium plated & Hard alloys: Chromium plating imparts hardness, resistance to abrasion & corrosion. Hard alloys of tungsten carbide may also be used.

Cast Iron: Used for bodies of frames of large gauges whose working surfaces are hard inserts of tool steel or cemented carbides.

Glass: They are free from corrosive effects due to perspiration from hands. Also they are not affected by temperature changes.

Invar: It is a nickel-iron alloy (36% nickel) which has low coefficient of expansion but not suitable for usage over long periods.

(The name, Invar, comes from the word invariable, referring to its lack of expansion or contraction with temperature changes. It was invented in 1896 by Swiss scientist Charles Eduard
Guillaume. He received the Nobel Prize in Physics in 1920 for this discovery, which enabled improvements in scientific instruments).

Taylor's Principle of Gauge Design:

According to Taylor, 'Go' and 'No Go' gauges should be designed to check maximum and minimum material limits which are checked as below;

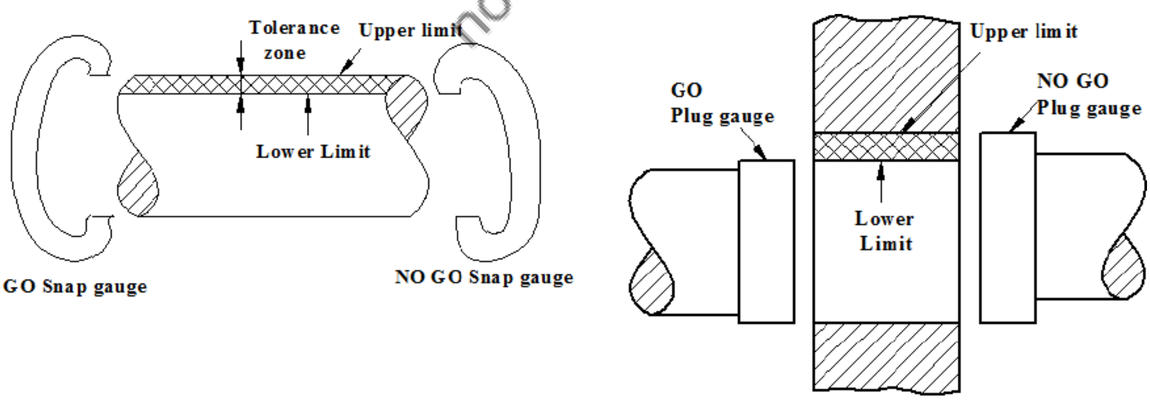
'GO' Limit. This designation is applied to that limit of the two limits of size which corresponds to the maximum material limit considerations, i.e. upper limit of a shaft and lower limit of a hole.

The GO gauges should be of full form, i.e. they should check shape as well as size.

'No Go' Limit:

This designation is applied to that limit of the two limits of size which corresponds to the minimum material condition. i.e. the lower limit of a shaft and the upper limit of a hole.

'No Go' gauge should check only one part or feature of the component at a time, so that specific discrepancies in shape or size can be detected. Thus a separate 'No Go' gauge is required for each different individual dimension.



Gauge Tolerance:

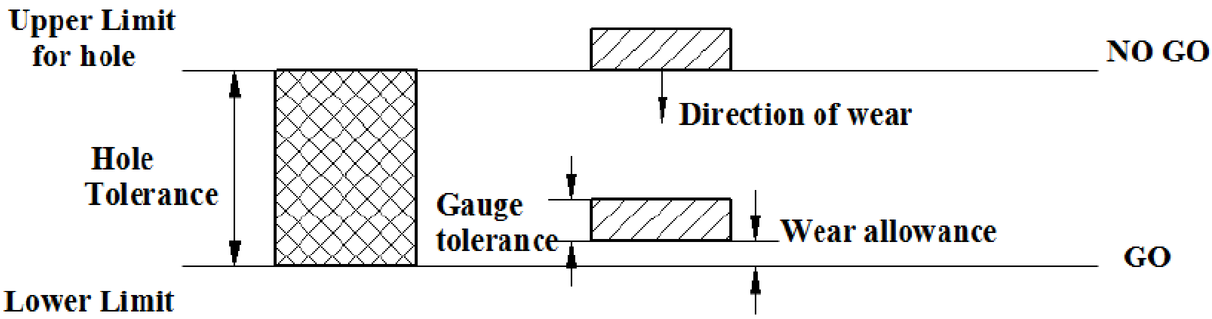
Gauges, like any other jobs require a manufacturing tolerance due to reasonableimperfections in the workmanship of the gauge maker. The gauge tolerance should bekept as minimum as possible though high costs are involved to do so. The tolerance onthe GO & NO GO gauges is usually 10% of the work tolerance.

Wear Allowance:

The GO gauges only are subjected to wear due to rubbing against the parts during inspection and hence a provision has to be made for the wear allowance. Wear allowances taken as 10% of gauge tolerance and is allowed between the tolerance zone of the gauge and the maximum material condition. (*i.e.* lower limit of a hole & upper limit of a shaft). If the work tolerance is less than 0.09 mm, wear allowance need not be given unless otherwise stated.

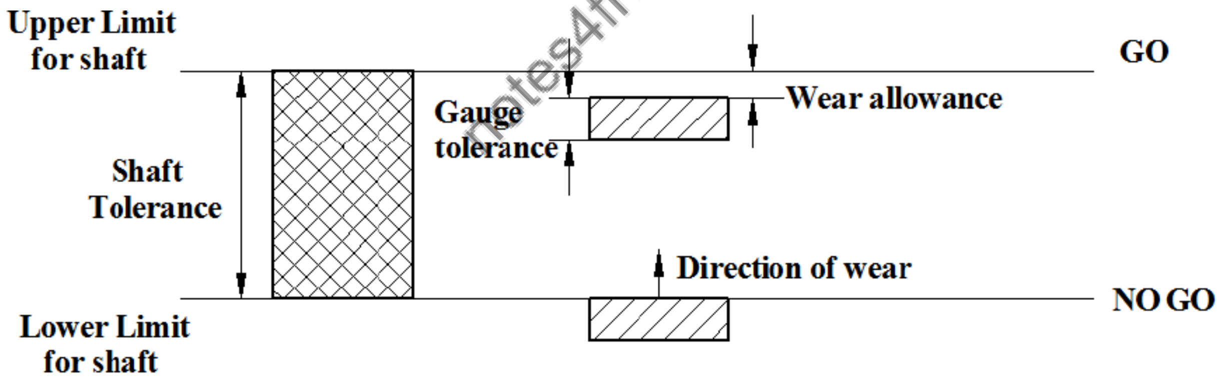
Present British System of Gauge & Wear Tolerance:

PLUG GAUGES: (For checking tolerances on holes)



GO & NO GO Plug Gauges (For checking hole tolerance)

RING/SNAP GAUGES: (For checking tolerances on shafts)



GO & NO GO Ring Gauges (For checking shaft tolerance)

Numerical Problem 1:

Calculate the dimensions of plug & ring gauges to control the production of 50 mm shaft & hole

pair of H_7d_8 as per IS specifications. The following assumptions may be made: 50 mm lies in diameter step of 30-50 mm. Upper deviation for 'd' shaft is $-16D^{0.44}$ and lower deviation for hole

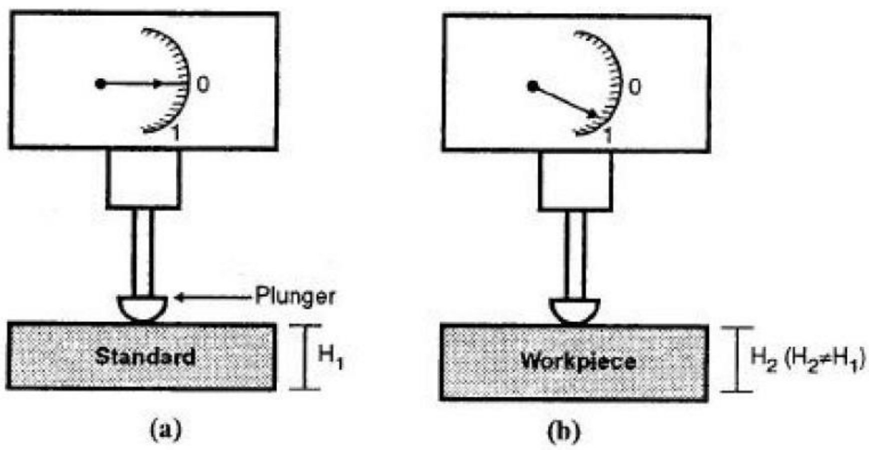
H is zero. Tolerance unit in 'i' in microns is $=0.45\sqrt[3]{D}+0.001D$ and IT6=10i and above IT6 grade, the tolerance is multiplied by 10 at each 5th step.

Numerical Problem 2

Determine the actual dimensions to be provided for a shaft and hole 90 mm size for H_8e_9type clearance fit. Size 90 mm falls in the diameter step of 80-100 mm. Value of standard tolerance unit $=0.45\sqrt[3]{D}+0.001D$. The values of tolerances for IT8 & IT9grades are 25i & 40i respectively. Value of fundamental deviation for 'e' type shaft is $-11D^{0.41}$. Also design the GO & NO GO gauges considering wear allowance as 10% of gauge tolerance.

2.6 COMPARATORS

Comparators can give precision measurements, with consistent accuracy by eliminating human error. They are employed to find out, by how much the dimensions of the given component differ from that of a known datum. If the indicated difference is small, a suitable magnification device is selected to obtain the desired accuracy of measurements. It is an indirect type of instrument and used for linear measurement. If the dimension is less or greater, than the standard, then the difference will be shown on the dial. It gives only the difference between actual and standard dimension of the workpiece. To check the height of the job H2 ,with the standard job of height H_1



Initially, the comparator is adjusted to zero on its dial with a standard job in positions shown in Figure(a). The reading H1is taken with the help of a plunger. Then the standard job is replaced by the work-piece to be checked and the reading H2 is taken. If H1and H2 are different, then the change i~ the dimension will be shown on the dial of the comparator. Thus difference is then magnified 1000 to 3000 X to get the clear variation in the standard and actual job.

In short, Comparator is a device which

(1) Picks up small variations in dimensions.

(2) Magnifies it.

(3) Displays it by using indicating devices, by which comparison can be made with somestandard value.

Characterstics or Basic requirements of comparators

1) The instrument must be of robust design and construction so as to withstand the effect of ordinary usage without impairing its measuring accuracy.
2) The including devices must be such that readings are obtained in least possible time. The system should be free from backlash, wear effects and the inertia should be minimum.
3) Provision for maximum compensation to temperature effects.
4) The scale must be linear and must have straight line characteristics.
5) The instrument must be versatile i.e., its design must be such that it can be used for a wide range of measurements.
6) The measuring pressure should be low and constant.
7) The indicator (pointer, liquid column etc) should be clear and free from oscillations.

2.6.1 Classification of comparators:

1. Mechanical Comparator: It works on gears pinions, linkages, levers, springs etc.

2. Pneumatic Comparator: Pneumatic comparator works by using high pressure air, valves,back pressure etc.

3. Optical Comparator: Optical comparator works by using lens, mirrors, light source etc.

4. Electrical Comparator: Works by using step up, step down transformers.

5. Electronic Comparator: It works by using amplifier, digital signal etc.

6. Combined Comparator: The combination of any two of the above types can give the best result.

Characteristics of Good Comparators:

1. It should be compact.

2. It should be easy to handle.

3. It should give quick response or quick result.

4. It should be reliable, while in use.

5. There should be no effects of environment on the comparator.

6. Its weight must be less.

7. It must be cheaper.

8. It must be easily available in the market.

9. It should be sensitive as per the requirement.

10. The design should be robust.

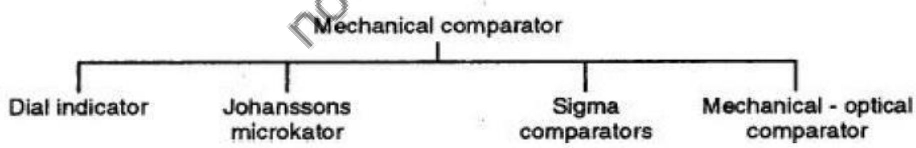
11. It should be linear in scale so that it is easy to read and get uniform response.

12. It should have less maintenance.

13. It should have hard contact point, with long life.

2.6.2 Mechanical Comparator:

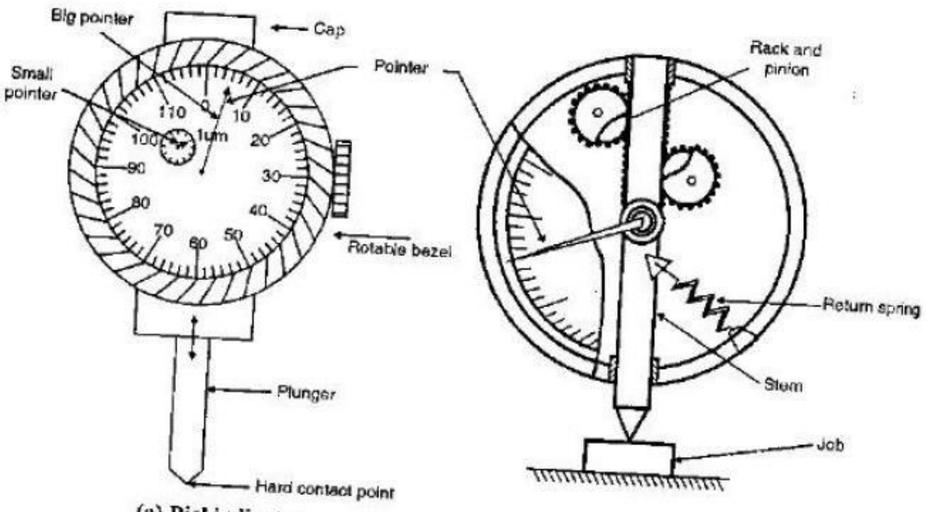
It is self controlled and no power or any other form of energy is required. It employs mechanical means for magnifying the small movement of the measuring stylus. The movement is due to the difference between the standard and the actual dimension being checked



The method for magnifying the small stylus movement in all the mechanical comparators is by means of levers, gear trains or combination of these. They are available of different make and each has it's own characteristic. The various types of mechanical comparators are dial indicator, rack and pinion, sigma comparator, Johansson mikrokator.

a. Dial Indicator:

It operates on the principle, that a very slight upward pressure on the spindle at the contact point is multiplied through a system of gears and levers. It is indicated on the face of the dial by a dial finger. Dial indicators basically consists of a body with a round graduated dial and a contact point connected with a spiral or gear train so that hand on the dial face indicates the amount of movement of the contact point. They are designed for use on a widerange of standard measuring devices such as dial box gauges, portal dial, hand gauges, dialdepth gauges, diameter gauges and dial indicator snap gauge.



(a) Dial indicator

(b) Mechanism of dial indicator

Corresponds to a spindle movement of 1 mm. The movement mechanism of the instrument is housed in a metal case for it's protection. The large dial scale is graduated into100 divisions. The indicator is set to zero by the use of slip gauges representing the basic size of part.

Requirements of Good Dial Indicator:

1. It should give trouble free and dependable readings over a long period.
2. The pressure required on measuring head to obtain zero reading must remain constant over the whole range.
3. The pointer should indicate the direction of movement of the measuring plunger.
4. The accuracy of the readings should be within close limits of the various sizes and ranges
5. The movement of the measuring plunger should be in either direction without affecting the accuracy.
6. The pointer movement should be damped, so that it will not oscillate when the readings are being taken.

Applications:

1. Comparing two heights or distances between narrow limits.
2. To determine the errors in geometrical form such as ovality, roundness and taper.
3. For taking accurate measurement of deformation such as intension and compression.
4. To determine positional errors of surfaces such as parallelism, squareness and alignment.
5. To check the alignment of lathe centers by using suitable accurate bar between the centers.

6. To check trueness of milling machine arbors and to check the parallelism of shaper arm with table surface or vice.

b) Johansson Mikrokator :

This comparator was developed by C.F. Johansson.

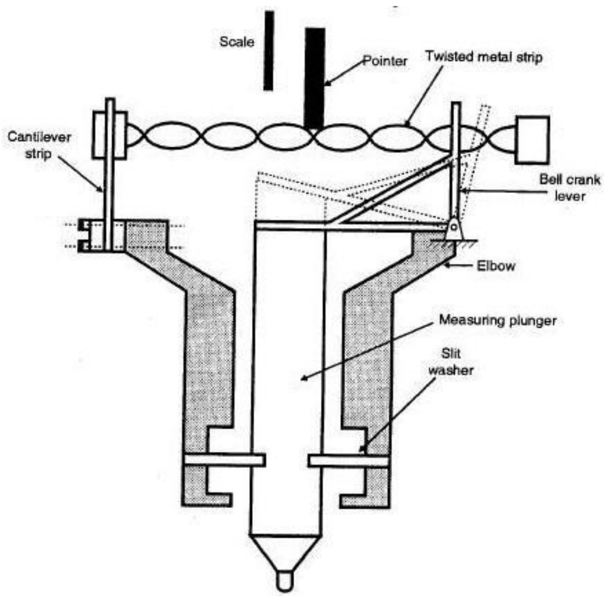
Principle:

It works on the principle of a Button spring, spinning on a loop of string like in the case ofChildren's toys.

Construction:

The method of mechanical magnification is shown in Figure. It employs a twisted metal strip. Any pull on the strip causes the centre of the strip to rotate. A very light pointer made of glass tube is attached to the centre of the twisted metal strip. The measuring plungers on the slit washer and transmits its motion through the bell crank lever to the twisted metal strip. The other end of the twisted metal strip is fastened to the cantilever strip. The overhanging length of the cantilever strip can be varied to adjust the magnification of the instrument. The longer the length of the cantilever, the more it will deflect under the pull of the twisted metal strip and less rotation of the pointer is obtained.

When the plunger moves by a small distance in upward direction the bell crank lever turns to the right hand side. This exerts a force on the twisted strip and it causes a change in its length by making it further twist or untwist. Hence the pointer at the centre rotates by some amount. Magnification up to 5000X can be obtained by this comparator



Advantages of Mechanical Comparator:

1. They do not require any external source of energy.

2. These are cheaper and portable.

3. These are of robust construction and compact design.

4. The simple linear scales are easy to read.

5. These are unaffected by variations due to external source of energy such air, electricityetc.

Disadvantages:

1. Range is limited as the pointer moves over a fixed scale.

2. Pointer scale system used can cause parallax error.

3. There are number of moving parts which create problems due to friction, and ultimatelythe accuracy is less.

4. The instrument may become sensitive to vibration due to high inertia.

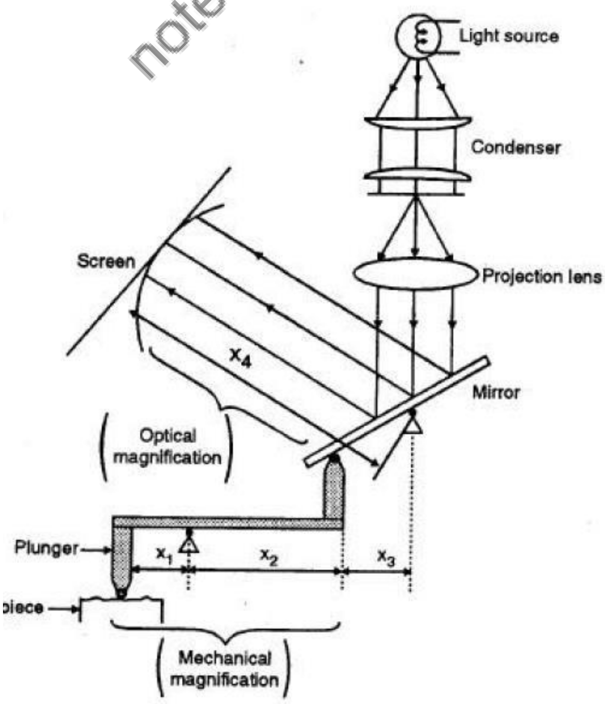
c) Mechanical - Optical Comparator:

Principle:

In mechanical optical comparator, small variation in the plunger movement is magnified: first by mechanical system and then by optical system.

Construction:

The movement of the plunger is magnified by the mechanical system using a pivoted lever. From the Figure the mechanical magnification = x2 / x1. High optical magnification is Mechanical Measurements and Metrology possible with a small movement of the mirror. The important factor is that the mirror used is of front reflection type only.



The back reflection type mirror will give two reflected images as shown in Figure,hence the exact reflected image cannot be identified.

Advantages:

1. These Comparators are almost weightless and have less number of moving parts, due tothis there is less wear and hence lessfriction.70

2. Higher range even at high magnification is possible as the scale moves past the index.

3. The scale can be made to move past a datum line and without having any parallax errors.

4. They are used to magnify parts of very small size and of complex configuration such asintricate grooves, radii or steps.

Disadvantages:

1. The accuracy of measurement is limited to 0.001 mm

2. They have their own built in illuminating device which tends to heat the instrument.

3. Electrical supply is required.

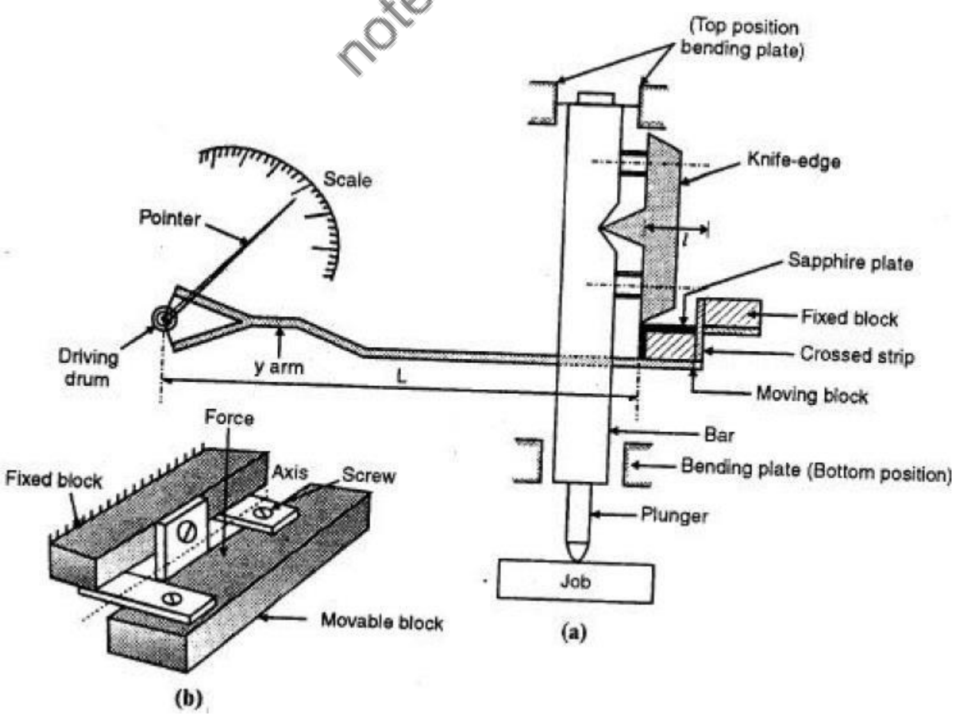
4. Eyepiece type instrument may cause strain on the operator.

5. Projection type instruments occupy large space and they are expensive.

6. When the scale is projected on a screen, then it is essential to take the instrument to a darkroom in order to take the readings easily.

d) Sigma Comparator:

The plunger is attached to a bar which is supported between the bending plates at thetop and bottom portion



The bar is restricted to move in the vertical direction. A knife edge is fixed to the bar.

The knife edge is attached to the sapphire plate which is attached to the moving block. The knife edge extorts a force on the moving block through sapphire plate. Moving block is attached to the fixed block with the help of crossed strips as shown in Figure (b). When the force is applied on the moving block, it will give an angular deflection. A Y-arm which is attached to the moving block transmits the rotary motion to the driving drum of radius r. This deflects the pointer and then the reading is noted.

If l = Distance from hinge pivot to the knife edge

L = Length of y-arm

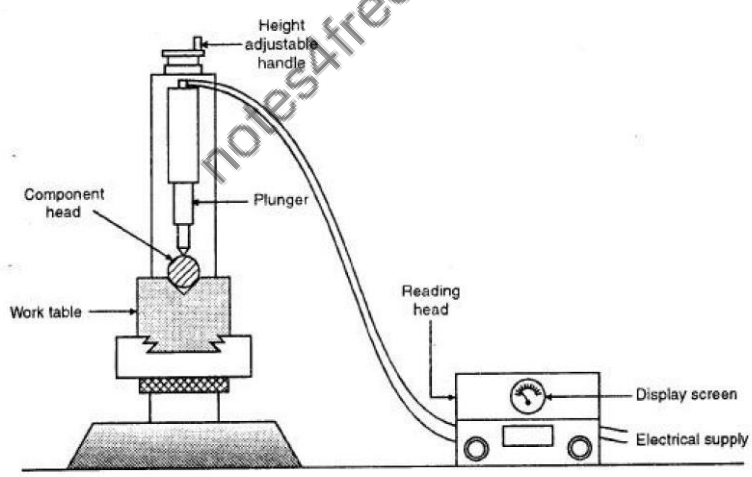
R = Driving drum radius

D Length of the pointer

Then the total magnification = (L/l) *(D/R)

2.6.3 Electrical Comparators

Electrical comparators give a wide range of advantages. As we know, components like levers, gears, racks and pinions, activate mechanical devices. The accuracy and life of the instruments are affected as they are subjected to wear and friction.



Electrical comparators have no moving parts. Thus a high degree of reliability is expected from these instruments. Generally there are two important applications of electrical comparators:

1. Used as measuring heads

2. Used for electrical gauging heads, to provide usual indication to check the dimensions within the limits laid down.

The first application is very important when there is a requirement for precise measurement for e.g. Checking or comparison of workshop slip gauges against inspection slip gauges. The second application is used to indicate with a green light if a dimension is within the limits. A red lamp indicates an undersize dimension; a yellow lamp indicates an oversize dimension. So the operator is not required to be aware of the actual tolerances on the dimension. After setting the instrument correctly, all that needs to be done is to place the component under the plunger of the gauging head. The signal lamps provide in standard positive indication of the acceptability of the dimension under test.

Advantages:

1. Measuring units can be remote from indicating units.
2. Variable sensitivity which can be adjusted as per requirement.
3. No moving parts, hence it can retain accuracy over long periods.
4. Higher magnification is possible as compared to mechanical comparator.

Disadvantages:

1. The accuracy of working of these comparators is likely to be affect due to temperature and humidity.
2. It is not a self contained unit; it needs stabilized power supply for its operation.
3. Heating of coils can cause zero drifts and it may alter calibration.
4. It is more expensive than mechanical comparator.

2.6.4 Pneumatic Comparators (Solex Gauge):

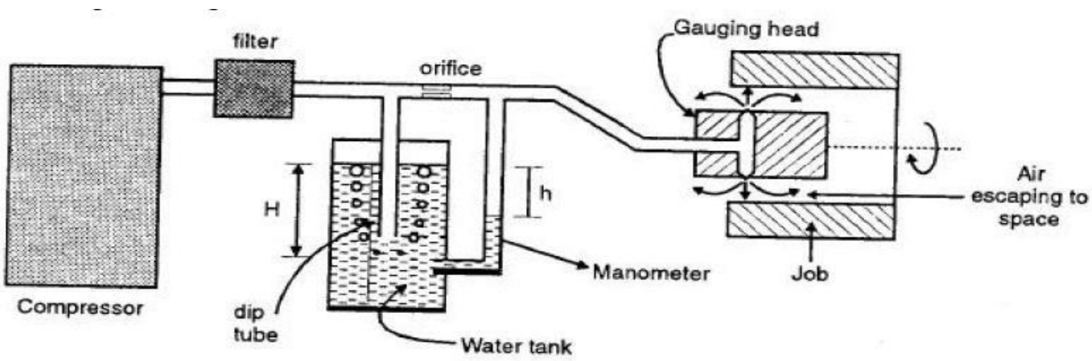
Principle:

It works on the principle of pressure difference generated by the air flow. Air issupplied at constant pressure through the orifice and the air escapes in the form of jetsthrough a restricted space which exerts a back pressure. The variation in the back pressure isthen used to find the dimensions of a component.

Working:

The air is compressed in the compressor at high pressure whichis equal to Water head H. The excess air escapes in the form of bubbles. Then the metric amount of air is passed through the orifice at the constant pressure. Due to restricted area, atA1 position, the back pressure is generated by the head of water displaced in the manometer tube. To determine the roundness of the job, the job is rotated along the jet axis, if no variation in the pressure reading is obtained then we can say that the job is perfectly circular at position A1.

Then the same procedure is repeated at various positions A2, A3, A4, position and variation in the pressure reading is found out. Also the diameter is measured at position A1corresponding to the portion against two jets and diameter is also measured at various position along the length of the bore.



Any variation in the dimension changes the value of h, e.g. Change in dimension of0.002 mm changes the value of h from 3 to 20 mm. Moderate and constant supply pressure is required to have the high sensitivity of the instrument.

Advantages:

1. It is cheaper, simple to operate and the cost is low.
2. It is free from mechanical hysteresis and wear.
3. The magnification can be obtained as high as 10,000 X.
4. The gauging member is not in direct contact with the work.
5. Indicating and measuring is done at two different places.
6. Tapers and ovality can be easily detected.
7. The method is self cleaning due to continuous flow of air through the jets and thismakes the method ideal to be used on shop floor for online controls.

Disadvantages:

1. They are very sensitive to temperature and humidity changes.
2. The accuracy may be influenced by the surface roughness of the component beingchecked.
3. Different gauging heads are needed for different jobs.
4. Auxiliary equipments such as air filters, pressure gauges and regulators are needed.
5. Non-uniformity of scale is a peculiar aspect of air gauging as the variation of backpressure is linear, over only a small range of the orifice size variation.

OUTCOMES

Students will be able to

1. Understand the concept of limits, fits, gauges
2. Analysis types of fits and gauges.
3. Understand the principle of Johnson Mikrokator, sigma comparator, dial indicator, LVDT, back pressure gauges, Solex comparators and Zeiss Ultra Optimeter

SELF ASSESEMENT QUESTIONS

1. What is a fit?
2. What is the difference between clearance and interference?
3. Mention the applications of clearance, interference and transitions fits.
4. Which of the following are clearance, transition and interference fits?
    i. Push fit,
    ii. Wringing fit,
    iii. Force fit, and
    iv. Slide fit.
5. Differentiate between „Hole basis system and „Shaft basis system.

FURTHER READING

1. Jain R. K., 1997, Engineering Metrology, Khanna Publishers.
2. Shawne A. K., 1998, Mechanical Measurement and Instrumentation, Dhanpat Rai and Co. (P) Ltd.
3. Hazra Chowdhury, 1995, Workshop Technology, Media Promoters and Publishers Pvt. Ltd

Module 3

INTERFEROMETER AND SCREW THREAD, GEAR MEASUREMENT

CONTENTS

OBJECTIVES

After studying this unit, you should be able to

1. familiarize yourself with the principle of interference, and
2. Understand the techniques and working of various devices based on the phenomenon of interference.

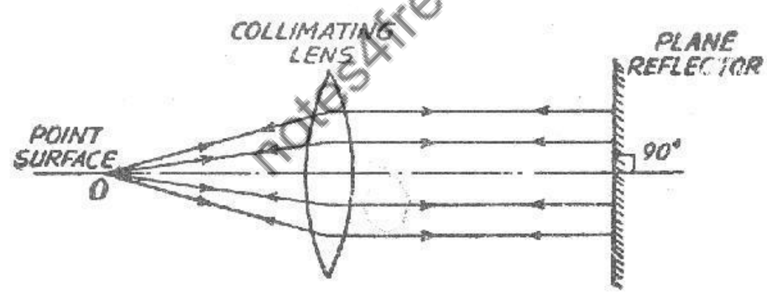
4.1 Interferometers:

They are optical instruments used for measuring flatness and determining the length of the slip gauges by direct reference to the wavelength of light. It overcomes the drawbacks of optical flats used in ordinary daylight. In these instruments the lay of the optical flat can be controlled and fringes can be oriented as per the requirement. An arrangement is made to view the fringes directly from the top and avoid any distortion due to incorrect viewing.

4.2 Autocollimators

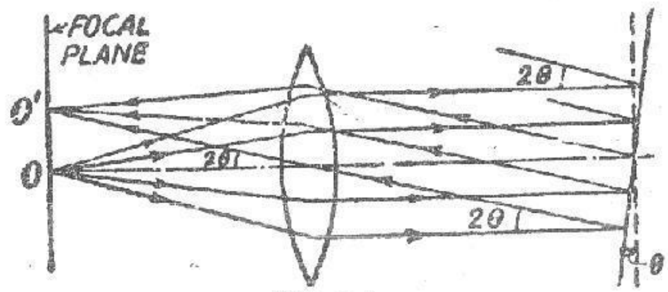
This is an optical instrument used for the measurement of small angular differences. For small angular measurements, autocollimator provides a very sensitive and accurate approach. Auto-collimator is essentially an infinity telescope and a collimator combined into one instrument. The principle on which this instrument works is given below. O is a point source of light placed at the principal focus of a collimating lens in Fig. 8.30. The rays of light from O incident on the lens will now travel as a parallel beam of light. If this beam now strikes a plane reflector which is normal to the optical axis, it will be reflected back along its own path and refocused at the same point O. If the plane reflector be now tilted through a

small angle 0, [Refer Fig] then parallel beam will be deflected through twice this angle, and will be brought to focus at O' in the same plane at a distance x from O. Obviously $OO'=x=2\theta.f$, where *f* is the focal length of the lens.



There are certain important points to appreciate here :

The position of the final image does not depend upon the distance of reflector from the lens, i.e.separation x is independent of the position of reflector from the lens. But if reflector is moved too much back then reflected rays will completely miss the lens and no image will be formed. Thus for full range of readings of instrument to be used, the maximum remoteness of the reflector is limited.



For high sensitivity, i.e., for large value of x for a small angular deviation θ, a long focal length is required.

1. Principle of the Autocollimator. A crossline "target" graticule is positioned at the focalplane of a telescope objective system with the intersection of the crossline on the optical axis, i.e. at the principal focus. When the target graticule is illuminated, rays of light diverging from the intersection point reach the objective via a beam splitter and are projected-from the objective as parallel pencils of light. In this mode, the optical system.is operating as a

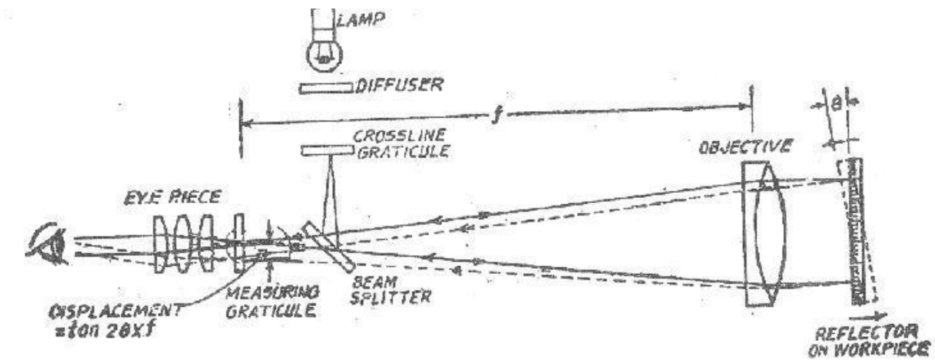
"collimator"

A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel pencils of light back along their original paths. They are then brought to focus in the plane of the target graticule and exactor coincident with its intersection. A proportion of the returned light passes straight through the beam splitter and the return image of the target crossline is therefore visible through the eyepiece. In this mode, the optical system is operating as a telescope focused at infinity.

If the reflector is tilted through a small angle the reflected pencils of light will be deflected by twice the angle of tilt (principle of reflection) and will be brought to focus in the

plane of the target graticule but linearly displaced from the actual target crosslines by an amount 2θ * *f*.

Linear displacement of the graticule image in the plane of the eyepiece is therefore directly proportional to reflector tilt and can be measured by an eyepiece graticule, optical micrometer no electronic detector system, scaled directly in angular units. The autocollimator is set permanently at infinity focus and no device for focusing adjustment for distance is provided or desirable. It responds only toreflector tilt (not lateral displacement of the reflector).



This is independent of separation between the reflector and the autocollimator, assuming no atmospheric disturbance and the use of a perfectly flat reflector. Many factors govern the specification of an autocollimator, in particular its focal length and its effective aperture. The focal length determines basic sensitivity and angular measuring range. The longer the focal length the larger is the linear displacement for a given reflector tilt, but the maximum reflector tilt which can be accommodated is consequently reduced. Sensitivity is

therefore traded against measuring range. The maximum separation between reflector and autocollimator, or "working distance", is governed by the effective aperture of the objective,

and the angular measuring range of the instrument becomes reduced at long working distances. Increasing the maximum working distance by increasing the effective aperture then demands a larger reflector for satisfactory image contrast. Autocollimator design thus involves many conflicting criteria and for this reason a range of instruments is required to optimally cover every application.

Air currents in the optical path between the autocollimator and the target mirror cause fluctuations in the readings obtained. This effect is more pronounced as. distance from autocollimator to target mirror increases. Further errors may also occur due to errors in flatness and reflectivity of the target mirror which should be of high quality.

When both the autocollimator and the target mirror gauge can remain fixed, extremely close readings may be taken and repeatability is excellent. When any of these has to be moved, great care is required.

Tests for straightness can be carried out by using spirit level or auto-collimator. Thestraightness of any surface could be determined by either of these instruments by measuring the relative angular positions of number of adjacent sections of the surface to be tested. So first a straight line is drawn on the surface whose straightness is to be tested. Then it is

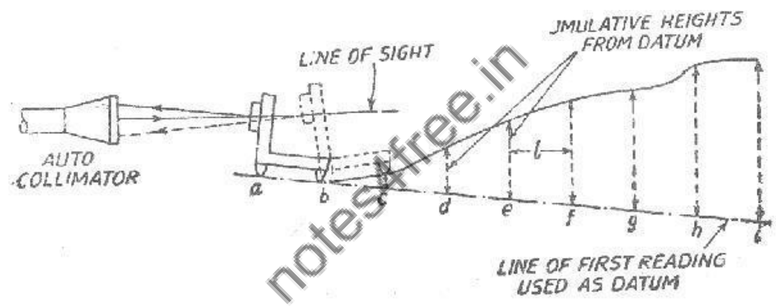
divided into a number of sections, the length of each section being equal to the length of spirit level base or the plane reflector's base in case of auto-collimator. Generally the bases of the

spirit level block or reflector are fitted with two feet so that only feet have line contact with the surface and whole of the surface of base does not touch the surface to be tested. This ensures that angular deviation obtained is between the specified two points. In this case length of each section must be equal to distance between the centre lines of two feet. The spirit level can be used only for the measurement of straightness of horizontal surfaces while auto-collimator method can be used on surfaces in any plane. In case of spirit level, the block is moved along the line on the surface to be tested in steps equal to the pitch distance between the centre lines of the feet and the angular variations of the direction of block are measured by the sensitive level on it. Angular variation can be correlated in terms of the difference of height between two points by knowing the least count of level and length of the base.

In case of measurement by auto-collimator, the instrument is placed at a distance of 0.5 to 0.75 metre from the surface to be tested on any rigid support which is independent of the surface to be tested. The parallel beam from the instrument is projected along the length of the surface to be tested. A block fixed on two feet and fitted with a plane vertical reflector is placed on the surface and the reflector face is facing the instrument. The reflector and the instrument are set such that the image of the cross wires of the collimator appears nearer the centre of the field and for the complete movement of reflect or along the surface straight line, the image of cross-wires will appear in the field of eyepiece. The reflector is then moved to the other end of the surface in steps equal to the centre distance between the feet and the tilt of the reflector is noted down in seconds from the eyepiece.

1 sec. of arc=0.000006 mm/mm

Therefore, 1 sec. of arc will correspond to a rise or fall of 0.000006* *l* mm, where I is the distance between centres of feet in mm. The condition for initial and subsequent readings is shown in Fig. 7.2 in which the rise and fall of the surface is shown too much exaggerated.



With the reflector set at a—b (1st reading), the micrometer reading is noted and this line is treated as datum line. Successive readings at b—c, c—d, d—e etc. are taken till the length of the surface to be tested has been stepped along. In other to eliminate any error in previous set of readings, the second set of readings could be taken by stepping the reflector in the reverse direction and mean of two taken. This mean reading represents the angular position of the reflector in seconds relative to the optical axis or auto-collimator.

Column 1 gives the position of plane reflector at various places at intervals of *'l'* e.g. a—b, b—c, c—d etc., column 2 gives the mean reading of auto-collimator or spirit level in seconds. In column 3, difference of each reading from the first is given in order to treat first reading as datum. These differences are then converted into the corresponding linear rise or fall in column 4 by multiplying column 3 by *'l'*. Column 5 gives the cumulative rise or fall, i.e., the heights of the support feet of the reflector above the datum line drawn through their first position. It should be noted that the values in column 4 indicate the inclinations only and are not errors from the true datum. For this the values are added cumulatively with due regard for sign. Thus it leaves a final displacement equal to L at the end of the run which of course does not represent the magnitude of error of the surface, but is merely the deviation from a straight line produced from the plane of the first reading. In column 5 each figure represents a point, therefore, an additional zero is put at the top representing the height of point *a*.

The errors of any surfaced may be required relative to any mean plane. If it be assumed that mean plane is one joining the end points then whole of graph must be swung round until the end point is on the axis (Fig. 7.3). This is achieved by subtracting the length L

proportionately from the readings in column 5. Thus if n readings be taken, then column 6 gives the adjustments— L/n, —2L/n… etc., to bring both ends to zero. Column 7 gives the

difference of columns 5 and 6 and represents errors in the surface from a straight line joining the end points. This is as if a straight edge were laid along the surface profile to be tested and touching the end points of the surface when they are in a horizontal plane and the various readings in column 7 indicate the rise and fall relative to this straight edge.

4.3 Optical Flat:

1. Optical flat are flat lenses, made from quartz, having a very accurate surface to transmit light.

2. They are used in interferometers, for testing plane surfaces.

3. The diameter of an optical flat varies from 50 to 250mm and thickness varies from 12 to 25 mm.

4. Optical flats are made in a range of sizes and shapes.
5. The flats are available with a coated surface.

6. The coating is a thin film, usually titanium oxide, applied on the surface to reduce the light lost by reflection.

7. The coating is so thin that it does not affect the position of the fringe bands, but a coated flat

The supporting surface on which the optical flat measurements are made must provide a clean, rigid platform. Optical flats are cylindrical in form, with the working surface and are of two types are **i) type A**, ii) **type B.**

- **Type A:** It has only one surface flat and is used for testing flatness of precisionmeasuring surfaces of flats, slip gauges and measuring tables.

  For these optical flats.their diameter and grade are important. The dimensions of an optical flat of grades I and II can be 25 x 10, 30 x 10,50 x 15, 75 x 20, 100x 25, 125 x 30, 160 x 35 (diameter thickness in mm). The tolerance on flat should be 0.05 µm for type A.

- **Type B:** It has both surfaces flat and parallel to each other. They are used for testingmeasuring surfaces of micrometers. measuring anvils and similar length of measuring devices for testing flatness and parallelism. For these instruments, their thickness and grades are important. The tolerances on flatness, parallelism and thickness should be 0.05 µm.

Care in the use of optical flats:

- Before using, it should be ensured that. that the workpiece and flat arc clean and free from dirt, dust and oil. Paper or chamois is used for polishing their surfaces.

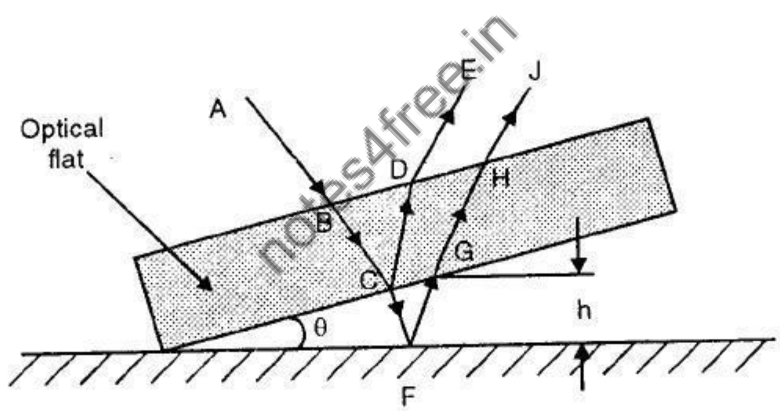
- Optical flats should never be slided over the workpiece but lifted from it. Sliding, creeping and wringing of flat over workpiece are extremely harmful and should be avoided.

3. Flats should never be wrung on workpiece because it scratches readily. It should be rested carefully on the workpiece.

4. If interference bands are not good. flat should be lifted and set down again, applying vertical finger pressure at various locations on the upper surface to obtain satisfactory bands.

Interference Bands by Optical Flat:

Optical flats arc blocks of glass finished to within 0.05 microns for flatness. When art optical flat is on a flat surface which is not perfectly flat then optical flat will not exactly coincide with it, but it will make an angle e with the surface as shown in Figure



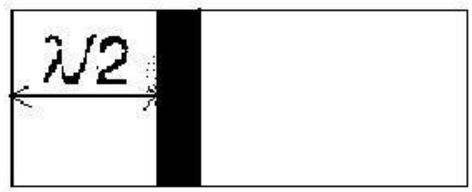
When a beam AB of monochromatic light falls on the optical flat, it travels further along BC. At C, part of this light is reflected by the bottom of the optical flat and goes along CDE, the remaining part goes along CF, reflected at F by the surface under test and goes further along FGHJ. The two beams DE and HJ differ in phase because of the extra distance

CFG traveled by HJ. If the air gap between the bottom of the optical flat and the test surface is denoted by 'h' since θ is very small, then for vertically incident beams h = CF = FG = (λ /

4) where λ = wavelength of source and thus beam HJ will lag behind DE by 2h. When this lag is half the wavelength, the two beams DE and HJ will be in opposite phase and a state of

darkness will be created. At all points where the air gap is present then darkness will be created. At all points where the air gap is present then darkness will be observed at λ / 2

distance as shown in Figure



In other words, all points with air gap h will form a dark band. As we move along the

wedge to the right side, to point K, L, value of h goes on increasing and hence the phase difference between the two rays will go on increasing from λ/2 and will reach A at some

point. At these points as the air gap increases, for every ~ increase, the bright bands will be seen as shown in Figure

To check the flatness of slip gauge surface using optical flat:

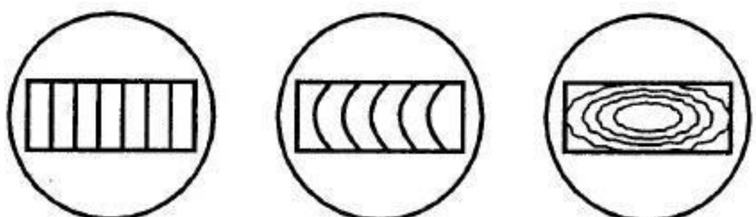
The apparatus required is a monochromatic light source and optical flat. If optical flat is placed on slip gauge, it will not form an intimate contact, but will be at some angle 'θ'

making an inclined plane. If the optical flat is illuminated by monochromatic light and eye if placed in proper position will observe number of bands. They are produced by interference of light rays reflected from lower plane of optical flat and top surface of slip gauge

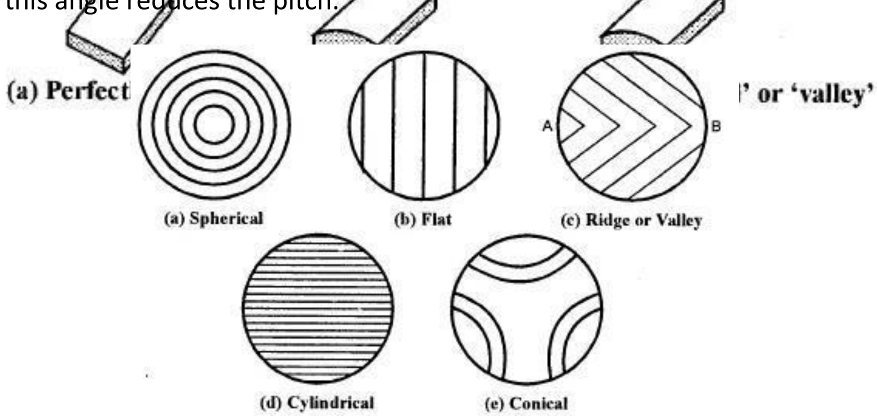
They are produced by interference of light rays reflected from lower plane of optical flat and top surface of slip gauge. As shown in Figure, if 'S' is monochromatic light source. At 'C' ray is reflected in direction CDE. The two reflected components are combined by eye, having traveled path whose wavelengths differ by an amount ACD. If path lengths differ by odd number of $\lambda/2$ then interference is said to have occurred. If surface is perfectly flat then

the surface will be crossed by the pattern of alternate light and dark bands which will be straight and dark line is seen passing at C. The next line occurs at $3\lambda / 2$ (i.e. FHI $=3\lambda / 2$)

alternate dark and bright fringes are seen and variation from the straightness of the bands measure the error in the flatness of slip gauge



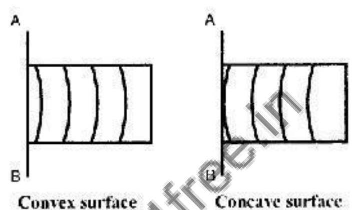
he pitch of the bands depends on the angle of the wedge and it can be easily seen that increase in this angle reduces the pitch.



The orientation of the bands depends on the orientation of the wedge. The spherical surface can be concave or convex and a little pressure on the optical flat at the centre will spread the bands outwards in a convex way. Figure shows interference band patterns on various surfaces. This fact can be used for drawing various conclusions about the nature of the surface by applying pressure on the optical flat at various points and observing the change in the pattern of bands.

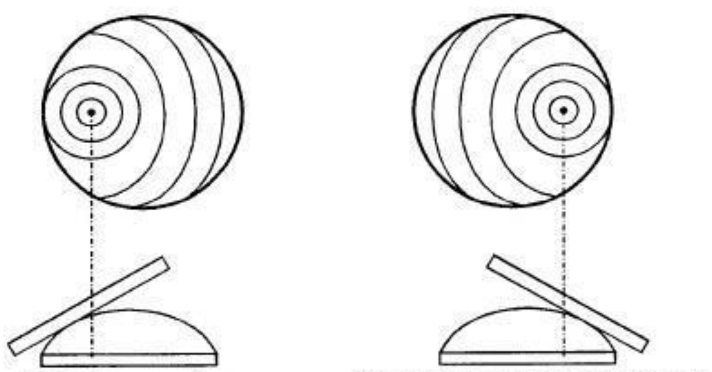
Concave and Convex Surface:

If AB is the line of contact then a general rule to identify the concave and convex surface is that if the band curve is around the point or line of contact, then the surface is convex and if the band curve is in the opposite direction then the surface is concave.



Spherical concave and convex surface can be identified by the following Figures.

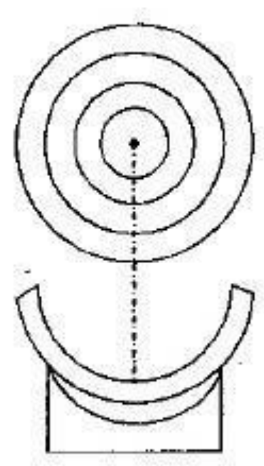
a. Convex surfac



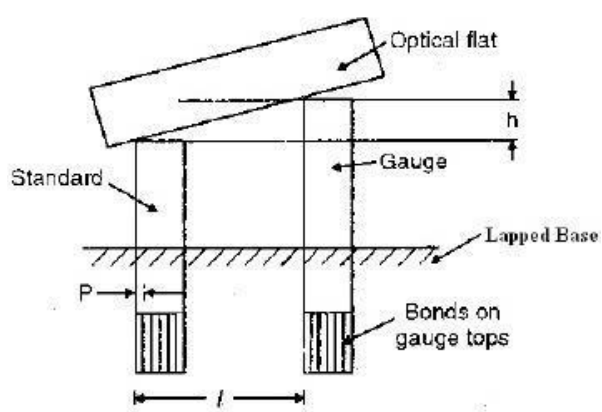
(a) Interference pattern of a spherical convex surface

(b) Interference pattern of a spherical convex surface changing with their reference

b. Concave Surface:



Checking of heights and Parallelism of Slip gauge with Optical Flat: The standard gaugeand the gauge under test have their ends perfectly flat and parallel, they differ in length by the amount 'h' shown, which may be a few microns. The experiment aims at finding the value of h. The standard and the gauge are wrung on to a perfectly flat lapped base. The optical flat is placed in good contact but not wrung to the gauge tops. The orientation of the flat is adjusted till pattern of bands parallel to the sides of the gauges is obtained.



Comparison of End Gauges

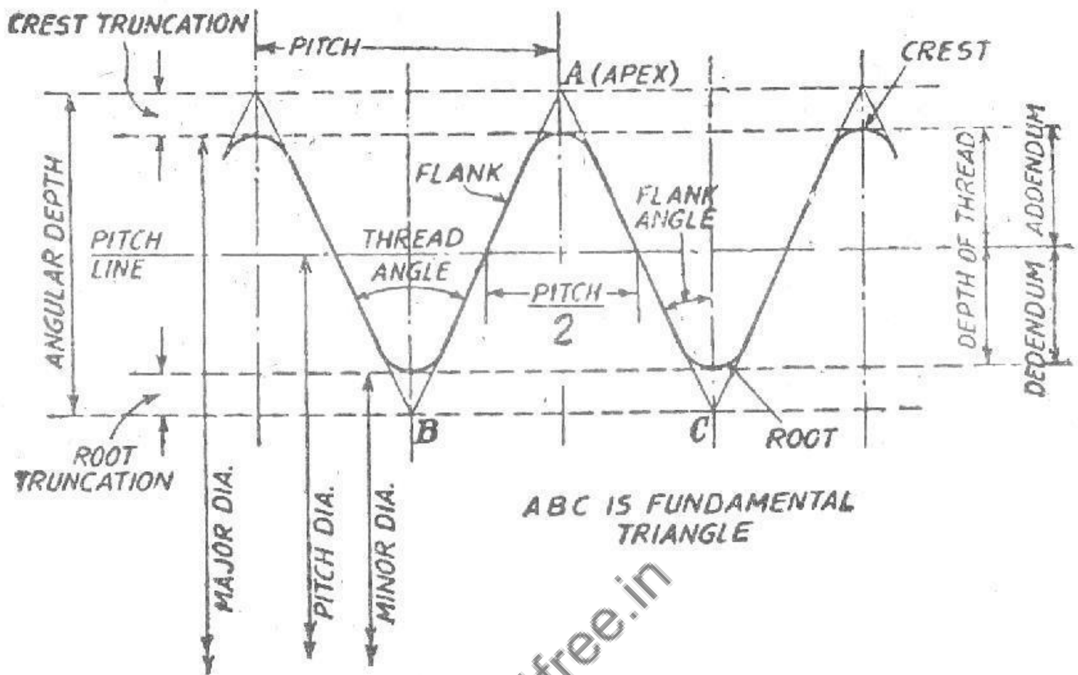
The distance l is noted down and the pitch P of the bands is found by counting the,

total number of bands on the gauge faces. As each band represents a air gap change of λ/2, the value of h will be (l / p) λ/2

Whether the length of the gauge is more or less than the master, can be found out by observing the change in the pitch of the bands on the two gauges, when a little pressure is applied at the centre of the flat.

An experimental method of comparing two end gauges is more of academic interest, than of any practical value is show Figure. In the situation shown in the Figure such pressure will decrease the wedge angle with standard and increase it with the gauge, thereby making the bands on the standard, wider and those on the gauge, narrower. Also the parallelism between the gauge and standard can be observed with optical flat. The variation in the band can be seen as shown in Figure.

4.5 Screw Threads Terminology:



1. **Screw thread.** A screw thread is the helical ridge produced by forming a continuoushelical groove of uniform section on the external or internal surface of a cylinder or cone. A screw thread formed on a cylinder is known as straight or parallel screw thread, while the one formed on a cone or frustum of a cone is known as tapered screw thread.

2. **External thread**. A thread formed on the outside of a workpiece is called external thread e.g., on bolts or studs etc.

3. **Internal thread**. A thread formed on the inside of a workpiece is called internal thread e.g. on a nut or female screw gauge.

4. **Multiple-start screw thread**. This is produced by forming two or more helical grooves, equally spaced and similarly formed in an axial section on a cylinder. This gives a 'quick traverse' without sacrificing core strength.

5. **Axis of a thread.** This is imaginary line running longitudinally through the centreof the screw.

6. **Hand (Right or left hand threads).** Suppose a screw is held such that the observer is looking along the axis. If a point moves along the thread in clockwise direction and thus moves away from the observer, the thread is right hand ; and if it moves towards the observer, the thread is left hand.

7. **Form, of thread.** This is the shape of the contour of one- complete thread as.seen in axial section.

8. **Crest of thread**. This is defined as the prominent part of thread, whether it beexternal or internal.

9. **Root of thread**. This is defined as the bottom of the groove between the two flanksof the thread, whether it be external or internal.

10. **Flanks of thread.** These are straight edges which connect the crest with the root.

11. **Angle of thread {Included angle).** This is the angle between the flanks or slope of the thread measured in an axial plane.

12. **Flank angle.** The flank angles are the angles between individual flanks and theperpendicular to the axis of the thread which passes through the vertex of the fundamental triangle. The flank angle of a symmetrical thread is commonly termed as the half- angle of thread.

13. **Pitch.** The pitch of a thread is the distance, measured parallel to the axis of thethread, between corresponding points on adjacent thread forms in the same axial plane and on the same side of axis. The basic pitch is equal to the lead divided by the number of thread starts. On drawings of thread sections, the pitch is shown as the distance from the centre of one thread crest to the centre of the next, and this representation is correct for single start as well as multi-start threads.

14. **Lead.** Lead is the axial distance moved by the threaded part, when it is given onecomplete revolution about its axis with respect to a fixed mating thread. It is necessary to distinguish between measurements of lead from measurement of pitch, as uniformity of pitch measurement does not assure uniformity of lead. Variations in either lead or pitch cause the functional or virtual diameter of thread to differ from the pitch diameter.

15. **Thread per inch.** This is the reciprocal of the pitch in inches.

16. **Lead angle**. On a straight thread, lead angle is the angle made by the helix of thethread at the pitch line with plane perpendicular to the axis. The angle is measured in an axial plane.

17. **Helix angle.** On straight thread, the helix angle is the angle made by the helix ofthe thread at the pitch line with the axis. The angle is measured in an axial plane.

18. **Depth of thread**. This is the distance from the crest or tip of the thread to the rootof the thread measured perpendicular to the longitudinal axis or this could be defined as the distance measured radially between the major and minor cylinders.

19. **Axial thickness.** This is the distance between the opposite faces of the samethread measured on the pitch cylinder in a direction parallel to the axis of thread.

20. **Fundamental triangle**. This is found by extending the flanks and joining the pointsB and C. Thus in Fig. 13.2, triangle ABC is referred to as fundamental triangle. Here BC=pitch and the vertical height of the triangle is called the angular or theoretical depth. The point A is the apex of the triangle ABC.

21. **Truncation.** A thread is sometimes truncated at the crest or at the root or at bothcrest and root. The truncation at the crest is the radial distance from the crest to the nearest apex of the fundamental triangle. Similarly the truncation at the root is the radial distance from the root to the nearest apex.

22. **Addendum.** For an external thread, this is defined as the radial distance between the major and pitch cylinders. For an internal thread this is the radial distance between the minor and pitch cylinders.

23. **Dedendum.** This is the radial distance between the pitch and minor cylinder forexternal thread, and for internal thread, this is the radial distance between the major and pitch cylinders.

24. **Major diameter.** In case of a straight thread, this is the diameter of the majorcylinder (imaginary cylinder, co-axial with the screw, which just touches the crests of an external thread or the root of an internal thread). It is often referred to as the outside diameter, crest diameter or full diameter of external threads.

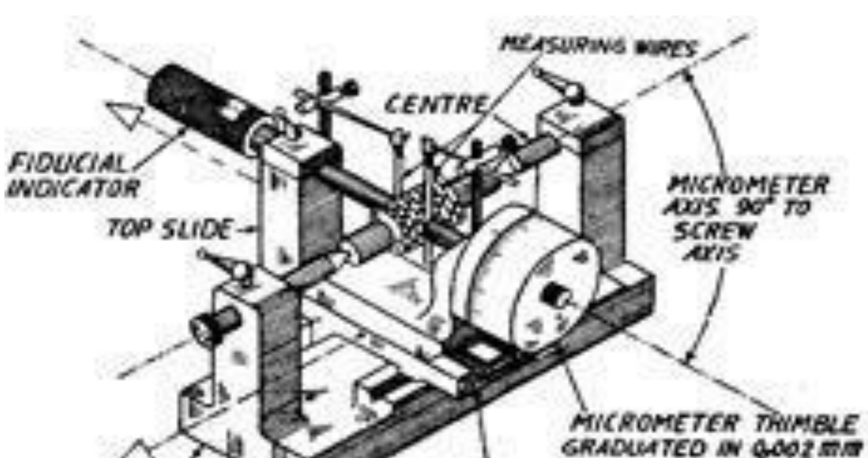
25. **Minor diameter.** In case of straight thread, this is the diameter of the minor cylinder(an imaginary cylinder, co-axial with the screw Which just touches the roots of an external thread or the crest of an internal thread). It is often referred to as the root diameter or cone diameter of external threads.

26. **Effective diameter or pitch diameter.** In case of straight thread, this is the diameterof the pitch cylinder (the imaginary' cylinder which is co-axial with the axis of the screw, and intersects the flank of the threads in such a way as to make the width of threads and width of the spaces between the threads equal). If the pitch cylinder be imagined as generated by a straight line parallel to the axis of screw, that straight line is then referred to as the pitch line. Along the pitch line, the widths of the threads and the widths of the spaces are equal on a perfect thread. This is the most important dimension at it decides the quality of the fit between the screw and the nut.

27. **Functional (virtual) diameter.** For an external or internal thread, this is the pitchdiameter of the enveloping thread of perfect pitch, lead and flank angles having full depth of engagement but clear at crests and roots. This is defined over a specified length of thread. This may be greater than the simple effective diameter by an amount due to errors in pitch and angle of thread. The virtual diameter being the modified effective diameter by pitch and angle errors, is the most important single dimension of a screw thread gauge.

In the case of taper screw thread, the cone angle of taper, for measurement of effective diameter, and whether pitch is measured along the axis or along the pitch cone generator also need to be specified.

Measurement of screw threads- principles of floating carriage micrometer,



It consists of three main units. A base casting carries a pair of centres, on which the threaded work-piece is mounted. Another carriage is mounted on it and is exactly at 90° to it. On this is provided another carriage capable of moving towards the centres. On this carriage one head having a large thimble enabling reading upto 0.002 mm is provided. Just opposite toit is a fixed anvil which is spring loaded and its zero position is indicated by a fiducial indicator. Thus the micrometer elements are exactly perpendicular to the axis of the centres as the two carriages are located perpendicular to each other. On the fixed carriage the centres are supported in two brackets fitted on either end. The distance between the two centres can be adjusted depending upon the length of tie threaded job. After job is fitted between the centres the second carriage is adjusted in correct position to take measurements and is located in position, The third carriage is then moved till the fiducial indicator is against the set point. The readings are noted from the thimble head. It is now obvious that the axis of the indicator and micrometer head spindle is same and is perpendicular to the line of two centres. The indicator is specially designed for this class of work and has only one index line, against which the pointer is always to be set. This ensures constant measuring pressure for all readings. Sufficient friction is provided by the conical pegs to restrain the movement of carriage along the line of centres. The upper carriage is free to float on balls and enables micrometer readings to be taken on a diameter without restraint. Squareness of the micrometer to the line of centre can be adjusted by rotating the pegs in the first carriage which is made eccentric in its mounting.

Above the micrometer carriage, two supports are provided for supporting the wires and Vee-pieces for measurement of effective diameter etc.

<u>(i) Measurement of Major Diameter.</u>

For the measurement of major diameter of external threads, a good quality hand micrometer is quite suitable. In taking readings, a light pressure must be used as the anvils make contact with the gauge at points only and otherwise the errors due to compression can be introduced. It is, however, also desirable to check the micrometer reading on a cylindrical standard of approximately the same size, so that the zero error etc., might not come into picture.

For greater accuracy and convenience, the major diameter is measured by bench micrometer. This instrument was designed by N.P.L. to estimate some deficiencies inherent in the normal hand micrometer. It uses constant measuring pressure and with this machine the error due to pitch error in the micrometer thread is avoided. In order that all measurements be made at the same pressure, a fiducial indicator is used in place of the fixed anvil. In this machine there is no provision for mounting the workpiece between the centres and it is to be held in hand. This is so, because, generally the centres of the workpiece are not true with its diameter. This machine is used as a comparator in order to avoid any pitch errors of micrometers, zero error setting etc. A calibrated setting cylinder is used as the setting standard.

The advantage of using cylinder as setting standard and not slip gauges etc., is that it gives greater similarity of contact at the anvils. The diameter of the setting cylinder must be nearly same as the major diameter. The cylinder is held and the reading of the micrometer is noted down. This is then replaced by threaded workpiece and again micrometer reading is noted for the same reading of fiducial indicator. Thus, if the size of cylinder is approaching, that of major diameter, then for a given reading the micrometer thread is used over a short length of travel and any pitch errors it contains are virtually eliminated.

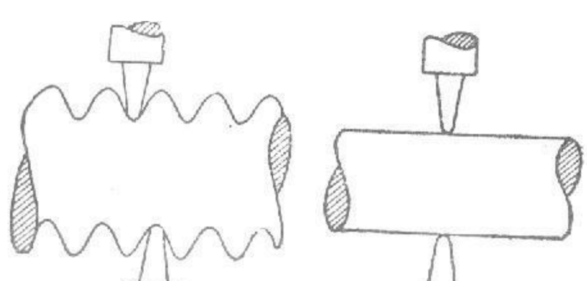
Then major diameter=D1+(R2−R1).

In order- to determine the amount of taper, the readings should' be taken at various positions along the thread and to detect the ovality, two or three readings must be taken at one plane in angular positions.

(ii) Measurement of Minor Diameter

This is also measured by a comparative process using small Vee-pieces which make

contact with a root of the thread. The Vee-pieces are available in several sizes having suitable radii at the edges. The included angle of Vee-pieces is less than the angle of the thread to be checked so that it can easily probe to the root of the thread. To measure the minor diameter by Vee-pieces is suitable for only Whitworth and B.A. threads which have a definite radius at the root of the thread. For other threads, the minor diameter is measured by the projector or microscope.



The measurement is carried out on a floating carriage diameter measuring machine in which the threaded work-piece is mounted between centres and a bench micrometer is constrained to move at right angles to the axis of the centre by a Vee-ball slide. The method of the application of Vee-pieces in the machine is shown diagrammatically in Fig.. The dimensions of Vee-pieces play no important function as they are interposed between the micrometer faces and the cylindrical standard when standard reading is taken.

It is important while taking readings, to ensure that the micrometer be located at right angles to the axis of the screw being measured. The selected Vees are placed on each side of the screw with their bases against the micrometer faces. The micrometer head is then advanced until the pointer of the indicator is opposite the zero mark, and note being made of the reading. The screw is then replaced by standard reference disc or a plain cylindrical standard plug gauge of approximately the core diameter of the screw to be measured and second reading of the micrometer is taken.

If reading on setting cylinder with Vee-pieces in position=R_1
and reading on thread =R_2

and diameter of setting cylinder=D_1
Then minor diameter =$D_1 + (R_2 - R_1)$

Readings may be taken at various positions in order to determine the taper and ovality.

(iii) Effective Diameter Measurements.

The effective diameter or the pitch diameter can be measured by .any one of the following methods :

(i) The micrometer method
(ii) The one wire, two wire, or three wire or rod method.

Two Wire Method.

The effective diameter of a screw thread may be ascertained by placing two wires or rods of identical diameter between the flanks of the thread, as shown in Fig. 13.15, and measuring the distance over the outside of these wires. The effective diameter E I s then calculated as

E=T+P

Where T= Dimension under the wires =M—2d

M=dimension over the wires, d= diameter of each wire

$E = T + P$
Where T=Dimension under the wires
$= M - 2d$
M=dimension over the wires, d=diameter of each wire

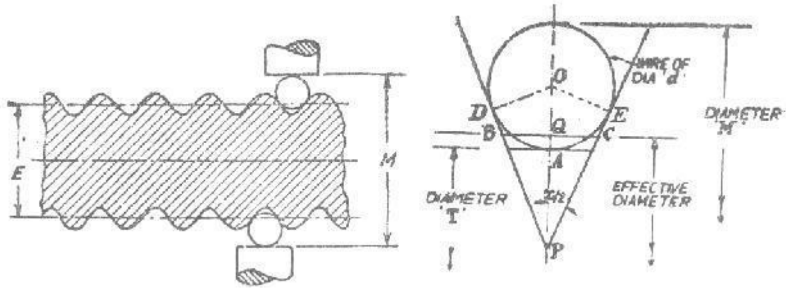


Fig (a) **Fig (b)**

The wires used are made of hardened steel to sustain the wear and tear in use. These are given a high degree of accuracy and finish by lapping to suit different pitches.

Dimension T can also be determined by placing wires over a standard cylinder of diameter greater than the diameter under the wires and noting the reading R_1 and then taking reading with over the gauge, say R_2. Then $T=S—(R_1—R_2)$.

P=It is a value which depends upon the dia of wire and pitch of the thread.

If P= pitch of the thread, then

$P= 0.9605p-1.1657d$ (for Whitworth thread).

$P= 0.866p—d$ (for metric thread).

Actually P is a constant Value which has to be added to the diameter under the wires to give the effective diameter. The expression for the value of P in terms of p (pitch), d (diameter of wire) and x (thread angle) can be derived as follows :

In Fig.13.15(b), since BC lies on the effective diameter line

$BC= ½\ pitch=½\ p$

$OP=d\ cosec\ x/2/2$

$PA=d(cosec x/2-1)/2$

$PQ=QC\ cot\ x/2=p/4\ cot\ x/2$

$AQ=PQ-AP=p\ cot\ x/2/4 - d(cosec\ x/2-1)/2$

AQ is half the value of P

$\therefore$ P value=2AQ

$=p/2\ cot\ x/2 - d\ (cosec x/2-1)$

Two wire method can be carried out only on the diameter measuring machine described for measuring the minor diameter, because alignment is not possible by 2 wires and can be provided only by the floating carriage machine. In the case of three wire method, 2 wire, on one side help in aligning the micrometer square to the thread while the third placed on the other side permits taking of readings.

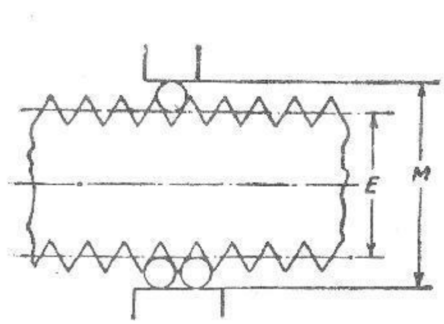
4.6 Three Wire Method.

This method of measuring the effective diameter is an accurate method. In this three wires or rods of known diameter are used ; one on one side and two on the other side {Fig. 13.17 (a) and (&)]. This method ensures the alignment of micrometer anvil faces parallel to the thread axis. The wires may be either held in hand or hung from a stand so as to ensure freedom to the wires to adjust themselves under micrometer pressure.

M=distance over wires E=effective diameter

r=radius of the wires d=diameter of wires

h =height of the centre or the wire or rod from the effective x=angle of thread.



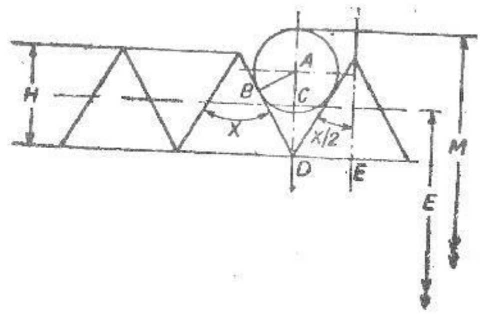


Fig (a) **Fig (b)**

From fig.(b),

AD = AB cosec $x/2$ = r cosec $x/2$

H = DE cot $x/2$ = $p/2$ cot $x/2$

CD = ½H = $p/4$ cot $x/2$

H = AD−CD

r = cosec $x/2$− $p/4$ cot $x/2$

Distance over wires=M = E+2h+2r

= E+2(r cosec $x/2$ – $p/4$ cot $x/2$)+2r

= E+2r (l+cosec $x/2$)– $p/2$ cot $x/2$

or M = E+d (1+cosec $x/2$) − $p/2$ cot $x/2$

(since 2r = 0)

(i) In case of Whitworth thread:

X = 55°, depth of thread = 0.64 p, so that

E= D—0.64 p and cosec $x/2$ = 2.1657

Cot $x/2$ = 1.921

M = E+d(1l+cosec $x/2$) — $p/2$ cot $x/2$

$= D - 0.64p + d(1 + 2.1657) - p/2(1.921)$

$= D + 3.1657d - 1.6005p$

$M = D + 3.1657d - 1.6p$

where D=outside dia.

(ii) In case of metric threads:

Depth of thread=0.6495p

so, $E = D - 0.6495p$.

$x = 60°$, $\text{cosec } x/2 = 2$; $\cot x/2 = 1.732$

$M = D - 0.6495\,p + d(l+2) - p/2\,(1.732)$

$= D + 3d - (0.6495 + 0.866)p$

$= D + 3d - 1.5155p$.

We can measure the value of M practically and then compare with the theoretical values with the help of formulae derived above. After finding the correct value of M and knowing d, E can be found out.

If the theoretical and practical values of M (i.e. measured over wires) differ, then this error is due to one or more of the quantities appearing in the formula.

Effect of lead angle on measurement by 3- wire method. If the lead angle is large (as withworms; quick traversing lead screw,etc .) then error in measurement is about 0’0125 mm

when lead angle is 41° for 60° single thread series.

For lead angles above 4£°, the compensation for rake and compression must also be taken into account.

There is no recommendation for **B.S.W.** threads.

Rake Correction in U.S. Standard :

$$E = M + \cot x/2/2n—- - x(1 + \mathrm{cosec}\, x/2 + s^2/2 \cos x/2 \cot x/2)$$

where

x/2 =half the included angle of threads.

E = effective diameter

M = actually measured diameter over wires:
n = number of threads/inch.

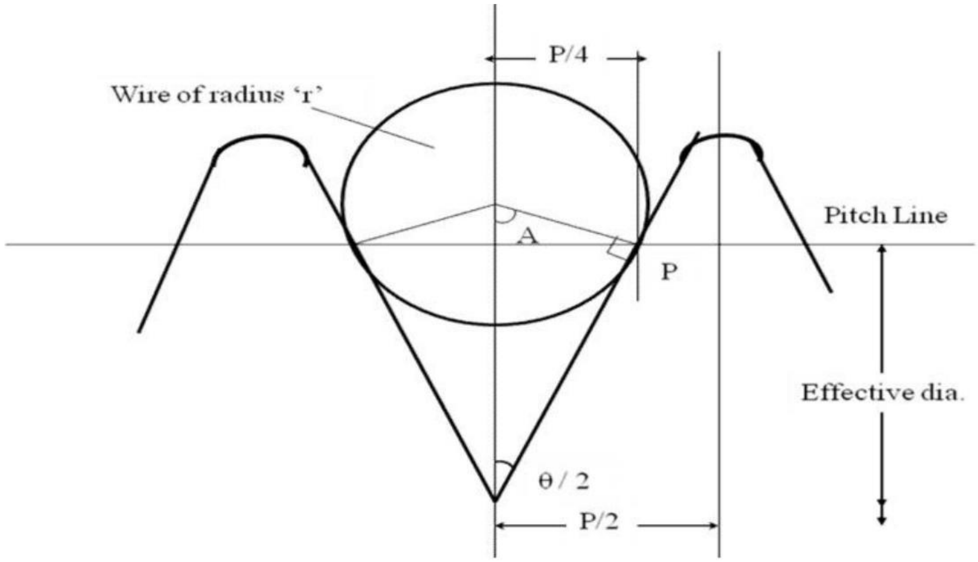
d = diameter of wire.

S = tangent of the helix angle in thread.

Best size wire Method.

This wire is of such diameter that it makes contact with the flanks of the thread on the effective diameter or pitch line. The effective diameter can be measured with any diameter

wire which makes contact on the true flank of the thread, but the values so obtained will differ from those obtained with ‘best size’ wires if there is any error in angle or form of thread. t is recommended that for measuring the effective diameter, always the best size wire should be used and for this condition the wire touches the flank at mean diameter line within ±1/5 of flank length



θ

Let the thread angle be $\frac{-}{2}$

Then in Δle OAP, Sin POA = $\frac{AP}{OP}$

Or sin $(90^0 - \frac{\theta}{2}) = \frac{AP}{OP}$

$$OP = \frac{AP}{\sin(90^0 - \frac{\theta}{2})} = \frac{AP}{\cos\frac{\theta}{2}} = AP \sec\frac{\theta}{2}$$

Since, $OP = r = AP \sec\frac{\theta}{2}$

And wire diameter $= D_b = 2r = 2AP \sec\frac{\theta}{2}$

Since AP lies on the pitch line

$AP = \frac{P}{4}$ where, p is the pitch of the thread

Therefore, $D_b = \frac{2P}{4} \sec\frac{\theta}{2}$

Therefore,

$$D_b = \frac{P}{2} \sec\frac{\theta}{2}$$

4.7 Tool Makers Microscope:

The toolmaker's microscope is an optical measuring machine equipped for external and internal length measurements as well as measurements on screw threads, profiles, curvatures and angles. For these purposes, the microscope is provide with several measuring attachments such as

1. Centre stage for mounting of cylindrical components,
2. Revolving and angle measuring oculars,
3. Double image ocular,
4. Optical feeder, and
5. Projection screen.

The applications of the instrument may be· summarized lows: broadly as follows.

1. The determination of the relative position of various Points on work by measuring the travel necessary to bring a second point to the position previously occupied by the first, and so on. .

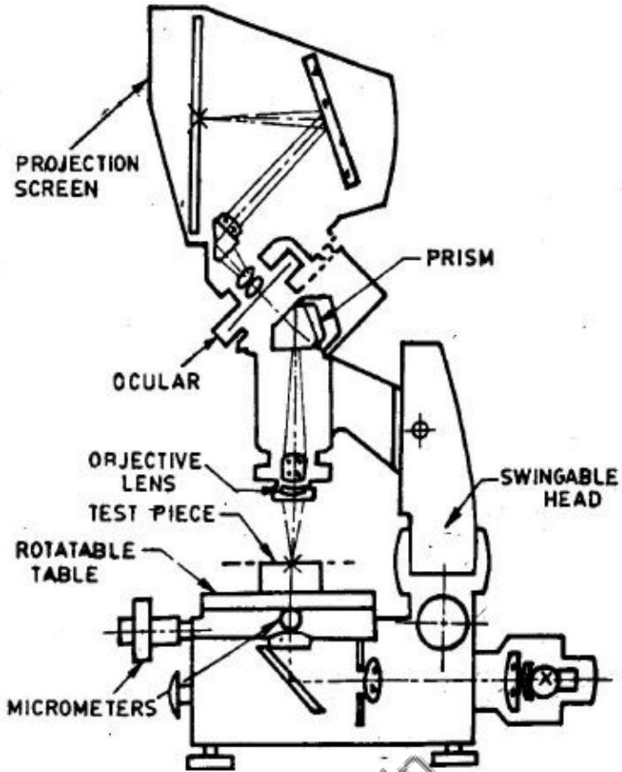
2. Measurement of angles by using a protractor eye-piece.

3. Comparison of thread forms with master profiles engraved in the eyepiece and measurement of pitch and effective diameter.

4. Comparison of an enlarged, projected image with a scale tracing fixed to the projection screen.

Figure shows a toolmaker's microscope. The main parts of the instrument are:

1. Rotatable table
2. Swingable head
3. Projection screen
4. Objective lens
5. Measuring stage
6. Ocular
7. Micrometers
8. Prism.



Construction:

The microscope consists of a rigid stand on which a swingable head is mounted. The measuring stage moves on ball guideways by actuating two measuring micrometersarranged perpendicular to each other in the length. and the cross-sections. The measuring range of each micrometer is 25 mm and the measuring capacity can be increased using slip gauges. A rotatable table is provided over the stage, on which the workpiece can be fixed either directly or between centers. This table can be rotated though 3600 and the angular rotation can be read by a fixed vernier to a scale value of 3'.

Working:

The component being measured is illuminated by the through light method. A parallel beam of light illuminates the lower side of workpiece which is then received by the objective lens in its way to a prism that deflects the light rays in the direction of the measuring ocular and the projection screen. Incident illumination can also be provided by an extra attachment. Exchangeable objective lens having magnification1X, 1.5X, 3X and 5X are available so that a total magnification of l0X,15X, 30 X and 50X can be achieved with an ocular of l0X. The direction of illumination can be tilted with respect to the workpiece by tilting the measuring head and the whole optical system. This inclined illumination is necessary in some cases as in screw thread measurements.

The scale value of this microscope:

- 0.01 mm for length measurement.
- 3' for angle measurement with rotatable table.
- 1' for angle measurement with the angle measuring ocular.

Applications

The applications of the instrument may be summarized broadly as follows.

(1) The determination of the relative position of various Points on work by measuring the travel necessary to bring a second point to the position previously occupied by the first, and so on.

(2) Measurement of angles by using a protractor eye-piece.

(3) Comparison of thread forms with master profiles engraved in the eyepiece and measurement of pitch and effective diameter.

(4) Comparison of an enlarged, projected image with a scale tracing fixed to the projection screen.

Gear Measurement

Gears is a mechanical drive which transmits power through toothed wheel. In this gear drive, the driving wheel is in direct contact with driven wheel. The accuracy of gearing is the very important factor when gears are manufactured. The transmission efficiency is almost 99 in gears. So it is very important to test and measure the gears precisely.

For proper inspection of gear, it is very important to concentrate on the raw materials, which are used to manufacture the gears, also very important to check the machining the blanks, heat treatment and the finishing of teeth.

The gear blank should be tested for dimensional accuracy (face width, bore, hub, length, and outside diameter), and eccentricity. As outside diameter forms the datum from where the tooth thickness is measured, it forms an important item to be controlled. Concentricity of the blanks is also essential and the side faces should be true to the bore. On very precise gears details like tip radius, shape of root provided and surface finish are also measured.

The most commonly used forms of gear teeth are

1. Involute
2. Cycloidal
    - The involute gears also called as straight tooth or spur gears.
    - The cycloidal gears are used in heavy and impact loads.
    - The involute rack has straight teeth.
    - The involute pressure angle is either 20° or 14.5°

Types of gears

1. Spur gear:-

- Cylindrical gear whose tooth traces is straight line.
- These are used for transmitting power between parallel shafts.

2. Spiral gear :-

- The tooth of the gear traces curved lines.

3. Helical gears:-

- These gears used to transmit the power between parallel shafts as well as non-parallel and non-intersecting shafts.
- It is a cylindrical gear whose tooth traces is straight line.

4. Bevel gears:-

- The tooth traces are straight-line generators of cone.
- The teeth are cut on the conical surface. It is used to connect the shafts at right angles.

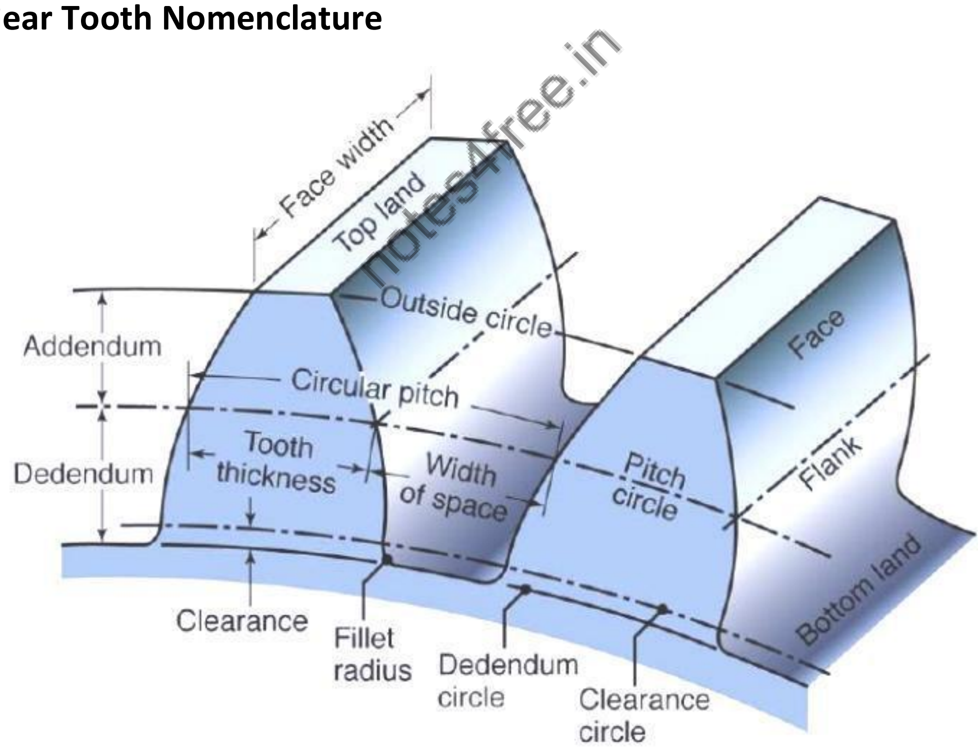
5. Worm and Worm wheel :

- It is used to connect the shafts whose axes are non-parallel and non-intersecting.

6. Rack and Pinion:-

- Rack gears are straight spur gears with infinite radius.

4.8 Gear Tooth Nomenclature



1. Tooth profile:

- It is the shape of any side of gear tooth in its cross section.

2. Base circle:

- It is the circle of gear from which the involute profile is derived.
- Base circle diameter Pitch circle diameter x Cosine of pressure angle of gear

3. Pitch circle diameter (PCD):

- The diameter of a circle which will produce the same motion as the toothed gear wheel

4. Pitch circle

- It is the imaginary circle of gear that rolls without slipping over the circle of its mating gear.

5. Addendum circle:

- The circle coincides with the crests (or) tops of teeth.

6. Dedendum circle (or) Root circle:

- This circle coincides with the roots (or) bottom on teeth.

7.Pressure angle (a):

- It is the angle making by the line of action with the common tangent to the pitch circles of mating gears.

8.Module(m):

 It is the ratio of pitch circle diameter to the total number of teeth.

$$m = \frac{d}{n}$$

Where, d = Pitch circle diameter.

n = Number f teeth

9. Circular pitch

- It is the distance along the pitch circle between corresponding points of adjacent teeth

10. Addendum:

- Radial distance between tip circle and pitch circle. Addendum value = 1 module.

11. Dedendum:

- Radial distance between itch circle and root circle, Dedendum value = 1 .25 module.

12. Clearance (C):

- A mount of distance made by the tip of one gear with the root of mating gear. Clearance = Difference between Dedendum and addendum values

13. Blank diameter:

- The diameter of the blank from which gear is out. Blank diameter = PCD + 2m

14. Face:

- Part of the tooth in the axial plane lying between tip circle and pitch circle.

15. Flank:

- Part of the tooth lying between pitch circle and root circle.

16. Top land:

- Top surface of a tooth

17. Lead angle:

- The angle between the tangent to the helix and plane perpendicular to the axis of cylinder.

18. Backlash:

- The difference between the tooth thickness and the space into which it meshes.

OUTCOMES

Students will be able to

1. Understand the principle and working of autocollimeter, toolmakers microscope.
2. Know the concept of screw thread and 2 wire – 3 wire method.

SELF ASSESMENT QUESTIONS

1. Describe the principle and operation of a Michelson Interferometer.
2. What are the uses and the advantages of a laser interferometer?
3. How is phase of light beam related to the fringes formed due to interference?
4. Explain the formation of white and dark fringes due to interference of light.
5. What are the differences between constructive and destructive interference?

FURTHER READING

1. Jain R. K., 1997, Engineering Metrology, Khanna Publishers.
2. Shawne A. K., 1998, Mechanical Measurement and Instrumentation, Dhanpat Rai and Co. (P) Ltd.
3. Hazra Chowdhury, 1995, Workshop Technology, Media Promoters and Publishers Pvt. Ltd

Module 4
MEASUREMENTS AND MEASUREMENT SYSTEMS
CONTENTS

OBJECTIVES

After studying this unit, you should be able to

1. Describe different type of sensors and transducers, and
2. Understand the concepts of digital to analog conversion and vice-versa.

Definition of measurement:

Measurement is defined as the process of obtaining a quantitative comparison between a predefined standard & an unknown magnitude. Example-consider the measurement of length of bar. We make use of a scale/steel ruler(i.e a standard)

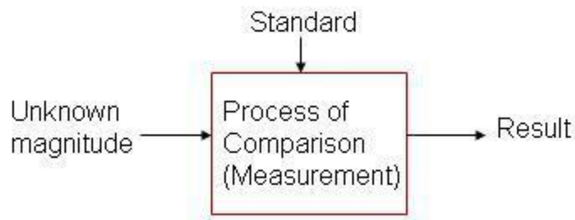
Definition of Standard

Standard is a value of some quantity which is setup and established by authority as a rule for measurement of a quantity.

The system of measurement must be related to a known standard or else the standard has no meaning.

- Any system may be represented by a simple block diagram.

- Simple diagrams of rectangles and circles connected by lines with indicators of input and output directions.
- Shows the essential elements of a system.
- Functional arrangements + functions of each element.



Length of the bar-unknown quantity (measure and)

Scale-pre-defined standard

} Compare

i.e. compare the unknown length of the bar with a known length/pre-defined standard.
We say that the bar measures so many mms, cms or inches in length.Definition-measurement is an act of quantitative comparison between an unknown magnitude and pre-defined standard.

Basic Requirements of Measuring System

Two main requirements must be met in the act of measurement. They are;

- The standard used for comparison must be accurately defined and commonly accepted.
- The procedure employed for the measurement & the apparatus used for comparison must be provable.

Significance of Measurements

1. We require measuring quantities for performance in our day to day activities.
2. Fundamental requirement of any process is the measurement. Example-

3 i.e. input is fed to the system it undergoes a process output is indicated.
4 i.e. output is compared with input-measurement.
5. Quantities pertaining to operation & performance of the device being developed.
6. Measurement provides the fundamental basis for research & development as it involves measurement of various quantities and parameters.
7. Also, a fundamental element of any control process, which requires the measured discrepancy between the actual & desired performances.
   - Measurement is also considered as a method of inspection
   - Measurement technology combined with computer integrated manufacturing and database management systems provide information based process control
   - I.e. to prevent the occurrence of more number of defects

8) To ensure proper performance in operations of modern power stations to monitor temperature, pressure, vibration amplitudes etc.
9) Establish the cost of products on the basis of amount of material, power, time & labor, etc.
10) Place/give realistic tolerance for each of the measured values.

To establish the validity of design

1. Design of manufactured goods
2. Design of machinery to perform manufacturing operations
3. Design of power sources
4. Design of roads, waterways and other system.
5. To study the operation features, limitation and difficulties that are inherent in the systems.
6. For proper maintenance of the equipment.
7. To determine the system response(Reply of the systems to given input)
8. For correct recording of the output data(weather forecasting, experimental values, interpretation etc.)

Other applications of measurements

1. Application of theory

- Broaden the engineering knowledge by application of theory.
- Learn to verify a theoretical model or to verify/modify it by conducting experiments.
- Develop ability to apply some basic principle in a variety of engineering studies- interdisciplinary approach.

2. Techniques of experimentation

- Become acquainted with available experimentation.
- Learn to interpret experimental data.
- Develop competence in sampling data.

3. Communication and reporting

- Learn to organize and direct experimental team.
- Learn procedures and develop abilities in report writing.
- Learn to support conclusions and recommend improvements.

4. Professional

- Provide examples of experimental research and development.
- Develop competence in applying engineering judgment.

Hence considering the above, it can be concluded that measurements are quite essential in the

- Design of a component.
- A process to be operated with minimum cost having maximum efficiency.

Fundamental methods of Measurement

Two basic methods are commonly employed for measurement.
(a) Direct comparison with primary or secondary standard.
(b) Indirect comparison through the use of calibrated system.

Two basic methods are commonly employed for measurement.
(a) Direct comparison with primary or secondary standard.
(b) Indirect comparison through the use of calibrated system.

Direct comparison

In this method, measurement is made directly by comparing the unknown magnitude with a standard & the result is expressed by a number. The simplest example for this would be, length measurement using a meter scale. Here we compare the bar's length(unknown quantity/ measure and) with a scale (Standard/predefined one). We say that the bar measures so many mms, cms or inches in length.

- Direct comparison methods are quite common for measurement of physical quantities like length, mass, etc.
- It is easy and quick.

Drawbacks of Direct comparison methods

- The main drawback of this method is, the method is not always accurate and reliable.
- Also, human senses are not equipped to make direct comparison of all quantities with equal facility all the times.
- Also, measurement by direct methods are not always possible, feasible and practicable.

Example: Measurement of temperature, Measurement of weight.

- One can experience or feel the hotness or coldness of a body with respect to a particular environment.
- But may not be able to exactly predict or say the temperature.
- Further , these measurements in most cases involve human factors.
- Hence this method in general is not preferred and employed for very accurate measurements.

Indirect comparison

- Most of the measurement systems use indirect method of measurement.
- In this method a chain of devices which is together called as *measuring system* is employed.
- The chain of devices transform the sensed signal into a more convenient form & indicate this transformed signal either on an indicator or a recorder or fed to a controller.
- i.e. it makes use of a transducing device/element which convert the basic form of input into an analogous form, which it then processes and presents as a known function of input.
- For example, to measure strain in a machine member, a component senses the strain, another component transforms the sensed signal into an electrical quantity which is then processed suitably before being fed to a meter or recorder.
- Further, human senses are not equipped to detect quantities like pressure, force or strain.
- But can feel or sense and cannot predict the exact magnitude of such quantities.
- Hence, we require a system that detects/sense, converts and finally presents the output in the form of a displacement of a pointer over a scale a , a change in resistance or raise in liquid level with respect to a graduated stem.

DIRECT COMPARISON	INDIRECT COMPARISON
1)Unknown quantity is measured comparing directly with primary or secondary standards	1)unknown magnitude is measured by comparing with a standard indirectly through the use of a calibrated system
2)human senses are very much necessary for measurement	2)Consists of a chain of devices which form a measuring system
3)Results obtained from direct comparison are not that dependable	3)this consists of a detector element to detect ,a transducer to transducer and a unit to indicate or record the processed signal
4)Not always accurate	4)Fairly accurate .

Primary, secondary and tertiary measurements

- Measurements are generally made by indirect comparison method through calibration.
- They usually make use of one or more transducing device.
- Based upon the complexity of measurement system, three basic categories of measurements have been developed. They are;

1. Primary measurement
2. Secondary measurement
3. Tertiary measurement

Primary measurement

- It is the one that can be very easily made by direct comparison method/direct observation.
- This can be done without any conversions or translation into lengths or displacements.
- Here, the sought value of the parameter is determined basically by comparing it directly with reference standards

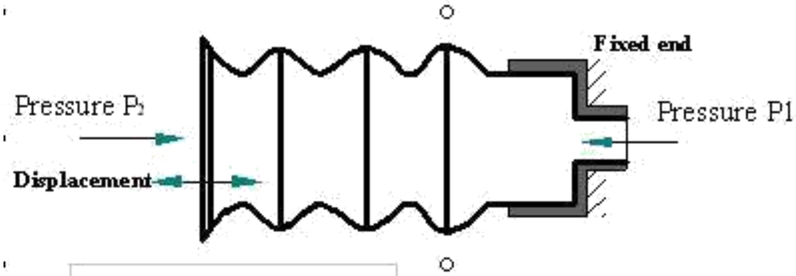
Examples:

- Matching of two colors-in finding the temperature of a red hot object.
- Use of a physical balance-in measuring weights
- Matching or comparing lengths-to find out the length of the object
- This measurement is quite easy, but takes more time.
- Provides only subjective information.

a. Example: An observer is in a position to tell that the contents of one container is heavier than the other or contents of one object is hot than other.

- Hence, this method is not always accurate and reliable. So, secondary measurements are resorted to.

Bellows



Metallic Bellow

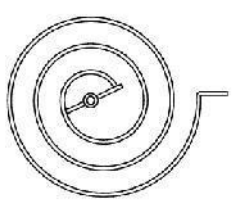
- Metallic bellows are thin walled tubes formed by hydraulic presses into a corrugated shape as shown in fig. Bellows can be of diameters upto 300 mm & are made of Brass, (80%copper & 20% zinc), Phosphor bronze, stainless steel, Beryllium copper.
- A differential pressure causes displacement of the bellows, which may be converted into an electrical signal.
- When pressure P above the atmosphere is applied, to the free/open end of the bellows, these expand.
- The resulting displacement is a measure of applied pressure.

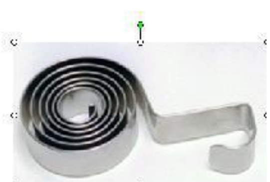
i.e. $x \alpha p$ k=proportionality constant

or $x= k.p$ x=Displacement in mms

p=applied pressure

Spiral Springs





- These are used to produce controlling torque in analogue type electrical instruments and clocks.
- The controlling torque will be proportional to the angle of deflection.
- Care must be taken *not to stress* the springs beyond *the elastic limit* as it will lead to permanent deformation.

Force to displacement by springs:

The spring stretches when force F is applied at its free end δαF or δ=k.F

δ=k.F/s

δ=spring deflection

k=proportionality constant

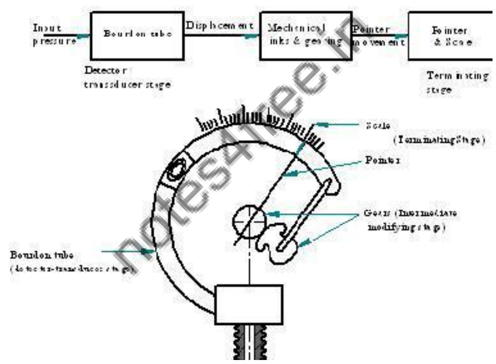
F=force applied

s=spring stiffness

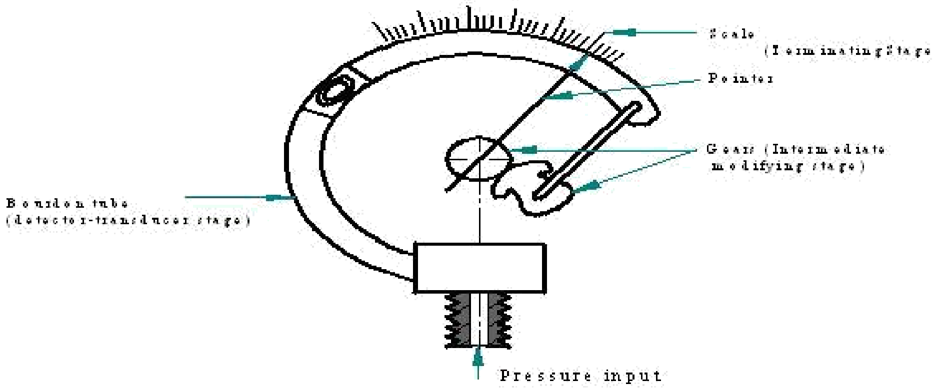
Strain gage Load Cell

- Load cell consists of a short column on which electrical resistance strain gauges are mounted.
- When force F is applied it deflects or strains the block.
- Here, the load is converted to strain and this is transformed into change in electrical resistance.
- In this, the block forms the primary detector transducer, the gauges mounted on the block acts as secondary transducer.

Bourdon Tube



- When pressure p, the primary signal is applied to the open end of the Bourdon tube, the other end deflects.
- This deflection will be very small(constitutes the secondary signal) and needs to be made larger for display purpose.
- This is obtained by the arrangement of gear, rack and pinion arrangement and a pointer moving against a graduated scale(which constitutes the tertiary signal).



- When pressure p, the primary signal is applied to the open end of the Bourdon tube, the other end deflects.
- This deflection will be very small(constitutes the secondary signal) and needs to be made larger for display purpose.
- This is obtained by the arrangement of lever, rack and pinion arrangement and a pointer moving against a graduated scale(which constitutes the tertiary signal).

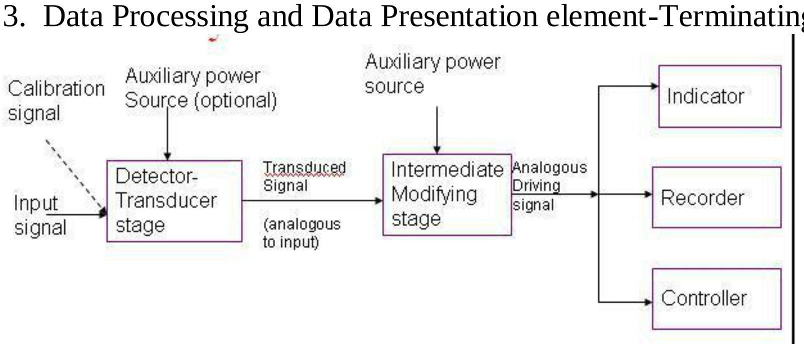
Tertiary Measurements

- These tertiary measurements involve two or more translations or conversions. Example: Bourdon pressure gauge for measurement of pressure

Generalized Measurement System

• It can be considered as a system that is used to measure the required quantity/parameter. Generalized measurement system consists of the following elements:

1. Primary Sensing Element(detecting element) (detector-transducer element)
2. Variable Conversion Element-Intermediate modifying element.
3. Data Processing and Data Presentation element-Terminating stage element.



Most measuring systems fall within the frame work of a generalized system Consisting Of three stages namely

(1) A *detector-transducer* or *sensor* stage
(2) An *intermediate modifying* stage or *signal conditioning* stage
(3) A *terminating* or *read-out* stage, as shown in the block diagram above.

Basic elements of a Measuring system:

Stage I-Detector Transducer Device	Stage II-Intermediate Modifying Device	Stage III-Terminating Device
Senses only the desired input & provides analogous output	Modifies Transduced signal into a form usable by final stage. Usually increases amplitude and power	Provides an indication or recording in a form that can be evaluated by human sense or by a controller

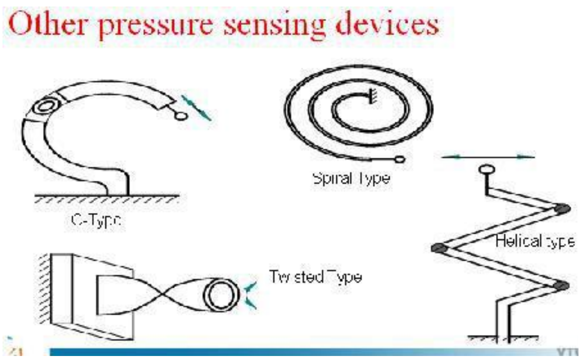
Types & Examples	*Types & Examples*	*Types & Examples*
Mechanical : Contacting spindle, Spring-mass, elastic devices such as bourdon tube, proving ring,etc. Hydraulic-Pneumatic: Buoyant-float, orifice, venturi, vane, propeller Optical: Photographic film, Photoelectric cell Electrical: Contactors, resistance, capacitance, Piezoelectric crystal, Thermocouple, etc.	Mechanical : Gearing, cranks, links, cams, etc. Hydraulic-Pneumatic: Piping, valves, dash-pots, etc Optical: Mirrors, lenses, Optical filters, light levers, Optical fibers. Electrical: Amplifying systems, matching devices, filters, telemetry systems, etc.	INDCATORS (a) Displacement types Moving pointer & scale, light beam & scale, CRO, liquid column, etc. (b) Digital types: Direct alphanumeric read out (c) Recorders: Digital printing, inked pen & chart Light beam & photographic Film, magnetic recording (d) Controllers: All types

Stage-I-Detector Transducer stage:
The important function of this stage is to detect or to sense the input signal. At the same time, it should be insensitive to every other possible input signals. For ex, if it is a pressure signal, it should be insensitive to acceleration. In the measurement of strain, the strain gauges should be insensitive to temperature.

- Automobile tyre gauge-used for measurement/checking air pressure of an automobile tyre.
- Construction: consists of a cylinder, a piston, a spring resisting the piston movement and a stem with graduation.
- As the air pressure bears against the piston, the resulting force compresses the spring until the spring force and air forces are balanced.

Stage-I-Detector Transducer stage

- Here, the piston and cylinder combination make up the detector transducer, spring other element.
- Other examples-refer fig

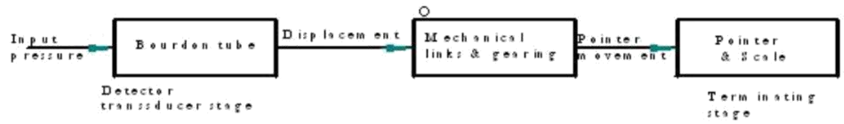


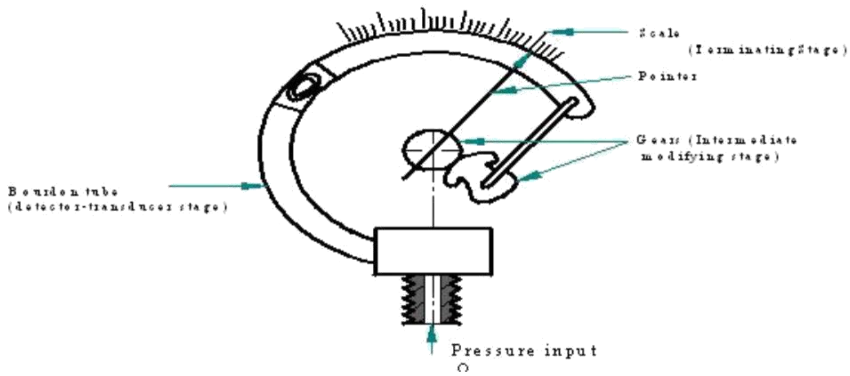
Stage-II-Intermediate modifying stage:

- As the name itself indicates, this lies between stage 1 and stage 3.
- The main function of this stage is to modify the detected/transduced information so that it is acceptable to the third, or terminating stage.
- The important function of this stage is to increase either amplitude or power of the signal or both, to the level required to drive the final terminating device.
- It may also perform selective filtering, integration, differentiation, etc. as required.
- Generally these will be electrical or electronics circuits.
- Examples: Amplifiers, mechanical levers

Stage III-Terminating stage

- This stage provides an indication or a recording of the signal in a form which can be understood by a human being or a control system.
- This is done by data presentation element.
- Here the information output may be obtained in different forms such as a pointer moving over a graduated scale, in digital form as in computers or as a trace on an oscilloscope etc.
- An example of a generalized measurement system is a simple Bourdon tube pressure gauge.
- In this case, the pressure is sensed by a tube of elliptical cross section which undergoes mechanical deformation. (c/s tends to become circular)
- The gearing arrangement amplifies the displacement at the end of the tube so that a relatively small displacement of the tube end produces a greater revolution of the center gear.
- The final indicator stage consists of a pointer and scale arrangement, which when calibrated with known pressure inputs, gives an indication of pressure signal acting on the bourdon tube.





In 1849 the Bourdon tube pressure gauge was patented in France by Eugene Bourdon. It is still one of the most widely used instruments for measuring the pressure of liquids and gases of all kinds, including steam, water, and air up to pressures of 100,000 pounds per square inch. Eugene Bourdon founded the Bourdon Sedeme Company to manufacture his invention.

Instrument Characteristics(Behaviour)

- The instrument and measurement system characteristics can be divided into two distinct categories-

1. Static characteristics
2. Dynamic characteristics

Static characteristics

- Pertain to a system where quantities to be measured, are constant or vary very slowly with time.
- Normally static characteristics of a measurement system are those that must be considered when the system\equipment is used to measure a condition not varying with respect to time.

Dynamic characteristics

- Pertain to a system where quantities to be measured vary rapidly with time.

- There are many phenomenon which can be conveniently described by the static response while on the other hand there are phenomenon which can only be reported by dynamic response.
- The overall performance of a system, many a times can be evaluated by semi-qualitative super position of static and dynamic characteristics.

Definitions & basic concepts

Readability: This term indicates the closeness with which the scale of the instrument may be read. *For ex, an instrument with 30 cm scale has a higher readability than that of a 15 cm scale*. *Least count:* It is the smallest difference between two indications that can be detected on the instrument scale.

Range: It represents the highest possible value that can be measured by an instrument *or* it is the difference between the largest & the smallest results of measurement. Example-

Data : Elemental items of information obtained by experimental means - assumed to be in numerical forms. Example-

Population(also called universe): A collection of data, either from finite or infinite in number all representing the same quantity. Example-

Sample : A portion of a population, represent the time value or should be a representative of the population.

- Multi sample test: A repeated measurement of a given quantity using altered test conditions - such as different observers or different instrumentation.
- Merely taking repeated reading with the same procedure and equipments does not provide multi sample results.
- Example : Many experimenters have conducted experiments to determine the velocity of light in vacuum.
- This has been done using different apparatus and techniques. Each leading measured is supposedly a unique quantity. Although, the results vary, taken together, these finding are multi sample results.
- Single sample test : A single reading or succession of reading taken under identical conditions except for time.
-

True value or actual value (Va): It is the actual magnitude of the input signal to a measuring system which may be approximated but never truly be determined. The true value may be defined as the average of an infinite number of measured values, when the average deviation of the various contributing factors tend to zero. *Indicated value (Vi):* The magnitude of the input signal indicated by a measuring instrument is known as indicated value. This is the supply of raw or directly recorded data.*Correction:* It is the revision applied to the indicated value which improves the worthiness of the result. Such revision may be in the form of either an additive factor or a multiplier or both.*Result (Vr) :* It is obtained by making all known corrections to the indicated value. Vr= AVi + B, where A & B are multiplicative & additive corrections.

Discrepancy : The difference between two indicated values or results determined from a supposedly fixed time value.

Error: It is the difference between the true value (Va) & the result (Vr). Error=(Vr-Va)

Accuracy: The accuracy of an instrument indicates the deviation of the reading from a known input. In other words, accuracy is the closeness with which the readings of an instrument approaches the true values of the quantity measured. It is the maximum amount by which the result differs from the true value.

Accuracy=Maximum error =Vr(max)-Va

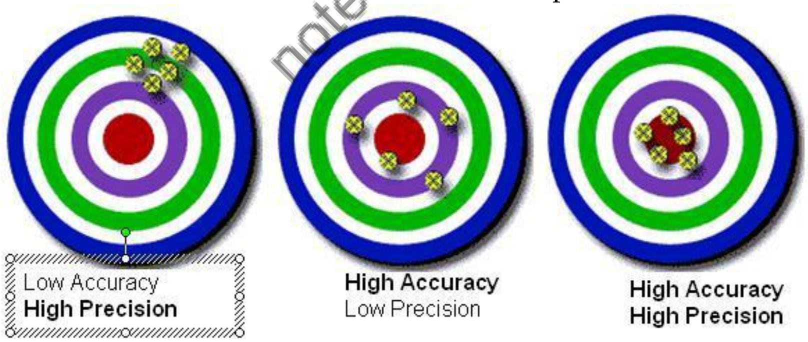
Accuracy is expressed as a percentage based on the actual scale reading / full scale reading. Percentage accuracy based on reading = (Vr(max or min) - Va)*100 Va

Percentage accuracy based on full scale reading = (Vr(max or min)-Va)*100
Vfs

Vfs = maximum reading the measuring system capable for the particular setting or scale being used. Also accuracy is based on the limits of application. The cost of the system increases rapidly if increased rapidly if increase accuracy is decreased. The limits should be made as wide as possible. Further, a system cannot be accurate 100% at all times because an error is required to initiate the corrective action.

Ex : pressure 100 bar +- 1 bar i.e. 100 bar pressure gauge having an accuracy of 1% would be accurate within +-1 bar over the entire range of gauge.

Precision: The precision of an instrument indicates its ability to reproduce a certain reading with a given accuracy. In other words, it is the degree of agreement between repeated results. Precision data have small dispersion (spread or scatter) but may be far from the true value. A measurement can be accurate but not precise, precise but not accurate, neither, or both. A measurement system is called *valid* if it is both accurate and precise.



Sl no	Accuracy	Precision
1	It is the closeness with the true value of the quantity being measured	It is a measure of reproducibility of the measurements
2	The accuracy of measurement means conformity to truth	The term precise means clearly or sharply defined
3	Accuracy can be improved	Precision cannot be improved
4	Accuracy depends upon simple techniques of analysis	Precision depends upon many factors and requires many sophisticated techniques of

		analysis
5	Accuracy is necessary but not sufficient condition for precision	Precision is necessary but not a sufficient condition for accuracy

Calibration: *It is very widely used* in industries. It *is the setting or correcting of a measuring device or a base level usually by adjusting it to match or conform to a dependably known value or act of checking or adjusting (by comparing with standard) the accuracy of a measuring instrument.*

It is the procedure employed for making adjustments or checking a scale for the readings of a system conforming to the accepted or pre defined standard i.e. to say that the system has to prove its ability to measure reliably. Every measuring system must be provable. The procedure adopted to prove the ability of a measuring system to measure reliably is called calibration.

In this process, known values of input are fed to the system and the corresponding output is measured. A graph relating the output with input is plotted which is known as 'calibration curve'

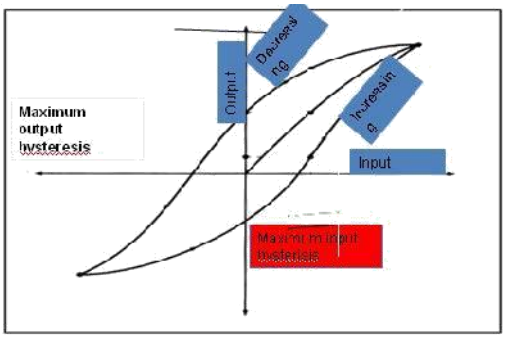
- During the process of experimentation known values of input magnitude are fed and the corresponding output is measured.
- A plot of output against the input is drawn and is called the calibration graph.

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

Hysterisis: An instrument is said to exhibit hysterisis when there is a difference in readings depending on whether the value of the measured quantity is approached from higher value or from a lower value as shown in

- Hysterisis arises because of mechanical friction, magnetic effects, elastic deformation or thermal effects.
- Hysterisis is a phenomenon which depicts different output effects when loading and unloading.
- It may be with respect to a mechanical system, electrical system or any system.
- Hysterisis is the non coincidence of loading and unloading curves.
- Consider an instrument which has no friction due to sliding or mating parts.
- When the input of this instrument is slowly varied from zero to full scale and then back to zero, its output varies as shown
- Hystersis in a system arises due to the fact that all the energy put into the stress parts when loading is not recoverable upon unloading.

Typical Hysteresis curve



Sensitivity: It is the ratio of the linear movement of the pointer on the instrument to the change in the measured variable causing this motion or is the ratio of the magnitude of output quantity(response) to the magnitude of the input quantity.

For ex, a 1 mV recorder might have a 10 cm scale. Its sensitivity would be 10 cm/mV, assuming that the measurement is linear all across the scale.

- The static sensitivity of an instrument can be defined as the slope of the calibration curve. The sensitivity of an instrument should be high and the instrument should not have a range greatly exceeding the value to be measured. However some margin should be kept for accidental overloads.
- Sensitivity of an instrument is the ratio of magnitude of the response (output signal) to the magnitude of the quantity being measured (input signal).
- Sensitivity (k)= change of output signal
- change of input signal
- Sensitivity is represented by the slope of the calibration curve.
- Sensitivity of the instrument system is usually required to be as high as possible as it becomes easier to take the measurement.

Resolution or Discrimination: It is defined as the smallest increment of input signal that a measuring system is capable of displaying. Resolution is defines the smallest measurable input change while threshold defines the smallest measurable input. Threshold is measured when the input is varied from zero while the resolution is measured when the input is varied from any arbitrary non- zero value.

Repeatability: It is defined as the ability of a measuring system to reproduce output readings when the same input is applied to it consecutively, under the same conditions, and in the same direction.
Reproducibility: It is defined as the degree of closeness with which the same value of a variable may be measured at different times.
Linearity: A measuring system is said to be linear if the output is linearly proportional to the input. A linear system can be easily calibrated while calibration of a non linear system is tedious, cumbersome & time consuming. Most of the systems require a linear behavior as it is desirable . I.e. output is linearly proportional to input.

- This is because the conversion from a scale reading to the corresponding measured value of input quantity is most convenient as one has to merely multiply by a fixed constant rather than a non linear calibration curve or compute from non linear curves and equation.
- Also it is to be noted that all non linear calibration curves are not inaccurate. Sometimes they may be more accurate than linear calibration curves.

Hence , many definition of linearity exists.
The best fitting straight line or method of least squares may be used to plot input vs. output data

Loading effect: The presence of a measuring instrument in a medium to be measured will always lead to extraction of some energy from the medium, thus making perfect measurements theoretically impossible.

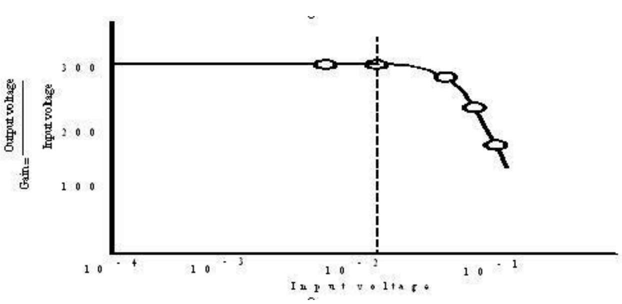
This effect is known as 'loading effect' which must be kept as small as possible for better measurements. For ex, in electrical measuring systems, the detector stage receives energy from the signal source, while the intermediate modifying devices and output indicators receive energy from auxiliary source. The loading effects are due to impedances of various elements connected in a system

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 & to exclude all others. If the output is faithful to input, i.e. the output signals have the same phase relationships as that of the input signal, the system is said to have good *System response.* If there is a lag or delay in the output signal which may be due to natural inertia of the system, it is known as *'measurement lag'*
"Rise time" is defined as the time taken for system to change from 5% to 95% of its final value. It is a measure of the speed of response of a measuring system and a short rise time is desirable.

Amplitude Response

- A system is said to have to good amplitude response if it treats all the input amplitudes uniformly. i.e. if an input amplitude of 5 units is indicated as 20 units on the output side, an input of 10 units should give 40 units on the output side.
- In practice a measuring system will have good amplitude response over an unlimited range of input amplitudes.
- For ex, a 3-stage amplifier used for strain measurement has good response upto an input voltage of 10-2 volts as shown in fig.

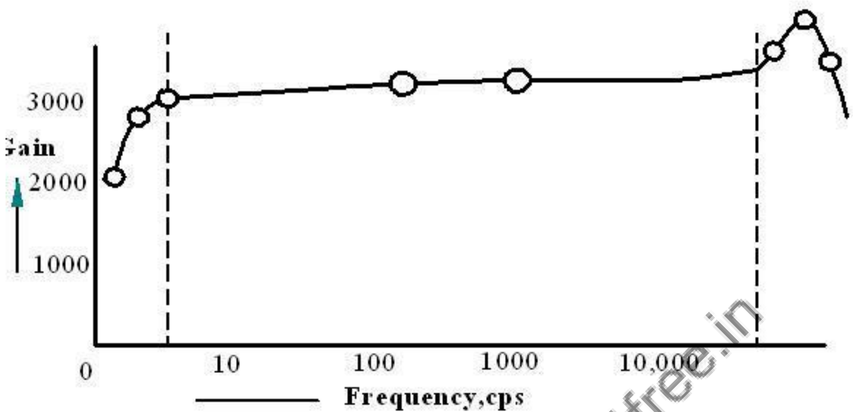
Amplitude response of 3-stage amplifier used for strain measurement



Frequency response

A system is said to have a good frequency response when it treats all input frequencies with equal faithfulness. For ex, if an input amplitude of 5 units at 60 Cps is indicated as 10 units on the output side, then irrespective of the change in input frequency, the output amplitude should not change as long as the input amplitude does not change. In practice a measuring system will have a lower & upper limits beyond which the system can not have a good frequency response. The fig shows response curve of a device which has good frequency response between 5 Cps & 30,000 Cps.

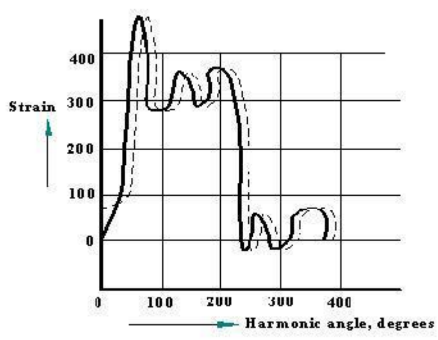
Frequency response of 3-stage amplifier used for strain measurement



Phase response

- Amplitude response and frequency response are important for all types of input signals whether simple or complex. The phase response is, however, important only for complex waves.
- If the input signal is simple like a sine wave, the amplitude of the output, though out of phase with input, will not be affected. This is because the shape of the cycle is repetitive and does not change between the limits of the cycle.
- If the input signal is simple like a sine wave, the amplitude of the output, though out of phase with input, will not be affected. This is because the shape of the cycle is repetitive and does not change between the limits of the cycle.

Effect of poor phase response on recording of strain



Errors in Measurements

Error may be defined as the difference between the measured value and the true value.
No measurement can be made without errors at all times i.e. 100% accurate measurements cannot be made at all times.

Error definition:

- Is defined as the difference between the best measured value and the true value of the quantity.
- A mistake, or in accuracy in action, speech or a typing error.
- A incorrect belief or a wrong judgment.
- Deviation from a standard.
- Measure of the difference between some quantity and an approximation to or estimate of it.
- Often expressed as a percentage.
- Difference between the true value of a measurement and the value obtained during the measurement process.

Error classification:
Classified in different ways

- Systematic error
- Random errors
- Illegitimate errors

Systematic errors:

- Generally the will be constant / similar form /recur consistently every time measurement is measured.
- May result from improper condition or procedures employed.

Calibration errors:
Calibration procedure-is employed in a number of instruments-act of checking or adjusting the accuracy of a measuring instrument.

Human errors:

- The term “human error” is often used very loosely.
- We assume that when we use it, everyone will understand what it means.
- But that understanding may not be same as what the person meant in using the term.
- For this reason, without a universally accepted definition, use of such terms is subject to misinterpretation.

Meanings- related to human error:

- Human error as a cause: Ex- a patients adverse reaction-allergic to some medicine-administered by nurse.
- Human error as an event or action: A doctor forgets to match the patient record to patient identified.

- Human error as a consequence: A nurse leaves some sponge material inside a patient after surgery.

In all the above, the focus is on the outcome, yet description is of the action. Hence, we must use the human error term and relate to the event/measurement. Human errors may also be systematic as in case of an individuals tendency to consistently read high or low values when synchronized reading are to be taken. The apparatus and equipment itself may cause or lead to built in errors resulting from incorrect design, fabrication, poor maintenance(Ex-defective gears, linkage mechanism etc.)

(1) *Systematic or fixed errors:*

(a) calibration errors
(b) Certain types of consistently recurring human errors
(c) Errors of technique
(d) Uncorrected loading errors
(e) Limits of system resolution Systematic errors are repetitive & of fixed value. They have a definite magnitude & direction

(2) Random or Accidental errors:

(a) Errors stemming from environmental variations
(b) Certain types of human errors
(c) Due to Variations in definition
(d) Due to Insufficient sensitivity of measuring system

Random errors are distinguishable by their lack of consistency. An observer may not be consistent in taking readings. Also the process involved may include certain poorly controlled variables causing changing conditions. The variations in temperature, vibrations of external medium, etc. cause errors in the instrument. Errors of this type are normally of limited duration & are inherent to specific environment.

(3) Illegitimate errors:

(a) Blunders or Mistakes
(b) Computational errors
(c) Chaotic errors

Illegitimate errors : should not exist and may be eliminated by careful exercise & repetition of measurement. Chaotic errors which may be due to extreme vibration, mechanical shock of the equipment, pick up of extraneous noise make the testing meaningless unless all these disturbances are eliminated. If a measuring instrument is not *calibrated* periodically it will lead to errors in measurement .

Human errors : are due to variation of physical & mental states of a person which may lead to systematic or random errors.

Errors of technique: are due to improper usage of measuring apparatus. This may include errors resulting from incorrect design, fabrication or maintenance.

Loading errors : result from influence exerted by the act of measurement on the physical system being tested.

Sources of errors

(1) Noise: It is defined as any signal that does not convey useful information.
(2) Design limitations: These are certain inevitable factors such as friction & resolving power which lead to uncertainty in measurements.
(3) Response time: It is the time lag between the application of input signal & output measurement.
4) Deterioration of measuring system: Physical and/or chemical deterioration or other alterations in characteristics of measuring system constitute a source of error in measurement.
(5) Environmental effects: The change in atmospheric temperature may alter the elastic constant of a spring, the dimensions of a linkage, electrical resistance etc. similarly other factors such as humidity, pressure etc. also affect measurements.
(6) Errors in observation & Interpretation: It is the mistake of operators in observing, interpreting & recording the data.
(7) Poor maintenance of the system

Introduction to Transducers

Transducer is a first stage element of the measurement system. It detects and transforms the sensed signal into a more useful form.
Transfer efficiency: It is the ratio of output information delivered by the pick up (Sensor) to the information received by the pick up.

Transfer efficiency $= \frac{I_{out}}{I_{in}}$

Where Iout=the information delivered by the unit, Iin=information received by the unit

Since the pick up can not generate any information , the transfer efficiency can not be greater than unity. The detector- transducer stage must be designed to have a high Transfer efficiency to the extent possible.

Active & Passive Transducers: Active transducers
Also known as self generating type transducers Develop their own voltage or current. Energy required for production of output signal is obtained by quantity being measured.Ex, Electronic & Piezo electric transducers.

Passive Transducers:

- *Also known as externally powered transducer*
- *Derive the power for energy conversion from an external power source*
- *Ex: Bonded electrical resistance strain gauges*

Detector Transducer or Primary Transducer

Here the sensing element may serve to transduce the sensed input and convert into a more convenient form.

For example

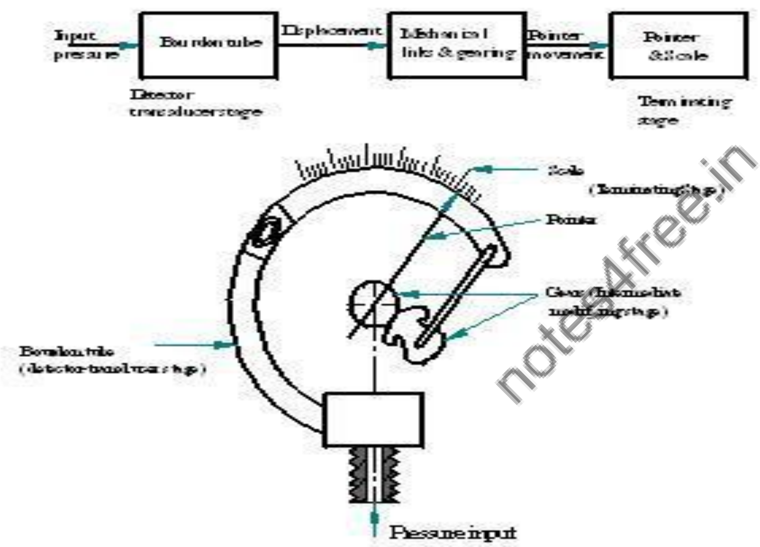
1. Ordinary dial indicator-Spindle acts as a detector.
2. Load cell detects the force/load applied and gives an output in the form of a deflection.

Secondary Transducer

- Example-Strain gauge load cell-It detects the force and gives an output in the form of deflection. This deflection may further be converted into an electrical output by strain gauges(whose resistance value changes) mounted on the load cell.

Bourdon Pressure gauge

- The tube acts as detecting-transducing element-primary detector transducer.
- Linkage acts as a secondary transducer.



Primary Detector Transducer-Classification

Based on the number of operations performed:

- Class I-First stage element used as detector only.
- Class II-First stage element used as detector as well as transducer.
- Class III-First stage element used as detector and two transducer.

Mechanical Transducers

- Mechanical quantities include force, pressure, displacement, flow, temperature, etc.

- The mechanical transducers commonly used to convert the applied force into displacement are elastic members.
- They may be subjected to either direct tension/compression, Bending or Torsion.

Spiral springs: These are used to produce controlling torque in analogue type electrical instruments and clocks.

- The controlling torque will be proportional to the angle of deflection.
- Care must be taken *not to stress* the springs beyond *the elastic limit* as it will lead to permanent deformation.

Torsion bars: These are used in torque meters to sense torque which causes a proportionate angular twist which in turn is used as a measure of applied torque. (with the help of a displacement transducer)

Some torque meters, the strain gauges are used to sense the angular deformation.

- **Proving rings:** They are used to measure weight, force or load. The deflection can be measured with the help of micrometers, dial gauges or electrical transducers.

Pressure sensitive elements

Most pressure measuring devices use elastic members to sense the pressure. These elastic members convert pressure into displacement & ca be of the following types;

(i) Bourdon tubes
(ii) Diaphragms
(iii) Bellows

BOURDON TUBES

Bourdon tubes are elliptical cross section tubes bent into shapes as shown in fig.

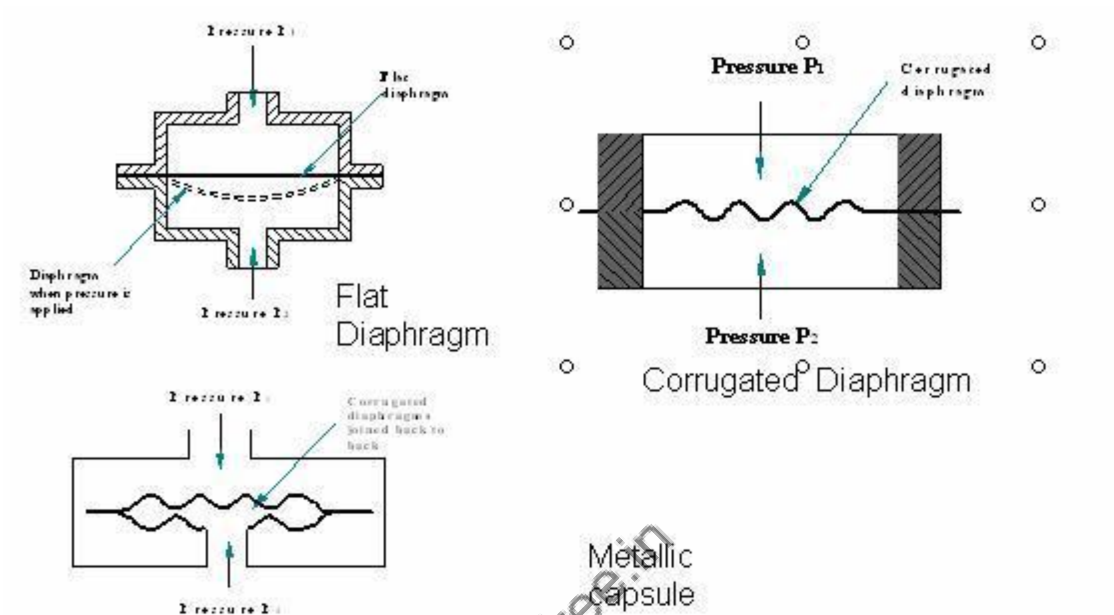
- One end of the tube is sealed and physically held while the other end is open for the fluid to enter.
- The fluid whose pressure is to be measured enters the tube and tends to straighten the tube.
- This causes the movement of the free end which can be measured.
- The commonly used materials for bourdon tubes are brass, Phosphor bronze, Beryllium copper, etc.

Diaphragms

Diaphragms: Elastic diaphragms are used as primary pressure transducers in many dynamic pressure measuring devices.

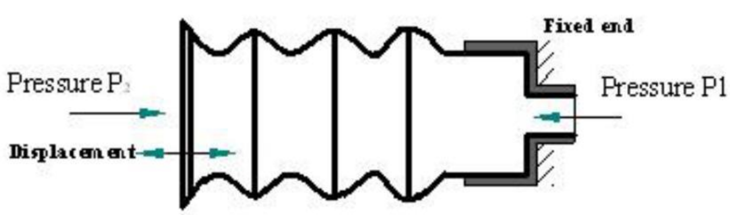
- These may be either ‘flat’ or ‘corrugated’ as shown in fig.
- A diaphragm is a thin flat plate of circular shape fixed around its circumference.
- When a differential pressure (P1-P2) occurs across the diaphragm, it will deflect as shown in fig.
- The deflection may be sensed by an appropriate displacement transducer such as strain gauge.
- A *flat diaphragm* is often used in conjunction with electrical secondary transducers whose sensitivity permits small diaphragm deflections.

- A *corrugated diaphragm* is useful when large deflections are required.
- An alternative form of diaphragm to obtain large deflections is a *metallic capsule* or pressure capsule, in which two corrugated diaphragms are joined back to back at their edges as shown in fig. Pressure P2 is applied to the inside of the capsule which is surrounded by the pressure P1



Bellow

Metallic bellows are thin walled tubes formed by hydraulic presses into a corrugated shape as shown in fig. Bellows can be of diameters upto 300 mm & are made of Brass, (80%copper & 20% zinc), Phosphor bronze, stainless steel, Beryllium copper. A differential pressure causes displacement of the bellows, which may be converted into an electrical signal.



Metallic Bellow

Electrical transducer elements

- Most measuring devices have electrical elements as secondary transducers that convert the displacement of a primary sensor into electrical current,resitance or voltage.
- The transducers may be of resistive, inductive or capacitive type

Advantages of electrical transducers:

(1) Very small size & compact.
(2) Frictional & inertial effects are reduced .
(3) Remote recording & control possible.
(4) Amplification & attenuation of signals may be easily obtained.
(5) Less power consumption.
(6) Signal output may be easily processed and transmitted.

Resistive Transducers

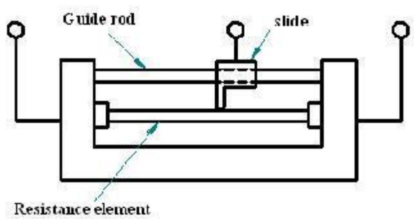
The resistance of an electrical conductor varies according to the relation,

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

where R= resistance in ohms, r= Resistivity of the material in ohm-cm, L= length of the conductor in cm, A= cross sectional area in cm2. Any method of varying one of the quantities involved may be the design criterion for the transducer. Following are some types:

Sliding contact devices:

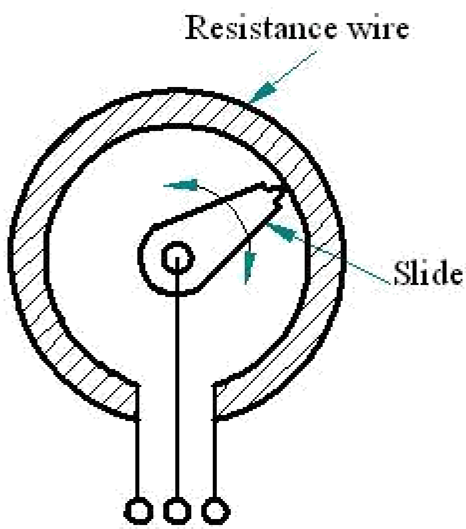
Convert mechanical displacement input into either current or voltage output - Achieved by changing the effective length of the conductor - The slide or contactor maintains electrical contact with the element and the slide is a measure of the linear displacement of the slide - Such devices are used for sensing relatively large displacements.



Sliding contact Resistive Transducer

Potentiometers:

The resistance elements may be formed by wrapping a resistance wire around a card as shown in fig. In this the effective resistance between either end of the resistance element and the slide is a measure of angular displacement of the slide.



Angular motion potentiometer

Angular motion potentiometer

- **Inductance** is the property in an electrical circuit where a change in the current flowing through that circuit induces an electromotive force (EMF) that opposes the change in current.
- In electrical circuits, any electric current *i* produces a magnetic field and hence generates a total magnetic flux *Φ* acting on the circuit.
- This magnetic flux, according to *Lenz's law* tends to oppose changes in the flux by generating a voltage (*a counter emf*) that tends to oppose the rate of change in the current.
- The ratio of the magnetic flux to the current is called the *self-inductance* which is usually simply referred to as the *inductance* of the circuit

Mutual Inductance:

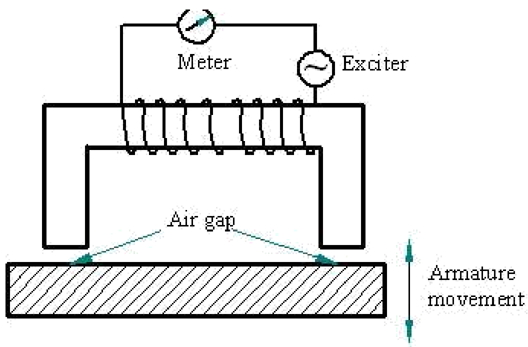
When the varying flux field from one coil or circuit element induces an emf in a neighboring coil or circuit element, the effect is called Mutual Inductance.

Magnetic reluctance

Magnetic reluctance or magnetic resistance, is analogous to resistance in an electrical circuit.
In likeness to the way an electric field causes an electric current to follow the path of least resistance, a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. Permeance is the reciprocal of reluctance

VARIABLE SELF INDUCTANCE TRASDUCER (Single Coil)

When a single coil is used as a transducer element, the mechanical input changes the permeance of the flux path generated by the coil, thereby changing its inductance.

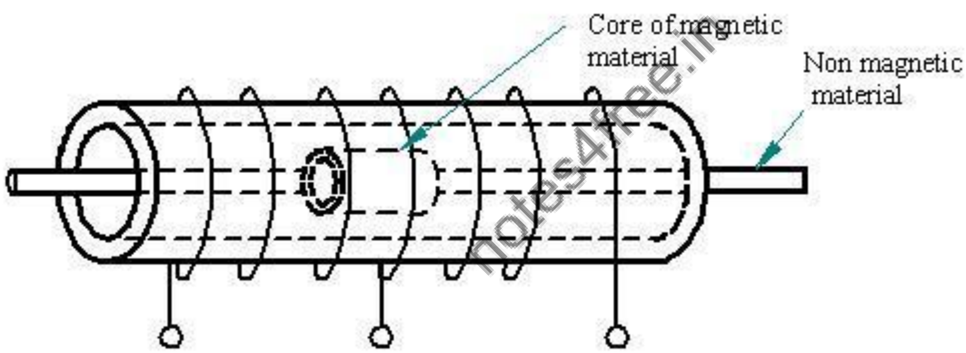


Single Coil
Self inductance
arrangement

This change can be measured by a suitable circuit, indicating the value of the input. As shown in fig, the flux path may be changed by a change in the air gap.

The Two Coil arrangement, shown in fig, is a single coil with a center tap. Movement of the core alters the relative inductance of the two coils. These transducers are incorporated in inductive bridge circuit in which variation in inductance ratio between the two coils provides the output. This is used as a secondary transducer for pressure measurement.

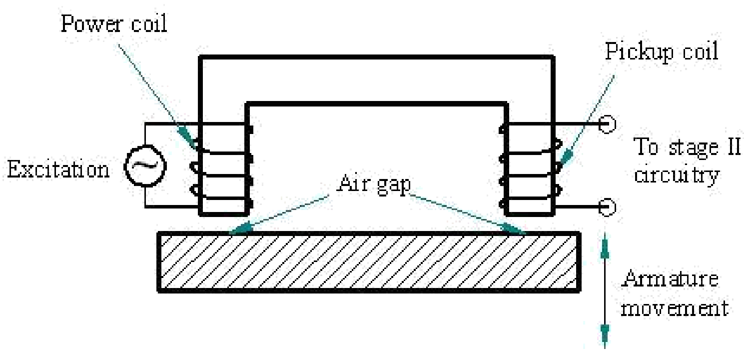
Variable self inductance -Two Coil (Single coil with center tap)



Variable Mutual inductance -Two Coil

- In this type, the flux from a power coil is coupled to a pickup coil, which supplies the output.
- Input information in the form of armature displacement, changes the coupling between the coils.
- The air gap between the core and the armature govern the degree of coupling.

Two Coil Mutual Inductance Transducer

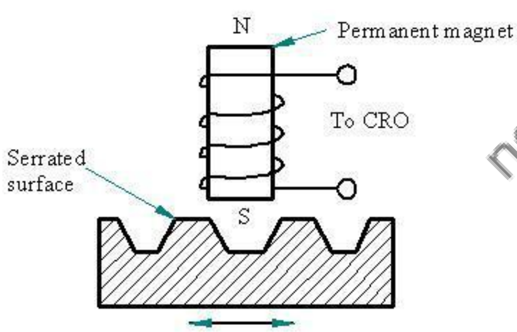


Note: Three Coil mutual inductance device (LVDT) is already discussed in Comparators Chapter.

A Variable reluctance Transducers are used for dynamic applications, where the flux lines supplied by a permanent magnet are cut by the turns of the coil. Some means of providing relative motion is included into the device.

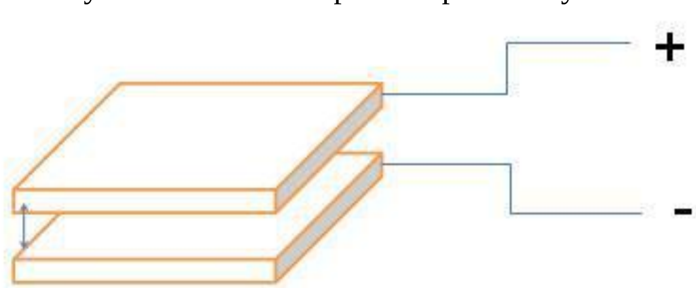
- The fig shows a simple type of reluctance pickup consisting of a coil wound on a permanent magnetic core.
- Any variation of the permeance of the magnetic circuit causes a change in the flux, which is brought about by a serrated surface subjected to movement.
- As the flux field expands or collapses, a voltage is induced in the coil.

Variable Reluctance Transducer



Capacitance Transducer

Generally it consists of two plates separated by a dielectric medium



The principle of these type is that variations in capacitance are used to produce measurement of many physical phenomenon such as dynamic pressure, displacement, force, humidity, etc.

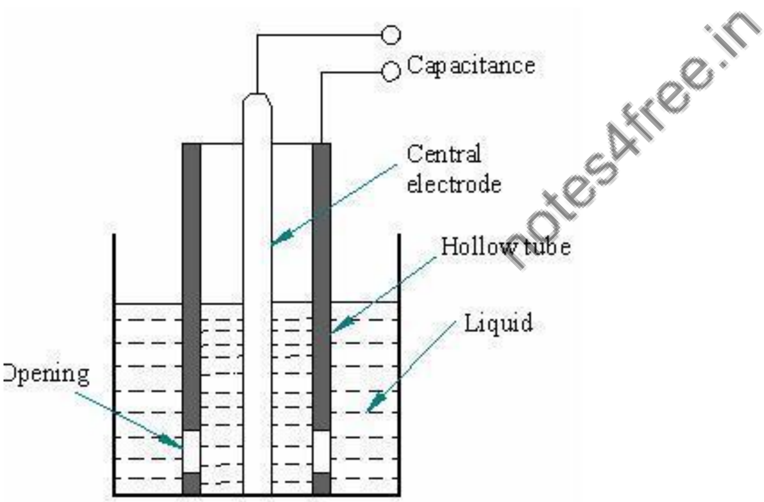
An equation for capacitance is $C = \frac{0.244KA(N-1)}{d}$ Farads

Where K= dielectric constant (for air K=1), A= area of one side of one plate, N= Number of plates, d= Separation of plate surfaces (cm)

The change in the capacitance may be brought about by three methods:

1. Changing the dielectric
2. Changing the area
3. Changing the distance between the plates
4. Fig shows a device used for the measurement of liquid level in a container.
5. The capacitance between the central electrode and the surrounding hollow tube varies with changing dielectric constant brought about by changing liquid level.
6. Thus the capacitance between the electrodes is a direct indication of the liquid level.
7. Variation in dielectric constant can also be utilized for measurements of thickness, density, etc.

Capacitance Pickup to measure liquid level (Changing dielectric constant)

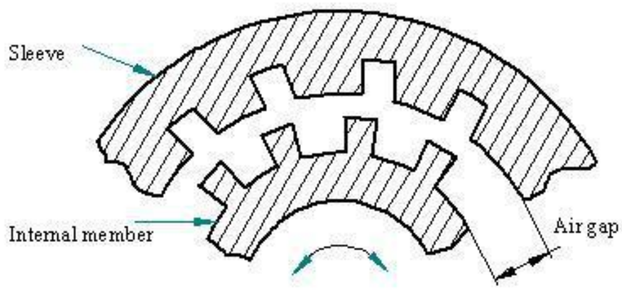


*****capacitance** is the ability of a body to hold an electrical charge.
Capacitance is also a measure of the amount of electric charge stored for a given electric potential. A common form of charge storage device is a two-plate capacitor. If the charges on the plates are +Q and −Q, and V gives the voltage between the plates, then the capacitance is given by $C=(Q/V)$
The SI unit of capacitance is the farad; 1 farad = 1 coulomb per volt

Capacitive Transducer- Changing area:

- Capacitance changes depending on the change in effective area.
- This principle is used in the secondary transducing element of a *Torque meter*.
- This device uses a sleeve with serrations cut axially and a matching internal member with similar serrations as shown in fig.

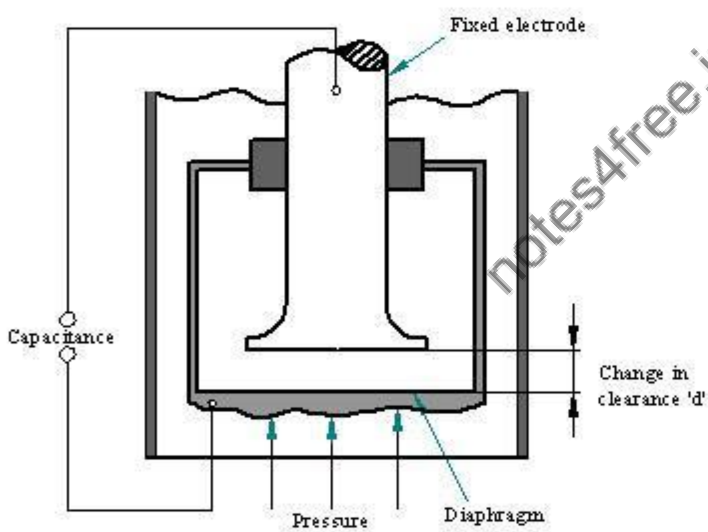
- Torque carried by an elastic member causes a shift in the relative positions of the serrations, thereby changing the effective area. The resulting capacitance change may be calibrated to read the torque directly.



Torque Meter (Capacitive type)

Capacitive Transducer-Changing distance

The capacitance varies inversely as the distance between the plates. The fig shows a capacitive type pressure transducer where the pressure applied to the diaphragms changes the distance between the diaphragm & the fixed electrode which can be taken as a measure of pressure.



Capacitive type pressure pickup

Advantages of Capacitive Transducers

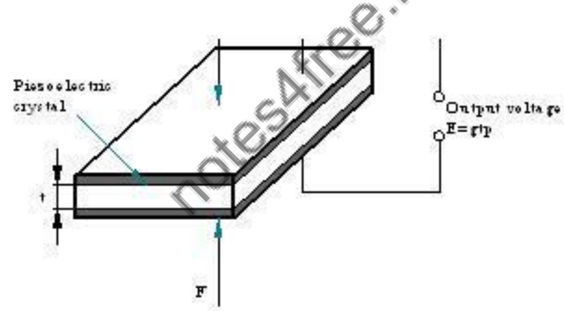
(1) Requires extremely small forces to operate and are highly sensitive
(2) They have good frequency response and hence useful for dynamic measurements.
(3) High resolution can be obtained.
(4) They have high input impedance & hence loading effects are minimum.
(5) These transducers can be used for applications where stray magnetic fields render the inductive transducers useless.

Disadvantages of Capacitive Transducers

(1) Metallic parts must be properly insulated and the frames must be earthed.
(2) They show nonlinear behaviour due to edge effects and guard rings must be used to eliminate this effect.
(3) They are sensitive to temperature affecting their performance.
(4) The instrumentation circuitry used with these transducers are complex.
(5) Capacitance of these transducers may change with presence of dust particles & moisture.

Piezoelectric Transducers :

- Certain materials can produce an electrical potential when subjected to mechanical strain or conversely, can change dimensions when subjected to voltage. This effect is called *'Piezoelectric effect'.*
- The fig shows a piezoelectric crystal placed between two plate electrodes and when a force 'F' is applied to the plates, a stress will be produced in the crystal and a corresponding deformation. The induced charge Q=d*F where 'd' is the piezoelectric constant
- The output voltage E=g*t*p where 't' is crystal thickness, 'p' is the impressed pressure & 'g' is called voltage sensitivity given by g=(d/e), e being the strain.
-



Piezoelectric effect

Piezoelectric materials

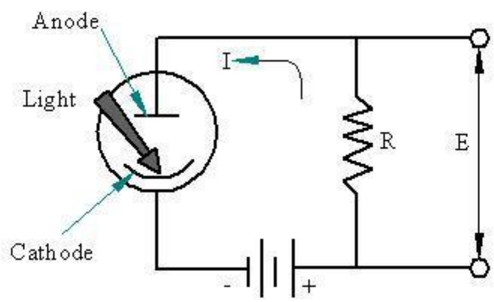
The common piezoelectric materials are quartz, Rochelle salt (Potassium sodium tartarate), ammonium dihydrogen phosphate and ordinary sugar. The desirable properties are stability, high output, insensitivity to temperature and humidity and ability to be formed into desired shape. Quartz is most suitable and is used in electronic oscillators. Its output is low but stable. Rochelle salt provides highest output, but requires protection from moisture in air & cannot be used above 45oC. Barium titanate is polycrystalline, thus it can be formed into a variety of sizes & shapes.

Piezoelectric transducers are used to measure surface roughness, strain, force & torque, Pressure, motion & noise. Desirable Properties of Piezoelectric Crystals Good stability, should be insensitive to temperature extremes, possess the ability to be formed to any desired shape.

Photoelectric Transducers:

A photoelectric transducer converts a light beam into a usable electric signal. As shown in the fig, light strikes the photo emissive cathode and releases electrons, which are attracted towards the anode, thereby producing an electric current in the circuit. The cathode & the anode are enclosed in a glass or quartz envelope, which is either evacuated or filled with an inert gas. The photo electric sensitivity is given by; I=s*f where I=Photoelectric current, s=sensitivity, f= illumination of the cathode. The response of the photoelectric tube to different wavelengths is influenced by

(i) The transmission characteristics of the glass tube envelope and
(ii) Photo emissive characteristics of the cathode material.

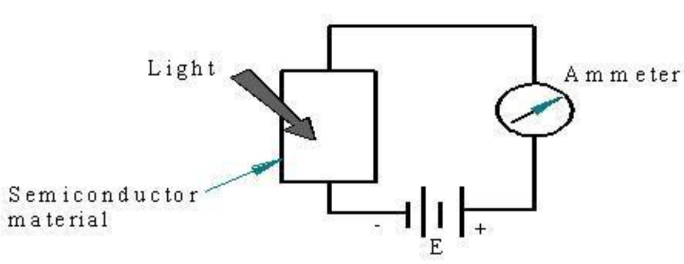


Photoelectric tubes are useful for counting purposes through periodic interruption of a light source

Photoconductive Transducers:

The principle of these transducers is when light strikes a semiconductor material, its resistance decreases, there by producing an increase in the current. The fig shows a cadmium sulphide semiconductor material to which a voltage is applied and when light strikes, an increase in current is indicated by the meter.

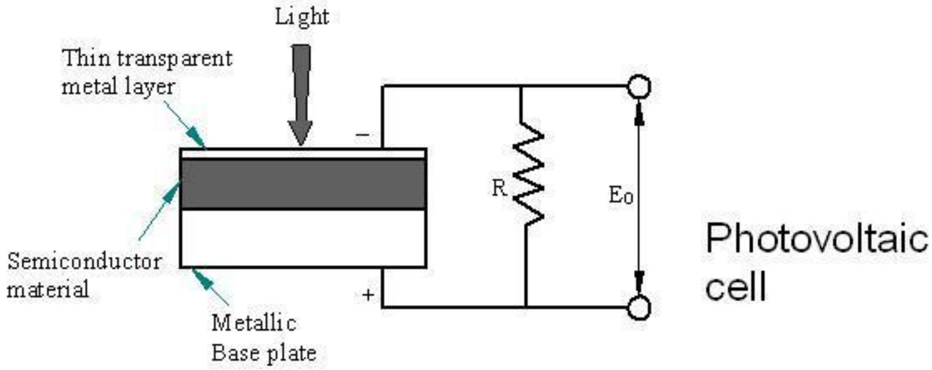
Photoconductive transducers are used to measure radiation at all wavelengths. But extreme experimental difficulties are encountered when operating with long wavelength radiations.



Photoconductive Transducer

The principle of *photovoltaic cell* is illustrated in the fig. It consists of a bas metal plate, a semiconductor material, and a thin transparent metal layer. When light strikes the transparent metal layer and the semiconductor material, a voltage is generated. This voltage depends on the load resistance R. The open circuit voltage is a logarithmic function, but linear behavior may be obtained by decreasing the load resistance.

- It is used in light exposure meter for photographic work.
-



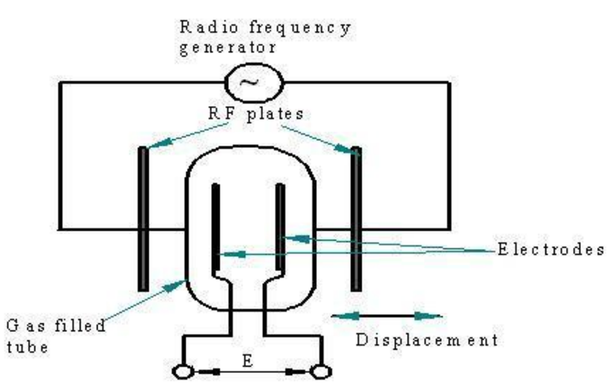
Ionization Transducers

- Ionization Transducers consist of a glass or quartz envelope with two electrodes A & B and filled with a gas or mixture of gases at low pressures.
- The radio frequency (RF) generator impresses a field to ionize the gas inside the tube.
- As a result of the RF field, a glow discharge is created in the gas, and the two electrodes A & B detect a potential difference in the gas plasma.
- It depends on the electrode spacing and the capacitive coupling between the RF plates and the gas
- When the tube is at the central position between the RF plates, the potentials on the electrodes will be the same, but when the tube is displaced from its central position, a D.C potential will be created.
- Thus ionization transducer is an useful device for measuring displacement.

Applications:

Pressure, acceleration & humidity measurements. They can sense capacitance changes of 10-15 farads or movements of 2.5x10-5 mm can be accurately measured with a linearity better than 1%.

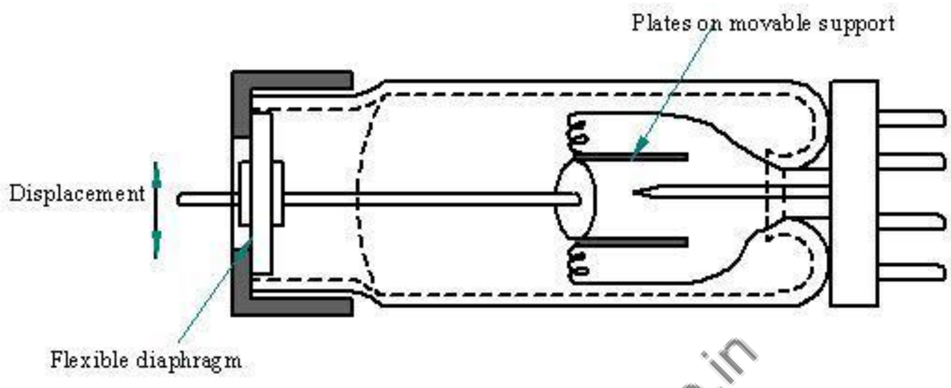
Ionization Transducer



- The fig shows the schematic diagram of an *Electronic transducer* element which is basically an electronic tube in which some of the elements are movable.
- Here, the plates are mounted on an arm which extends through a flexible diaphragm in the end of the tube.
- A mechanical movement applied to the external end of the rod is transferred to the plates within the tube thereby changing the characteristics of the tube.

Applications:

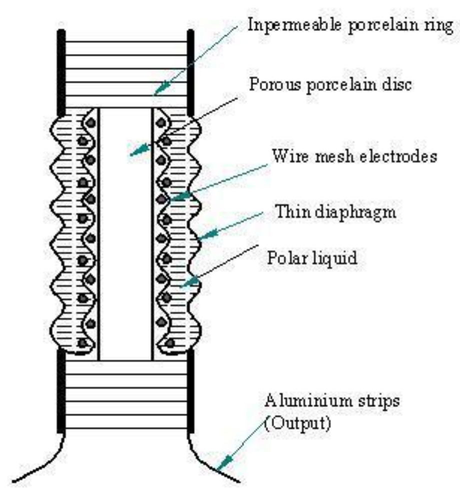
Electronic transducer element is used as surface roughness



Electrokinetic Transducer

- The Electrokinetic phenomenon is also referred to as 'Streaming Potential' which occurs when a polar liquid such as water, Methanol, or acetonitrile (CH3CN) is forced through a porous disc.
- When the liquid flows through the pores, a voltage is generated which is in phase with and directly proportional to the pressure across the faces of the disc.
- When direction of flow is reversed, the polarity of the signal is also reversed.

Electrokinetic Transducer



An unlimited supply of liquid is required on the upstream to measure static differential pressure with this type of pickup. Since this is impractical, finite amount of liquid is constrained within the electrokinetic cell. i.e. the device is used for dynamic rather than static pressure measurements.

- *Fig. shows a typical electrokinetic cell. It consists of a porous porcelain disc fitted into the center of an impermeable porcelain ring.*
- *The diaphragms are tightly sealed on either side to retain the polar liquid, which fills the space between the diaphragms.*
- *A wire mesh electrode is mounted on either side of the porous disc, with electrical connections via the aluminium strips.*
- *The whole assembly is fitted in a suitable housing.*

Applications: Measurement of small dynamic displacements, pressure & acceleration. **Limitations**: Can not be used for measurement of static quantities.

OUTCOMES

Students will understand

1. Concept of measurements and measuring devices.
2. Concept of transducers.

SELF ASSESMENT QUETIONS

1. What is the difference between active and passive sensors and continuous and discrete sensors?
2. Briefly explain the principles of operation of limit switch, proximity switch andphotoelectricsensors.

FURTHER READING

1. Jain R. K., 1997, Engineering Metrology, Khanna Publishers.
2. Shawne A. K., 1998, Mechanical Measurement and Instrumentation, Dhanpat Rai and Co. (P) Ltd.
3. Hazra Chowdhury, 1995, Workshop Technology, Media Promoters and Publishers Pvt. Ltd

MODULE 5

MEASUREMENTS OF FORCE, TORQUE AND PRESSURE

CONTENTS

OBJECTIVES

1. Is to get knowledge of force, pressure and temperature measuring devices and their applications.

5.1 Introduction

A force is defined as the reaction between two bodies. This reaction may be in the form of a tensile force (pull) or it may be a compressive force (push). Force is represented mathematically as a vector and has a point of application. Therefore the measurement of force involves the determination of its magnitude as well as its direction. The measurement of force may be done by any of the two methods.

- Direct method: This involves a direct comparison with a known gravitational force on a standard mass example by a physical balance.
- Indirect method: This involves the measurement of the effect of force on a body. For example.

a) Measurement of acceleration of a body of known mass which is subjected to force.

b) Measurement of resultant effect (deformation) when the force is applied to an elastic member.

Direct method

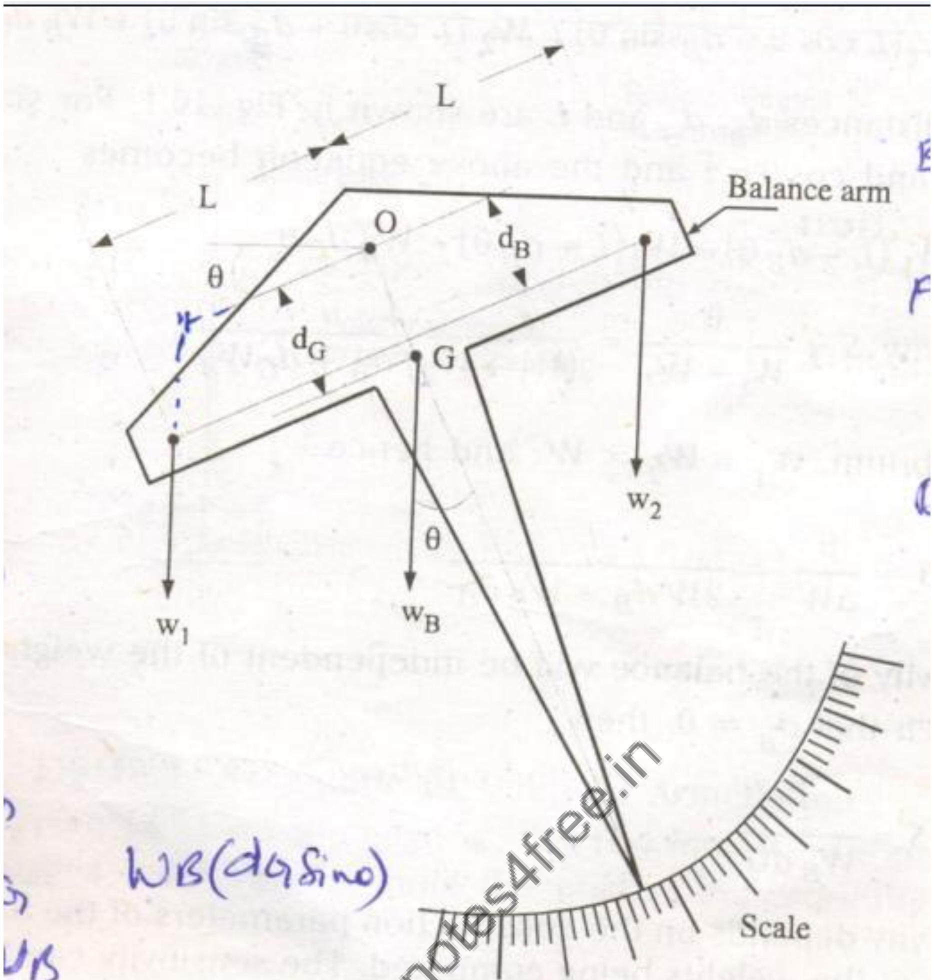
A body of mass "m" in the earth's gravitational field experiences a force F which is given by F = ma = W.

Where 'W' is the weight of the body 'a' is the acceleration due to gravity. Any unknown force may be compared with the gravitational force (ma) on the standard mass 'm'. The values of 'm' and 'a' should be known accurately in order to know the magnitude of the gravitation force.

Mass is a fundamental quantity and its standard kilogram is kept at France. The other masses can be compared with this standard with a precision of a few parts in109. On the other hand, 'a' is a derived quantity but still makes a convenient standard. Its value can be measured with an accuracy of 1 part in 106. Therefore any unknown force can be compared with the gravitational force with an accuracy of about this order of magnitude.

5.2 Analytical Balance : (Equal arm balance)

Direct comparison of an unknown force with the gravitational force can be explained with the help of an analytical balance. The direction of force is parallel to that of the gravitational force, and hence only its magnitude needs to be determined. The constructional details of an analytical balance are as shown in Fig.



The balance arm rotates about the point "O" and two forces W1 and W2 are applied at the ends of the arm. W1 is an unknown force and W2 is the known force due to a standard mass. Point G is the centre of gravity of the balance arm, and WB is the weight of the balance arm and the pointer acting at G. The above figure show the balance is unbalanced position when the force W1 and W2 are unequal. This unbalance is indicated by the angle θ which the pointer makes with the vertical.

In the balanced position $W_1 = W_2$, and hence θ is zero. Therefore, the weight of the balance arm and the pointer do not influence the measurements.

The sensitivity S of the balance is defined as the angular deflection per unit of unbalance is between the two weight W_1 and W_2 and is given by

$$S = \frac{\theta}{w_1 - w_2} \quad = \quad \frac{\theta}{\Delta W}$$

where, ΔW is the difference between W_1 and W_2. The sensitivity S can be calculated by writing the moment equation at equilibrium as follows:

$W_1 (L \cos\theta - d_B \sin\theta) = W_2 (L \cos\theta + d_B \sin\theta) + W_B d_G \sin\theta$

where the distances d_B, d_G and L are shown in Fig. For small deflection angles $\sin\theta = \theta$ and $\cos\theta = 1$ and the above equation becomes

$W_1 (L - d_B \theta) = W_2 (L + d_B \theta) + W_B d_G \theta$

$$\therefore \textit{The Sensitivity} \quad S = \frac{\theta}{w_1 - w_2} = \frac{L}{(w_1 + w_2)d_B + d_G W_B}$$

Near Equilibrium, $W_1 = W_2 = W$ and hence

$$S = \frac{\theta}{\Delta w} = \frac{L}{2Wd_B + W_B d_G}$$

The sensitivity of the balance will be independent of the weight W Provided it is designed such that $d_B = 0$ then

$$S = \frac{L}{W_B d_G}$$

The sensitivity depends on the construction parameters of the balance arm and is independent of the weights being compared. The sensitivity can be improved by decreasing both d_G and W_B and increasing L. A compromise however, is to be struck between the sensitivity and stability of the balance.

5.3 UNEQUAL ARM BALANCE

An equal arm analytical balance suffers from a major disadvantage. It requires a set of weights which are at least as heavy as the maximum weight to be measured. In order that the heavier weights may be measured with the help of lighter weights, balances with unequal arms are used.

The unequal arm balance uses two arms. One is called the **load arm** and the other is called the **power arm.** The load arm is associated with load i.e., the weight force to be measured, while power arm is associated with power i.e, the force produced by counter posing weights required to set the balance in equilibrium.

Fig. shows a typical unequal arm balance. Mass 'm' acts as power on the beam and exerts a force of F_g due to gravity where $F_g = m \times g$. This force acts as counterposing force against the load which may be a test force F_t.

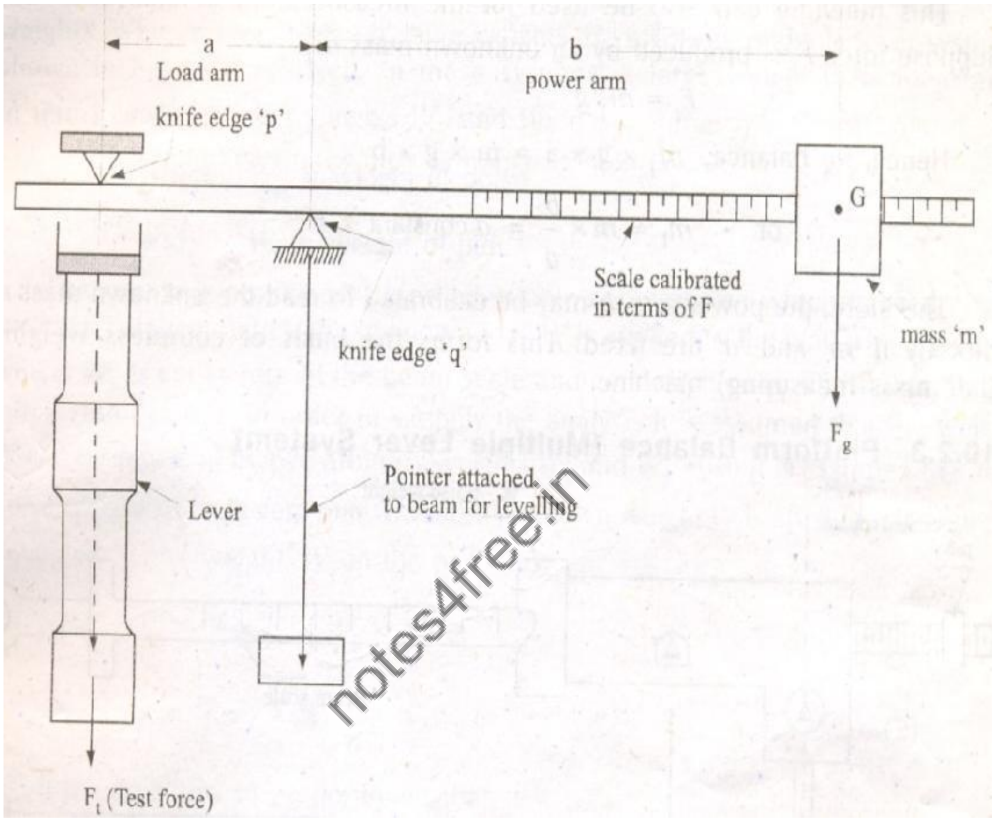


Fig. Schematic of Unequal Arm Balance

The beam is pivoted on a knife edge *'q'*. The test force F_t is applied by a screw or a lever through a knife edge *'p'* until the pointer indicates that the beam is horizontal.

For balance of moments, $F_t (a) = F_g (b)$

or test force $F_t = F_g (b/a)$

$= m \times g \times b/a$

$=$ constant x b (provided that g is constant).

Therefore the test force is proportional to the distance 'b' of the mass from the pivot. Hence, if mass 'm' is constant and the test force is applied at a fixed distance 'a' from the knife edge 'q' (i.e., the load arm is constant), the right hand of the beam (i.e., the power arm) may be calibrated in terms of force F_t. If the scale is used in different gravitational fields, a correction may be made for change in value of 'g'.

The set-up shown in Fig. is used for measurement of tensile force. With suitable modifications, it can be used for compression, shearing and bending forces.

This machine can also be used for the measurement of unknown mass. Suppose force F_t is produced by an unknown mass m_t.

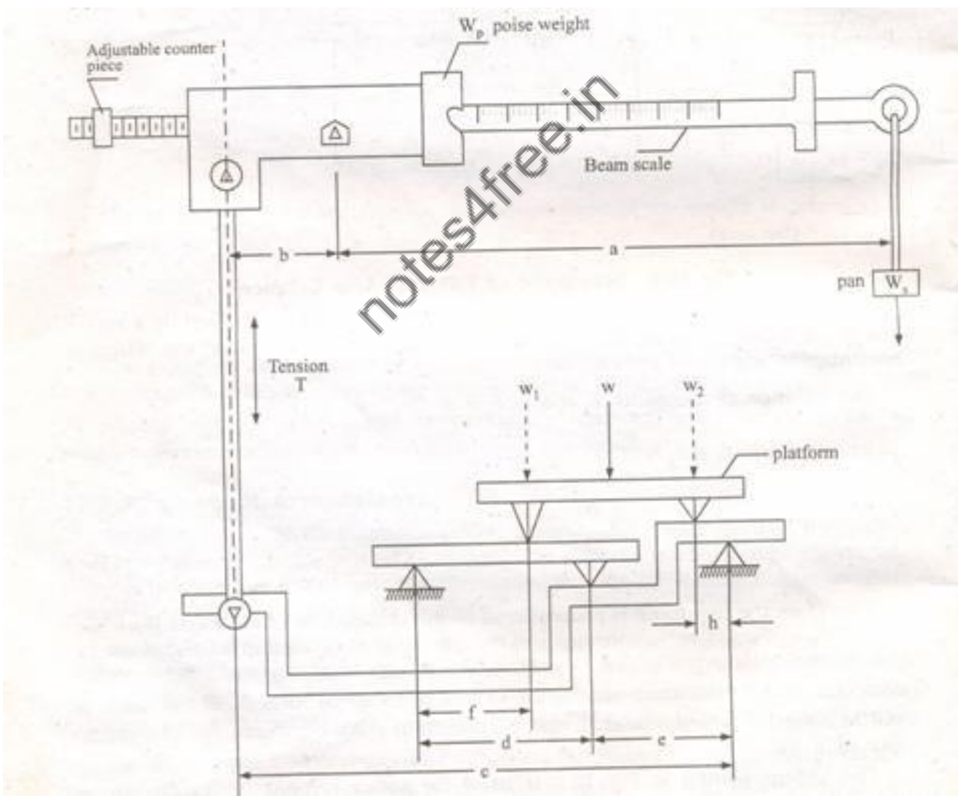
Therefore Ft = mt g

Hence, for balance, m1 x g x a = m x g x b

or m1 = m x b/a = a constant x b

Therefore, the power arm b may be calibrated to read the un known mass m1 directly if 'm' and 'a' are fixed. This forms the basis of countless weighing (i.e., mass measuring) machine.

5.4 Platform Balance (Multiple Lever System)



Schematic of Multiple Lever System

An equal and unequal arm balances are not suited for measurement of large weights. When measurement of large weights is involved, multiple lever systems shown in Fig. are used.

In these systems, a large weight W is measured in terms of two smaller weights Wp and Wg where, Wp = weight of poise and Ws = Weight of Pan

The system is provided with an adjustable counterpoise which is used to get an initial balance. Before the unknown load W is applied to the platform, the poise weight W_p is set at zero of the beam scale and counter piece is adjusted to obtain Initial zero balance.

In order to simplify the analysis it is assumed that the weight W can be replaced by two arbitrary weights W_1 and W_2. Also it is assumed that the poise weight W_p is at zero and when the unknown weight W is applied it is entirely balanced by the weight, W_S in the pan.

Therefore T x b = W_s x a ….(1)

and T x c = W_1 f/d e + W_2 h …(2)

If the links are so proportioned that h/e = f/d

We get : T x c = h (W_1 + W_2) hW ….(3)

From the above equation (3) it is clear that the weight W may be placed anywhere on the platform and its position relative to the two knife edges of the platform is immaterial.

T can be eliminated from equations. (l) and (3) to give

$$WS\frac{a}{b} = \frac{Wh}{d}$$

$$Unknown\ weight\ W = \frac{a}{b}\frac{c}{h}W_s$$

$$where\ m = \frac{a}{b}\frac{c}{h} \quad is\ called\ the multiplication\ ration\ of the\ scale$$

The multiplication ratio *M,* is indicative of weight that should be put in the pan to balance the weight on the platform. Suppose the scale has a multiplication ratio of 1000. It means that a weight of 1 kg put in the pan can balance a weight of 1000 kg put on the platform. Scales are available which have multiplication ratios as high as 10,000.

If the beam scale is so divided that a movement of poise weight Wp by 1 scale division represents a force of *x* kg, then a poise movement of y scale divisions should produce the same result as a weight W_p placed on the pan at the end of the beam. Hence,

$$Wp\ \ y = x\ y\ a$$

$$or \quad x = \frac{W_p}{a}$$

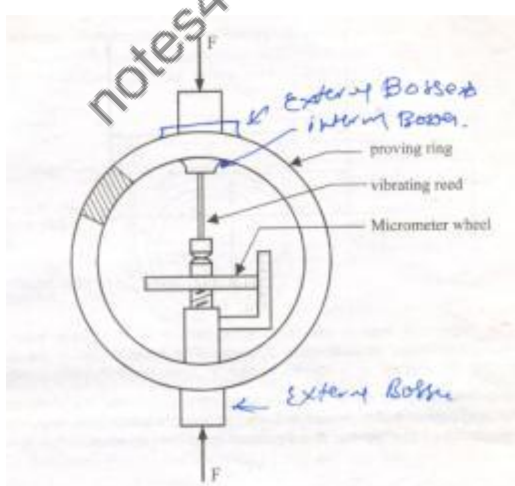
The above equation represents a relationship that determines the required scale divisions on the beam for any poise weight Wp.

5.5 Proving Ring

This device has long been the standard for calibrating tensile testing machines and is in general, the means by which accurate measurement of large static loads may be obtained. A proving ring is a circular ring of rectangular cross section as shown in the Fig. which may be subjected to tensile or compressive forces across its diameter. The force-deflection relation for a thin ring is

$$F=\frac{16}{\frac{\pi}{2}-\frac{4}{\pi}}\frac{EI}{d^3}y$$

where, *F* is the force, E is the young's modulus, I is the moment of inertia of the section about the centroidal axis of bending section. *D* is the outside diagram of the ring, y is the deflection. The above equation is derived under the assumption that the thickness of the ring is small compared to the radius. And also it is clear that the displacement is directly proportional to the force.



The deflection is small and hence the usefulness of the proving ring as a calibration device depends on the accuracy with which this small deflection is measured. This is done by using a precision micrometer shown in the figure. In order to obtain precise measurements one edge of the micrometer is mounted on a vibrating reed device which is plucked to obtain a vibratory motion.

The micrometer contact is then moved forward until a noticeable damping of the vibration is observed.

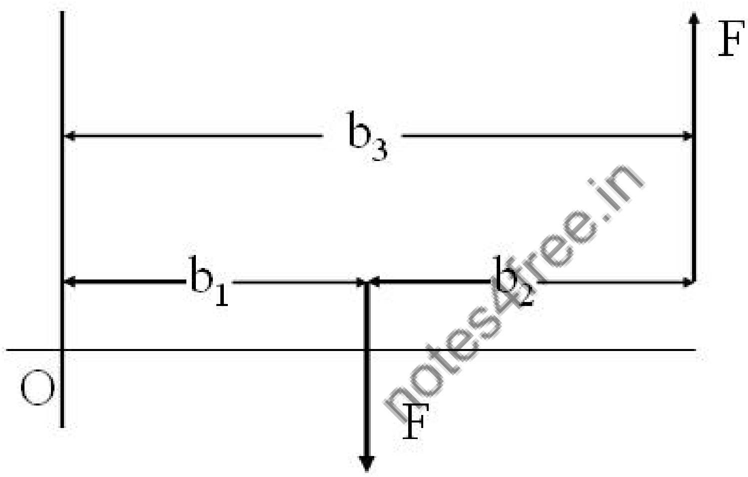
Proving rings are normally used for force measurement within the range of 1.5 KN to 1.5 MN. The maximum deflection is typically of the order of 1% of the outside diameter of the ring.

5.6 Torque Measurement

The force, in addition to its effect along its line of action, may exert a turning effort relative to any axis other than those intersecting the line of action as shown in Fig. Such a turning effect is called torque or couple

Torque or couple = $Fb_1 - Fb_3$

$= Fb_2$



The important reason for measuring torque is to obtain load information necessary for stress or deflection analysis. The torque T may be computed by measuring the force F at a known radius 'r' from the following relation T=Fr.

However, torque measurement is often associated with determination of mechanical power, either power required to operate a machine or power developed by the machine. The power is calculated from the relation.

$$P = 2\pi NT$$

where *N* is the angular speed in revolutions per second. Torque measuring devices used in this connection are commonly known as **dynamometers.**

There are basically three types of dynamometers.

1. Absorption dynamometers: They absorb the mechanical energy as torque is measured, and hence are particularly useful for measuring power or torque developed by power sources such as engines or electric motors.

2. Driving dynamometers: These dynamometers measure power or torque and as well provide energy to operate the devices to be tested. They are, therefore, useful in determining performance characteristics of devices such as pumps, compressors etc

3. Transmission dynamometers: These are passive devices placed at an appropriate location within a machine or in between machines to sense the torque at that location. They neither add nor subtract the transmitted energy or power and are sometimes referred to as **torque meters.**

The first two types can be grouped as mechanical and electrical dynamometers.

These dynamometers are of absorption type. The most device is the prony brake as shown in Fig.

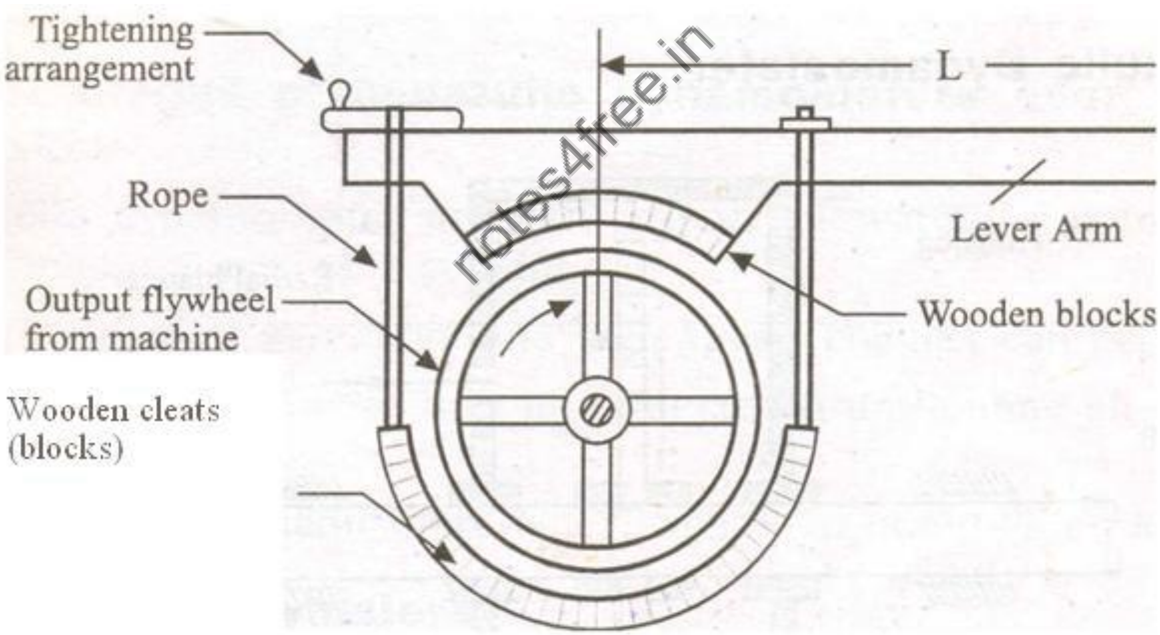


Fig. Schematic of Prony Brake

Two wooden blocks are mounted diametrically opposite on a flywheel attached to the rotating shaft whose power is to be measured. One block carries a lever arm, and an arrangement is provided to tighten the rope which is connected to the arm. The rope is tightened so as to increase the frictional resistance between the blocks and the flywheel. The torque exerted by the prony brake is T = F.L where force F is measured by conventional force measuring instruments, like balances or load cells etc. The power dissipated in the brake is calculated by the following equation.

$$P = \frac{2\pi\ NT}{60} = \frac{2\pi\ FLN}{60}\ Watts.$$

where force F is in Newtons, L is the length of lever arm in meters, N is the angular speed in revolution per minute, and P in watts. The prony brake is inexpensive, but it is difficult to adjust and maintain a specific load.

Limitation : The prony brake is inherently unstable. Its capacity is limited by the following factors.

i). Due to wear of the wooden blocks, the coefficient of friction varies between the blocks and the flywheel. This requires continuous tightening of clamp. Therefore, the system becomes unsuitable for measurement of large powers especially when used for long periods

ii) The use of prony brake results in excessive temperature rise which results in decrease in coefficient of friction leading to brake failure. In order to limit the temperature rise, cooling is required. This is done by running water into the hollow channel of the flywheel.

iii) When the machine torque is not constant, the measuring arrangement is subjected to oscillations. There may be changes in coefficient of friction and hence the reading of force F may be difficult to take.

Hydraulic Dynamometer

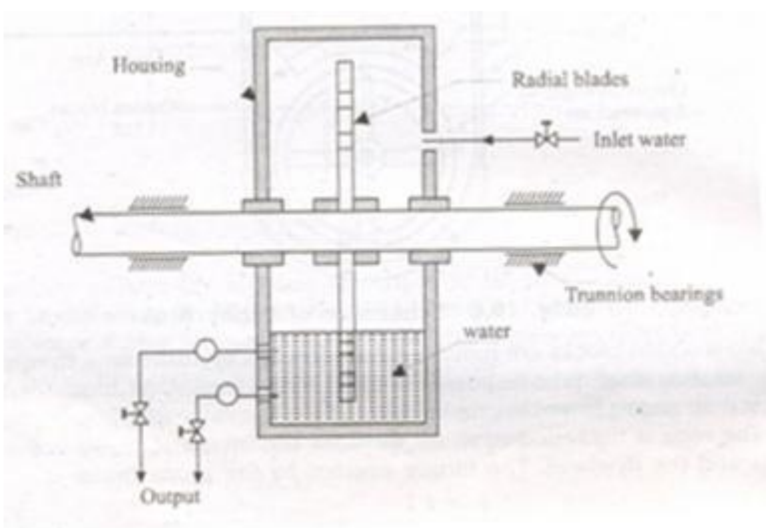


Fig. Section through a typical water brake

Fig. shows a hydraulic dynometer in its simplest form which acts as a water brake. This is a power sink which uses fluid friction for dissipation of the input energy and thereby measures the input torque-or power.

The capacity of hydraulic dynamometer is a function of two factors, speed and water level. The power consumed is a function of cube of the speed approximately. The torque is measured with the help of a reaction arm. The power absorption at a given speed may be controlled by adjustment of the water level in the housing. This type of dynamometer may be made in considerably larger capacities than the simple prony brake because the heat generated can be easily removed by circulating the water into and out of the housing. Trunnion bearings support the dynamometer housing, allowing it a freedom to rotate except for the restraint imposed by the reaction arm.

In this dynamometer the power absorbing element is the housing which tends to rotate with the input shaft of the driving machine. But, such rotation is constrained by a force-measuring device, such as some form of scales or load cell, placed at the end of a reaction arm of radius. By measuring the force at the known radius, the torque T may be computed by the simple relation.

Advantages of hydraulic dynamometers over mechanical brakes

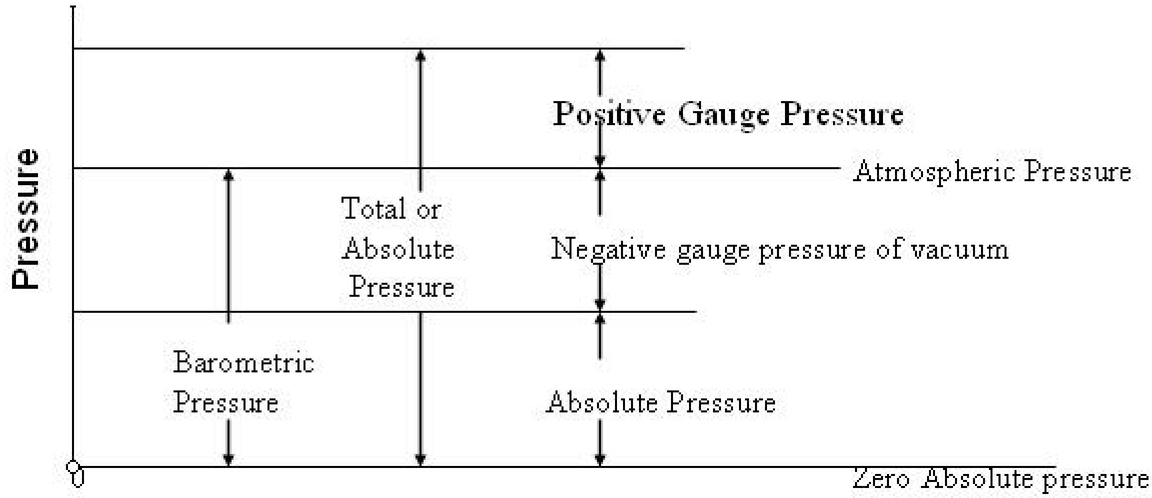
- In hydraulic dynamometer constant supply of water running through the breaking medium acts as a coolant.
- The brake power of very large and high speed engines can be measured.
- The hydraulic dynamometer may be protected from hunting effects by means of dashpot damper.
- In hydraulic dynamometer there is a flexibility in controlling the operation

5.7 Pressure Measurements

Introduction

Pressure is represented as a force per unit area exerted by a fluid on a container. The standard SI unit for pressure is Newton / Square meter (N/m2) or Pascal (Pa). High pressures can be conveniently expressed in KN/m2 while low pressure are expressed in terms of mm of water or mm of mercury.

Pressure is the action of one force against another over, a surface. The pressure P of a force F distributed over an area A is defined as: P = F/A.



Relationship between Pressure Terms

Absolute Pressure.

It refers to the absolute value of the force per unit are exerted on the containing wall by a fluid.

Atmospheric Pressure

It is the pressure exerted by the earth's atmosphere and is usually measured by a barometer. At sea level. Its value is close to 1.013 x 105 N/m2 absolute and decreases with altitude.

Gage Pressure

It represents the difference between the absolute pressure and the local atmosphere pressure

Vacuum

It is an absolute pressure less the atmospheric pressure i.e. a negative gage pressure.

Static and Dynamic pressures

If a fluid is in equilibrium, the pressure at a point is identical in all directions and independent of orientation is referred as pressure. In dynamic pressure, there exist a pressure gradient within the system. To restore equilibrium, the fluid flows from regions of higher pressure t regions of lower pressure.

Types of Pressure Measuring Devices

(i) Mechanical Instruments: These devices may be of two types. The first type includes those devices in which the pressure measurement is made by balancing an unknown pressure with a known force. The second types include those employing quantitative deformation of an elastic member for pressure measurements.

(ii) Electro-mechanical Instruments: this instrument employs a mechanical means for detecting the pressure and electrical means for indicating or recording the detected pressure.

(iii) Electronic Instruments: these instruments depend on some physical change which can be detected and indicated or recorded electronically.

Use of Elastic Members in Pressure Measurement

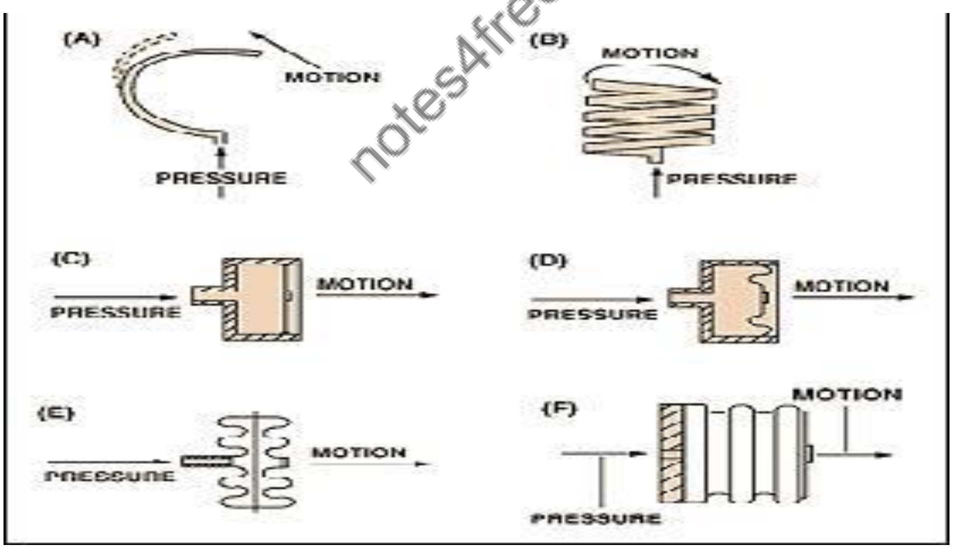
Application of pressure to certain materials causes elastic deformations. The magnitude of this elastic deformation can be related either analytically or experimentally to the applied pressure. Following are the three important elastic members used in the measurement of pressure.

(i) Bourdon tube,

(ii) Diaphragms and

(iii) Bellows

Sensing Elements



The basic pressure sensing element can be configured as a C-shaped Bourdon tube (A); a helical Bourdon tube (B); flat diaphragm (C); a convoluted diaphragm (D); a capsule (E); or a set of bellows (F).

The Bridgman Gage

The resistance of fine wires changes with pressure according to the following linear relationship. $R = R1 (1 + \alpha p)$

Where R1 Resistance at 1 atmosphere (100 KN/m2) in ohms

α Pressure coefficient of resistance in ohms/100 KN M-2

p gage pressure in KN/m2.

The above said resistance change may be used for measurement of pressures as high as 100,000 atm., 10.00KN/m2. A pressure transducer based on this principle is called a Bridgman gage. A typical gage uses a fine wire of manganin (84% Cu, 12% Mn, 4% Ni) wound in a coil and enclosed in a suitable pressure container. The pressure coefficient of resistance for this material is about 2.5x10-11 Pa-1. The total resistance of the wire is about 100Ω and conventional bridge circuits are employed for measuring the change in the resistance. Such gages are subjected to aging over a period of time, so that frequent calibration is required. However, when properly calibrated, the gage can be used for high pressure measurement with an accuracy of 0.1%. The transient response of the gage is exceedingly good. The resistance wire itself can respond of variations in the mega hertz range. Of course, the overall frequency response of the pressure-measurement system would be limited to much lower values because of the acoustic response of the transmitting fluid.

Low-Pressure measurement

In general, pressures below atmospheric may be called low pressures or vacuums. Its unit is micron, which is one-millionth of a meter (0.001 mm) of mercury column. Very low pressures may be defined as that pressures which are below 1 mm (1 torr) of mercury. An Ultra low pressure is one which has pressure less than a millimicron(10-3 micron). An ultralow pressure is one which has pressure less than a millimicron (10-3 micron). Following are the two methods of measuring low pressure.

Direct Method: In this, direct measurement resulting in displacement caused by the action of pressure. Devices used in this method are Bourdon tubes, flat and corrugated-diaphragms, capsules and various forms of manometers. These devices are limited to a lowest pressure measurement of about 10mm of mercury.

Indirect or Inferential method: In this pressure is determined through the measurement of certain other pressure-controlled properties, such as volume, thermal conductivity etc.

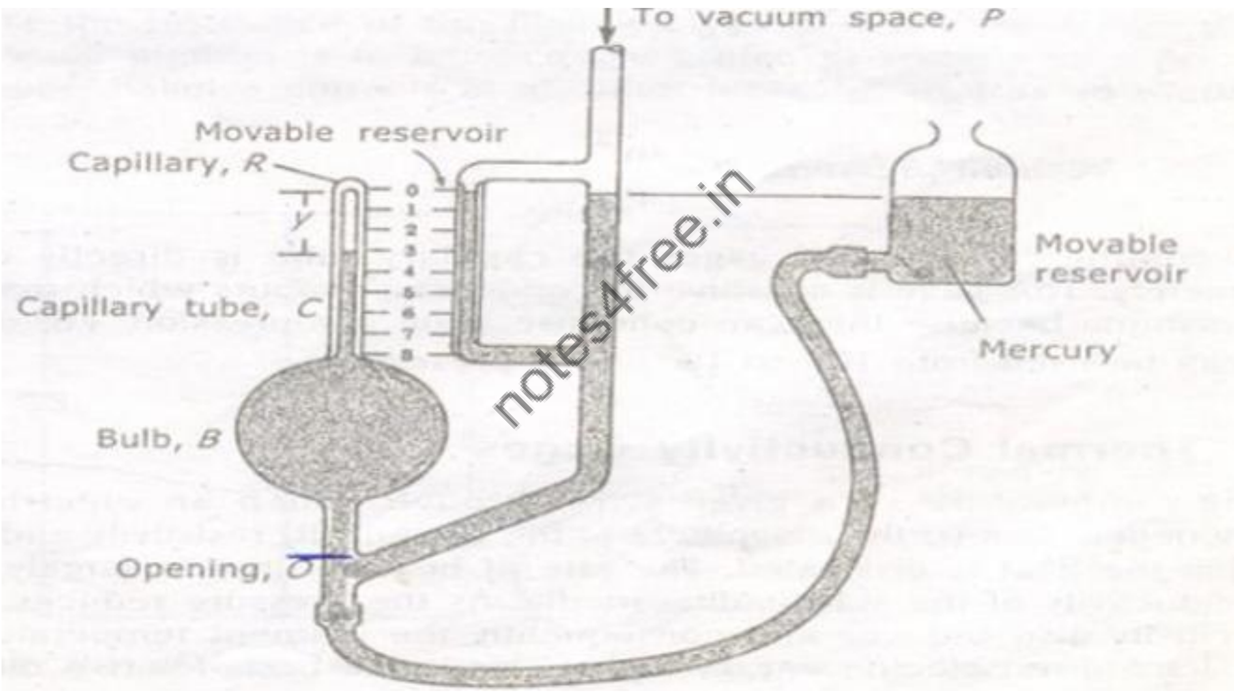
The Mcleod Gage

The operation of McLeod gage is based on Boyle's law.

$$p_1 = \frac{p_2\, v_2}{v_1}$$

Where, p1 andp2 are pressures at initial and conditions respectively, and v1 and v2 are volumes at the corresponding conditions. By compressing a known volume of low pressure gas to a higher pressure and measuring the resulting volume and pressure we can calculate the initial pressure.

The McLeod gage is a modified mercury manometer as shown in the Fig. 11.2. The movable reservoir is lowered until the mercury column drops below the opening O.



The Bulb B and capillary tube C are then at the same pressure as that of the vacuum pressure P. The reservoir is subsequently raised until the mercury fills the bulb and rises in the capillary tube to a point where the level in the reference capillary R is located at the zero point. If the volume of the capillary tube per unit length is 'a' then the volume of the gas in the capillary tube is Vc = ay----(1).

Where 'y' is the length of gas occupied in capillary tube.

If the volume of capillary tube, bulb and the tube down to the opening is VB. Assuming isothermal Compression, the pressure of the gas in the capillary tube is

$$P_C = P\frac{V_B}{V_C} \quad \text{-------}(2)$$

The pressure indicated by the capillary tube is

Pc - P = --------(3)

Where, we are expressing the pressure in terms of the height of the mercury column. And combining equations (1), (2) and (3)

$$P = \frac{ay^2}{V_B - ay}$$

Usually ay << VB

$$\therefore\ Vacuumpressur,\ P = \frac{ay^2}{V_B}$$

In commercial McLeod gages the capillary tube is directly calibrated in micrometers. This gage is sensitive to condensed vapours which may be present in the sample because they can condense upon compression. For dry gases the gage can be used from 10^{-2} to 10^{2} µm of pressure.

Thermal Conductivity Gages

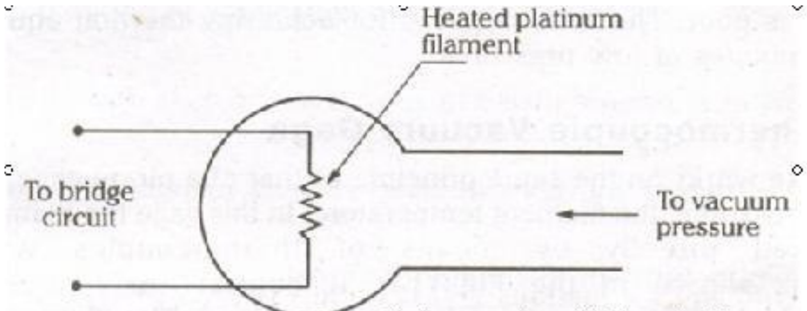
The temperature of a given wire through which an electric current is flowing depend, on (i) the magnitude of the current (ii) resistivity and (iii) the rate at which the heat is dissipated. The rate of heat dissipation largely depends on the conductivity of the surrounding media. As the pressure reduces, the thermal conductivity also reduces and consequently the filament temperature becomes higher for a given electric energy input. This is the basis for two different forms of gages to measure low pressures.

i). Pirani thermal conductivity gage

ii). Thermocouple vacuum gage

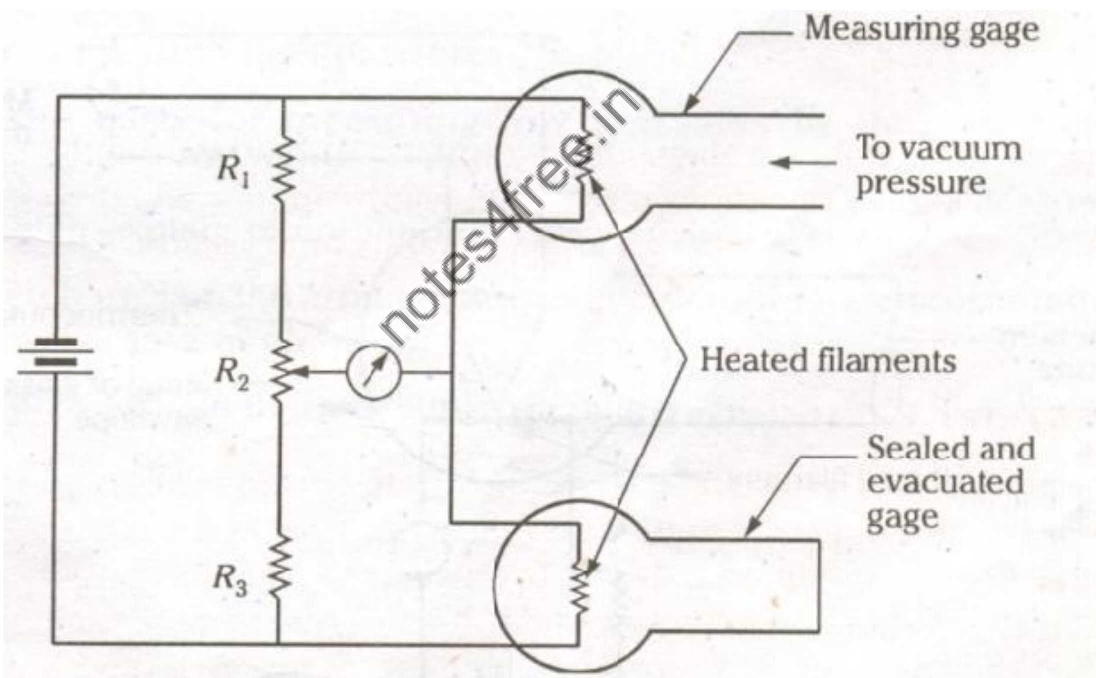
Pirani Thermal Conductivity Gages

The pirani gage as shown in the Fig. operates on the principle that if a heated wire is placed in a chamber of gas, the thermal conductivity of the gas depends on pressure. Therefore the transfer of energy from the wire to the gas is proportional to the gas pressure. If the supply of heating energy to the filament is kept constant and the pressure of the gas is varied, then the temperature of the filament will alter and is therefore a method of pressure measurement.



Schematic of Pirani Gage

To measure the resistance of the filament wire a resistance bridge circuit is used. The usual method is to balance the bridge at some datum pressure and use the out-of-balance currents at all other pressures as a measure of the relative pressures.



Pirani gage arrangement to compensate for ambient temperature Changes

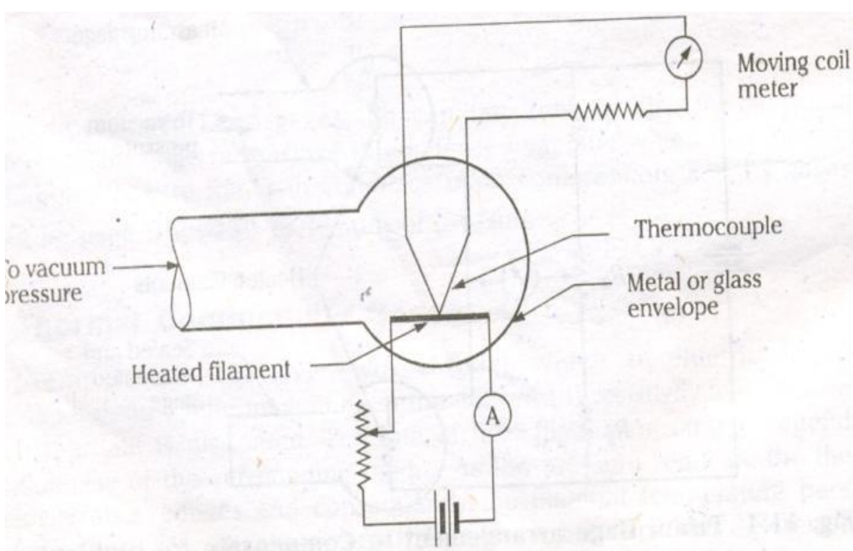
The heat loss from the filament is also a function of ambiet temperature and compensation for this effect may be achieved by connecting two gages in series as shown in Fig. The measuring gage is first evacuated and both the measuring and sealed gages are exposed to the same environment conditions. The bridge circuit is then adjusted through the resistor *R2* to get a null condition. When the measuring gage is exposed to the test vacuum pressure, the deflection of the bridge from the null position will be compensated for changes in environment temperature.

Pirani gages require calibration and are not suitable for use at pressures below l) lm and upper limit is about 1 torr. For higher pressures, the thermal conductivity changes very little with pressure. It must be noted that the heat loss from the filament is also a function of the conduction losses to the filament supports and radiation losses to the surroundings. The transient response of the pirani gage is poor. The time required for achieving thermal equilibrium may be of several minutes at low pressures.

Thermocouple Vacuum gage

This gage works on the same principle as that of a pirani gage, but differs in the means for measuring the filament temperature. In this gage the filament temperature is measured directly by means of thermocouples welded directly to them as shown in the Fig. 11.5. It consists of heater filament and thermocouple enclosed in a glass or metal envelope.

The filament is heated by a constant current and its temperature depends upon the amount of heat lost to the surroundings by conduction and convection. At low pressures, the temperature of the filament is a function of the pressure of surrounding gas. Thus, the thermocouple provides an output voltage which is a function of temperature of the filament and consequently the pressure of the surrounding gas. The moving coil instrument may be directly calibrated to read the pressure.



Thermocouple Vacuum Gage

5.8 Temperature Measurements

Introduction

Temperature measurement is the most common and important measurement in controlling any process. Temperature may be defined as an indication of intensity of molecular kinetic energy within a system. It is a fundamental property similar to that of mass, length and time, and hence it is difficult to define. Temperature cannot be measured using basic standards through direct comparison. It can only be determined through some standardized calibrated device.

Change in temperature of a substance causes a variety of effects such as:

i) Change in physical state,

ii) Change in chemical state,

iii) Change in physical dimensions,

iv) Change in electrical properties and

v) Change in radiating ability.

The change in physical and chemical states cannot be used for direct temperature measurement. However, temperature standards are based on changes in physical state. A change in physical dimension due to temperature shift forms the basis of operation for liquid in- glass and bimetallic thermometers. Changes in electrical properties such as change in electrical conductivity and thermoelectric effects which produce electromotive force forms the basis for thermocouples. Another temperature-measuring method using the energy radiated from a hot body forms the basis of operation of optical radiation and infrared pyrometers.

Temperature Measurement by Electrical Effects

Electrical methods of temperature measurement are very convenient because they provide a signal that can be easily detected, amplified, or used for control purposes. In addition, they are quite accurate when properly calibrated and compensated. Several temperature-sensitive electrical elements are available for measuring temperature. Thermal emf and both positive and negative variations in resistance with temperature are important among them.

Thermo resistive Elements

The electrical resistance of most materials varies with temperature. Resistance elements which are sensitive to temperature are made of metals and are good conductors of electricity. Examples are nickel, copper, platinum and silver. Any temperature-measuring device which uses these elements is called resistance thermometers or resistance temperature detectors (RTD). If semiconducting materials like combination of metallic oxides of cobalt, manganese and nickel having large negative resistance co- efficient are used then such devices are called thermistors.

The differences between these two kinds of devices are:

Sl. No	Resistance Thermometer	Thermistor
1	In this resistance change with temperature shift is small and positive.	In this resistance change with temperature shift is relatively large and negative
2	Provides nearly a linear temperature-resistance relation	Non-linear temperature resistance relation.
3	Practical operating temperature range is -250 to 1000°C	Practical operating temperature range is -100 to 275°C.
4	More time-stable hence provide better reproducibility with low hysteresis	Not time-stable

Electrical Resistance Thermometers

The desirable properties of resistance-thermometer materials are:

i) The material should permit fabrication in convenient sizes.

ii) Its thermal coefficient of resistivity should be high and constant

iii) They must be corrosion-resistant and should not undergo phase changes with in the temperature ranges.

iv) Provide reproducible and consistent results.

Electrical Resistance Thermometers

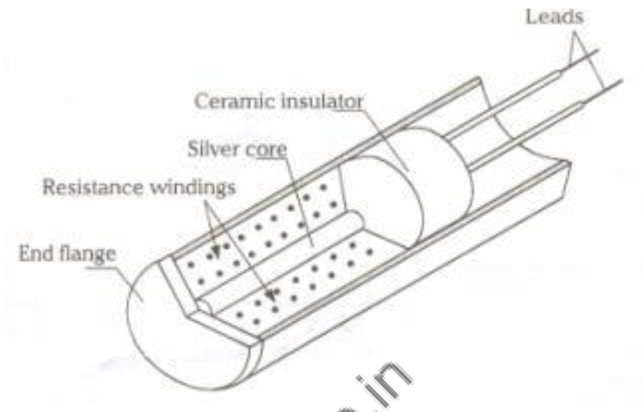
Unfortunately, there is no universally acceptable material and the selection of a particular material depends on the compromises. Although the actual resistance-temperature relation must be determined experimentally, for most metals the following empirical equation may be used.

$$R_t = Ro\,(l + aT + bT^2)$$

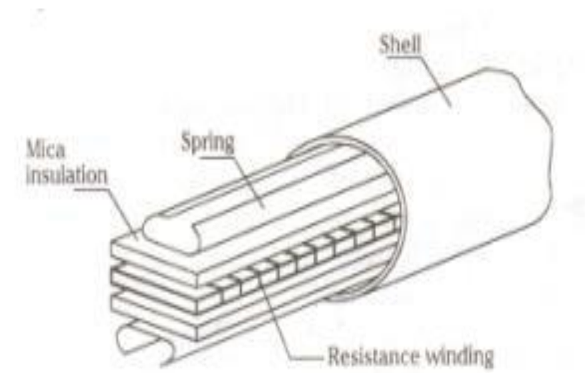
Where, Rt is the resistance at temperature T, Ro is the resistance at the reference temperature, T is the temperature and a and b are constants depending on the material.

Usually platinum, nickel and copper are the most commonly used materials, although others like tungsten, silver and iron can also be used.

Fig. shows the construction of two forms of resistance thermometer In Fig. (a) the element consists of a number of turns of resistance wire wrapped around a solid silver core. Heat is transmitted quickly from the end flange through the core to the windings.



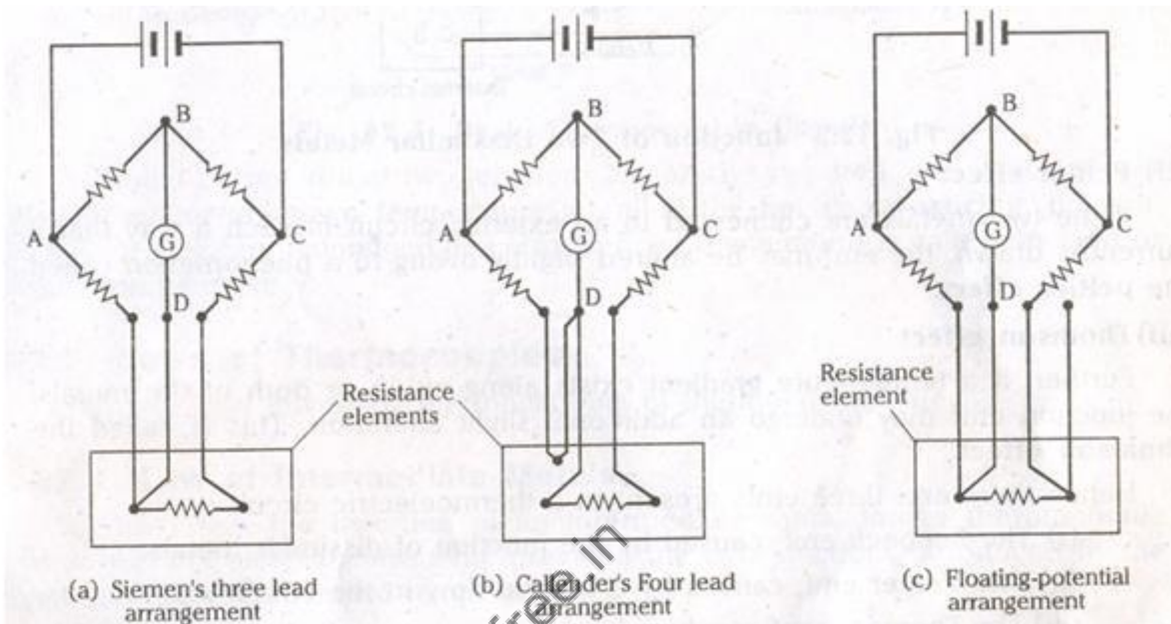
Another form of construction is shown in Fig. (b) in which the resistance wire is wrapped around a mica strip and sandwiched between two additional mica strips. These resistance thermometers may be used directly. But, when permanent installation with corrosion and mechanical protection is required a well or socket may be used.



Instrumentation for Resistance Thermometers

Some type of bridge circuit is normally used to measure resistance change in the thermometers. Leads of appropriate length are normally required, and any resistance change in them due to any cause affects the measurement. Hence, the lead resistance must be as low as possible relative to the element resistance.

Three methods of compensating lead resistance error are as shown in the Fig. The arms AD and DC each contain the same length of leads. If the leads have identical properties and are at identical ambient conditions, then the effects introduced by one arm will be cancelled by the other arm.



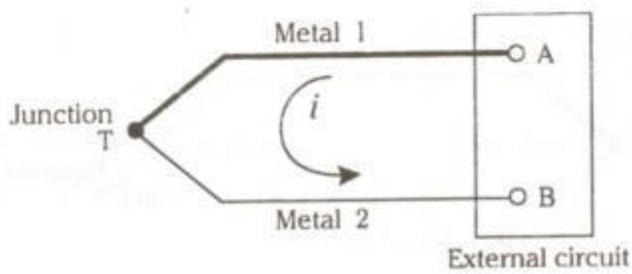
Methods of Compensating Lead Resistance Error

The Siemen's three-lead arrangement is the simplest corrective circuit. At balance conditions the centre lead carries no current, and the effect of the resistance of the other two leads is cancelled out. The Siemen's three-lead arrangement is the simplest corrective circuit. At balance conditions the centre lead carries no current, and the effect of the resistance of the other two leads is cancelled out. The calendar's four-lead arrangement solves the problem by inserting two additional lead wires in the adjustable leg of the bridge so that the effect of the lead wires on the resistance thermometer is cancelled out. The floating-potential arrangement is same as the Siemens' connection, but with an extra lead. This extra lead may be used to check the equality of lead resistance. The thermometer reading may be taken in the position shown, followed by additional readings with the two right and left leads interchanged, respectively. By averaging these readings, more accurate results may be obtained.

Usually, null-balance bridge is used but is limited to static or slowly changing temperatures. While the deflection bridge is used for rapidly changing temperatures.

1. See beck Effect:

When two dissimilar metals are joined together as shown in the Fig. an electromotive force (emf) will exists between the two points A and B, which is primarily a function of the junction temperature. This phenomenon is called the **see beck effect.**



Junction of Two Dissimilar Metals

2. Peltier effect

If the two metals are connected to an external circuit in such a way that a current is drawn, the emf may be altered slightly owing to a phenomenon called the **peltier effect.**

3.Thomson effect

Further, if a temperature gradient exists along either or both of the metals, the junction emf may undergo an additional slight alteration. This is called the **Thomson effect**.

Hence there are, three emfs present in a thermoelectric circuit:

i) The Seebeck emf, caused by the junction of dissimlar metals

ii) The Peltier emf, caused by a current flow in the circuit and

iii) The Thomson emf, resulting from a temperature gradient in the metals.

The Seebeck emf is important since it depends on the junction temperature.

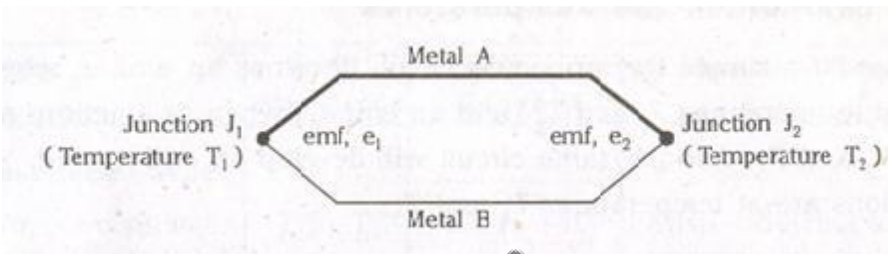
If the emf generated at the junction of two dissimilar metals is carefully measured as a function of temperature, then such a junction may be used for the measurement of temperature.

The above effects forms the basis for a thermocouple which is a temperature measuring element.

Thermocouple

If two dissimilar metals are joined an emf exists which is a function of several factors including the temperature.When junctions of this type are used to measure temperature, they are called thermocouples.

The principle of a thermocouple is that if two dissimilar metals *A* and *B are* joined to form a circuit as shown in the Fig. It is found that when the two junctions J_1 and J_2 are at two different temperatures T_1 and T_2, small emf's e_1 and e_2 are generated at the junctions. The resultant of the two emf's causes a current to flow in the circuit. If the temperatures T_1 and T_2 are equal, the two emf's will be equal but opposed, and no current will flow. The net emf is a function of the two materials used to form the circuit and the temperatures of the two junctions. The actual relations, however, are empirical and the temperature-emf data must be based on experiment. It is important that the results are reproducible and therefore provide a reliable method for measuring temperature.



Basic Thermocouple Circuit

It should be noted that two junctions are always required, one which senses the desired or unknown temperature is called the **hot** or **measuring** junction. The other junction maintained at a known fixed temperature is called the **cold** or **reference** junction.

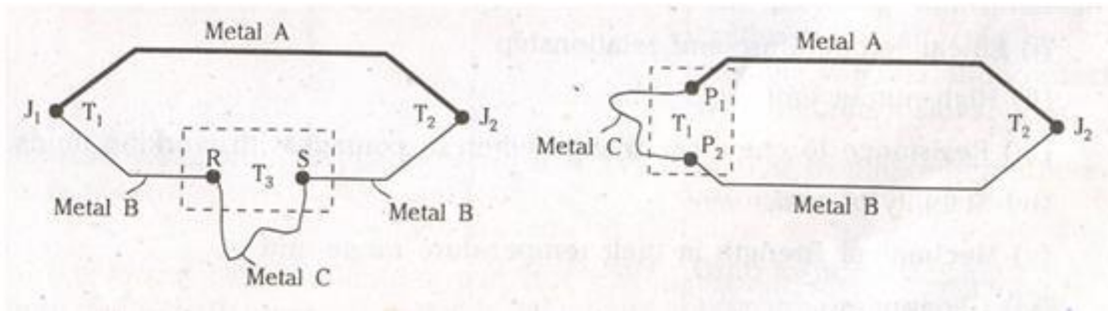
Laws of Thermocouples

The two laws governing the functioning of thermocouples are:

i) Law of Intermediate Metals:

It states that the insertion of an intermediate metal into a thermocouple circuit will not affect the net emf, provided the two junctions introduced by the third metal are at identical temperatures.

Application of this law is as shown in Fig. In Fig. (a), if the third metal C is introduced and the new junctions R and S are held at temperature T3, the net emf of the circuit will remain unchanged. This permits the insertion of a measuring device or circuit without affecting the temperature measurement of the thermocouple circuit

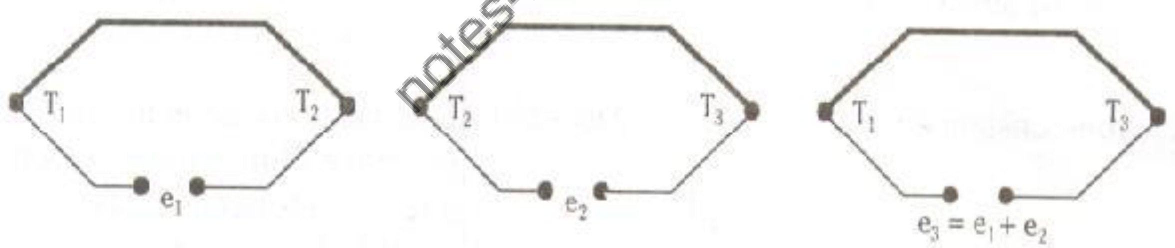


Circuits illustrating the Law of Intermediate Metals

In the Fig. (b) the third metal is introduced at either a measuring or reference junction. As long as junctions P_1 and P_2 are maintained at the same temperature T_P the net emf of the circuit will not be altered. This permits the use of joining metals, such as solder used in fabricating the thermocouples. In addition, the thermocouple may be embedded directly into the surface or interior of a conductor without affecting the thermocouple's functioning.

i) Law of Intermediate Temperatures:

It states that "If a simple thermocouple circuit develops an emf, e_1 when its junctions are at temperatures T_1 and T_2, and an emf e_2, when its junctions are at temperature T_2 and T_3. And the same circuit will develop an emf $e_3 = e_1 + e_2$, when its junctions are at temperatures T_1 and T_3.

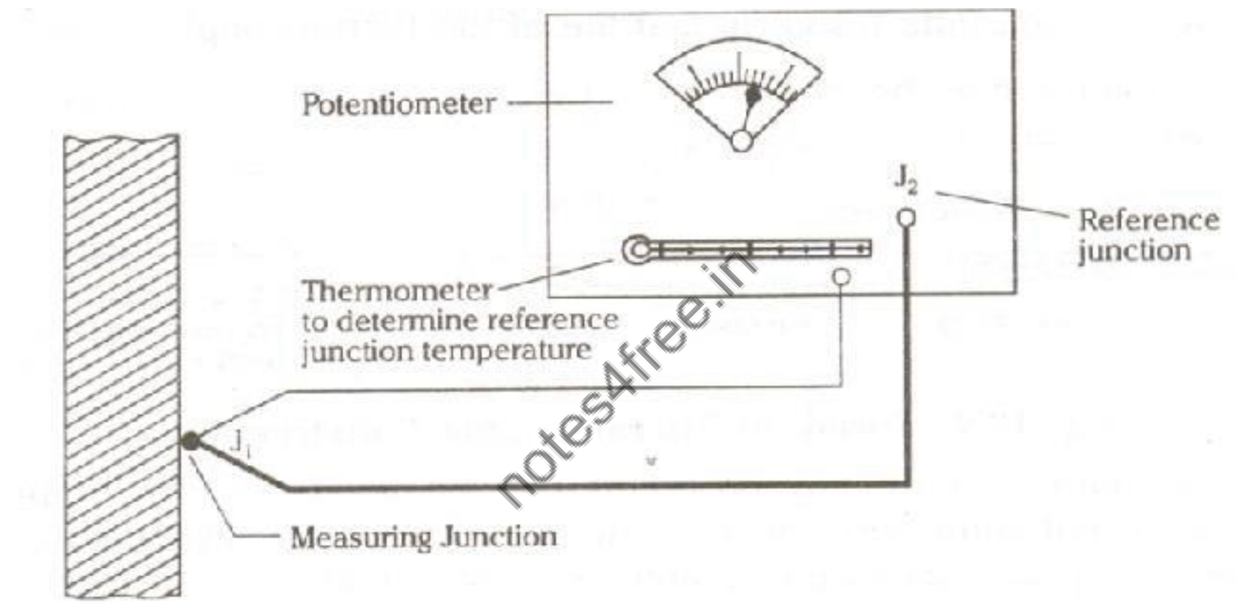


Circuits illustrating the Law of Intermediate Temperatures

This is illustrated schematically in the above Fig. This law permits the thermocouple calibration for a given temperature to be used with any other reference temperature through the use of a suitable correction. Also, the extension wires having the same thermo-electric characteristics as those of the thermocouple wires can be introduced in the circuit without affecting the net emf of the thermocouple.

Measurement of Thermal emf

The magnitude of emf developed by the thermocouples is very small (0.01 to 0.07 millivolts/^{0}C), thus requires a sensitive devices to measure. Measurement of thermocouple output may be obtained by various ways. like millivolt meter or voltage-balancing potentiometer etc. Fig. shows a simple temperature-measuring system using a thermocouple as the sensing element and a potentiometer for indication. The thermoelectric circuit consists of a measuring junction J_1 and reference junction J_2, at the potentiometer. By the law of intermediate metals the potentiometer box may be considered to be an intermediate conductor. Assuming the two potentiometer terminals to be at identical temperature, the reference junction can be formed by the ends of the two thermocouple leads as they attach to the terminals. The reference temperature is determined using liquid-in-glass thermometer placed near the terminals. The value of the emf developed by the thermocouple circuit is measured using the potentiometer. Then using the table (values of emf Vs temperature) the temperature of the measuring junction can be determined.



Temperature measuring Arrangement using Thermocouple

Advantages and Disadvantages of Thermocouples

Advantages

1. Thermocouples are cheaper than the resistance thermometers.

2. Thermocouples follow the temperature changes with small time lag thus suitable for recording rapidly changing temperatures.

3. They are convenient for measuring the temperature at a particular point.

Disadvantages

1. Possibility of inaccuracy due to changes in the reference junction temperature hence they cannot be used in precision work.

2. For long life, they should be protected to prevent contamination and have to be chemically inert and vacuum tight.

3. When thermocouples are placed far from the measuring systems, connections are made by extension wires. Maximum accuracy is obtained only when compensating wires are of the same material as that of thermocouple wires, thus the circuit becomes complex.

Principles used for Radiation Temperature Measuring Devices

1. Total Radiation Pyrometry:

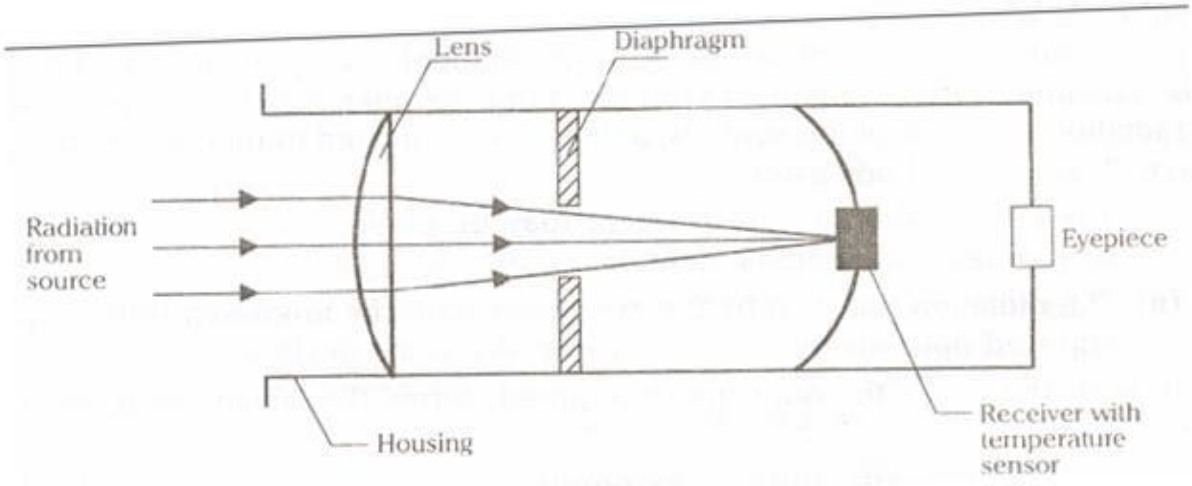
In this case the total radiant energy from a heated body is measured. This energy is represented by the area under the curves of above Fig. and is given by Stefen – Boltzmann law. The radiation pyrometer is intended to receive maximum amount of radiant energy at wide range of wavelengths possible.

2. Selective Radiation Pyrometry:

This involves the measurement of spectral radiant intensity of the radiated energy from a heated body at a given wavelength. For example, if a vertical line is drawn in Fig. the variation of intensity with temperature for given wavelength can be found. The optical pyrometer uses this principle.

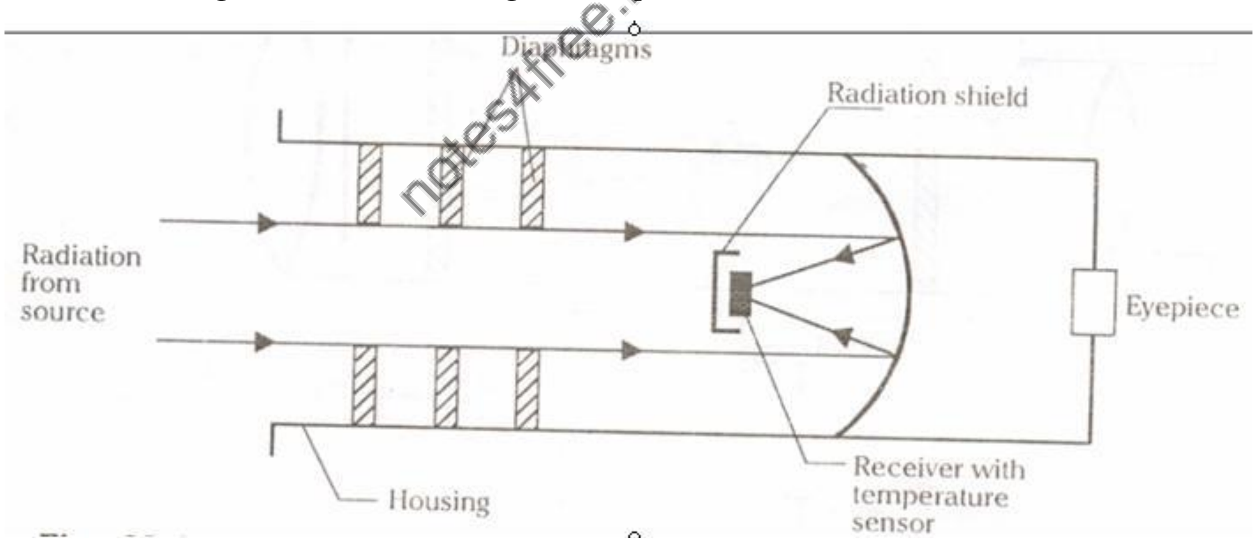
Total Radiation Pyrometers

The total radiation pyrometers receives all the radiations from a hot body and focuses it on to a sensitive temperature transducer like thermocouple, resistance thermometer etc. It consists of a radiation-receiving element and a measuring device to indicate the temperature. The most common type is shown in the Fig. A lens is used to concentrate the total radiant energy from the source on to the temperature sensing element. The diaphragms are used to prevent reflections. When lenses are used, the transmissibility of the glass determines the range of frequencies passing through. The transmission bands of some of the lens materials are shown in the Fig. The radiated energy absorbed by the receiver causes a rise of temperature. A balance is established between the energy absorbed by the receiver and that dissipated to the surroundings. Then the receiver equilibrium temperature becomes the measure of source temperature, with the scale established by calibration.



Schematic of Lens Type Radiation Receiving Device

The mirror type radiation receiver is another type of radiation pyrometer as shown in the Fig. Here the diaphragm unit along with a mirror is used to focus the radiation onto a receiver. The distance between the mirror and the receiver may be adjusted for proper focus. Since there is no lens, the mirror arrangement has an advantage a absorption and reflection effects are absent.



Mirror Focussing Type Radiation Receiving Device

Although radiation pyrometers may theoretically be used at any reasonable distance from a temperature source, there are practical limitations.

i) The size of target will largely determine the degree of temperature averaging, and in general, the greater the distance from the source, the greater the averaging.

ii) The nature of the intervening atmosphere will have a decided effect on the pyrometer indication. If smoke, dust or certain gases present considerable energy absorption may occur.

This will have a particular problem when such absorbents are not constant, but varying with time. For these reasons, minimum practical distance is recommended.

Optical pyrometers

Optical pyrometers use a method of matching as the basis for their operation. A reference temperature is provided in the form of an electrically heated lamp filament, and a measure of temperature is obtained by optically comparing the visual radiation from the filament with that from the unknown own source. In principle, the radiation from one of the sources, as viewed is adjusted to match with that from the other source. The two methods used are :

i) The current through the filament may be controlled electrically with the help of resistance adjustment or

ii) The radiation received by the pyrometer from the unknown source may be adjusted optically by means of some absorbing devices.

In both the cases the adjustment required, forms the means of temperature measurement. The variable intensity optical pyrometer is, as shown in the Fig. The pyrometer is positioned towards an unknown temperature such that the objective lens focuses the source· in the plane of the lamp filament.

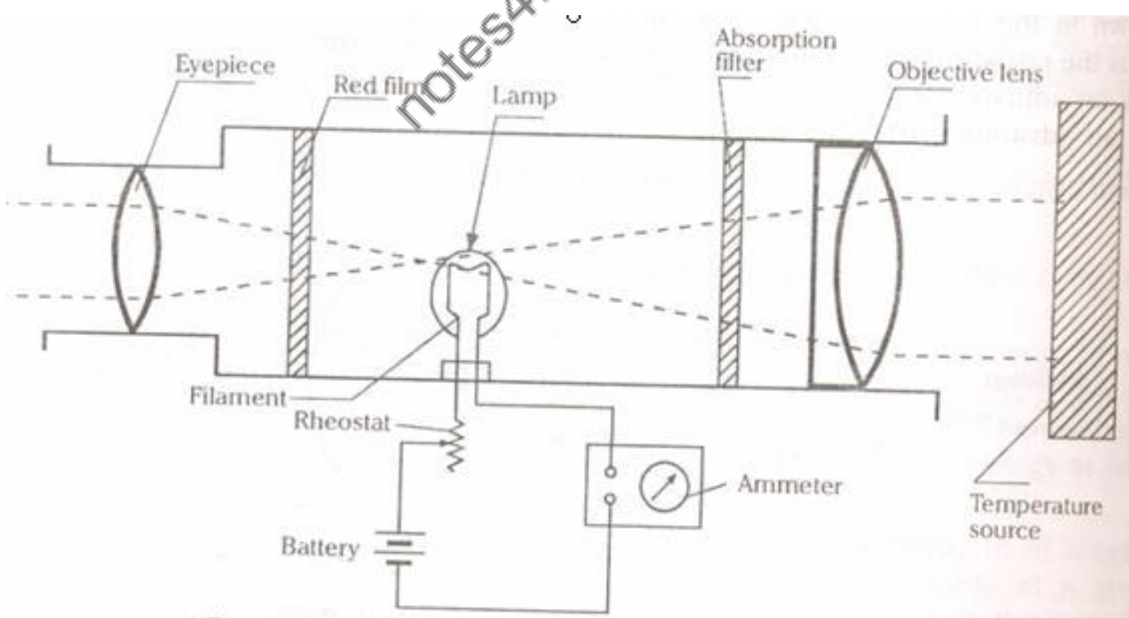
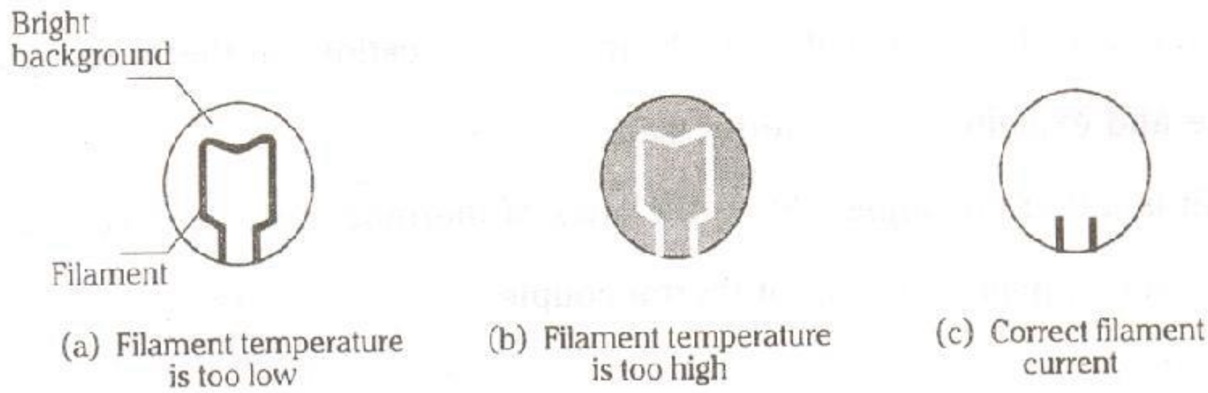


Fig. 12.13 Schematic of an Optical Pyrometer

The eyepiece is then adjusted such that the filament and the source appear superimposed. The filament may appear either hotter or colder than the unknown source as shown in the Fig.The current through the filament is adjusted by means of rheostat.



Filament Appearance

When the current passing through the filament is too low, the filament will emit radiation of lesser intensity than that of the source, it will thus appear dark against a bright background as in Fig. (a). When the current is too high it will appear brighter than the background as in Fig. (b). But when correct current is passed through the filament. The filament “disappears” into the background as in Fig. because it is radiating at the some intensity as the source. In this way the current indicated by the ammeter which disappears the filament may be used as the measure of temperature. The purpose of the red filter is to obtain approximately monochromatic conditions, while an absorption filter is used so that the filament may be operated at reduced intensity.

5.9 Strain Measurements

When a system of forces or loads act on a body, it undergoes some deformation. This deformation per unit length is known as **unit strain** or simply a strain mathematically

Strain € = δl /l where, δl = change in length of the body

l= original length of the body.

If a net change in dimension is required, then the term, **total strain** will be used. Since the strain applied to most engineering materials are very small they are expressed in **"micro strain"**

Strain is the quantity used for finding the stress at any point. For measuring the strain, it is the usual practice to make measurements over shortest possible gauge lengths. This is because, the measurement of a change in given length does not give the strain at any fixed point but rather gives the average value over the length. The strain at various points might be different depending upon the strain gradient along the gauge length, then the average strain will be the point strain at the middle point of the gauge length. Since, the change in length over a small gauge length is very small, a high magnification system is required and based upon this, the strain gauges are classified as follows:

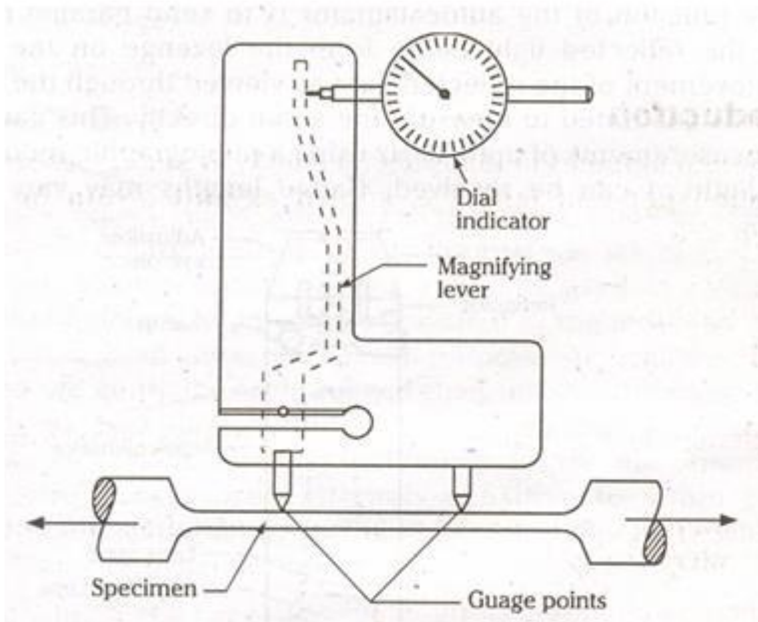
i) Mechanical strain gauges

ii) Optical strain gauges

iii) Electrical strain gauges

Mechanical Strain Gauges

This type of strain gauges involves mechanical means for magnification. Extensometer employing compound levers having high magnifications was used. Fig. shows a simple mechanical strain gauge. It consists of two gauge points which will be seated on the specimen whose strain is to be measured. One gauge point is fixed while the second gauge paint is connected to a magnifying lever which in turn gives the input to a dial indicator. The lever magnifies the displacement and is indicated directly on the calibrated dial indicator. This displacement is used to calculate the strain value. The most commonly used mechanical strain gauges are Berry-type and Huggen berger type. The Berry extensometer as shown in the Fig. is used for structural applications in civil engineering for long gauge lengths of up to 200 mm.



Mechanical Strain Gauge (Berry Extensometer)

Advantages

1. It has a self contained magnification system.

2. No auxiliary equipment is needed as in the case of electrical strain gauges.

Disadvantages

1. Limited only to static tests.

2. The high inertia of the gauge makes it unsuitable for dynamic measurements and varying strains.

3. The response of the system is slow and also there is no method of recording the readings automatically.

4. There should be sufficient surface area on the test specimen and clearance above it in order to accommodate the gauge together with its mountings.

OUTCOME

Students will be able to

1. Learn the concepts of force, torque, pressure, temperature measuring devices.

SELF-ASSESSMENT QUESTIONS

1. With a neat sketch explain force measuring devices.
2. With a neat sketch explain torque measuring devices.
3. With a neat sketch explain pressure measuring devices.
4. With a neat sketch explain temperature measuring devices.

FURTHER READING

1. Jain R. K., 1997, Engineering Metrology, Khanna Publishers.
2. Shawne A. K., 1998, Mechanical Measurement and Instrumentation, Dhanpat Rai and Co. (P) Ltd.
3. Hazra Chowdhury, 1995, Workshop Technology, Media Promoters and Publishers Pvt. Ltd