MODULE 1

Linear and Angular measurement

Definition, objectives and concept of metrology, Classification of standards, Material Standard, Wavelength Standards, Line and End standards, calibration of End bars (Numerical). Slip gauges-Indian standards on slip gauge, wringing of slip gauge, types of slip gauges, Numerical on building of slip gauges (M87, M112),Sine Bar and Sine centre, Bevel protractor, Numerical on angle gauge.

Introduction

- Metrology is a science of measurement. Metrology may be divided depending upon the quantity under consideration into: metrology of length, metrology of time etc. Depending upon the field of application it is divided into industrial metrology, medical metrology etc.
- Engineering metrology is restricted to the measurement of length, angles and other quantities which are expressed in linear or angular terms.
- For every kind of quantity measured, there must be a unit to measure it. This will enable the quantity to be measured in number of that unit. Further, in order that this unit is followed by all; there must be a universal standard and the various units for various parameters of importance must be standardized.
- It is also necessary to see whether the result is given with sufficient correctness and accuracy for a particular need or not. This will depend on the method of measurement, measuring devices used etc.
- Thus, in a broader sense metrology is not limited to length and angle measurement but also concerned with numerous problems theoretical as well as practical related with measurement such as:

1. Units of measurement and their standards, which is concerned with the establishment, reproduction, conservation and transfer of units of measurement and their standards.
2. Methods of measurement based on agreed units and standards.
3. Errors of measurement.
4. Measuring instruments and devices.
5. Accuracy of measuring instruments and their care.
6. Industrial inspection and its various techniques.
7. Design, manufacturing and testing of gauges of all kinds.

Need of Inspection

- Inspection means checking of all materials, products or component parts at various stages during manufacturing. It is the act of comparing materials, products or components with some established standard.

- In old days the production was on a small scale, different component parts were made and assembled by the same craftsman. If the parts did not fit properly at the time of assembly, he used to make the necessary adjustments in either of the mating parts so that each assembly functioned properly.
- Therefore, it was not necessary to make similar parts exactly alike or with same accuracy as there was no need of inspection.
- Due to technological development new production techniques have been developed. The products are being manufactured on a large scale due to low cost methods of mass production. So, hand fit method cannot serve the purpose any more. The modern industrial mass production system is based on interchangeable manufacture, when the articles are to be produced on a large scale.
- In mass production the production of complete article is broken up into various component parts. Thus the production of each component part becomes an independent process. The different component parts are made in large quantities in different shops. Some parts are purchased from other factories also and then assembled together at one place. Therefore, it becomes essential that any part chosen at random should fit properly with any other mating parts that too selected at random. This is possible only when the dimensions of the component parts are made with close dimensional tolerances. This is only possible when the parts are inspected at various stages during manufacturing.
- When large number of identical parts are manufactured on the basis of interchangeability if their dimensions are actually measured every time lot of time will be required. Hence, to save the time gauges are used, which can tell whether the part manufactured is within the prescribed limits or not.

Thus, the need of inspection can be summarized as:

1. To ensure that the part, material or a component conforms to the established standard.
2. To meet the interchangeability of manufacture.
3. To maintain customer relation by ensuring that no faulty product reaches the customers.

4. Provide the means of finding out shortcomings in manufacture. The results of inspection are not only recorded but forwarded to the manufacturing department for taking necessary steps, so as to produce acceptable parts and reduce scrap.
5. It also helps to purchase good quality of raw materials, tools, equipment which governs the quality of the finished products.
6. It also helps to co-ordinate the functions of quality control, production, purchasing and other departments of the organization.

   To take decision on the defective parts i.e., to judge the possibility of making some of these parts acceptable after minor repairs.

Objectives of Metrology

While the basic objective of a measurement is to provide the required accuracy at minimum cost, metrology would have further objective in a modern engineering plant with different shops like Tool Room, Machine Shop, Press Shop, Plastic Shop, Pressure Die Casting Shop, Electroplating and Painting Shop, and Assembly Shop; as also Research, Development and Engineering Department. In such an engineering organization, the further objectives would be as follows:

1. Thorough evaluation of newly developed products, to ensure that components designed is within the process and measuring instrument capabilities available in the plant.
2. To determine the process capabilities and ensure that these are better than the relevant component tolerance.
3. To determine the measuring instrument capabilities and ensure that these are adequate for their respective measurements.
4. To minimize the cost of inspection by effective and efficient use of available facilities and to reduce the cost of rejects and rework through application of Statistical Quality Control Techniques
5. Standardization of measuring methods. This is achieved by laying down inspection methods for any product right at the time when production technology is prepared.
6. Maintenance of the accuracies of measurement. This is achieved by periodical calibration of the metrological instruments used in the plant.
7. Arbitration and solution of problems arising on the shop floor regarding methods of measurement.

8. Preparation of designs for all gauges and special inspection fixtures.

Development of Material Standard

- The need for establishing standard of length was raised primarily for determining agricultural land areas and for the erection of buildings and monuments. The earliest standard of length was established in terms of parts of human body. The Egyptian unit was called a cubit. It was equal to the length of the forearm (from the elbow to the tip of the middle figure).
- Rapid advancement made in engineering during nineteenth century was due to improved materials available and more accurate measuring techniques developed. It was not until 1855 that first accurate standard was made in England. It was known as imperial standard yard. This was followed by International Prototype meter made in France in the year 1872. These two standards of lengths were made of material (metal alloys) and hence they are called as material standards in contrast to wavelength standard adopted as length standard later on.

Imperial Standard Yard

- The imperial standard yard is made of 1 inch square cross-section bronze bar (82% copper, 13% tin, 5% zinc) 38 inches long. The bar has two 1/2 inch diameter X 1/2 inch deep holes. Each hole is fitted with 1/10th inch diameter gold plug. The top surface of these plugs lie on the neutral axis of the bronze bar.

  The purpose of keeping the gold plug lines at neutral axis has the following advantages.

- Due to bending of beam the neutral axis remains unaffected
- The plug remains protected from accidental damage.

  The top surface of the gold plugs is highly polished and contains three lines engraved transversely and two lines longitudinally.

  The yard is defined as the distance between two central transverse lines on the plugs when,

1. The temperature of the bar is constant at 62°F and,
2. The bar is supported on rollers in a specified manner to prevent flexure.

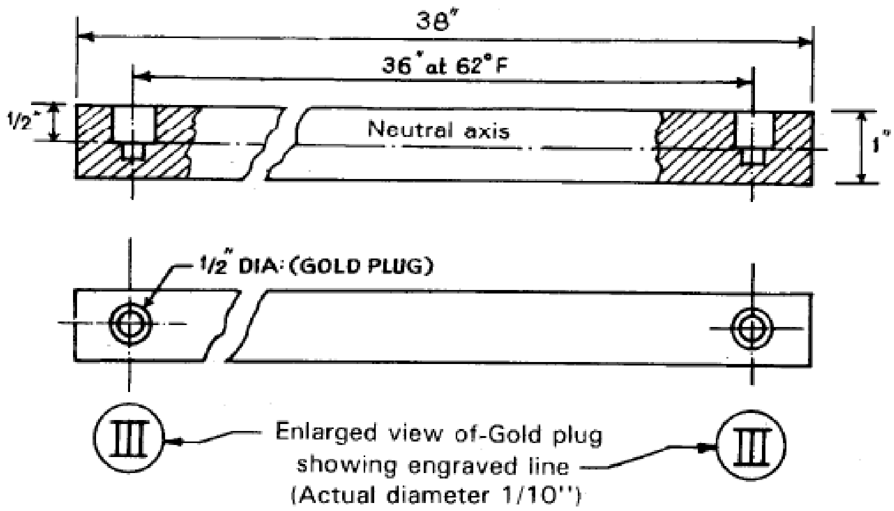


Figure 1.1 Imperial Standard Yards

International Standard Meter (Prototype)

- This standard was established originally by International Bureau of Weights and Measures in the year 1875. The prototype meter is made of platinum-iridium alloy (90% platinum and 10% iridium) having a cross-section as shown in Fig. 1.2.
- The upper surface of the web is highly polished and has two fine lines engraved over it. It is in-oxidisable and can have a good finish required for ruling good quality of lines. The bar is kept at 0°C and under normal atmospheric pressure. It is supported by two rollers of at least one cm diameter symmetrically situated in the same horizontal plane. The distance between the rollers is kept 589 mm so as to give minimum deflection. The web section chosen gives maximum rigidity and economy of costly material. The distance between the centers portions of two lines engraved on the polished surface of this bar of platinum-iridium alloy is taken as one meter.
- According to this standard, the length of the meter is defined as the straight line distance, at 0°C between the centre portions of pure platinum-iridium alloy (90% platinum, 10% iridium) of 102 cm total length and having a web cross-section as shown in Fig. 1.2.

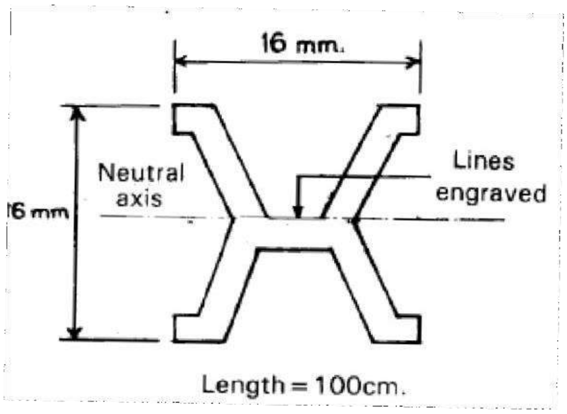


Figure 1.2 International Prototype Meter Cross-sections

- The metric standard when in use is supported at two points which are 58.9 cm apart as calculated from Airy's formula, according to which the best distance between the supporting points is given by

  √

  Where, L = total length of bar (assumed uniform), b = distance between points, n = number is supports
- For prototype meter,

  √

- This reference was designated as International Prototype Meter M in 1899. It is preserved by (BIPM) at Sevres in France. The BIPM is controlled by the International Committee of Weights and Measure.
- The imperial standard yard was found to be decreasing in length at the rate of one- millionth of an inch for the past 50 years when compared with internal standard meter. The prototype meter is quite stable. There-fore, yard relationship had to be defined in terms of meter as 1 yard = 0.9144 meter, or inch = 25.4 mm.

  Disadvantages of Material Standard

1. The material standards are influenced by effects of variation of environmental conditions like temperature, pressure, humidity and ageing etc., and it thus changes in length.
2. These standards are required to be preserved or stored under security to prevent their damage or destruction.
3. The replica of these standards was not available for use somewhere else.

4. These are not easily reproducible.
5. Conversion factor was to be used for changing over to metric working.
6. Considerable difficulty is experienced while comparing and verifying the sizes of gauges.

Wavelength Standard

- The major drawback with the metallic standards meter and yard is that their length changes slightly with time. Secondly, considerable difficulty is experienced while comparing and verifying the sizes of gauges by using material standards. This may lead to errors of unacceptable order of magnitude. It therefore became necessary to have a standard of length which will be accurate and invariable. Jacques Babinet a French philosopher suggested that wavelength of monochromatic light can be used as natural and invariable unit of length.
- In 1907 the International Angstrom (A) unit was defined in terms of wavelength of red cadmium in dry air at 15°C (6438.4696 A = 1 wavelength of red cadmium). Seventh General Conference of Weights and Measures approved in 1927, the definition of standard of length relative to the meter in terms of wavelength of the red cadmium as an alternative to International Prototype meter.
- Orange radiation of isotope krypton-86 was chosen for new definition of length in 1960, by the Eleventh General Conference of Weights and Measures. The committee decided to recommend that Krypton-86 was the most suitable element and that it should be used in a hot-cathode discharge lamp maintained at a temperature of 63° Kelvin. According to this standard meter was defined as equal to 1650763.73 wavelengths of the red orange radiation of Krypton isotope 86 gases.
- The standard as now defined can be reproduced to an accuracy of about 1 part in 10^9. The meter and yard were redefined in terms of wave length of orange Kr-86 radiation as,

  1 meter = 1650763.73 wavelengths, and

  1 yard = 0.9144 meter

  = 0.9144 x 1650763.73 wavelengths

  = 1509458.3 wavelengths.

Meter as of Today

- Although Krypton-86 standard served well, technologically increasing demands more accurate standards. It was through that a definition based on the speed of light would be technically feasible and practically advantageous. Seventeenth General Conference of Weights and Measure. Agreed to a fundamental change in the definition of the meter on 20th October 1983.
- Accordingly, meter is defined as the length of the path travelled by light in vacuum in 1/299792458 seconds. This can be realized in practice through the use of an iodine- stabilized helium-neon laser.
- The reproducibility is 3 parts in 1011, which may be compared to measuring the earth's mean circumference to an accuracy of about 1 mm. With this new definition of meter, one standard yard will be the length of the path travelled by light travelled in 0.9144 x 1/299792458 sec. I. e., in 3 x 10^{-9} sec.

The advantages of wavelength standard are:

1. It is not a material standard and hence it is not influenced by effects of variation of environmental conditions like temperature, pressure, humidity and ageing.
2. It need not be preserved or stored under security and thus there is no fear of being destroyed as in case of meter and yard.
3. It is not subjected to destruction by wear and tear.
4. It gives a unit of length which can be produced consistently at all the times in all the circumstances, at all the places. In other words it is easily reproducible and thus identical standards are available with all.
5. This standard is easily available to all standardizing laboratories and industries.
6. There is no problem of transferring this standard to other standards meter andyard.
7. It can be used for making comparative measurements of very high accuracy. The error of reproduction is only of the order of 3 parts in 10^{11}

Subdivision of standards

The international standard yard and the international prototype meter cannot be used for general purposes. For practical measurement there is a hierarchy of working standards. Thus depending upon their importance of accuracy required, for the work the standards are subdivided into four grades;

1. Primary standards
2. Secondary standards

3. Territory standards
4. Working standards.

1. Primary Standards

For precise definition of the unit, there shall be one, and only one material standard, which is to be preserved under most careful conditions. It is called as primary standard. International yard and International meter are the examples of primary standards. Primary standard is used only at rare intervals (say after 10 to 20 years) solely for comparison with secondary standards. It has no direct application to a measuring problem encountered in engineering.

2. Secondary Standards

Secondary standards are made as nearly as possible exactly similar to primary standards as regards design, material and length. They are compared with primary standards after long intervals and the records of deviation are noted. These standards are kept at number of places for safe custody. They are used for occasional comparison with tertiary standards whenever required.

3. Tertiary Standards

The primary and secondary standards are applicable only as ultimate control. Tertiary standards are the first standard to be used for reference purposes in laboratories and workshops. They are made as true copy of the secondary standards. They are used for comparison at intervals with working standards.

4. Working Standards

Working standards are used more frequently in laboratories and workshops. They are usually made of low grade of material as compared to primary, secondary and tertiary standards, for the sake of economy. They are derived from fundamental standards. Both line and end working standards are used. Line standards are made from H-cross-sectional form.

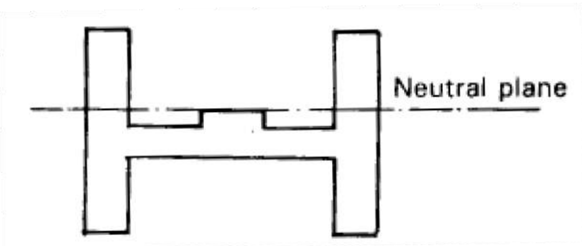


Figure 1.3 Working Line Standards

Most of the precision measurement involves the distance between two surfaces and not with the length between two lines. End standards are suitable for this purpose. For shorter lengths up to 125 mm slip gauges are used and for longer lengths end bars of circular cross- section are used. The distance between the end faces of slip gauges or end bars is controlled to ensure a high degree of accuracy.

Sometimes the standards are also classified as:

1. Reference standards- Used for reference purposes.
2. Calibration standards - Used for calibration of inspection and working standards.
3. Inspection standards - Used by inspectors.
4. Working standards - Used by operators, during working.

Line and End Measurements

A length may be measured as the distance between two lines or as the distance between two parallel faces. So, the instruments for direct measurement of linear dimensions fall into two categories.

1. Line standards.
2. End standards.

Line Standards

When the length is measured as the distance between centers of two engraved lines, it is called line standard. Both material standards yard and meter are line standards. The most common example of line measurements is the rule with divisions shown as lines marked on it.

Characteristics of Line Standards

1. Scales can be accurately engraved but the engraved lines themselves possess thickness and it is not possible to take measurements with high accuracy.
2. A scale is a quick and easy to use over a wide range.
3. The scale markings are not subjected to wear. However, the leading ends are subjected to wear and this may lead to undersize measurements.
4. A scale does not possess a "built in" datum. Therefore it is not possible to align the scale with the axis of measurement.
5. Scales are subjected to parallax error.
6. Also, the assistance of magnifying glass or microscope is required if sufficient accuracy is to be achieved.

End standards

When length is expressed as the distance between two flat parallel faces, it is known as end standard. Examples: Measurement by slip gauges, end bars, ends of micrometer anvils, vernier calipers etc. The end faces are hardened, lapped flat and parallel to a very high degree of accuracy.

Characteristics of End Standards

1. These standards are highly accurate and used for measurement of close tolerances in precision engineering as well as in standard laboratories, tool rooms, inspection departments etc.
2. They require more time for measurements and measure only one dimension at a time.
3. They are subjected to wear on their measuring faces.
4. Group of slips can be "wrung" together to build up a given size; faulty wringing and careless use may lead to inaccurate results.
5. End standards have built in datum since their measuring faces are f l at and parallel and can be positively locked on datum surface.
6. They are not subjected to parallax effect as their use depends on feel.

Comparison between Line Standards and End Standards:

Sr. No.	**Characteristic**	**Line Standard**	**End Standard**
1.	Principle	Length is expressed as the distance between two lines	Length is expressed as the distance between two flat parallel faces
2.	Accuracy	Limited to ± 0.2 mm for high accuracy, scales have to be used in conjunction with magnifying glass or microscope	Highly accurate for measurement of close tolerances up to ± 0.001 mm.
3.	Ease and time & measurement	Measurement is quick and easy	Use of end standard requires skill and is time consuming.
4.	Effect of wear	Scale markings are not subject to wear. However, significant wear may occur on leading ends. Thus it may be difficult to assume zero of scale as datum.	These are subjected to wear on their measuring surfaces.
5.	Alignment	Cannot be easily aligned with the	Can be easily aligned

		axis of measurement.	with the axis of measurement.
6.	Manufacture and cost	Simple to manufacture at low cost.	Manufacturing process is complex and cost is high.
7.	Parallax effect	They ate subjected to parallax error	They ate not subjected to parallax error
8.	Examples	Scale (yard, meter etc.)	Slip gauges, end bars, V-caliper, micrometers etc.

The accuracy of both these standards is affected by temperature change and both are originally calibrated at 20 ± 0.5°C. It is also necessary to take utmost case in their manufacture to ensure that the change of shape with time, secular change is reduced to negligible.

Classification of Standards and Traceability

- In order to maintain accuracy and interchangeability in the items manufactured by various industries in the country, it is essential that the standards of units and measurements followed by them must be traceable to a single source, i.e., the National Standards of the country. Further, the National Standards must also be linked with International Standard to maintain accuracy and interchangeability in the items manufactured by the various countries.
- The national laboratories of well-developed countries maintain close tolerance with International Bureau of Weights and Measures, there is assurance that the items manufactured to identical dimensions in different countries will be compatible.

Application of precise measurement has increased to such an extent that it is not practicable for a single national laboratory to perform directly all the calibrations and standardizations required by a large country. It has therefore become necessary that the process of traceability technique needs to be followed in stages, that is, National laboratories, standardizing laboratories, etc. need to be established for country, states, and industries but all must be traceable to a single source as shown in Fig. 1.4 below.

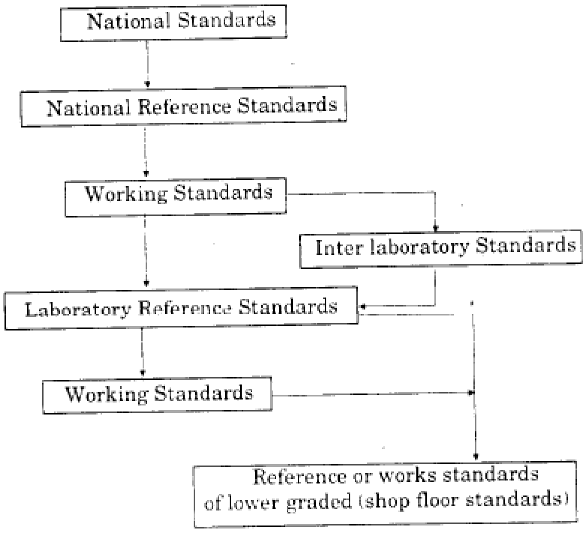


Figure 1.4 Classifications of Standards in Order

Clearly, there is degradation of accuracy in passing from the defining standards to the standard in use. The accuracy of a particular standard depends on a combination of the number of times it has been compared with a standard of higher order, the recentness of such comparisons, the care with which it was done, and the stability of the particular standard itself

Measuring system element

A measuring system is made of five basic elements. These are:

1. Standard
2. Work piece
3. Instrument
4. Person
5. Environment.

The most basic element of measurement is a standard without which no measurement is possible. Once the standard is chosen a measuring instrument incorporations this standard is should be obtained. This instrument is then used to measure the job parameters, in terms of units of standard contained in it. The measurement should be performed under standard environment. And, lastly, there must be some person or mechanism (if automatic) to carry out the measurement.

Methods of Measurement

These are the methods of comparison used in measurement process. In precision measurement various methods of measurement are adopted depending upon the accuracy required and the amount of permissible error.

The methods of measurement can be classified as:

1. Direct method
2. Indirect method
3. Absolute/Fundamental method
4. Comparative method
5. Transposition method
6. Coincidence method
7. Deflection method
8. Complementary method
9. Contact method
10. Contactless method etc.

1. Direct method of measurement.

This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations. For example, measurements by using scales, vernier calipers, micrometers, bevel protector etc. This method is most widely used in production. This method is not very accurate because it depends on human insensitiveness in making judgment.

2. Indirect method of measurement.

In indirect method the value of quantity to be measured is obtained by measuring other quantities which are functionally related to the required value. E.g. angle measurement by sine bar, measurement of screw pitch diameter by three wire method etc.

3. Absolute or Fundamental method.

It is based on the measurement of the base quantities used to define the quantity. For example, measuring a quantity directly in accordance with the definition of that quantity, or measuring a quantity indirectly by direct measurement of the quantities linked with the definition of the quantity to be measured.

4. Comparative method.

In this method the value of the quantity to be measured is compared with known value of the same quantity or other quantity practically related to it. So, in this method only the deviations from a master gauge are determined, e.g., dial indicators, or other comparators.

5. Transposition method.

It is a method of measurement by direct comparison in which the value of the quantity measured is first balanced by an initial known value A of the same quantity, and then the value of the quantity measured is put in place of this known value and is balanced again by another known value B. If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is√ . For example, determination of a mass by means of a balance and known weights, using the Gauss double weighing method.

6. **Coincidence method.**

It is a differential method of measurement, in which a very small difference between the value of the quantity to be measured and the reference is determined by the observation of the coincidence of certain lines or signals. For example, measurement by vernier caliper micrometer.

7. **Deflection method.**

In this method the value of the quantity to be measured is directly indicated by a deflection of a pointer on a calibrated scale.

8. **Complementary method.**

In this method the value of the quantity to be measured is combined with a known value of the same quantity. The combination is so adjusted that the sum of these two values is equal to predetermined comparison value. For example, determination of the volume of a solid by liquid displacement.

9. **Method of measurement by substitution.**

It is a method of direct comparison in which the value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same.

10. **Method of null measurement.**

It is a method of differential measurement. In this method the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero.

11. **Contact method.**

In this method the sensor or measuring tip of the instrument actually touches the surface to be measured. e.g., measurements by micrometer, vernier caliper, dial indicators etc. In such cases arrangement for constant contact pressure should be provided to prevent errors due to excessive contact pressure.

12. Contactless method.

In contactless method of measurement, the there is no direct contact with the surface to be measured. e.g., measurement by optical instruments, such as tool makers microscope, projection comparator etc.

Precision and Accuracy

Precision

- The terms precision and accuracy are used in connection with the performance of the instrument. Precision is the repeatability of the measuring process.
- It refers to the group of measurements for the same characteristics taken under identical conditions. It indicates to what extent the identically performed measurements agree with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. The set of observations will scatter about the mean. The scatter of these measurements is designated as 0, the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of 0, the more precise is the instrument.

Accuracy

- Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement.
- It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

Distinction between Precision and Accuracy

- Accuracy is very often confused with precision though much different. The distinction between the precision and accuracy will become clear by the following example. Several measurements are made on a component by different types of instruments (A, B and C respectively) and the results are plotted.
- In any set of measurements, the individual measurements are scattered about the mean, and the precision signifies how well the various measurements performed by same instrument on the same quality characteristic agree with each other.

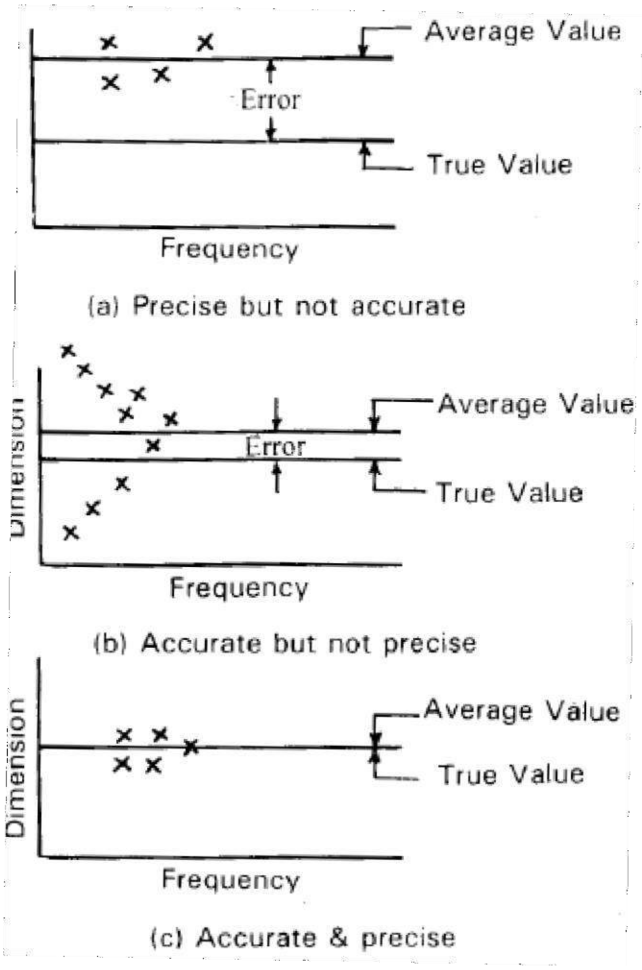


Figure 1.5 Precision And Accuracy

- The difference between the mean of set of readings on the same quality characteristic and the true value is called as error. Less the error more accurate is the instrument. Figure 1.5 shows that the instrument A is precise since the results of number of measurements are close to the average value. However, there is a large difference (error) between the true value and the average value hence it is not accurate.
- The readings taken by the instruments are scattered much from the average value and hence it is not precise but accurate as there is a small difference between the average value and true value. Fig. 1.5 (c) shows that the instrument is accurate as well as precise.

Errors in Measurement

- It is never possible to measure the true value of a dimension, there is always some error. The error in measurement is the difference between the measured value and the true value of the measured dimension.

- Error in measurement =Measured value - True value. The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.

Absolute Error

- True absolute error. It is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.
- Apparent absolute error. If the series of measurement are made then the algebraic difference between one of the results of measurement and the arithmetical mean is known as apparent absolute error.

Relative Error

- It is the quotient of the absolute error and the value of comparison used for calculation of that absolute error. This value of comparison may be the true value, the conventional true value or the arithmetic mean for series of measurement.

The accuracy of measurement, and hence the error depends upon so many factors, such as:

- Calibration standard
- Work piece
- Instrument
- Person
- Environment etc. as already described.

No matter, how modern is the measuring instrument, how skillful is the operator, how accurate the measurement process, there would always be some error. It is therefore attempted to minimize the error. To minimize the error, usually a number of observations are made and their average is taken as the value of that measurement.

- If these observations are made under identical conditions i.e., same observer, same instrument and similar working conditions excepting for time, then, it is called as Single Sample Test'.

- If however, repeated measurements of a given property using alternate test conditions, such as different observer and/or different instrument are made, the procedure is called as

  `Multi-Sample Test'. The multi-sample test avoids many controllable errors e.g., personal error, instrument zero error etc. The multi-sample test is costlier than the single sample test and hence the later is in wide use.

– In practice good numbers of observations are made under single sample test and statistical techniques are applied to get results which could be approximate to those obtainable from multi-sample test.

Types of Error

During measurement several types of error may arise, these are

1. Static errors which includes
   - Reading errors
   - Characteristic errors
   - Environmental errors.
2. Instrument loading errors.
3. Dynamic errors.

Static errors

These errors result from the physical nature of the various components of measuring system. There are three basic sources of static errors. The static error divided by the measurement range (difference between the upper and lower limits of measurement) gives the measurement precision.

Reading errors

Reading errors apply exclusively to the read-out device. These do not have any direct relationship with other types of errors within the measuring system.

Reading errors include: Parallax error, Interpolation error.

Attempts have been made to reduce or eliminate reading errors by relatively simple techniques. For example, the use of mirror behind the readout pointer or indicator virtually eliminates occurrence of parallax error.

<u>Interpolation error.</u>

It is the reading error resulting from the inexact evaluation of the position of index with regards to two adjacent graduation marks between which the index is located. How accurately can a scale be readthis depends upon the thickness of the graduation marks, the spacing of the scale division and the thickness of the pointer used to give the reading Interpolation error can be tackled by increasing; using magnifier over the scale in the viscinity of pointer or by using a digital read out system.

Characteristic Errors

It is defined as the deviation of the output of the measuring system from the theoretical predicted performance or from nominal performance specifications.

Linearity errors, repeatability, hysteresis and resolution errors are part of characteristic errors if the theoretical output is a straight line. Calibration error is also included in characteristic error.

Loading Errors

Loading errors results from the change in measurand itself when it is being measured, (i.e., after the measuring system or instrument is connected for measurement). Instrument loading error is the difference between the value of the measurand before and after the measuring system is connected/contacted for measurement. For example, soft or delicate components are subjected to deformation during measurement due to the contact pressure of the instrument and cause a loading error. The effect of instrument loading errors is unavoidable. Therefore, measuring system or instrument should be selected such that this sensing element will minimize instrument loading error in a particular measurement involved.

Environmental Errors

These errors result from the effect of surrounding such as temperature, pressure, humidity etc. on measuring system.

External influences like magnetic or electric fields, nuclear radiations, vibrations or shocks etc. also lead to environmental errors.

Environmental errors of each component of the measuring system make a separate contribution to the static error. It can be reduced by controlling the atmosphere according to the specific requirements.

Dynamic Errors

Dynamic error is the error caused by time variations in the measurand. It results from the inability of the system to respond faithfully to a time varying measurement. It is caused by inertia, damping, friction or other physical constraints in the sensing or readout or display system.

For statistical study and the study of accumulation of errors, these errors can be broadly classified into two categories

1. Systematic or controllable errors, and
2. Random errors.

Systematic Errors

Systematic errors are regularly repetitive in nature. They are of constant and similar form. They result from improper conditions or procedures that are consistent in action. Out of the systematic errors all except the personal error varies from individual to individual depending on the personality of observer. Other systematic errors can be controlled in magnitude as well as in sense. If properly analyzed they can be determined and reduced. Hence, these are also called as controllable errors.

Systematic errors include:

1. Calibration Errors. These are caused due to the variation in the calibrated scale from its normal value. The actual length of standards such as slip gauge and engraved scales will vary from the nominal value by a small amount. This will cause an error in measurement of constant magnitude. Sometimes the instrument inertia and hysteresis effect do not allow the instrument to transit the measurement accurately. Drop in voltage along the wires of an electric meter may include an error (called single transmission error) in measurement.

2. Ambient or Atmospheric conditions (Environmental Errors). Variation in atmospheric condition (i.e., temperature, pressure, and moisture content) at the place of measurement from that of internationally agreed standard values (20° temp. and 760 mm of Hg pressure) can give rise to error in the measured size of the component. Instruments are calibrated at these standard conditions; therefore error may creep into the given result if the atmosphere conditions are different at the place of measurement. Out of these temperatures is the most significant factor which causes error in, measurement due to expansion or contraction of component being measured or of the instrument used for measurement.

3. Stylus Pressure. Another common source of error is the pressure with which the work piece is pressed while measuring. Though the pressure involved is generally small but this is sufficient enough to cause appreciable deformation of both the stylus and the work piece.

In ideal case, the stylus should have simply touched the work piece. Besides the deformation effect the stylus pressure can bring deflection in the work piece also.

Variations in force applied by the anvils of micrometer on the work to be measured results in the difference in its readings. In this case error is caused by the distortion of both micrometer frame and work-piece.

4. Avoidable Errors. These errors may occur due to parallax, non-alignment of work piece centers, improper location of measuring instruments such as placing a thermometer in

sunlight while measuring temperature. The error due to misalignment is caused when the centre line of work piece is not normal to the centre line of the measuring instrument.

5. Random Errors. Random errors are non-consistent. They occur randomly and are accidental in nature. Such errors are inherent in the measuring system. It is difficult to eliminate such errors. Their specific cause, magnitudes and source cannot be determined from the knowledge of measuring system or conditions of measurement.

The possible sources of such errors are:

1. Small variations in the position of setting standard and work piece.
2. Slight displacement of lever joints of measuring instruments.
3. Operator error in scale reading.
4. Fluctuations in the friction of measuring instrument etc.

Comparison between Systematic Errors and Random Errors

Systematic Errors	**Random Errors**
These errors are repetitive in nature and are of constant and similar form	These are non-consistent. The sources giving rise to such errors are random.
These errors result from improper conditions or procedures that are consistent in action.	Such errors are inherent in the measuring system or measuring instruments.
Except personal errors, all other systematic errors can be controlled in magnitude and sense.	Specific causes, magnitudes and sense of these errors cannot be determined from the knowledge of measuring system or condition.
If properly analyzed these can be determined and reduced or eliminated.	These errors cannot be eliminated, but the results obtained can be corrected.
These include calibration errors, variation in contact pressure, variation in atmospheric conditions, parallax errors, misalignment errors etc.	These include errors caused due to variation in position of setting standard and work-piece, errors due to displacement of lever joints of instruments, errors resulting from backlash, friction etc.

Errors likely to creep in Precision Measurements

The standard temperature for measurement is 20°C and all instruments are calibrated at this temperature. If the measurements are carried out at temperature other than the standard temperature, an error will be introduced due to expansion or contraction of instrument or part to be measured. But if the instrument and the work piece to be measured are of same material, accuracy of measurement will not be affected even if the standard temperature is not maintained. Since both will expand and contract by the same amount.

The difference between the temperature of instrument and the work piece will also introduce an error in the measurement, especially when the material of the work piece or instrument has higher coefficient of expansion. To avoid such errors, instrument and the work piece to be measured should be allowed to attain the same temperature before use and should be handled as little as possible. For example, after wringing together several slip gauges to form a stock for checking a gauge, they should be left with the gauge for an hour, if possible preferably on the table of the comparator which is to be used for performing the comparison.

To attain accurate results, high grade reference gauges should be used only in rooms where the temperature is maintained very close to the standard temperature.

Handling of gauges changes its temperature, so they should be allowed to stabilize.

There are two situations to be considered in connection with the effect of temperature, these are:

(a) Direct measurement. Let us consider a gauge block being measured directly by interferometry. Here, the effect of using a non-standard temperature produces a proportional error, $E = l$ □ $(t - t_s)$, where

- L = nominal length
- □ = coefficient of expansion
- $(t - t_s)$ = deviation from standard temperature
- t = temperature during measurement
- t_s = standard temperature

(b) Comparative measurement. If we consider two gauges whose expansion coefficients are respectively α_1 and α_2, then the error due to nonstandard temperature will be, Error, $E = l\ (\alpha_1 - \alpha_2)\ (t - t_s)$

As the expansion coefficients are small numbers, the error will be very small as long as both parts are at the same temperature. Thus, in comparative measurement it is important that all components in the measuring system are at the same temperature rather than necessarily at the standard temperature.

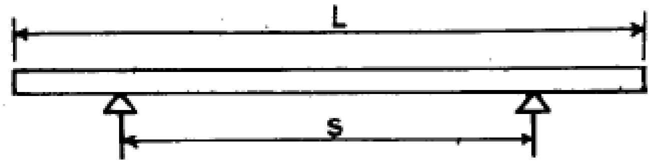
Other ambient conditions may affect the result of measurement. For example, if a gauge block is being measured by interferometry, then relative humidity, atmospheric pressure and CO_2 of the air affects the refractive index of the atmosphere. These conditions should all be recorded during the measurement and the necessary correction made.

Internationally accepted temperature for measurement is 20°C and all instruments are calibrated at this temperature. To maintain such controlled temperature, the laboratory should be air-conditioned.

Effect of supports

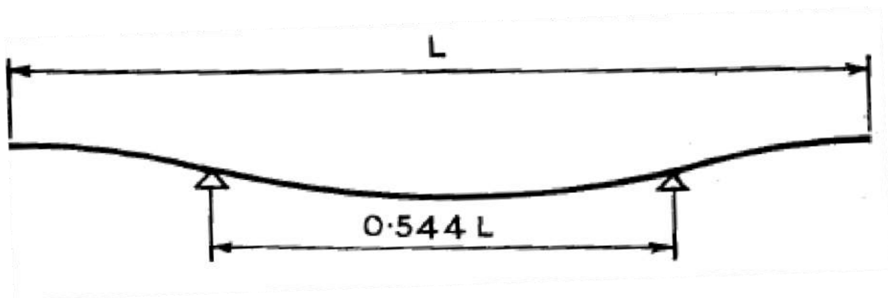
When long measuring bars, straight edges are supported as beam, they are defected or deformed. This elastic deformation occurs because a long bar, supported at to ends sags under their own weight. This problem was considered by Sir G.B. Airy, who showed that the position of the supports can be arranged to give minimum error. The amount of deflection depends upon the positions of the supports.

Figure 1.6 Effect of support

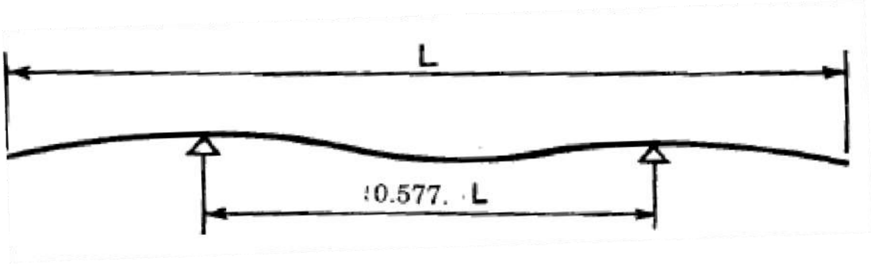


Two conditions are considered, as shown in Fig. 1.7,

(1) A bar of length L supported, equidistant from the centre. In this case the slope at the ends of the bar is zero. For minimum deflection, the distance between the supports should be 0.554 times the length of the bar S = 0.544 L or S/L = 0.544



(a) *Line standard and End bars (slope at ends zero)*



(b) Straight edges (deflection at ends equals' deflection).

Figure 1.7 Support Positions for Different Conditions of Measurement

(2) A straight edge of length L supported, equidistant from the centre. The straight edges are used to check the straightness and flatness of the parts. They are maker of H section.

In this case the deflection at the ends is equal to the deflection at the centre. For minimum deflection the distance between the supports should be 0.577 times the length i.e. for any points

–

Effect of alignment

Abbe's alignment principle: It states that "the axis or line of measurement should coincide with the axis of measuring instrument or line of the measuring scale."

If while measuring the length of a work piece the measuring scale is inclined to the true line of the dimension being measured there will be an error in the measurement.

The length recorded will be more than the true length. This error is called "Cosine error". In many cases the angle 0 is very small and the error will be negligible.

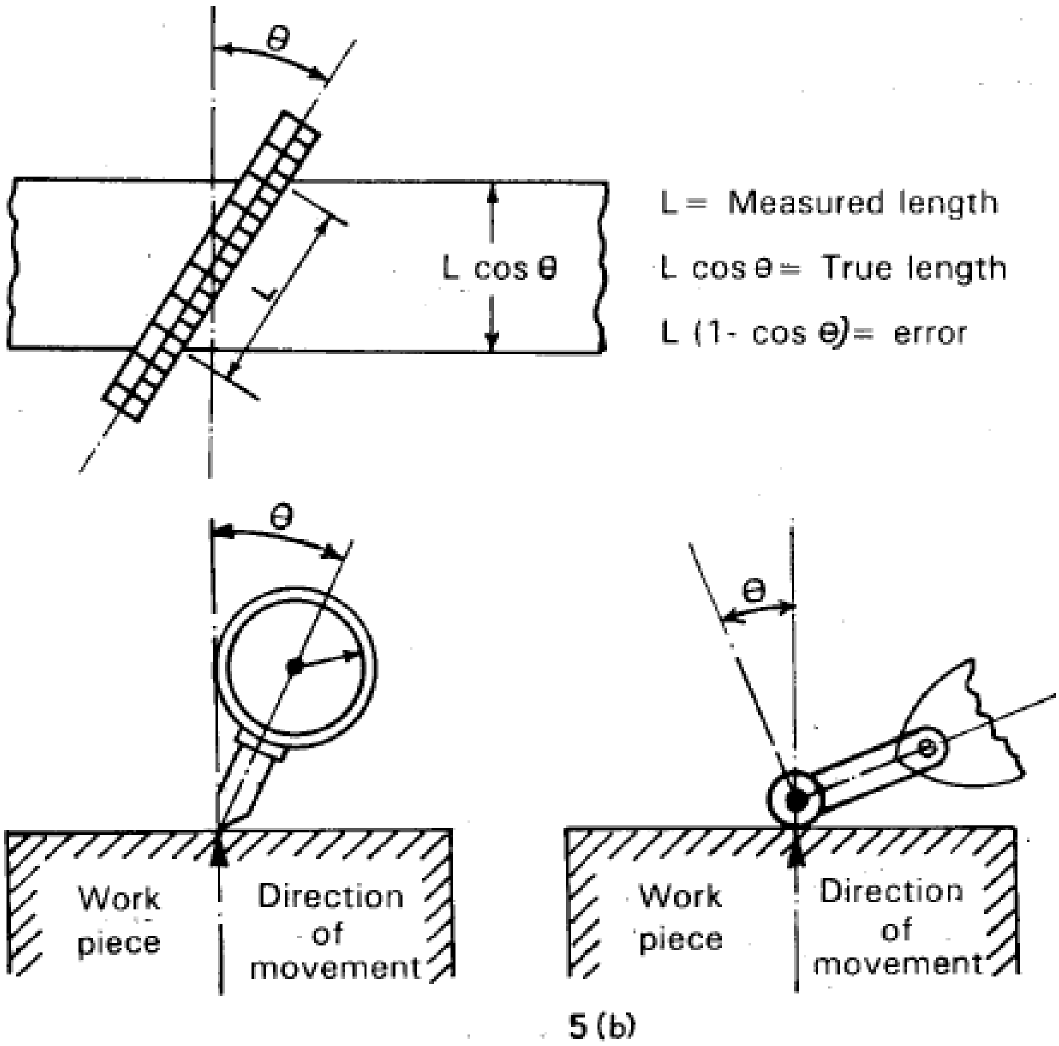


Figure 1.8 (A) And (B) Effect of Misalignment

The cosine error may also, occur while using dial gauge, if the axis of the pointer is not along the direction of measurement of work. Also, when in indicator is fitted with a ball-end stylus form, the arm should be so set that the direction of movement of the work is tangential to the arc along which the ball moves, otherwise cosine error will be introduced.

The combined cosine and sine error will occur if the micrometer axis is not truly perpendicular to the axis of the work piece (Refer Fig. 1.9). The same error occurs while measuring the length of the end gauge in a horizontal comparator if the gauge is not supported so that its axis is parallel to the axis of the measuring or anvils or if its ends, though parallel to each other are not square with ends.

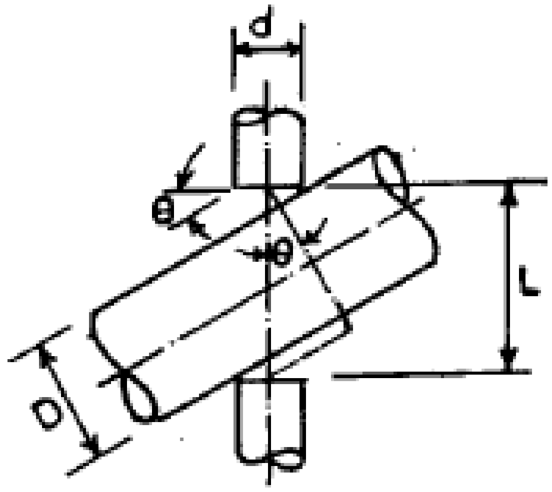


Figure 1.9 Combined Sines and Cosine Error

Referring Fig.1.9, if D = true diameter, L =apparent length, d = micrometer anvil diameter Then

D = (L cos θ) - d sin θ = L cos θ – d sin θ

And error, = L – D = L – (L cos θ – d sin θ) = L (1- cos θ) + d sin θ

The errors of above nature are avoided by using with spherical ends.

Contact pressure

The variation in the contact pressure between the anvils of the instrument and the work being measured produce considerable difference in reading. Though the pressure involved is generally small, but it is sufficient enough to came appreciable deformation of both the anvil (and stylus) and the work piece. The deformation of the work piece and the anvils of instrument depend -upon the contact pressure and the shape of the contact surfaces. When there is a surface contact between the instrument anvils and work piece, there is very little deformation, but when there is a point contact the deformation is appreciable.

Figure 1.10 Effect of Contact Pressure on Measurement

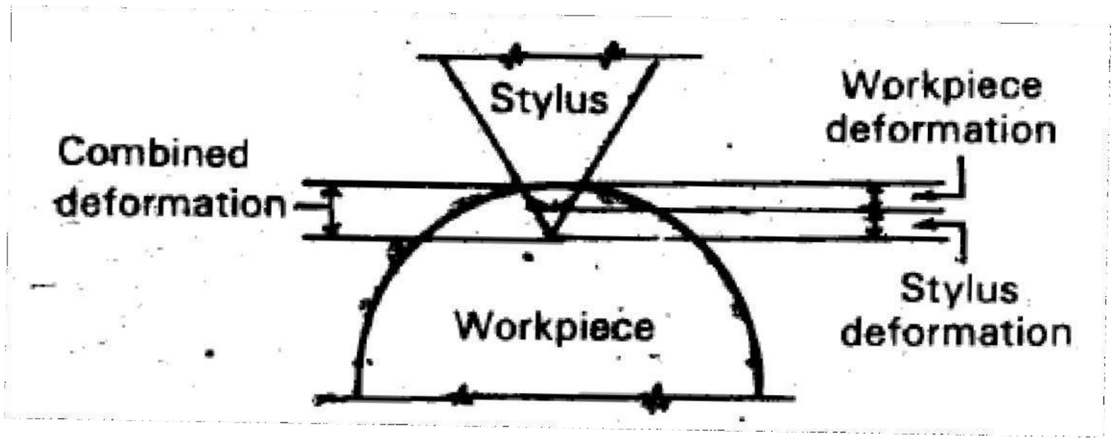


Fig. 1.10 shows the error caused by combined deformation of the stylus and the work piece.

To minimize this error the development of correct feel is one of the skills to be acquired by the inspector. To avoid this effect of contact pressure the micrometer is fitted with a ratchet mechanism to apply the correct pressure during measurement. The ratchet slips when the applied pressure exceeds the minimum required operating pressure.

Parallax Error

A very common error that may occur in an instrument while taking the readings is parallax error.

Parallax error occurs when:

- The line of vision is not directly in line with the measuring scale
- The scale and the pointer are separated from each other (hot in the same plane). Refer Fig. 1.11

Let d = separation of scale and pointer

D = distance between the pointer and eye of the observer

ϴ = angle which the line of sight makes with the normal to scale.

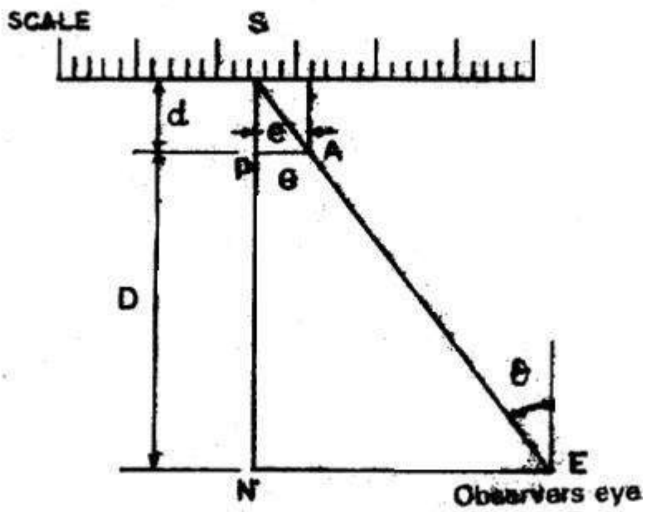


Figure 1.11 Parallax Errors

Now generally, ϴ is small therefore, tan ϴ = ϴ and error e = dϴ.

Forleasterrordshouldbeminimumpossible,valueofϴcanbereducedtozerobyplacing mirror behind the pointer which ensures normal reading of scale.

Dust

The dust present in the atmosphere may change the reading by a fraction of micron, where accuracy of the order of micron is desired such as while using slip gauges the effect of dust can be prevented by

1. Incorporating electrostatic precipitators in laboratory or in the air ducts in addition to air filters.
2. The work pieces and masters should be cleaned by clean chamois or by a soft brush.
3. Gauges should never be touched with moist fingers.
4. The contact surfaces should be sprayed with suitable filtered clean solvent.

Errors due to vibrations

Vibrations may affect the accuracy of measurement. The instrument anvil will not give consistent and repetitive reading if it is subjected to vibration.

For eliminating or reducing effect of vibration on measurement, the following precautions should be taken:

1. The laboratory should be located away from the sources of vibration.
2. Slipping cork, felt, rubber pads should be used under the gauge.
3. Putting a gauge on a surface plate resting in turn on a heavy plate also reduces the effect of vibrations.
4. Precision measurement -should be carried out away from shop floor.
5. Errors due to location

The part to be measured is located on a table or a surface plate which forms the datum for comparison with the standard. The reading taken by the comparator is thus the indication of the displacement of the upper surface of the measured part from the datum. If the datum surface is not flat, or if the foreign matter such as dirt, chips etc. are present between the datum and the Work piece surface then error will be introduced in the reading taken.

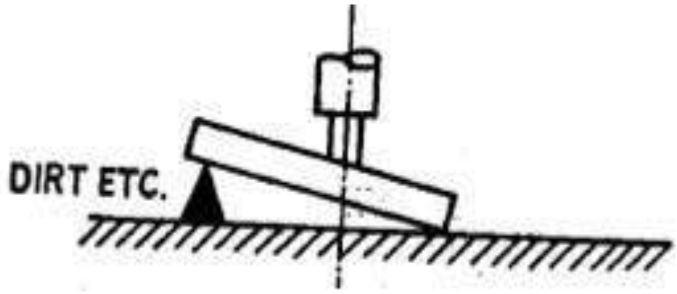


Figure 1.12 Surface Displacements

Error due to poor contact

Fig. 1.13 shows how the poor contact between the working gauge or instrument and the work piece causes an error. Although, everything feels all right, yet the error is bound to occur. To avoid this type of error the gauge with wide area of contact should not be used while measuring irregular or curved surface and correct pressure should be applied while making the contact.

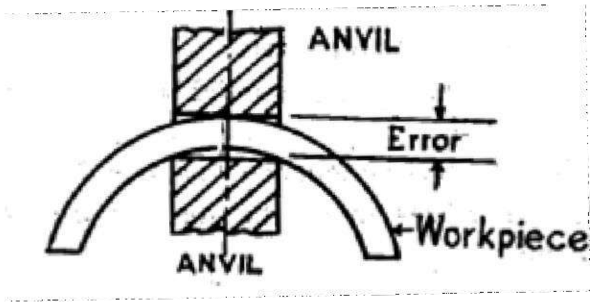


Figure 1.13 Errors Due To Poor Contact

Error due to wear in gauges

The measuring surfaces of instrument such as the anvils of the micrometer are subjected to wear due to repeated use. The internal instrument error such as threads of the micrometer spindle can also lead to error in measurement.

Wear can be minimized by keeping gauge, masters and work pieces clean and away from dust. Gauge, anvils and such other part s of the instrument which are subjected to wear should be properly hardened. Chrome plated parts are more resistant to wear.

The lack of parallelism due to wear of anvils can be checked by optical flats; and, the-wear on spherical contacts of the instrument by means of microscope.

Standardization and Standardizing Organization

- For overall higher economy, efficiency and productivity in a factory and country, it is essential that diversity be minimized and interchangeability among parts encouraged. All this is possible with standardization. Standardization is done at various levels, viz. International, National, association, company.
- Realizing the role of standardization in the development of industry, organizations to handle the complexities of standardization have been evolved in each of the chief industrial countries. In India, Bureau of Indian Standards (BIS) is responsible for evolving standards on metrological instruments, etc.
- There are several sectional committees, each dealing with various main branches of industry, in BIS. The detailed work of drawing up specifications is done by more specialized technical committees who prepare a draft standard based on practice in other countries and the needs of the country, and circulate it to relevant industries, government and service departments, research and teaching organizations, and others likely to be interested.
- Comments are invited both from producer and user to consider all aspects; meetings help to discuss the matters in depth and final standards issued. The technical committees also keep on revising the existing standards from time to time.
- The Bureau of Indian Standards is the National body for standardization in India. The functions of the Bureau are:

1. Formulation, publication and promotion of Indian Standards
2. Inspection of articles or process under Certification Scheme;
3. Establishment, maintenance and recognition of laboratories;

4. Formulate, implement and coordinate activities relating to quality maintenance and improvement in products and processes;
5. Promote harmonious development in standardization, quality systems and certification and matters connected therewith both within the country and at international level;
6. Provide information, documentation and other services to consumers and recognized consumer organizations on such terms and conditions as may be mutually agreed upon;
7. Give recognition to quality assurance systems in manufacturing or processing units on such terms and conditions as mutually agreed upon;
8. Bring out handbooks, guides and other special publications; and for conformity to any other standard if so authorized.

   Thus, the main functions of the Bureau can be grouped under standards formulation, certification marking and laboratory testing, promotional and international activities.

   Bureau of Indian Standards has under the Mechanical Engineering Division Council, EDC, a separate Engineering Metrology Sectional Committee. This Committee was set up in 1958 and its main task is to formulate standards for the various aspects of dimensional metrological measuring instruments and accessories used in the mechanical engineering field. A large number of Indian Standards in the field of engineering metrology have been formulated.

- In Great Britain, British Standards Institution plays similar role to BIS.
- In Europe, the International Federation of National Standardizing Association, known as I.S.A., coordinates the work of the continental countries. Before Second World War, U.K. and U.S.A. did not take any part in it, but after war, the countries like. U.K., U.S.A. and Russia have taken part in its works. In 1946, the I.S.A., was re-formed as the International Organization for Standardization, I.S.O. In fact, for engineering matters, the foremost standards organization at international level is I.S.O. The national standards organisations of individual countries are the members of I.S.O. The I.S.O. recommendations are used as basis for national and company standards. Lot of co-operative discussions in the field of standardization has also been carried out in three countries-America, Britain and Canada known was ABC conference. The International Electro-technical Commission (IEC) deals with electrical engineering standards. Both ISO and IEC have published recommendations on some aspects of engineering metrology.
- National Physical Laboratories (NPL) carry out lot of research work in various fields; responsible for defining standards, and also issue certification marks for quality instruments.

International organization of Weights and Measurements

It was established in 1975 under the "International meter convention" in Paris with the object of maintaining uniformity of measurements throughout the world. It comprises of:

1. The General Conference of Weights and Measures
2. The International Committee of Weights and Measures.
3. The International Organization of Legal Metrology.

General Conference of Weights and Measures

Its objects are:

- To draw up and promote the decisions necessary for the propagation and perfection of an international system of units and standards of measurement.
- To approve the results of new fundamental metrological determinations and the various scientific resolutions in the field of metrology which are of international interest.

International Committee of Weights and Measures

This Committee is placed under the authority of the General Conference of Weights and Measures and is responsible for promoting the decisions taken by the latter. Its objects are:

- To direct and supervise the work of the International Bureau of Weights and Measures.
- To establish co-operation among national laboratories of metrology for executing the metrological work which the General Conference of Weights and Measures decides to execute jointly by the member states of the organization.
- To direct such work and co-ordinate the results and to look after the conservation of the International Standards.

OIML has made a number of international recommendations. They have also published a "Vocabulary of Legal Metrology-Fundamental Terms" the English translation of which is published in India by the Directorate of Weights and Measures, Ministry of Industry.

The functions of the Directorate of Weights and Measures are:

- To ensure the conservation of national standards and to guarantee their accuracy by comparison with international standards.
- To guarantee and impart proper accuracy to the secondary standards by comparison with national standards.
- To carry out scientific and technical work in all fields of metrology and methods of measurements.
- To take part in the work of other national organizations interested in metrology.
- To draw up draft laws relating to legal metrology and to promulgate the corresponding regulations.
- To regulate and advise on, supervise and control the manufacture and repair of measuring instruments.
- To inspect the use of instruments and the measurement operations when such use and such operations are covered under public guarantee.
- To detect frauds in measurement or sale of goods and to book offender for trials where necessary.
- To coordinate the activities of authorities exercising metrological supervision.
- To cooperate with all to ensure respect for the regulations of legal metrology.
- To organize training in legal metrology
- To represent the country in international activities regarding legal metrology.

National Service of Legal Metrology: The National Service of Legal Metrology has following organizations to assist it in discharge of its duties:

- National Bureau of Legal Metrology. (It is the directing organization)
- National Institute of Legal Metrology. (It is entrusted with the performance of scientific and research work)
- National Bureau of Verification.

There are regional bureau of verification, local bureau of verification, mobile bureau of verification, and verification centers to assist national bureau of verification in ensuring

appropriate accuracy of the standards, carrying out metrological supervision, verifying measuring instruments.

- Verification agents (Authorized to exercise the functions of verification)

ANGULAR MEASUREMENT

Slip Gauges

- Slip gauges or gauge blocks are universally accepted end standard of length in industry. These were introduced by Johnson, a Swedish engineer, and are also called as johanson gauges

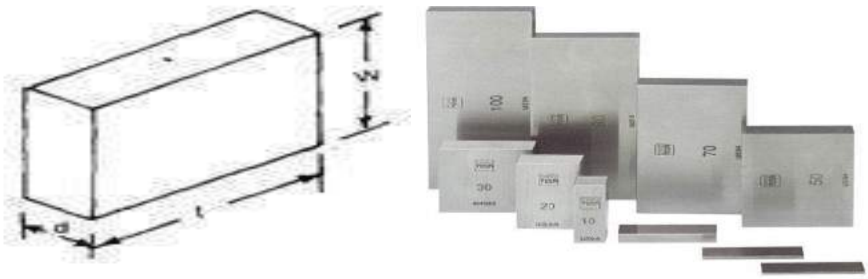


Figure 2.11 Dimensions of a Slip Gauge

- Slip gauges are rectangular blocks of high grade steel with exceptionally close tolerances. These blocks are suitably hardened through out to ensure maximum resistance to wear.
- They are then stabilized by heating and cooling successively in stages so that hardening stresses are removed,After being hardened they are carefully finished by high grade lapping to a high degree of finish, flatness and accuracy.
- For successful use of slip gauges their working faces are made truly flat and parallel. A slip gauge is shown in fig. 3.36. Slip gauges are also made from tungsten carbide which is extremely hard and wear resistance.
- The cross-sections of these gauges are 9 mm x 30 mm for sizes up to 10 mm and 9 mm x 35 mm for larger sizes. Any two slips when perfectly clean may be wrung together. The dimensions are permanently marked on one of the measuring faces of gauge blocks

- Gauges blocks are used for:
  1. Direct precise measurement, where the accuracy of the work piece demands it.
  2. For checking accuracy of vernier callipers, micrometers, and such other measuring instruments.
  3. Setting up a comparator to a specific dimension.
  4. For measuring angle of work piece and also for angular setting in conjunction with a sine bar.
  5. The distances of plugs, spigots, etc. on fixture are often best measured with the slip gauges or end bars for large dimensions.
  6. To check gap between parallel locations such as in gap gauges or between two mating parts.

Introduction to Angular Measurement

- Angular measurements are frequently necessary for the manufacture of interchangeable parts. The ships and aero planes can navigate confidently without the help of the site of the land; only because of precise angular measuring devices can be used in astronomy to determine the relation of the stars and their approximate distances.
- The angle is defined as the opening between two lines which meet at a point. If one of the two lines is moved at a point in an arc, a complete circle can be formed.
- The basic unit in angular measurement is the right angle, which is defined as the angle between two lines which intersect so as to make the adjacent angles equal.
- If a circle is divided into 360 equal parts. Each part is called as degree (^{0}). Each degree is divided in 60 minutes (‘), and each minute is divided into 60 seconds (“).
- This method of defining angular units is known as sexagesimal system, which is used for engineering purposes.
- An alternative method of defining angle is based on the relationship between the radius and arc of a circle. It is called as radian.
- Radian is defined as the angle subtended at the centre by an arc of a circle of length equal to its radius.
- It is more widely used in mathematical investigation.

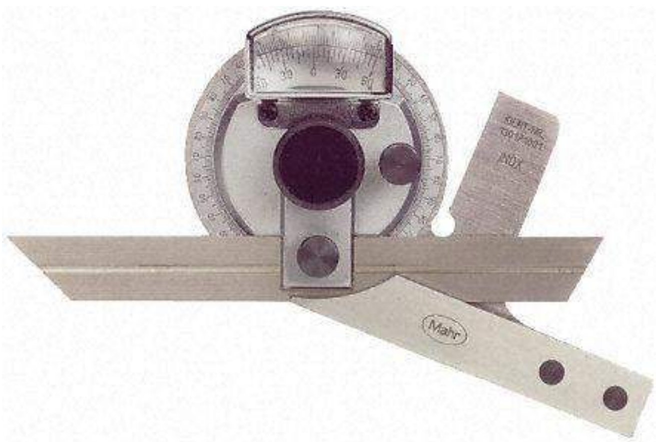
  2 radians = 360, giving,

  1 radian = 57.2958 degrees.

- In addition linear units such as 1 in 30 or millimeters per meter are often used for specifying tapers and departures from squareness or parallelism.

Bevel Protector

- It is probably the simplest instrument for measuring the angle between two faces of component.
- It consists of a base plate attached to the main body, and an adjustable blade which is attached to a circular plate containing vernier scale. The adjustable blade is capable of rotating freely about the centre of the main scale engraved on the body of the instrument and can be locked in any position.
- An acute angle attachment is provided at the top; as shown in fig. for the purpose of measuring acute angles. The base of the base plate is made flat so that it could be laid flat upon the work and any type of angle measured. It is capable of measurement from 0^0 to 360^0
- The vernier scale has 24 divisions coinciding with 23 main scale divisions. Thus the least count of the instrument is 5'. This instrument is most commonly used in workshops for angular measurements till more precision is required.
- A recent development of the vernier bevel protector is optical bevel protector. In this instrument, a glass circle divided at 10' intervals throughout the whole 360^0 is fitted inside the main body.
- A small microscope is fitted through which the circle graduations can be viewed. The adjustable blade is clamped to a rotating member who carries this microscope. With the aid of microscope it is possible to read by estimation to about 2'.



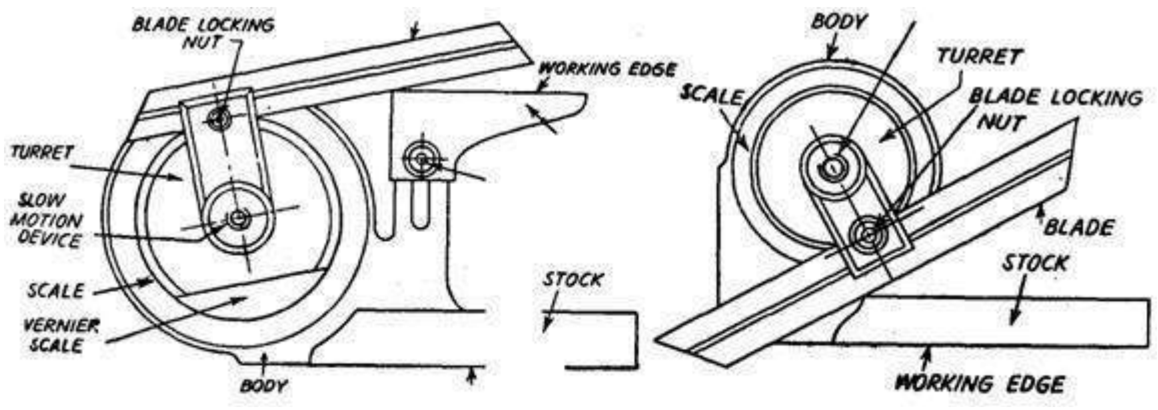


Figure 2.12 Bevel Protector

Universal Bevel Protector

- It is used for measuring and laying out of angles accurately and precisely within 5 minutes. The protector dial is slotted to hold a blade which can be rotated with the dial to the required angle and also independently adjusted to any desired length. The blade can be locked in any position.

Bevel Protectors as Per Indian Standard Practice

The bevel protectors are of two types, viz.

1. Mechanical Bevel Protector, and
2. Optical Bevel Protector.

1. Mechanical bevel protector:

- The mechanical bevel protectors are further classified into four types; A, B, C and D.
- In types A and B, the vernier is graduated to read to 5 minutes of arc whereas in case of type C, the scale is graduated to read in degrees and the bevel protector is without vernier or fine adjustment device or acute angle attachment.
- The difference between types A and B is that type A is provided with fine adjustment device or acute angle attachment whereas type B is not. The scales of all the types are graduated either as a full circle marked 0—90—0—90 with one vernier or as semicircle marked 0—90—0 with two verniers 180^0 apart.
- Type D is graduated in degrees and is not provided with either vernier or fine adjustment device or acute angle attachment.

2. Optical bevel protector:

- In the case of optical bevel protector, it is possible to take readings up to approximately 2 minutes of arc. The provision is made for an internal circular scale which is graduated in divisions of 10 minutes of arc.

- Readings are taken against a fixed index line or vernier by means of an optical magnifying system which is integral with the instrument. The scale is graduated as a full circle marked 0—90—0—90. The zero positions correspond to the condition when the blade is parallel to the stock. Provision is also made for adjusting the focus of the system to accommodate normal variations in eye-sight. The scale and vernier are so arranged that they are always in focus in the optical system.

Various Components of Bevel Protectors

Body: It is designed in such a way that its back is flat and there are no projections beyond its back so that when the bevel protector is placed on its back on a surface plate there shall be no perceptible rock. The flatness of the working edge of the stock and body is tested by checking the squareness of blade with respect to stock when blade is set at 90^0.

Stock: The working edge of the stock is about 90 mm in length and 7 mm thick. It is very essential that the working edge of the stock be perfectly straight and if at all departure is there, it should be in the form of concavity and of the order of 0.01 mm maximum over the whole span.

Blade: It can be moved along the turret throughout its length and can also be reversed. It is about 150 or 300 mm long, 13 mm wide and 2 mm thick and ends beveled at angles of 45^0 and 60^0 within the accuracy of 5 minutes of arc. Its working edge should be straight upto
0.02 mm and parallel upto 0.03 mm over the entire length of 300 mm. It can be clamped in any position.

Actual Angle Attachment

It can be readily fitted into body and clamped in any position. Its working edge should be flat to within 0.005 mm and parallel to the working edge of the stock within 0.015 mm over the entire length of attachment.

The bevel protectors are tested for flatness, squareness, parallelism, straightness and angular intervals by suitable methods.

Sine Principle and Sine Bars

- The sine principle uses the ratio of the length of two sides of a right triangle in deriving a given angle. It may be noted that devices operating on sine principle are capable of "self generation."

- The measurement is usually limited to 450 from loss of accuracy point of view. The accuracy with which the sine principle can be put to use is dependent in practice, on some form of linear measurement.
- The sine bar in itself is not a complete measuring instrument. Another datum such as a surface plate is needed, as well as other auxiliary equipment, notably slip gauges, and indicating device to make measurements. Sine bars used in conjunction with slip gauges constitute a very good device for the precise measurement of angles.
- Sine bars are used either to measure angles very accurately or for locating any work to a given angle within very close limits.
- Sine bars are made from high carbon, high chromium, corrosion resistant steel, hardened, ground and stabilized.

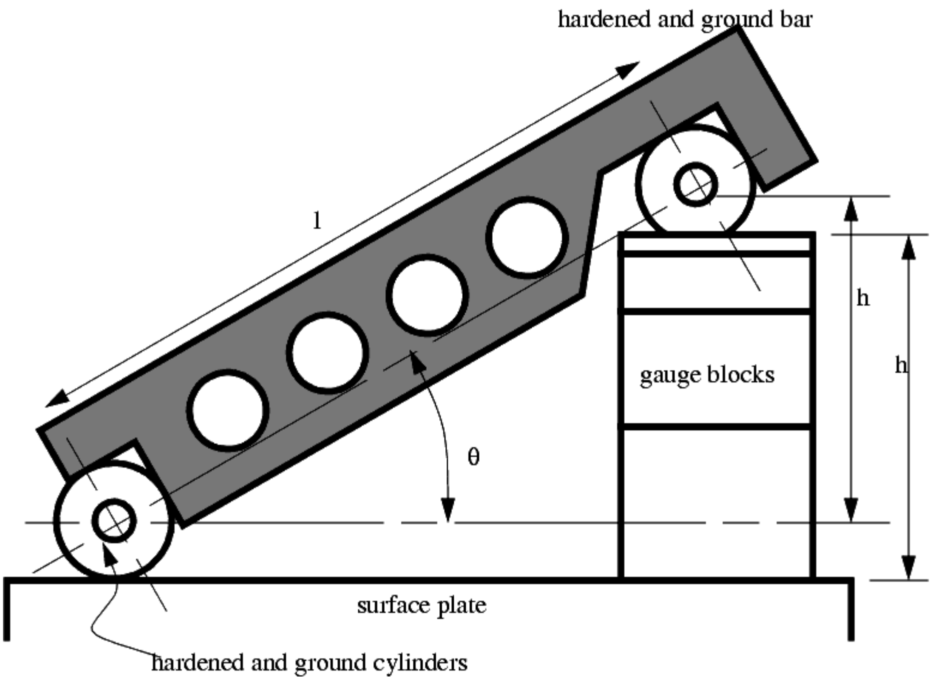


Figure 2.13 Use of sine bar

Where, L = distance between centers of ground cylinder (typically 5'' or 10'') H = height of the gauge blocks

Θ = the angle of the plane Θ =

a sin (h/l)

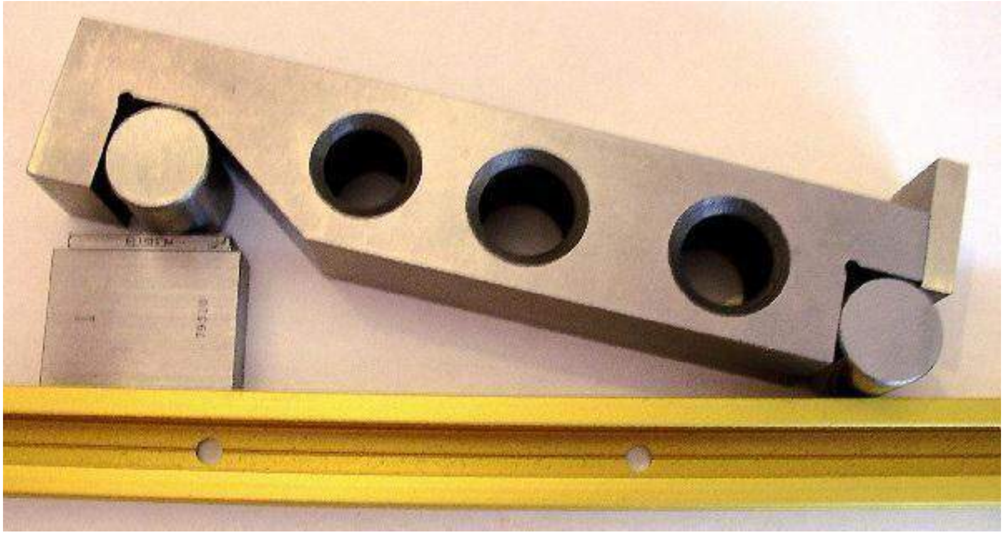


Figure 2.14 Practical Application of sine bar

Use of sinebar:

1. Measuring known angles or locating any work to a given angle. For this purpose the surface plate is assumed to be having a perfectly flat surface, so that its surface could be treated as horizontal.

   One of the cylinders or rollers of sine bar is placed on the surface plate and other roller is placed on the slip gauges of height h. Let the sine bar be set at an angle q. Then sin = h/l, where l is the distance between the center of the rollers. Thus knowing, h can be found out and any work could be set at this angle as the top face of sine bar is inclined at angle to the surface plate.

   The use of angle plates and clamps could — also be made in case of heavy components.

   For better results, both the rollers could also be placed on slip gauges checking of unknown angles. Many a times, angle of a component to be checked is unknown. In such a case, it is necessary to first find the angle approximately with the help of a bevel protector.

   Let the angle be 8. Then the sine bar is set at an angle and clamped to an angle plate. Next, the work is placed on sine bar and clamped to angle plate as shown in Fig. And a dial indicator is set at one end of the work and moved to the other, and deviation is noted. Again slip gauges are so adjusted (according to this deviation) that dial indicator reads zero across work surface.

   Fig.

   If deviation noted down by the dial indicator is ôh over a length *l'* of work, then height of slip gauges by which it should be adjusted is equal to = ôh x *l/l'*

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 fiducially 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. Surface plate shows the use of height gauge for obtaining two readings for either of the Fig. 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.

1.4 Angle Gauges

- The first set of combination of angle gauges was devised by Dr. Tomlinson of N.P.L. With thirteen separate gauges used in conjunction with one square block and one parallel straight-edge, it is possible to set up any angle to the nearest 3" In the same way, as slip gauges are built up to give a linear dimension, I the angle gauges can be build up to give a required angle.
- Angle gauges PIVOT are made of hardened steel and seasoned carefully to ensure permanence of angular accuracy, and the measuring faces are lapped and polished to a high degree of accuracy and flatness like slip gauges. These gauges are about 3 inch (76.2 mm) long, 5/8 inch (15.87 mm) wide with their faces lapped to within 0.0002 mm and angle between the two ends to ±2 seconds.
- The secret of this system in having any angle in step of 3'' is the adoption of a mathematical series of the values of the angles of various gauges of the set.
- The thirteen gauges can be divided into three series; degrees, minutes and fractions of a

minute. The gauges available in first series are of angle 1^0, 3^0, 9^0, 27^0, and 41^0. Second series comprises 1', 3', 9’ and 27’ angle gauges and this series has 0.05’, 0.1', 0.3’ and 0.5’ (or 3”, 6”, 18” and 30”) angle gauges.

- All these angle gauges in combination can be added or subtracted, thus, making a large number of combinations possible. There are two sets of gauges available, designated as A and B. The standard A contains all the above 13 gauges. Standard B contains only 12 gauges and does not have, the 0.05' angle gauge.
- Direct combination enables computation of any angle up to 81^0 40.9’and angles larger than this can be made up with the help of the square block. However, an additional gauge of 9^0 can also be supplied with the set to obtain a full 90^0 angle without the use of the square. Fig. illustrates how the gauges can be used in addition and subtraction. The procedure used for making various angles is as follows e.g. say, we have to build up an angle of 57^0 38’ 9”.
- First we pay our attention towards degree only. So 57^0 could be built up as $41^0 + 27^0 - 9^0 + 1^0 - 3^0$
- Next if the minutes are less than 40’, they could be built up directly, otherwise number of degrees must be increased by 1^0 and the number of minutes necessary to correct the total is subtracted. Here now 34’ could be built 27’+9’—3’+ 1' and lastly 9” is built up as 0.1'+ 0.05’.
- It may be noted that each angle gauge is marked with engraved V which indicates the direction of included angle. When the angles of individual angle gauges are to be added up then the V_S of all angle gauges should be in line and when any angle is to be subtracted, its engraved V should be in other direction.
- Thus it is seen that any angle could be made up but the block formed by the combination of a number of these gauges is rather bulky and, therefore, cannot be always directly applied to the work. But these gauges being used as reference and taking the aid of other angle measuring devices will be a good proposal at manyplaces.
- Angle gauge blocks seem to lack the requisites for use as primary standards because errors are easily compounded when angle blocks are wrung in combination. Further the absolute verification of angle blocks is usually dependent on some other primary standard.

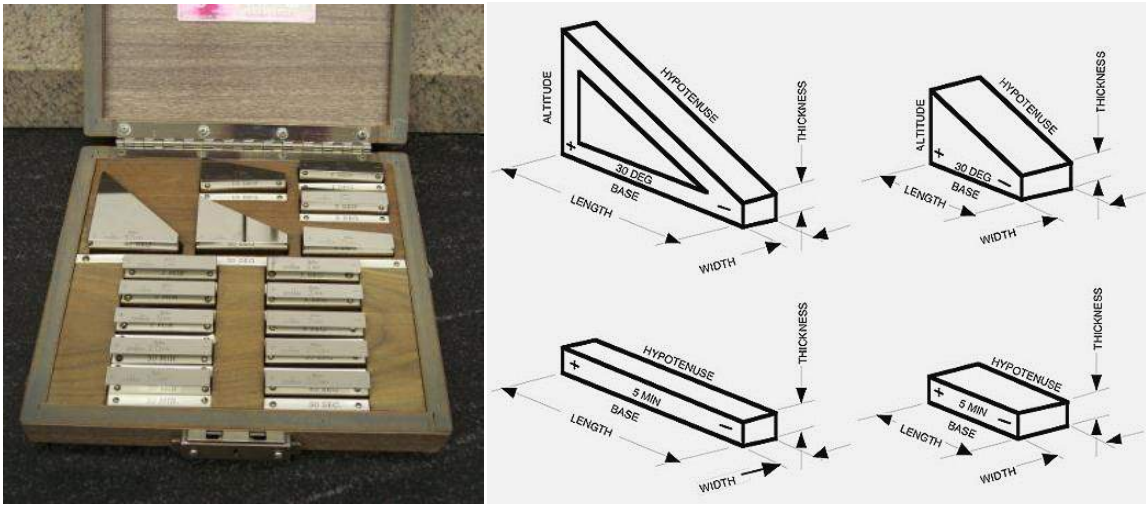


Figure 2.15 Set of angle gauges

Uses of Angle Gauges

- Direct use of angle gauges to measure the angle in the die insert:
- To test the accuracy of the angle in the die insert, the insert is placed against an illuminated glass surface plate or in front of an inspection light box. The combination of angle gauges is so adjusted and the built-up combination, of angle gauges carefully inserted in position so that no white light can be seen between the gauge faces and die faces. It may be noted that when all the engraved Vs on the angle gauges are in the same line, all angles are added up. In case some engraved Vs on angle gauges are on other side, those angles are subtracted.

Use of angle gauges with square plate:

- As already indicated, the use of square plate increases the versatility of the application of angle gauges. Generally, the square plate has its 90^0 angles guaranteed to within 2 seconds of arc. Where very high degree of accuracy is required, the four corners of the square plate are numbered as A, B, C and D, and a test certificate are issued with each set of angle gauges, giving the measured angle of each corner. The whole set up is placed against an illuminated glass surface plate. It may be noted that the use of slip gauges has to be made in order to facilitate the testing.

So far, we have used angle gauges to obtain a visual comparison of an angular dimension under test. It has also been realized that though it may be possible to obtain good results but it is difficult to give an estimate of the actual angular error. For very precise angular measurements, angle gauges are used i

MODULE 2

SYSTEM OF LIMITS, FITS, TOLERENCE AND GUAGING

Specification in assembly, Principle of interchangeability and selective assembly, limits of size, Indian standards, concept of limits of size and tolerances, definition of fits, hole basis system, shaft basis system, types of fits and their designation (IS 919- 1963).Classification of gauges, brief concept of design of gauges (Taylor's principles), Numerical on design of Gauges

SYSTEM OF LIMITS, FITS, TOLERANCE AND GAUGING

Limits & Fits:

1. Why study Limits & Fits?

Exact size is impossible to achieve. Establish boundaries within which deviation from perfect form is allowed but still the design intent is fulfilled. Enable interchangeability of components during assembly

Definition of 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. The difference between the uppe rand lower limit is called tolerance.

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 work piece on the machine, some errors are likely to creep in.

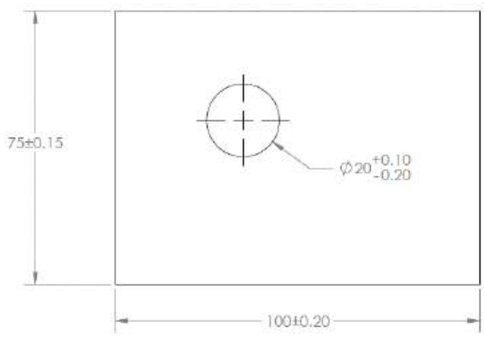


Figure 1 Tolerance

Consider the dimension shown in fig. When trying to achieve a diameter of 40 mm (Basic or 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, the dimension 40.05 mm is known as Upper limit and the dimension 39.95 mm is known as Lower limit of size. Tolerance in the above example is (40.05-39.95) =0.10 mm Tolerance is always a positive quantitative number.

Type of tolerance

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 above or below) the tolerances are said to be unilateral. For unilateral tolerances, a case may occur when one of the limits coincide with the basic size.

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,

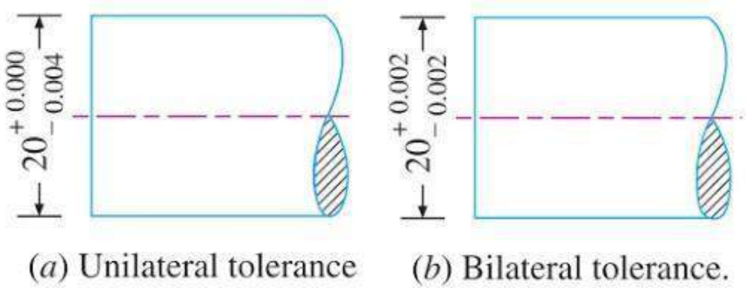


Figure 2 Unidirectional/Bidirectional tolerance

are preferred over bilateral because the operator can machine to the upper limit of the shaft (or lower limit of a hole) still having the whole tolerance left for machining to avoid rejection of parts.

Tolerance build up or Tolerance accumulation

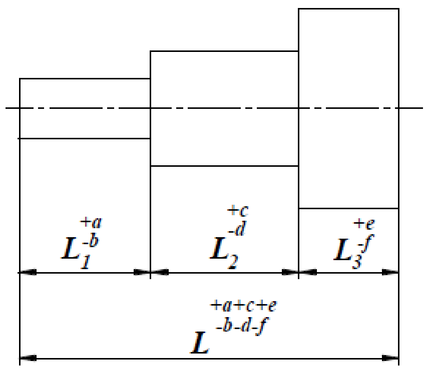


Figure 3 Tolerance build up

If a part comprises of several steps, each step having some tolerance specified over its length, then the overall tolerance on the complete length will be the sum of tolerances on individual lengths as shown in fig (a). The effect of accumulation of tolerances can be minimized by adopting progressive dimensioning from a common datum as shown in fig (b). Another example of tolerance build up is shown below.

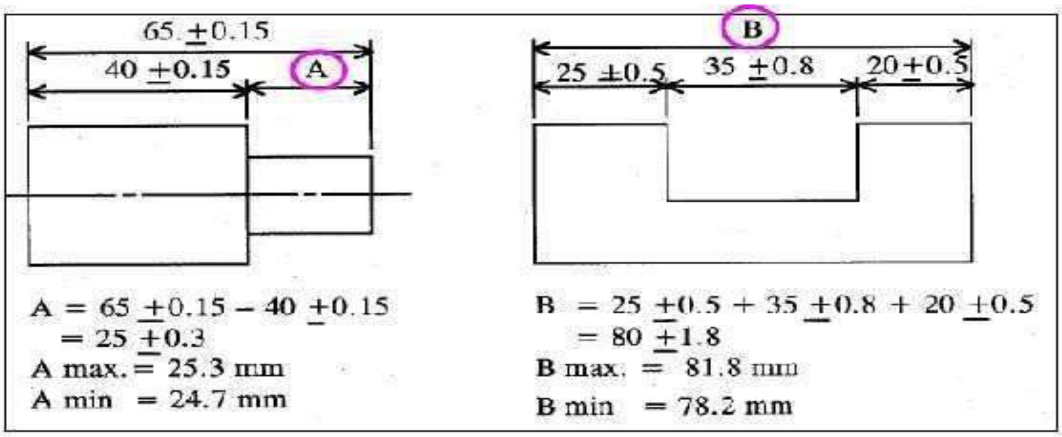


FIGURE 2.4: TOLERANCE BUILD UP

Compound Tolerances: A compound tolerance is one which is derived by considering the effect of tolerances on more than one dimension.

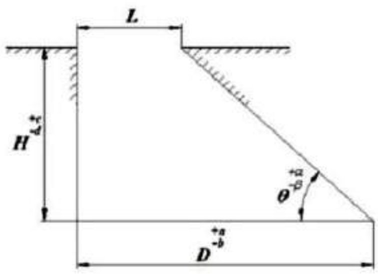


FIGURE 2.5 COMPOUND TOLERANCE

For ex, the tolerance on the dimension L is dependent on the tolerances on D, H
The dimension L will be maximum when the base dimension is (D+a), the angle is (+a), and the vertical dimension is (H-d).
The dimension L will be minimum when the base dimension is (D-b), the angle is (-b), and the vertical dimension is (H+c).

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.

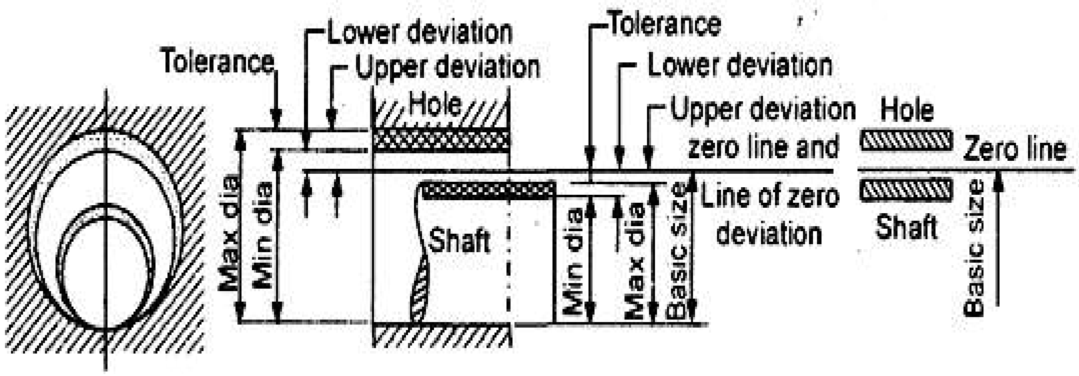


Figure 2.6 BASIC SIZE/DEVIATION/TOLERANCE

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.

3. SYSTEM OF FITS

- ***It is an assembly condition between 'Hole' & 'Shaft'***
- ***The degree of tightness or looseness between two mating parts is called a fit.***

Hole: A feature engulfing a component.

Shaft: A feature being engulfed by a component.

Type of fit:

CLEARANCE FIT:

- A fit that always provides a clearance (gap) between the hole and shaft when assembled is known as clearance fit.
- There is a clearance or looseness in this type of fits. These fits maybe slide fit, easy sliding fit, running fit etc.
- 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.

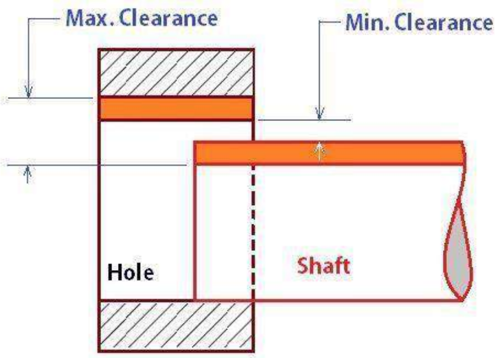


Figure 4 Clearance fit representation

Figure 5 Clearance fit

Example: The feed movement of the spindle quill in a drilling machine, Idle Pulleys,

- Maximum Clearance:

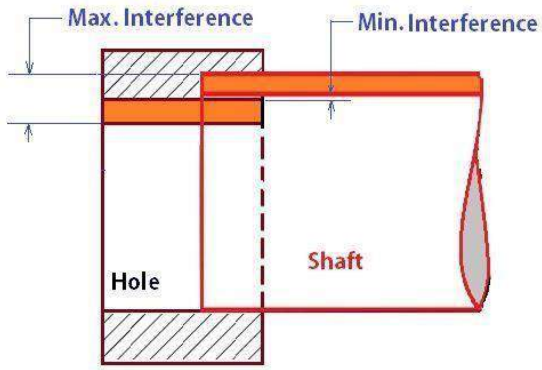
  = maximum size of hole - minimum size of shaft.

- Minimum clearance :

  = maximum size of shaft - minimum size of hole.

INTERFERENCE FIT:

- It is defined as the fit established when a negative clearance exists between the sizes of holes and the shaft.
- The minimum allowable diameter of the shaft is larger than the maximum permissible diameter of the hole.
- The diameter of the shaft is larger then the diameter of hole.
- The hole and shaft is intended to be attached permanently.



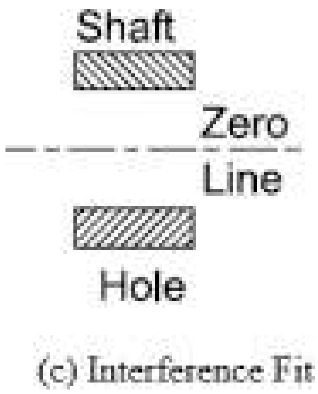


Figure 6 Interference fit representation

Figure 7 Interference fit

Example: bearings in casing, dowel pins

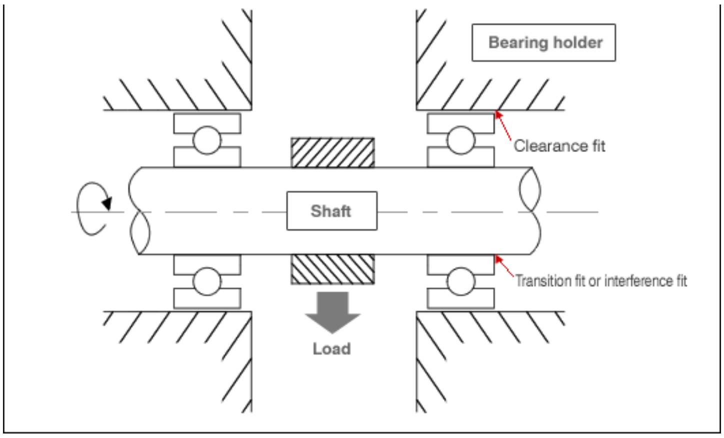


Figure 8 bearings in casing

TRANSITION FIT:

- In this type of fit, the limits for the mating parts are so selected that either a clearance or interference may occur depending upon the actual size of the mating parts.
- In this type of fit, the diameter of the largest allowable hole is greater than the smallest diameter of shaft, but the smallest hole is smaller than the largest shaft.
- Hand press or hammering is required to cause the entry of shaft.

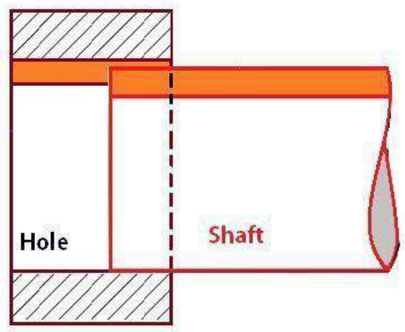


Figure 9 Representation of transition fit

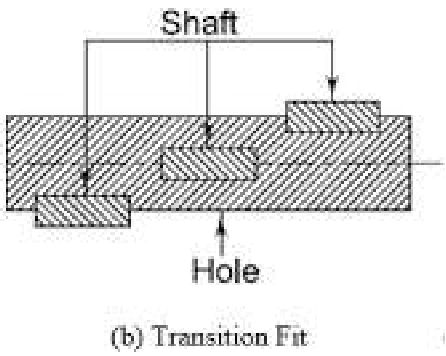


Figure 10 Transition fit

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

Figure 11 Coupling ring

4. 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.

5. SELECTIVE ASSEMBLY:

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

Least Material Condition (LMC): The condition in which a feature contains the least amount of material within the stated limits. e.g. maximum hole diameter, minimum shaft diameter.

Regardless of Feature Size (RFS): This is the default condition for all geometric tolerances.

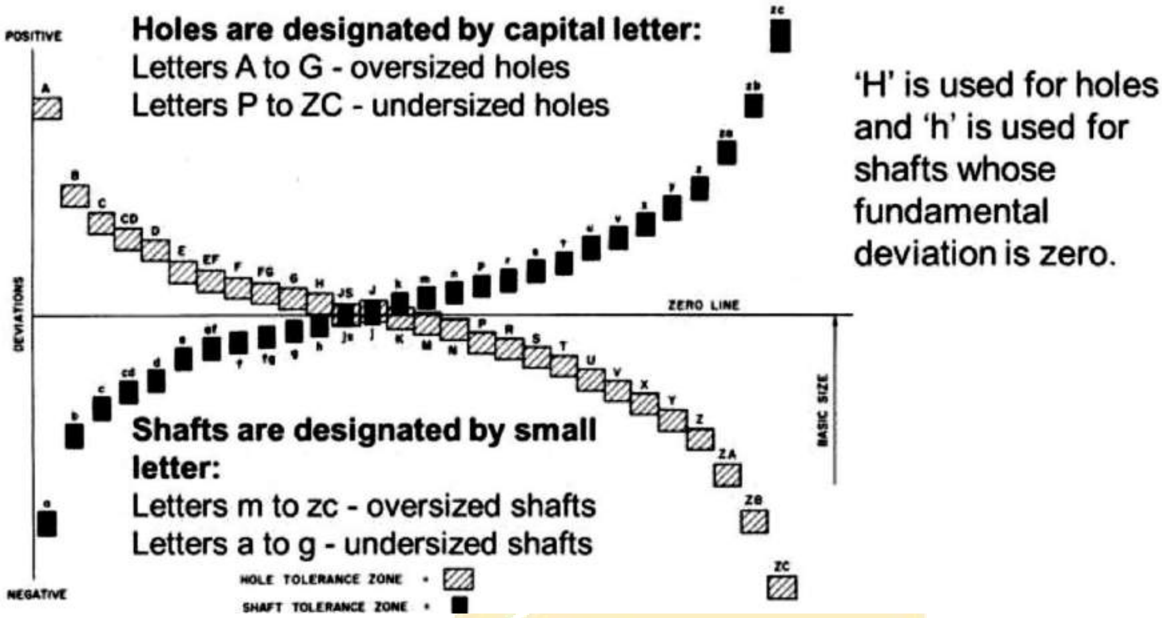


FIGURE 2.8 SHAFT DESIGNATION

6. Terms & symbols used:

Basic shaft: It is a shaft whose upper deviation is zero. i.e. the maximum limit of shaft coincides 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 hole oincides with the nominal size.(zero line). *Eg*: shaft 'H'

7. BASIS OF FITS

HOLE BASIS:

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

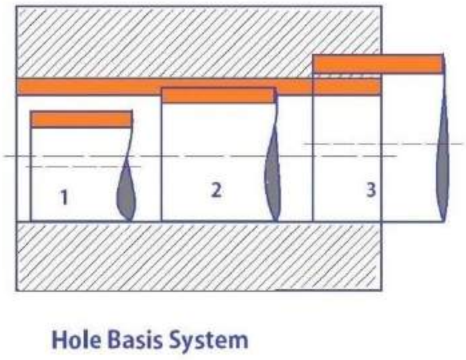


Figure 12 Hole basis system (1. Clearance fit, 2. Transition fit, 3. Interference fit)

Significance of Hole basis system: The bureau of Indian Standards (BIS) recommends both hole basis and shaft basis systems, but their selection depends on the production methods. 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 types of fits, number of holes of different sizes are required, which in turn requires tools of different sizes. If the hole basis system is used, there will be reduction in production costs as only one tool is required to produce the ole and the shaft can be easily machined to any desired size. Hence hole basis system is preferred over shaft basis system.

SHAFT BASIS SYSTEM:

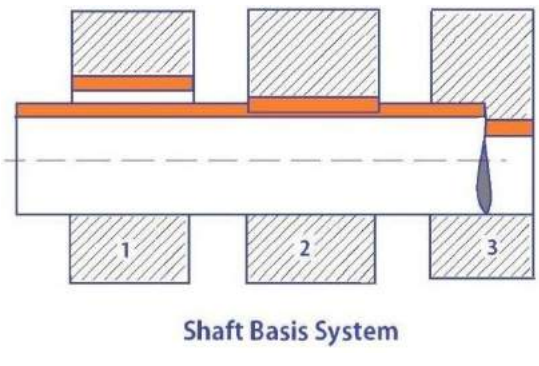


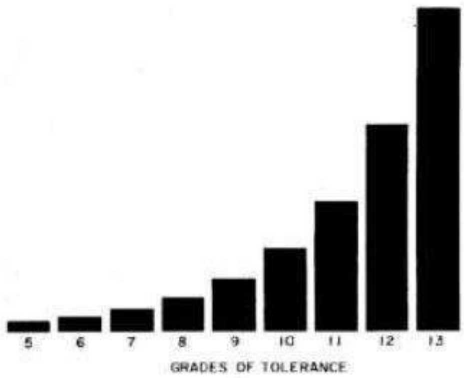
Figure 13 Shaft basis system (1. Clearance fit, 2. Transition fit, 3. Interference fit)

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.

8. GRADES OF TOLERANCES

Grade is a measure of the magnitude of the tolerance. Lower the grade the finer the tolerance. 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.



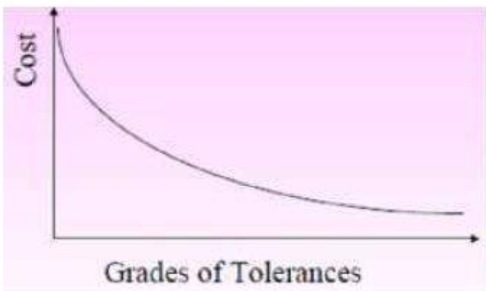


FIGURE 2.11 GRADES OF TOLERANCES

9. 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 upto 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 parabolically 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=10 x IT 6 = 10 x10 i =100 i, IT12=10 x IT7 = 10 x16 i=160 i, etc.

10. Taylor's Principle of Gauge Design

Taylor's Principle of gauge design gives two statements Statement 1:

- The "Go" gauge should always be so designed that it will cover the maximum metal ondition (MMC), whereas a "NOT-GO" gauge will cover the minimum (least) metal condition (LMC) of a feature, whether external or internal.

Statement 2:

- The "Go" gauge should always be so designed that it will cover as many dimensions as possible in a single operation, whereas the "NOT-GO" gauge should cover only one dimension.

Importance of **Statement 1** understand trough following example: Example for Taylors Principle statement 1: **Hole**

- Example 1:

➢ High limit of hole = 38.70 mm tow limit of hole = 38.00 mm

➢ Maximum Metal Limit of hole (Low limit of hole) = 38.00 mm

➢ "Go" gauge dimension become = 38.00 mm

➢ Minimum Metal Limit of hole (high limit of hole) = 38.70 mm

➢ "Not -Go" gauge dimension become = 38.70 mm

➢ For the bearing (hole) to be within 38.00S mm the Go-gauge should enter and NOT- GO gauge should refuse to enter.

- If the GO-gauge does not enter, the hole is smaller in dimension and if the NOT-GO gauge also goes in the hole, then the hole is bigger in dimension.

Example for Taylors Principle statement 1: **Shaft**

Dimensions of shaft to be controlled $38.00^{+0.20}_{-0.04}$mm High limit of shaft $=$ 37.98mm Low limit of shaft $=$ 37.96 mm

- Maximum Metal and Limit of shaft (high limit of shaft) = 37.98 mm
- "GO" gauge dimension become = 37.98mm
- Minimum Metal Limit of shaft (low limit of shaft) = 37.96 mm
- "NOT-GO" gauge dimension become = 37.96mm.
- For the shaft to be within mm, the Go-gauge should slide over and NOT- GO gauge should not slide over the shaft.
- Is the GO-gauge does not go (slide) then the shaft is bigger in dimension and if NOT- GO gauge slide over the shaft, then the shaft size is smaller in dimension.

Importance of **Statement 2:**

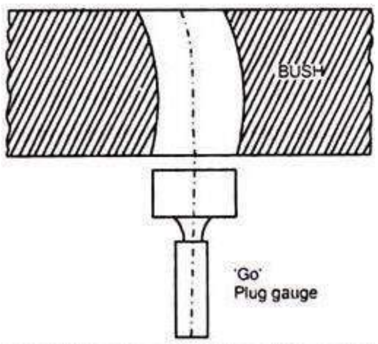


Figure 14 GO plug gauge in a curvy hole

- If a short length Go-plug gauge is employed to check the curved bush, it will pass through all the curves of the bend busing. This will lead to wrong selection of curved bush.

- On the other hand, a GO-plug gauge of adequate length will not pass through a bent or curved bush. This eliminates the wrong selection.

- The length of NOT-GO gauge is kept smaller than GO-gauge.

Example to illustrate Taylor's Principle of Gauge Design:

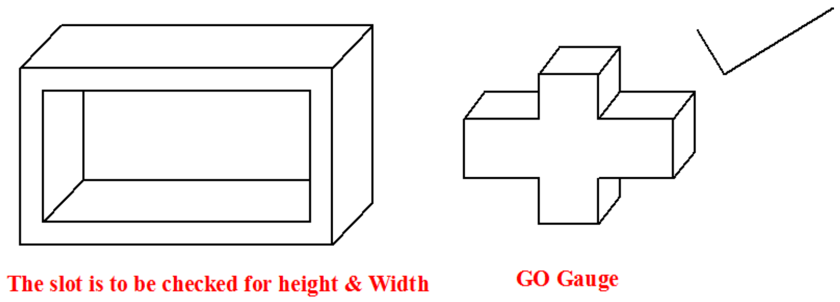


Figure 15 GO gauge for rectangular slot (hole)

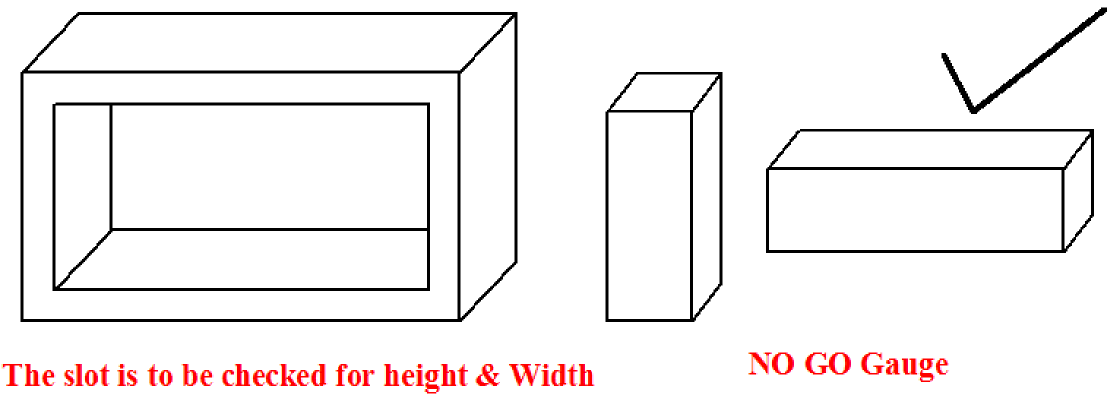


Figure 16 NO - GO gauge for rectangular slot (hole)

A GO gauge must check the dimensions as well as form (perpendicularity) of the slot at a time. Hence the GO gauge must be as shown in fig on the right.

A NO GO gauge must check the dimensions of the slot one at a time and hence two separate gauges must be used.

If the single gauge as shown is used, the gage is likely to pass a component even if one of the dimensions is less than desirable limit because it gets stuck due to the other dimension which is within correct limit.

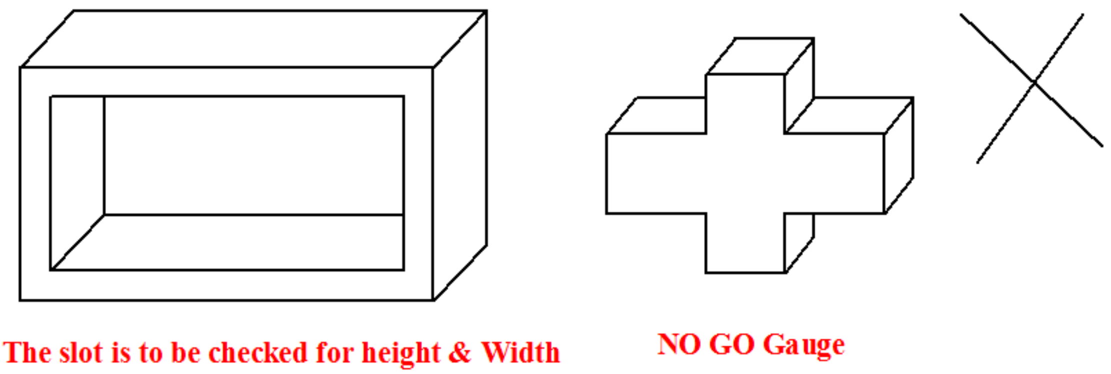


Figure 17 Wrong No Go gauge selection

11. LIMIT GAUGES

A ***Go-No GO*** gauge refers to an inspection tool used to check a workpiece against its allowed tolerances. It derives its name from its use: the gauge has two tests; the check involves 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 industry to 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 within tolerance 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.

Type of LIMIT GAUGES

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.

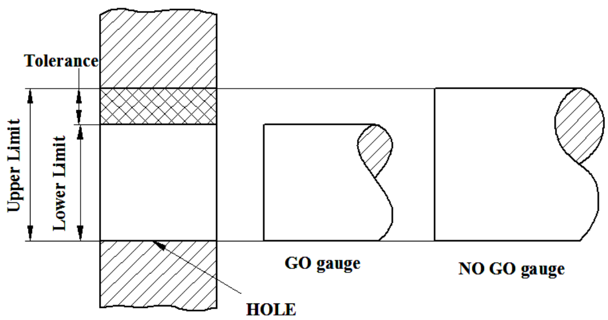


Figure 18 PRINCIPLE OF PLUG GAUGES

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

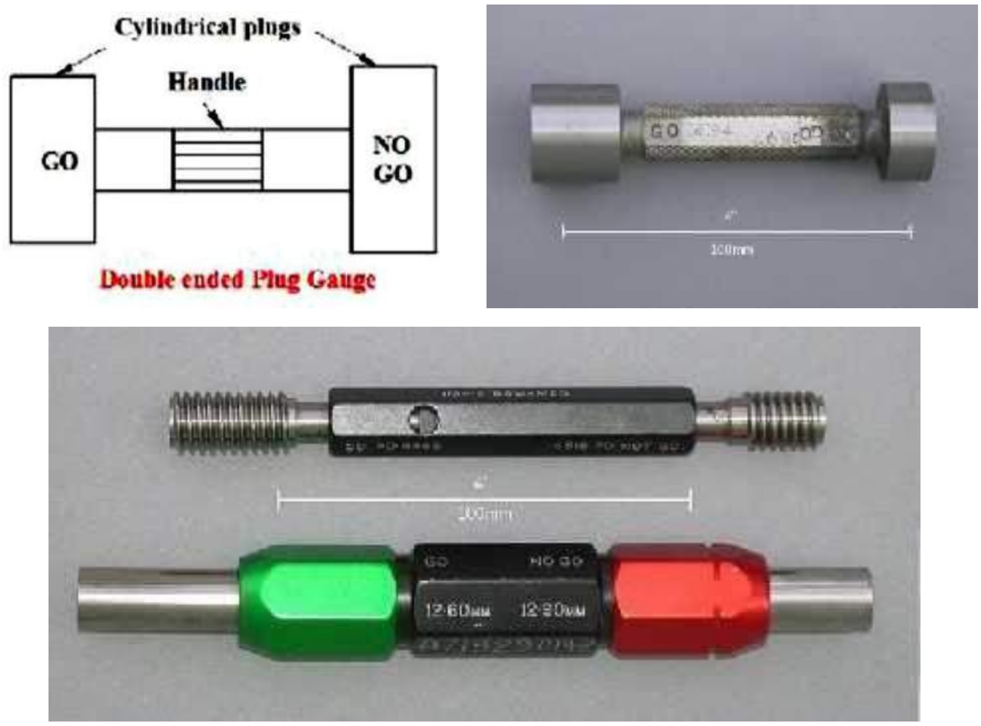


Figure 19 PLUG GAUGES

Progressive plug gauges:

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

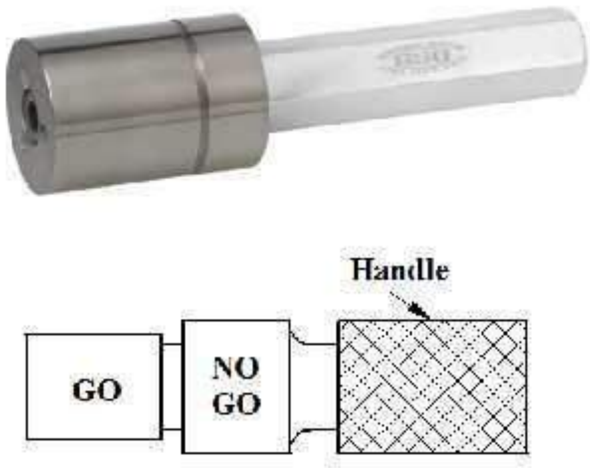


Figure 20 Progressive plug gauges

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 with a hole of required size is bored.

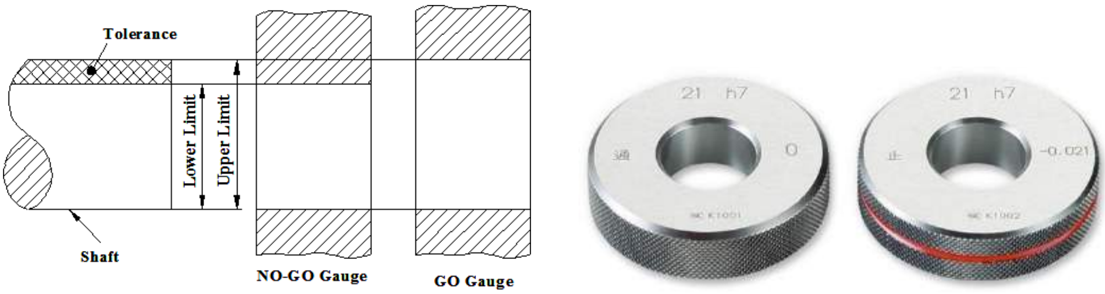


Figure 21 Figure 21 RING GAUGES

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.

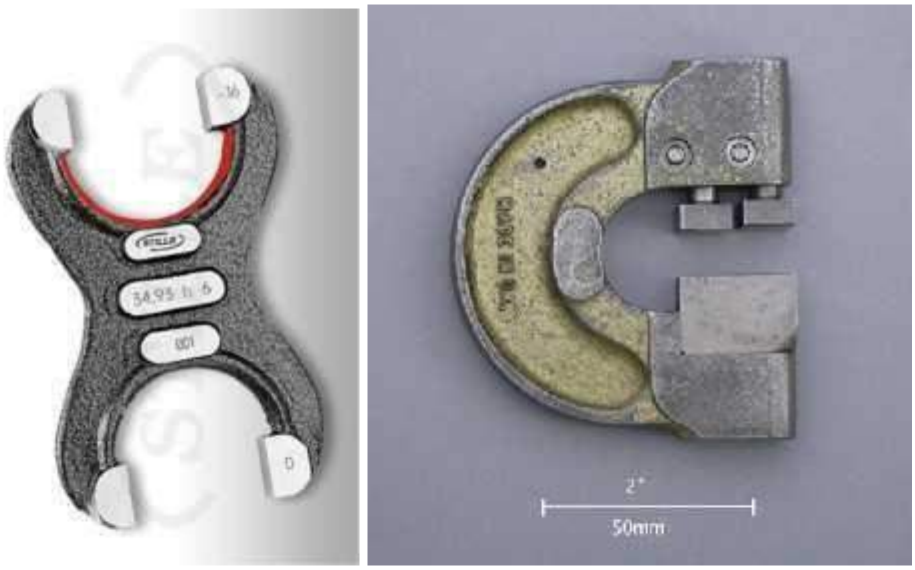


Figure 22 SNAP GAUGES

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.

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 allowance is 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.

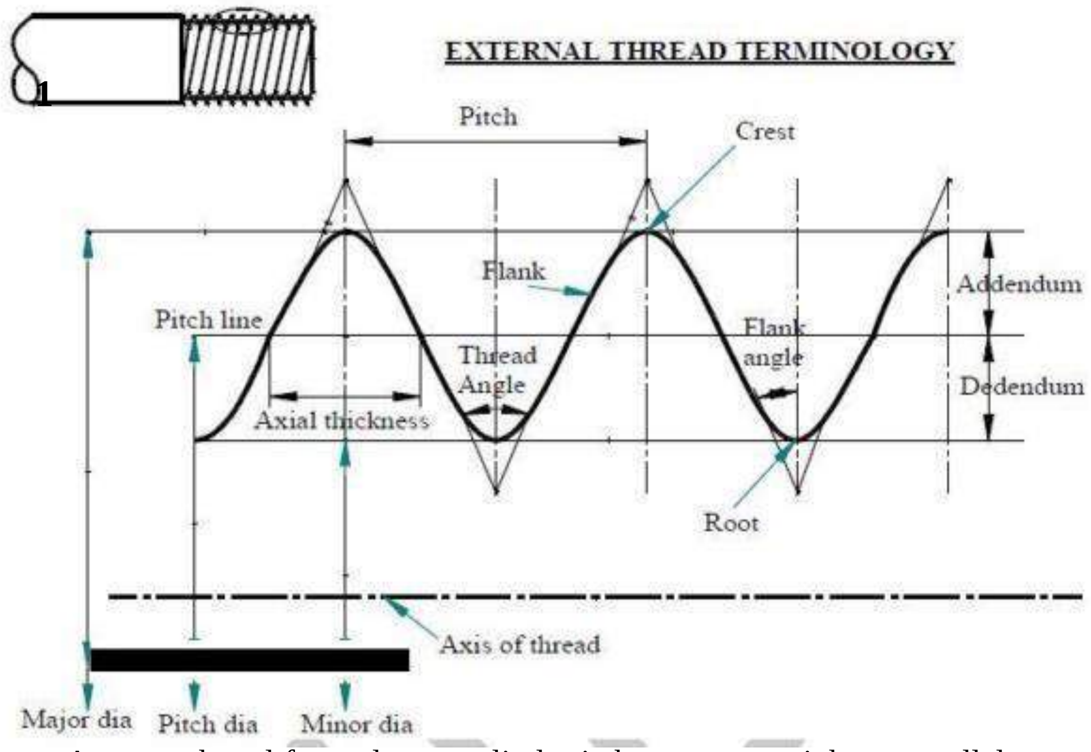
Module-3

MEASUREMENT OF THREAD PARAMETERS AND COMPARATORS

Terminology of screw threads, measurement of major diameter, minor diameter, 2- wire and 3-wire methods, best size wire.

Functional requirements of comparators, classification, mechanical - dial indicator, Johnson Mikrokator, sigma comparators, Electrical Comparator, LVDT, Pneumatic comparator -back pressure, solex comparators and optical comparators-Zeiss ultraoptimeter

Terminology of screw threads:



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 centre of 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 be external or internal.

9. **Root of thread**. This is defined as the bottom of the groove between the two flanks of 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 the perpendicular 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 the thread, 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 one complete 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 the thread 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 of the 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 root of 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 same thread measured on the pitch cylinder in a direction parallel to the axis of thread.

21. **Truncation.** A thread is sometimes truncated at the crest or at the root or at both crest 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 for external 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 major cylinder (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 diameter of 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 pitch diameter 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.

2. MEASUREMENT OF VARIOUS ELEMENTS OF THREAD

To find out the accuracy of a screw thread it will be necessary to measure the following:

1) Major diameter.
2) Minor diameter.

4. Measurement of Major Diameter of outer threads

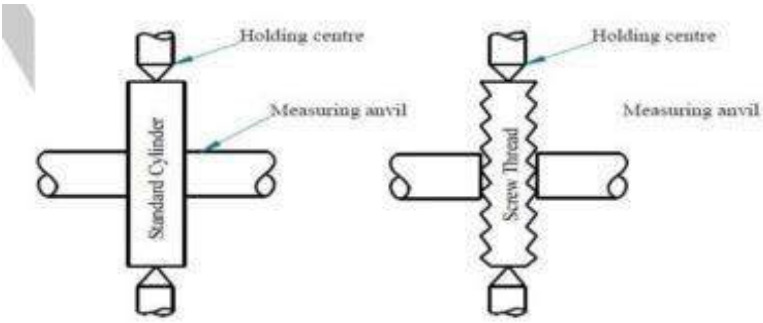


Figure 2 MEASUREMENT OF MAJOR DIAMETER

In this process the variation in measuring Pressure, pitch errors are being neglected.

- The fiducial indicator is used to ensure all the measurements are made at same pressure. The
- instrument has a micrometer head with a vernierscale to read the accuracy of 0.002mm.

- Calibrated setting cylinder having the same diameter as the major diameter of the thread to be measured is used as setting standard.
- After setting the standard, the setting cylinder is held between the anvils and the reading is taken
- then the cylinder is replaced by the threaded work piece and the new reading is taken

Then the major diameter,

Where S = size of the setting,

R1 = micrometer reading over setting gauge

R2 = micrometer reading over thread

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.

[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.]

Using micrometer

Same procedure is followed in this method also but the reading are taken using micrometer

5. Measurement of Minor Diameter of outer threads

Using Bench micrometer

(Include basic construction of bench micrometer)

- This is 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 should be 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.

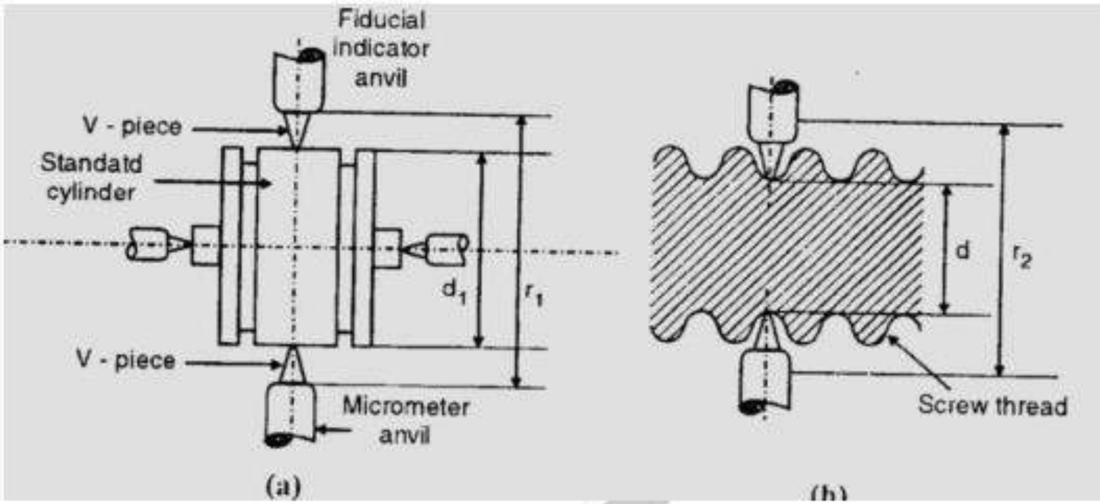


Figure 3 measurement of minor diameter

The measurement is carried out on a floating carriage diameter measuring machine in which the threaded work-piece is mounted between centers 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.

Method:

- The selected Vees are placed on each side of the grove of standard cylinder with their bases against the micrometer faces.
- The micrometer head is then advanced until the pointer of the indicator is opposite the zero mark (or specific value), and note being made of the reading.
- The cylinder is then replaced by screw thread, whose minor diameter being measured, keeping the Vee piece between the thread at diametrically opposite location ensuring the the Vee piece touches the root. Then the 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.

6. Measurement of Minor diameter of Internal threads

The Minor diameter of Internal threads are measured by

1. Using taper parallels

2. Using Rollers.

6.1.1. Using taper parallels:

- For diameters less than 200mm the use of Taper parallels and micrometer is very common.
- The taper parallels are pairs of wedges having reduced and parallel outer edges.
- The diameter across their outer edges can be changed by sliding them over each other.

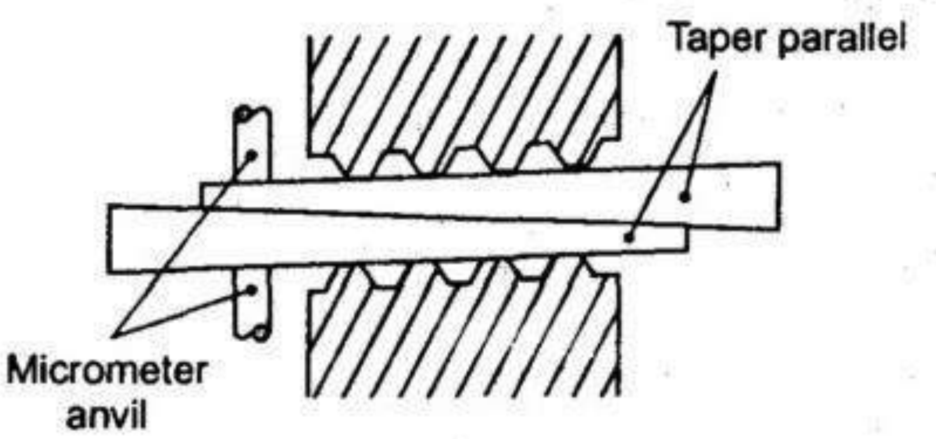


Figure 4 Measurement of internal tread minor diameter

6.2.2. Using rollers

For more than 200mm diameter this method is used. Precision rollers are inserted inside the thread and proper slip gauge is inserted between the rollers.

The minor diameter is then the length of slip gauges plus twice the diameter of roller

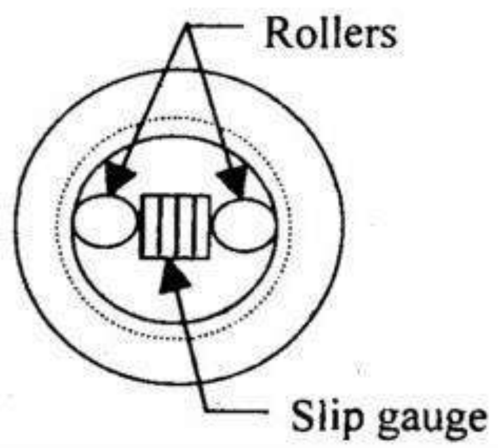


Figure 5 internal tread minor diameter measurement using slip gauges and rollers

7. 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 two wires or three wire or rod methods.

Two Wire Method.

Usually bench micrometer is used for two wire method as it has dedicated provisions to hold the wires and screw thread. (Include basic construction of bench micrometer.)

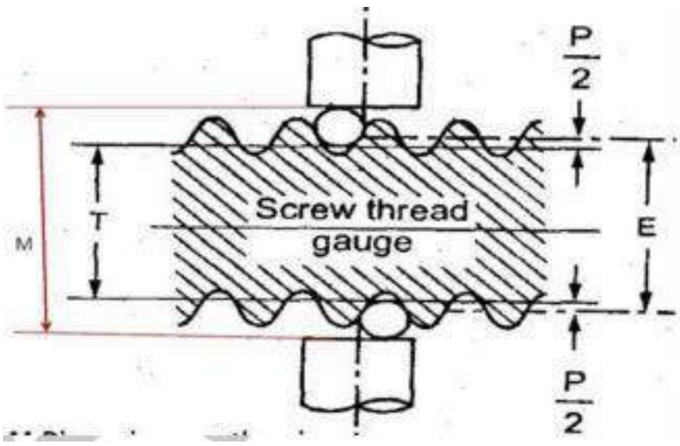
The effective diameter of a screw thread may be ascertained by placing two wires or rods of identical diameter between the flanks of the thread, as shown in Fig. and measuring the distance over the outside of these wires. The effective diameter E is then calculated as

E=T+P

Where T= Dimension under the wires

=M—2d

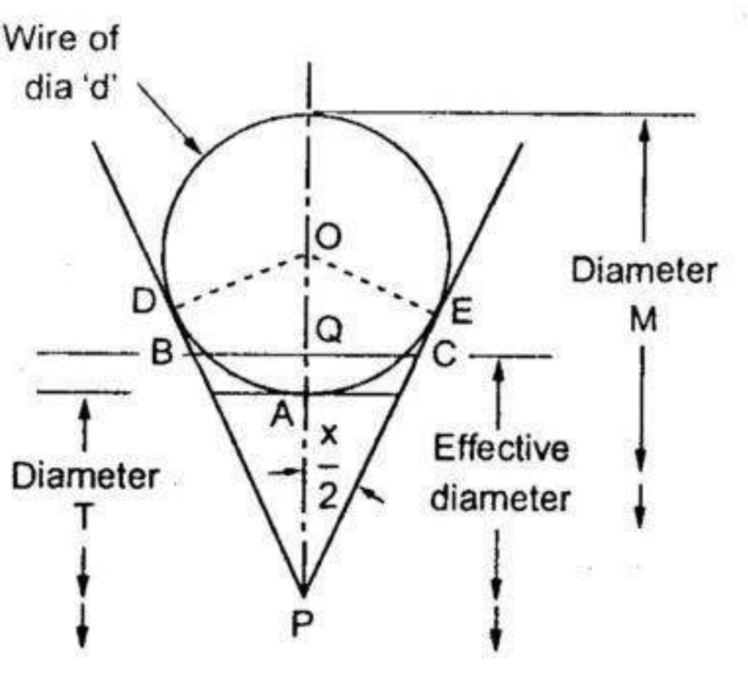
M=dimension over the wires, d= diameter of each wire



MEASUREMENT USING TWO WIRE METHOD (a)

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.



MEASUREMENT USING TWO WIRE METHOD (b)

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 since BC lies on the effective diameter line

BC= ½ pitch=½ p

OP=d/2 cosec x/2

AP=d(cosecx/2−1)⁄2

PQ=QC cot x⁄2 = p⁄4 cot x⁄2

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

AQ is half the value of p

∴ P value=2AQ

(□)

P = 0.9605p−1.1657d (for Whitworth thread, $x = 55^0$).

P= 0.866p—d (for metric thread, $x = 60^0$).

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.

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.). This method ensures the alignment of micrometer anvil faces parallel to the thread axis. Usually bench micrometer is used to hold required components (give brief on bench micrometer and its holding mechanisms).

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 diameter
x=angle of thread.

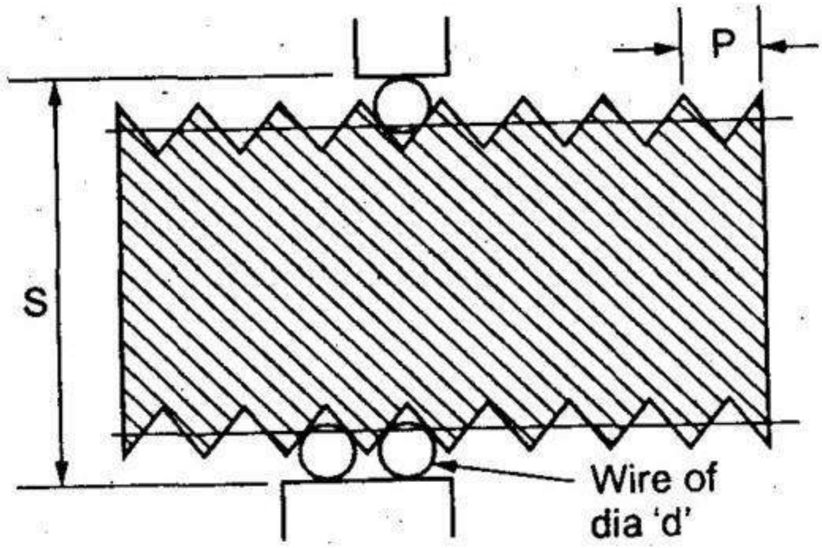


FIGURE 2.6: THREE WIRE METHOD

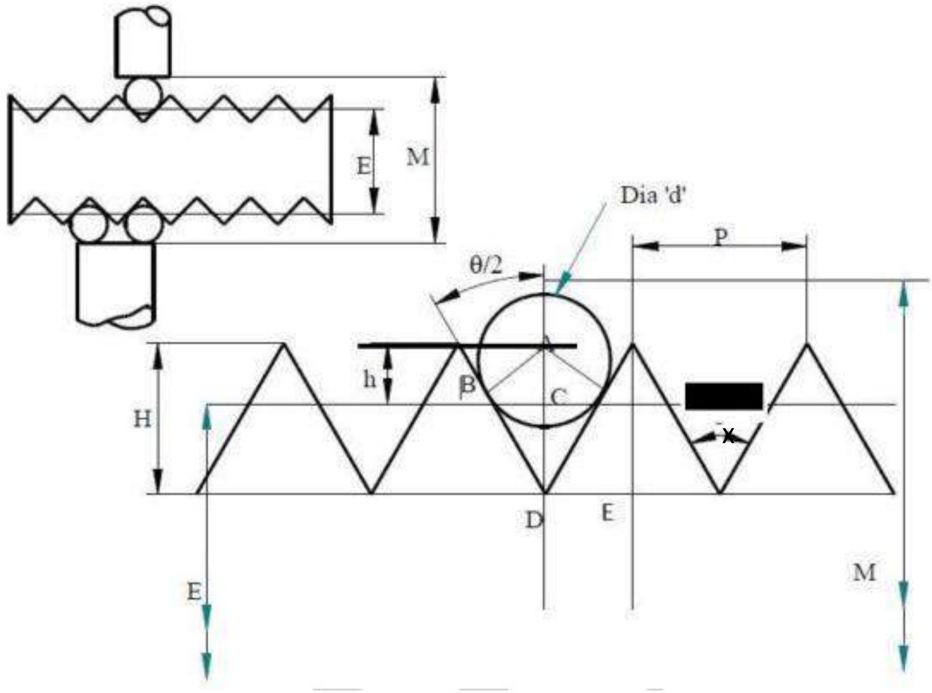


Figure 7 THREE WIRE METHOD (b)

From figure,

From triangle ABD, AB/AD = sin x/2

$AD = AB / \sin x/2 = B \operatorname{cosec} x/2 = r \operatorname{cosec} x/2$ (1)

DE/H = tan x/2 or

$H = DE \cot x/2 = /2 \cot x/2$ (2)

$CD = ½H = p/4 \cot x/2$ h

$= AD - CD$

$h = r \operatorname{cosec} x/2 - p/4 \cot x/2$ (3)

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

$= E+2(r \operatorname{cosec} x/2 - p/4 \cot x/2)+2r$

$= E+2r (l+\operatorname{cosec} x/2) - p/2 \cot x/2$

or $M = E+d (1+\operatorname{cosec} x/2) - p/2 \cot x/2$ (4)

(since 2r = d)

(i) In case of Whitworth thread:

X = 55°, and 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 (1+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—1.6005p where D=outside dia.

(ii) In case of metric threads:

Depth of thread=0.6495p

so, E = D-0.6495p.

x = 60°, 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

M= 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.

Best size wire Method.

The best size wire is one which makes contacts at the pitch line or effective diameter of the screw thread. In other word, as shown in figure, OB is perpendicular to flank portion of the thread at the pitch line.

In the triangle OAB,

Sin (OAB) = AB/OB

Or sin (90-θ/2) =AB/OB

OB = AB/ sin (90-θ/2) = AB/cosθ/2 = AB sec θ/2

But OB = radius of wire = ½ . dia of best wire(D_b)

D_b = 2. AB sec θ/2

AB = p/4 (p - pitch of thread)

D_b = p/2 sec θ/2

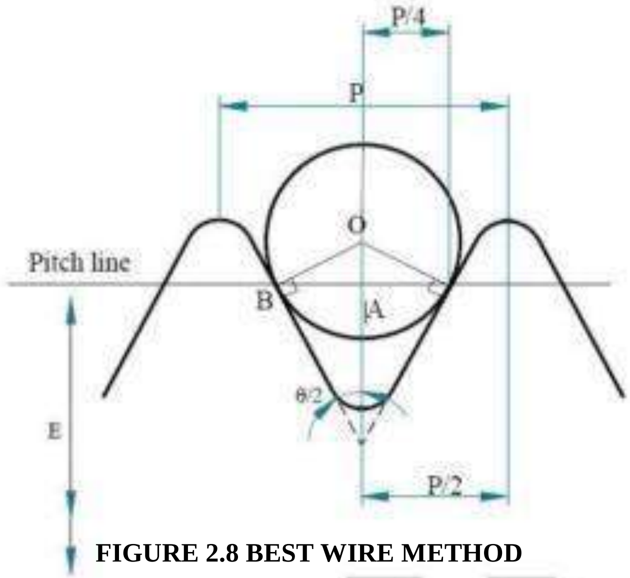


FIGURE 2.8 BEST WIRE METHOD

COMPARATORS

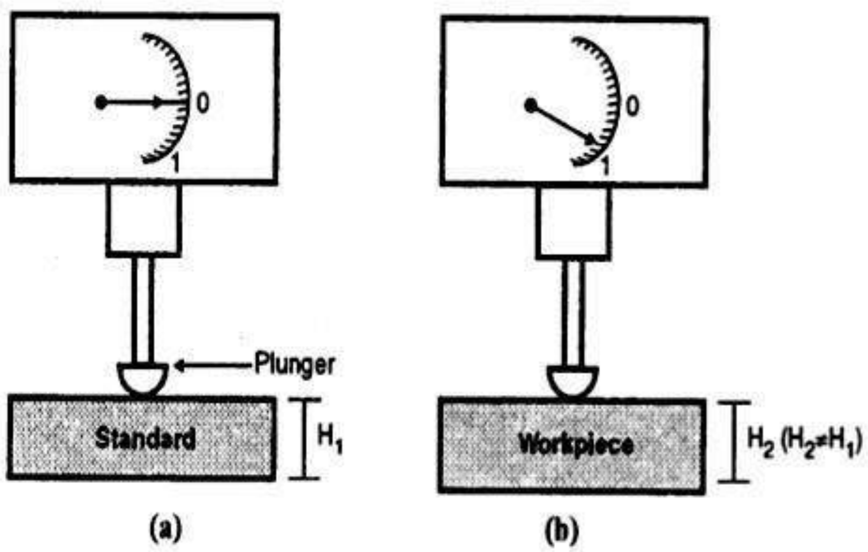
- They are employed to find out, by how much the dimensions of the given component differ from that of a known datum.
- It is an indirect type of instrument and used for linear measurement.
- If the dimension is less or greater, than the standard, then the difference will be shown on the dial.
- It gives only the difference between actual and standard dimension of the work piece.

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 some standard value.



Eg; To check the height of the job H2 ,with the standard job of height H1.

Initially, the comparator is adjusted to zero on its dial with a standard job in position as 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.

Classification:

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/functional requirements:

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.
14. It should be free from backlash and wear.

14. MECHANICAL COMPARATOR:

Required magnification is obtained from mechanical linkage, levers, gearing etc. All functions are carried out using mechanical linkages only. Reading is carried out using spindle. Magnified reading is displayed on dial. Return springs are used for maintain initial position.

Eg: Read comparator, dial guage, Johansson Mikrokator, sigma comparator etc.

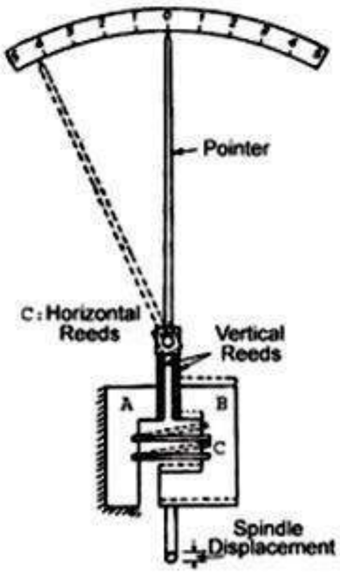
Figure shows Read type comparator

Construction:

- It consists of a pointer which moves over a circular scale.
- The pointer is connected to 2 reeds, one fixed and another movable.
- the other end of the moveable reed is connected to the displacement spindle.

Working

- Any movement or displacement is given, is absorbed by the displacement spindle, which is inturn transferred to movable reed.
- It moves the pointer on the circular scale.
- In order to return the spindle to original position, the fixed and movable reeds are attached with flexible strips.
- These strips helps the reeds to bring them to their original positon after the displacement is removed



REED TYPE MECHANICAL COMPARATOR

DIAL INDICATOR

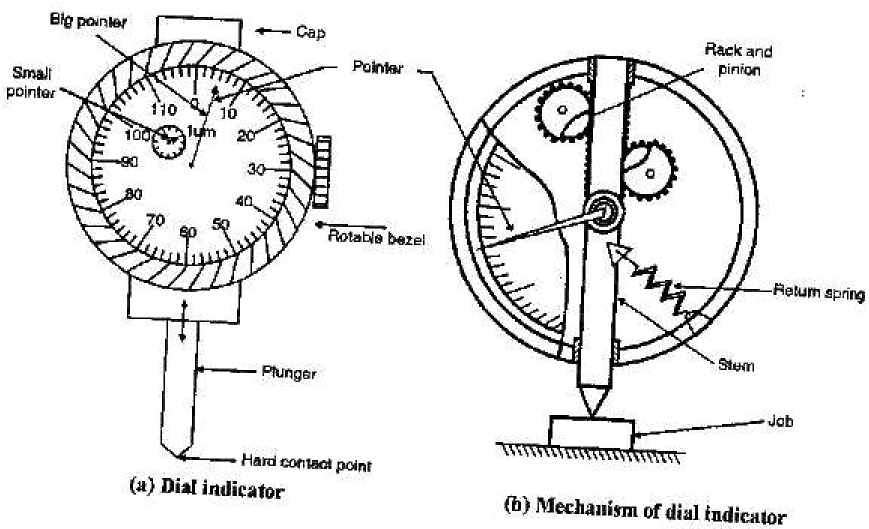
- It operates on the principle, that a very slight upward pressure on the spindle at the contact point is multiplied through a system of gears and levers.

Construction

- Dial indicators basically consists of a body with a round graduated dial and a contact point (plunger)
- The plunger is connected to pointer though a rack and pinion gear train connected
- Return spring is connected to plunger to retain its initial position

Working

- Pointer on the dial face indicates the amount of movement of the contact point.
- The linear movement of the plunger is magnified using rack and pinion arrangement.
- Movement is indicated by rotation of the pointer.
- The dial can be rotated to set the needle to zero so as to set the datum.
- Any further change is indicated by the deflection of the pointer from the datum.



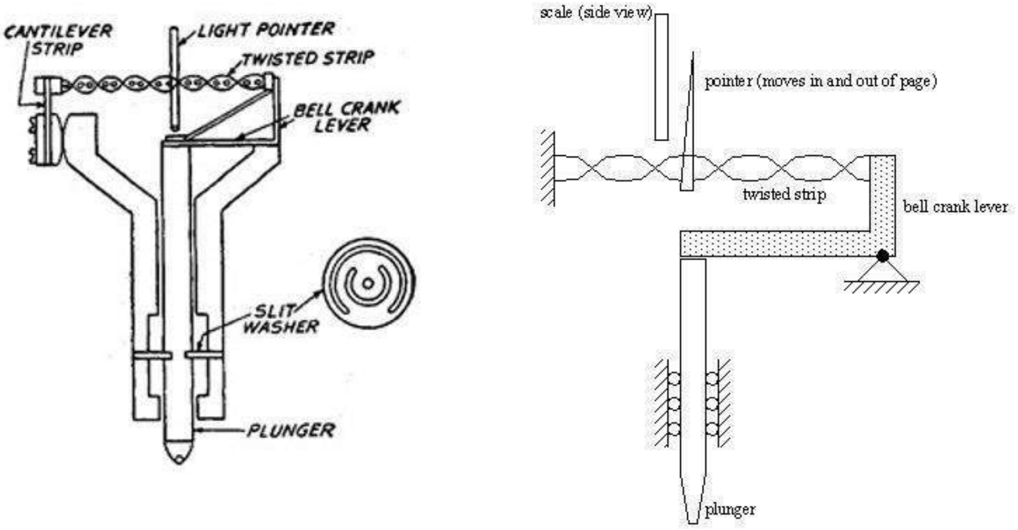
DIAL INDICATORS

JOHANSSON MIKROKATOR

This comparator was developed by C.F. Johansson. It works on the principle of a Button spring, spinning on a loop of string like in the case of Children's toys.

CONSTRUCTION:

- 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 plunger is 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.



PRINCIPLE OF JOHANSSON MIKROKATOR

Working

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.

Amplification given by:

Where, – twist of strip at midpoint wrt end

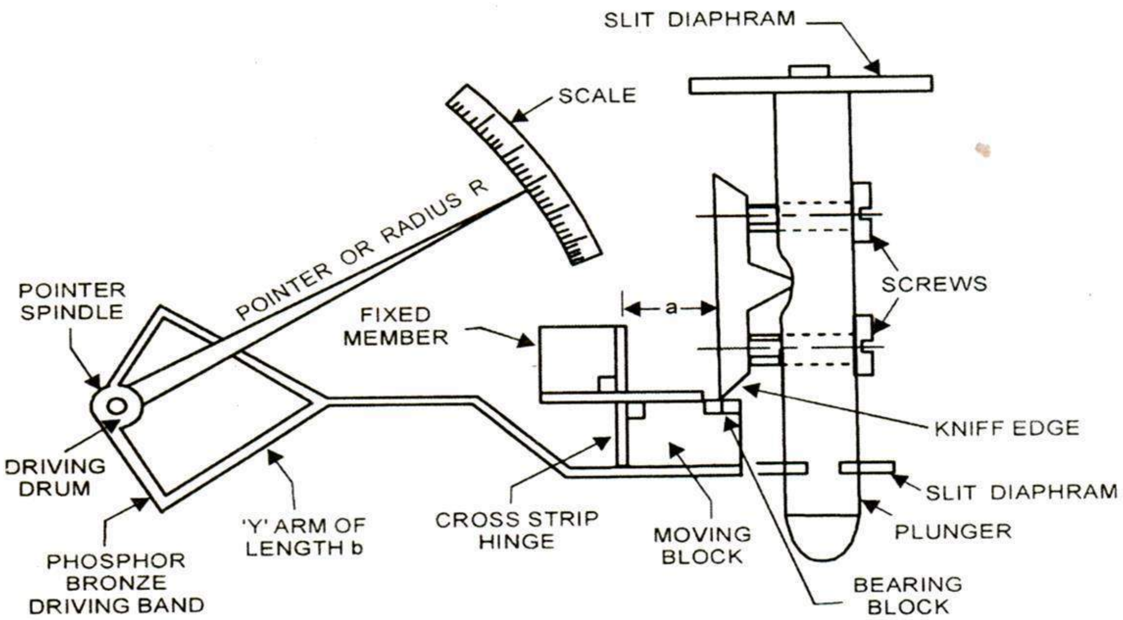
L – length od

strip w – width of strip

n – no of turns

Sigma Comparator: Construction

- The plunger is attached to a rectangular bar which is supported between the bending plates (slit diaphragm) at the top and bottom portion as shown in Figure (2.25)



SIGMA COMPARATOR

- 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 exterts 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.
- 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)

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, electricity etc.

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 ultimately the accuracy is less.
4. The instrument may become sensitive to vibration due to high inertia.

Requirements of Good mechanical comparator:

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 centres by using suitable accurate bar between the centres.
6. To check trueness of milling machine arbours and to check the parallelism of shaper arm with table surface or vice.

15. ELECTRICAL COMPARATOR:

- Electrical comparators give a wide range of advantages.
- 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 less moving parts.
- Thus a high degree of reliability is expected from these instruments.

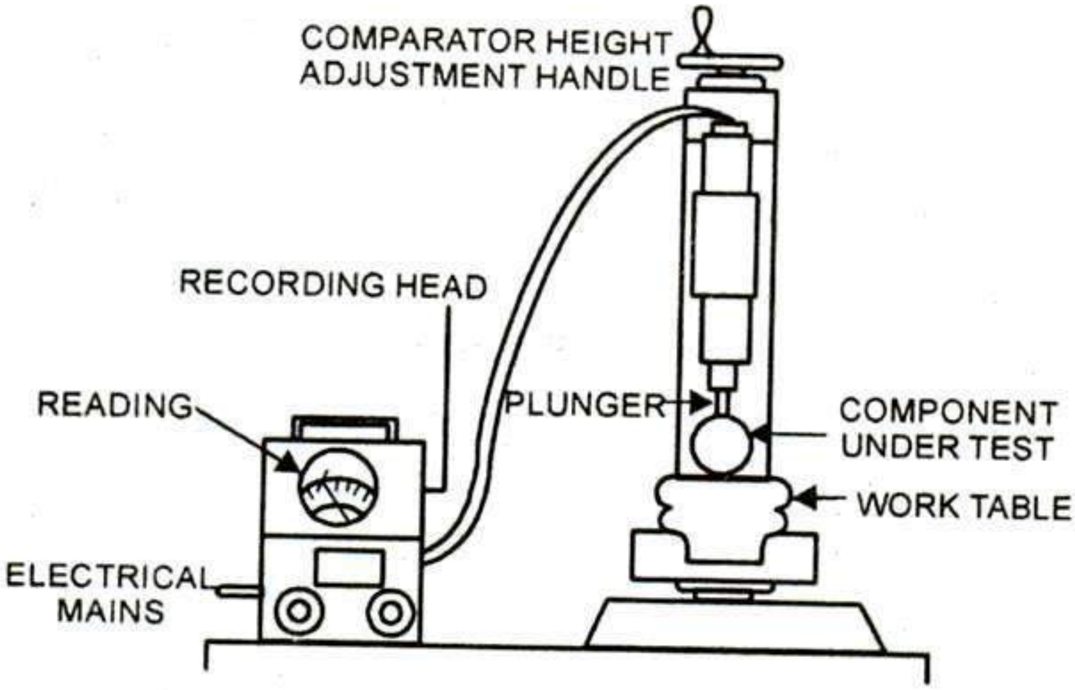


FIGURE2.26: ELECTRIC COMPARATOR

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.

5. Compact sizes of probes arc available.

Disadvantages:

1. The accuracy of working of these comparators is likely to be affecting 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.

15.1. Linear Variable Differential Transformer (LVDT)

- Used for linear measurement.

Construction

- It works on the mutual inductance principle.
- It consit of
  - primary coil
  - two secondary coils, identical to each other, are wound on an insulating form, as shown in Fig.
- An external AC power source is applied to the primary coil and the two secondary coils are connected together in phase opposition.
- In order to protect the device from humidity, dust, and magnetic influences, a shield of ferromagnetic material is spun over the metallic end washers.
- The magnetic core is made of an alloy of nickel and iron.

Working

- An LVDT provides an alternating current (AC) voltage output proportional to the relative displacement of a transformer core with respect to a pair of electrical windings.
- An LVDT produces an output proportional to the displacement of a movable core within the field of several coils.
- When the core is in null position, no output voltage is produce as the secondary coils are in phase opposition (180^0 phase difference)
- As the core moves from its ‘null’ position, the voltage induced by the coils change, producing an output representing the difference in induced voltage.
- The motion of the core varies the mutual inductance of secondary coils.
- This change in inductance determines the electrical voltage induced from the

primary coil to the secondary coil.

- Since the secondary coils are in series, a net differential output results for any given position of the core.
- The phase relation existing between power source and output changes 180° through the null. Therefore, it is easy, through phase determination, to distinguish between outputs resulting from displacements on either side of the null.

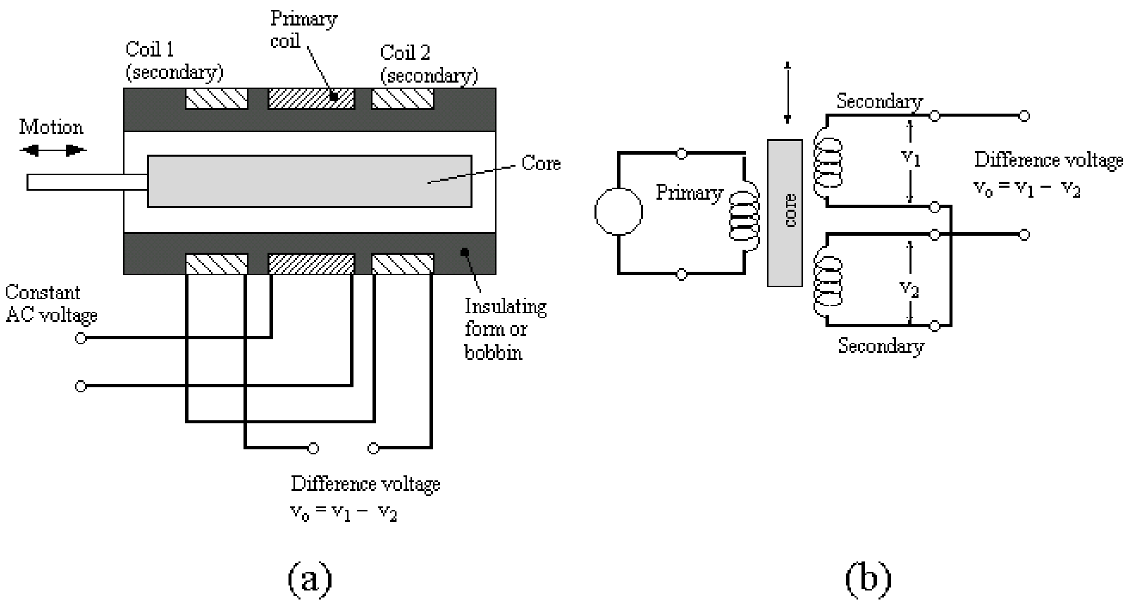


FIGURE 2.28 LVDT

Advantages of LVDTs

1. It directly converts mechanical displacement into a proportional electrical voltage. This is unlike an electrical strain gauge, which requires the assistance of some form of elastic member.

2. It cannot be overloaded mechanically. This is because the core is completely separated from the remainder of the device.

3. It is highly sensitive and provides good magnification.

4. It is relatively insensitive to temperature changes.

5. It is reusable and economical to use.

6. It provides a high degree of amplification and is very popular because of its ease of use.

7. Moreover, it is a non-contact-type device, where there is no physical contact between the plunger and the sensing element. As a consequence, friction is avoided, resulting in better

accuracy and long life for the comparator.

8. It can be conveniently packaged in a small cartridge.

Disadvantage of an LVDT

- it is not suited for dynamic measurement.
- Its core has appreciable mass. The resulting inertial effects may lead to wrong measurements.

16. PNEUMATIC COMPARATORS (SOLEX GAUGE):

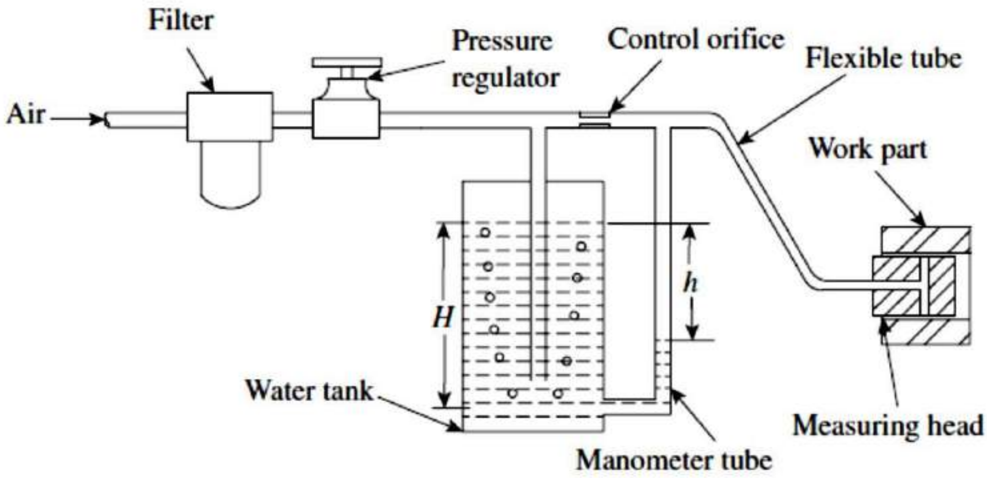


FIGURE2.27 : SOLEX COMPARATOR

Principle:

- It works on the principle of pressure difference generated by the air flow.
- Air is supplied at constant pressure through the orifice and the air escapes in the form of jets through a restricted space in the work piece which exerts a back pressure.
- The variation in the back pressure is then used to find the dimensions of a component.

Construction

- Consist of:
    - constant air pressure supply
    - Air filter
    - Pressure regulating valve
    - Water manometer
    - Orifice

- Measuring head
- Connecting pipes

- Manometer is used to measure the pressure difference across orifice

Working:

- As shown in Figure (a) the air is compressed in the compressor at high pressure which is 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, at A1 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 A1 corresponding 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 of 0.002 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 this makes 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 being checked.
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 back pressure is linear, over only a small range of the orifice size variation.

Optical Comparator: Zeiss ultra-optimeter

Principle:

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

Construction and working

- 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 possible with a small movement of the mirror.
- The important factor is that the mirror used is of front reflection type only.

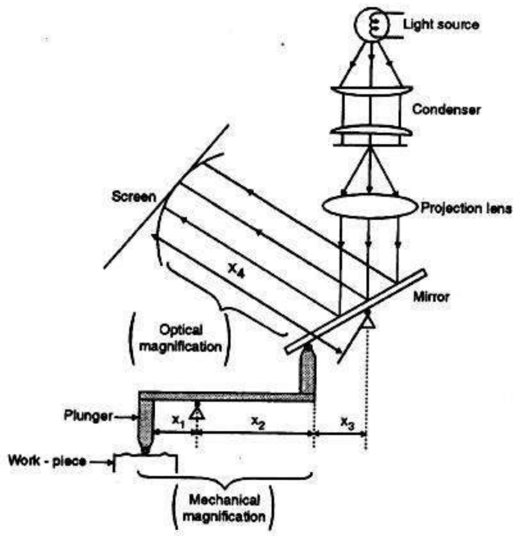


FIGURE 2.24: MECHANICAL- OPTICAL COMPARATOR

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 to this there is less wear and hence lessfriction.70
2. Higher range even at high magnification is possible as the scale moves past theindex.
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 as intricate 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 theoperator.
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 dark room in order to take the readings easily.

Question Bank

1. Explain the concept of interchangeability (**Dec 2013, June 2015, Dec 2019)**
2. Explain the advantages of interchangeability over selective assembly **(June 2016, Dec 2018)**
3. define the following: unilateral tolerance, bilateral tolerance, basic size, shaft, hole, upper limit, lower limit, tolerance, nominal size, zero line, deviation, upper/lower deviation, fundamental deviation, allowance, fit, clearance fit, interference fit, transition fit **(June 2011)**
4. Explain the concept of limits and its significances **(Dec 2013)**
5. Explain hole basis system with a neat sketch **(June 2013)**
6. Explain the shaft basis system with a neat sketch**(Dec 2012)**
7. Write a note on geometrical tolerance and positional tolerance **(June 2014)**
8. Explain with a neat sketch GO- Gauge and NO-GO Gauge **(June 2017)**
9. Explain with a neat sketch ring gauges**(Dec 2013, Dec 2018)**
10. Write a note on Taylors principle of design of gauges. **(June 2015)**
11. Write a note on wear allowances of gauges **(June 2016)**
12. Write a note on gauge materials **(June 2011)**
13. Explain with a neat sketch snap gauges **(Dec 2014)**
14. Define a comparator and explain the functional requirements of comparators **Dec 2018 ,(June 2007)**
15. Write a note of classification of comparators **(Dec 2013)**
16. Explain with a neat sketch Johansom Mikrokator**(June 2008)**
17. Explain with a neat sketch the working of sigma comparator
18. Explain with a neat sketch the working of dial indicator **(Dec 2015)**
19. Explain the working of LVDT with a neat sketch. State its advantages and disadvantages **(June 2010)**
20. Explain the working principles of solex comparator **(June 2009)**
21. Explain the working of Zeiss ultra optimeter with a neat sketch. **(Dec 2016)**
22. What is meant by interchangeability? Show its advantages. (06 Marks, Dec 2019)
23. Explain hole basis system in detail (06 Marks, Dec 2019)
24. Explain with neat sketch, working of a dial indicator. (08 Marks, Dec 2019)

25. Briefly explain GO-Gauge and NO~GO Gauge. (06 Marks, Dec 2019)

26. Define tolerance. Also explain grades of Tolerance. (06 Marks, Dec 2019)

27. Determine the dimensions of theshall and hole for a fit 30H8dl0. given the following data: (i) Diameter 30 falls in the dia range I8 - 30. ' (ii) Upper deviation of the shaft is $-l6D^{0.44}$, (iii) $I = 0.45D^{0.33} + 0.001D$. (iv) Tolerance for IT8 = 25i. (v) Tolerance for IT10 = 64i (08 Marks, Dec 2019)

Module-4

MEASUREMENT SYSTEMS

Block diagram of generalized measurement system, definitions and concept of accuracy, precision, calibration, threshold, sensitivity, hysteresis, repeatability, linearity, loading effect, Errors in measurement, classification of errors.
Transducers, transfer efficiency, primary and secondary transducers, electrical,mechanical, electronic transducers.
Mechanical systems, inherent problems, electrical intermediate modifying devices,ballast circuit.
Terminating devices- Cathode ray oscilloscope, Oscillographs.

Definitions & basic concepts of measurement

Measurement is the assignment of a number to a characteristic of an object or event, which can be compared with other objects or events Or Measurment is defined as process of determining the value of unknown quantity by comparing itwith some pre-defined standard.

The word "measurement" comes from the Greek word "metron," which means "limited proportion." Measurement is a technique in which properties of an object are determined by comparing them to a standard.

The seven base units of the SI system are listed in the table below.

Measurement	Base Unit
Length	**Meter (m)**
Mass	**Kilogram (kg)**
Time	**Second (s)**
Temperature	**Kelvin (K)**
Amount of substance	**Mole (mol)**
Electric current	**Ampere (A)**
Luminous intensity	**Candela (cd)**

Significant of measurements

1. Measurement provides the fundamental basis for research and development.
2. Measurement is the fundamental element of any control process.
3. Many operations or process require measurement of different quantities for proper performance.

   Eg; modern engine monitoring system

4. Measurement is also a base of commerce: cost of production are established based on amount of material, power and expenditure required.

2. Generalized Measurement System

Any measurement system can be summarised with different sub system.. Generalized measurement system consists of the following elements:

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

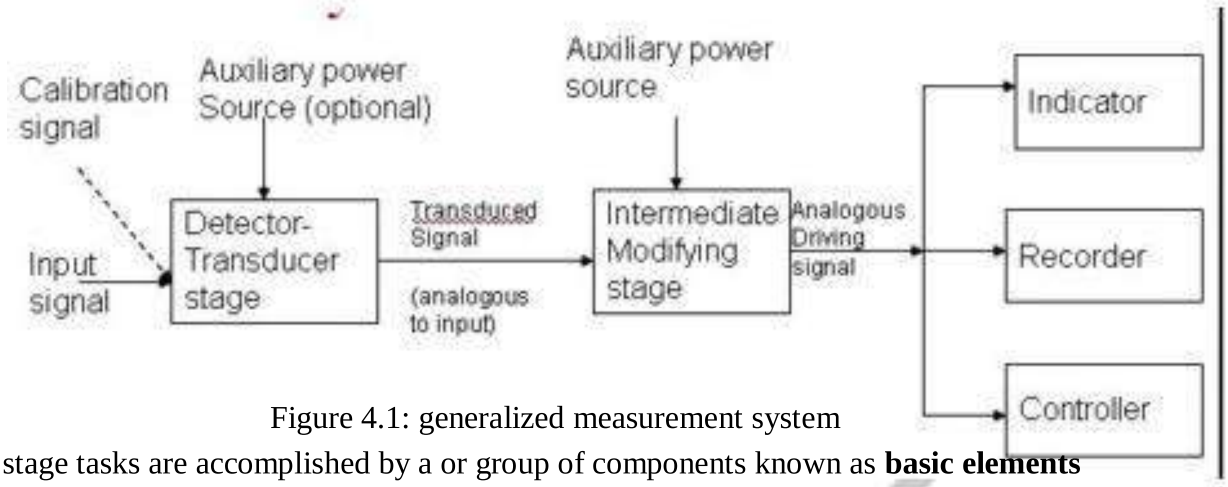


Figure 4.1: generalized measurement system

Each stage tasks are accomplished by a or group of components known as **basic elements**

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.

Eg: 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-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, ADC, signal conditioner, noise filters etc

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.

Basic elements of a Measuring system: Summary

Stage I-Detector Transducer Device	Stage II-Intermediate Modifying Device	Stage III-Terminating Device
input analogous output	Senses only the desiredModifies Transduced signalProvides & providesinto a form usable by finalrecording in	an indication or increasesevaluated by human sense or by a controller
Types & Examples	*Types & Examples*	*Types & Examples*
Mechanical : Contacting Spring-mass, elasti c devices such as bourdon tube, proving ring,etc. Hydraulic-Pneumatic: Buoyant-float, orifice , venturi, vane, propeller Optical: Photographic film, Photoelectric cell Electrical: capacitance, Piezoelectric crystal ,	Mechanical : Gearing, cranks,INDCATORS spindle,links, cams, etc. Hydraulic-Pneumatic: Piping,Direct alphanumeric read out valves, dash-pots, etc Optical: Mirrors, Optical filters, light levers, Optical fibers. Electrical: Amplifying systems, matching devices, Contactors, resistance,filters, telemetry systems, etc.	(a) Displacement types Moving pointer & scale, light beam & scale, CRO, liquid column, etc. (b) Digital types: (c) Recorders: Digital printing, inked pen & chart lenses,Light beam & photographic Film, magnetic recording (d) Controllers: All types

Static Characteristics of Measurement

Readability: This term indicates the closeness with which the scale of the instrument may be read. Or It refers to the ease with which the readings of a measuring instrument can be read.

For ex, digital thermometer has high readability than mercury column thermometer.

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

LC = Value of minimum division on main scale/number of sub division of the same main scale division on the subscale (vernier 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.

Data **:** Elemental items of information obtained by experimental means

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

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

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.

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 = $\frac{(Vr(\text{max or min}) - Va)}{Va} \times 100$

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. Precise 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.

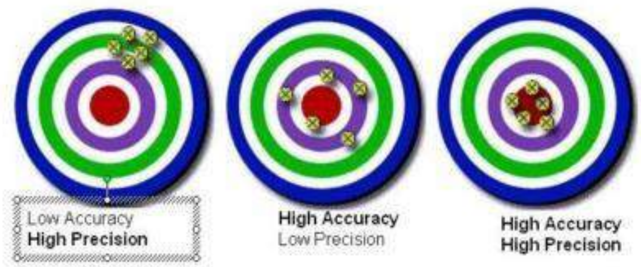


Figure 4.2 precession

Sl no	Accuracy	Precisio N
1	quantity being measured	It is the closeness with the true value of theIt is a measure of reproducibility of the Measurements
2	conformity to truth	The accuracy of measurement meansThe term precise means clearly or sharply
3	Accuracy can be improved	Precision cannot be improved
4	Accuracy depends upon techniques of analysis	simplePrecision depends upon many factors and requires many sophisticated techniques of analysis
5	Accuracy is necessary but sufficient condition for precision	notPrecision is necessary but not a sufficient

Calibration:. 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.*

It is the procedure employed for making adjustments or checking a scale for the readings of a system conforming to the accepted w r t 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 of value at same condition depending on whether the value of the measurement taken during loading or unloading.

- 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.
- 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

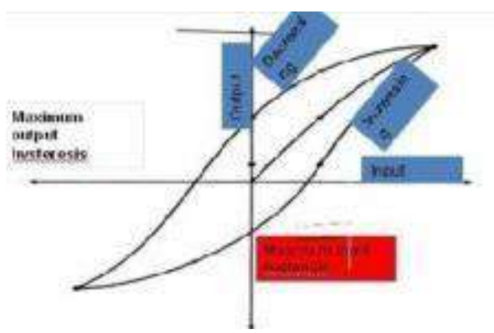


FIGURE 4.3 HYSTERSIS CURVE

***Sensitivity*:** It is the ratio of the linear movement of the pointer on the instrument to the change in the variable to be measured 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 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.

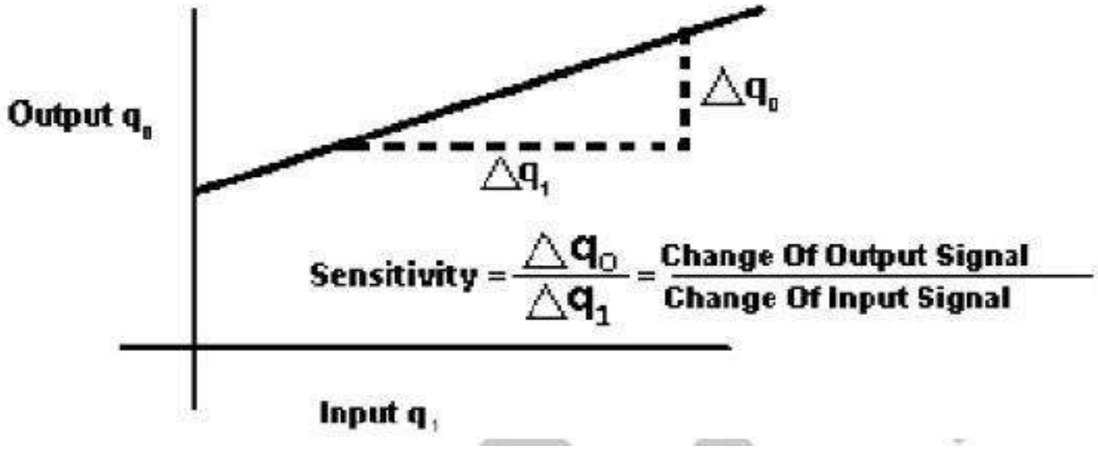
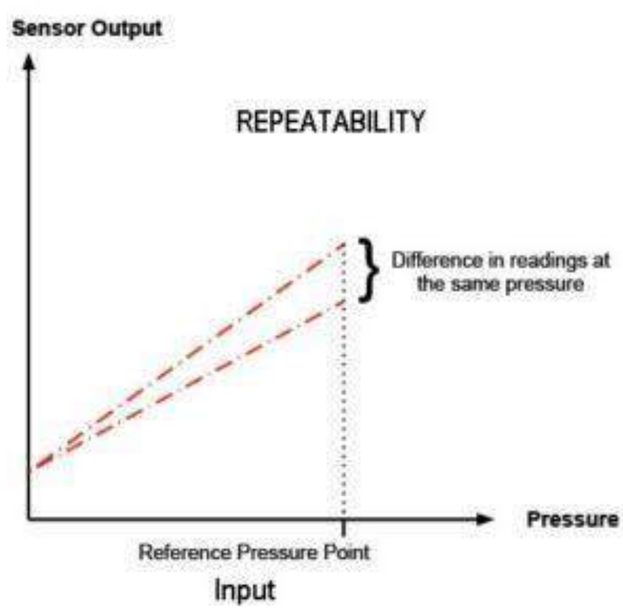


Figure 2 Sensitivity

Resolution: It is defined as the smallest increment of input signal that a measuring system is capable of displaying.

Note: 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, Measurement with hot wire anemometer - exchange some heat energy to surrounding which make measured value slightly inaccurate.

6. Transducers

Transducer is a first stage element of the measurement system. It detects and transforms the sensed signal into useful or convenient signal form.

Eg; Thermocouple - transform temperature to electrical signals.

Transfer efficiency: It is the ratio of output information delivered by the sensor to the information received by the sensor.

Transfer efficiency

$$I_{in}$$

Where I_{out}= the information delivered by the unit,

I_{in}= 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*

Primary Transducer

The transducer which sense input parameter and transform into more convenient form for further processing of are called primary transducers.

For example

1. Ordinary dial indicator - Spindle acts as a detector. The surface imperfection is converted into mechanical action (linear motion).
2. Thermocouple - Detected temperature signal is converted into electrical signal.

Secondary Transducer

Transducers which convert signal from primary transducers into convenient readable or recordable form.

1. Ordinary dial indicator - The spindle movement is converted into pointer rotation using appropriate links and gears. The related elements for this action comes under secondary transducers.

2. Thermocouple - The electrical signal from thermocouple wire is converted into readable digital form or in recordable form. The element which does the work comes under secondary transducer.

Another example: Bourdon Pressure gauge

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

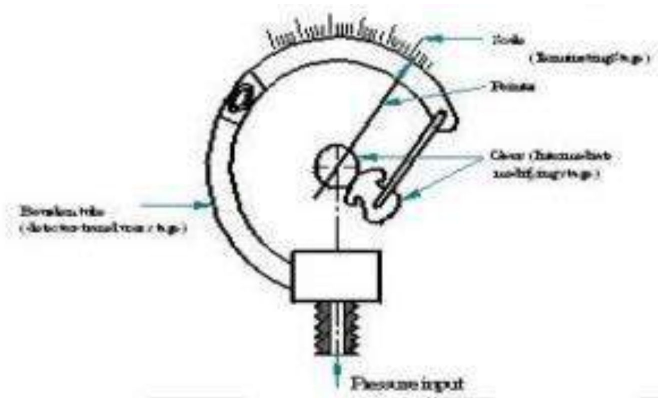


FIGURE 4.7 PRIMARY STANDARD (BOURDON TUBE GAUGE)

Primary Transducer-Classification

Based on the number of operations performed:

- Class I- First stage element used as detector only. Eg: Dial indictor
- Class II- First stage element used as detector as well as transducer. Eg: Thermocouple
- Class III- First stage element used as detector and two transducer. Eg: Mechnical bellow coupled to LVDT

7. Mechanical Transducers

- Mechanical quantities include force, pressure, displacement, flow, temperature, etc.
- The mechanical transducers commonly used to convert the applied input signal onto displacement are elastic members.
- They may be subjected to either direct tension/compression, Bending or Torsion.

Classification of Mechanical Transducers

7.1.Mechanical springs

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.
- The angular deflection is converted into elastic energy and stored in it.

- Care must be taken *not to stress* the springs beyond *the elastic limit* as it will lead to permanent deformation.

Figure 3 Spiral springs

Torsion bars:

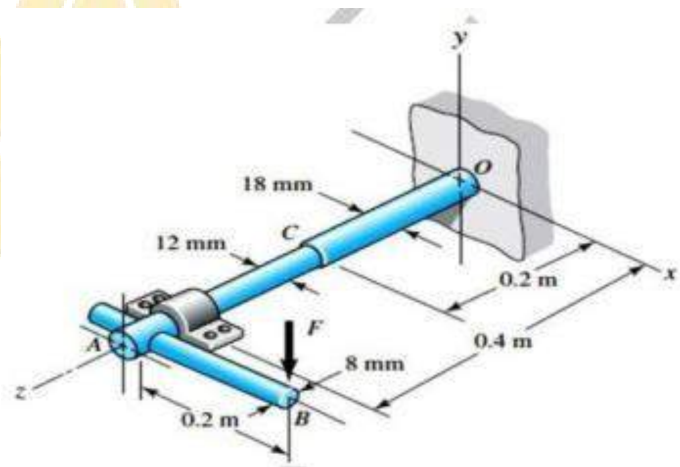


Figure 4 Torsion bar

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 (spring balance):

They are used to measure weight, force or load. The weight or force is converted into elongation of spring. The deflection can be measured with the help of micrometers, dial gauges or electrical transducers.

Figure 5 Proving rings

Pressure sensitive elements

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

(i) Bourdon tubes

(ii) Diaphragms

(iii) Bellows

BOURDON TUBES

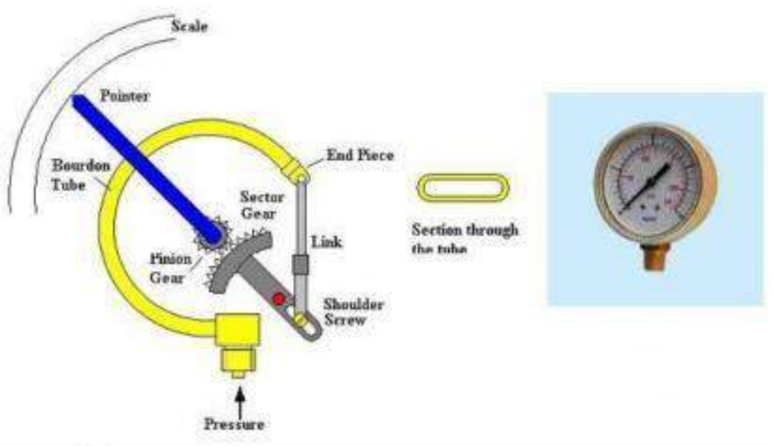


Figure 6 BOURDON TUBES

Construction

Bourdon tubes are elliptical cross section tubes made out of brass, Phosphor bronze, Beryllium copper, etc and is bent into arch shapes as shown in fig.

One end of the tube is sealed and while the other end is open for the fluid to enter.

The closed end is connected to pointer through proper gear mechanisms to read out the pressure from dial.

The outward movement of the tube is converted into angular movement of indicator.

Working

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.

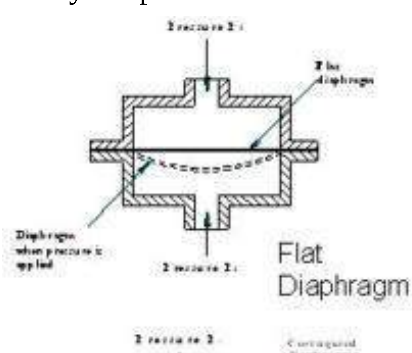
Diaphragms

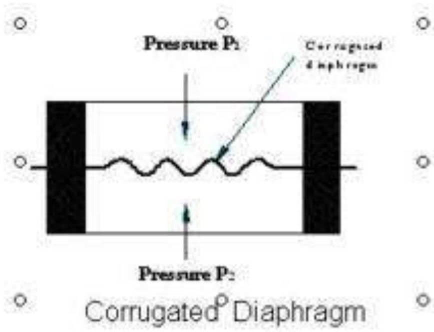
Principle: Bending of diaphragm is converted into readable quantity.

Construction and working:

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

- A diaphragm is a thin flat plate circular shaped elastic membrane fixed around its circumference.
- When a differential pressure (P1-P2) occurs across the diaphragm, it will deflects upward or downward as shown in fig.
- The deflection may be sensed by an appropriate displacement transducer such as strain gauge.
- These may be either „flat" or „corrugated" as shown in fig.
- 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





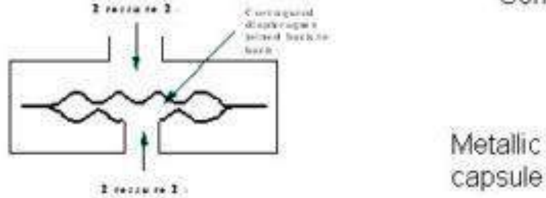


FIGURE 4.9 DIAPHRAMGS

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.
- One end will be closed and other will be connected to fluid, whose pressure to be measured. · A differential pressure causes displacement of the bellows, which may be converted into an electrical signal.

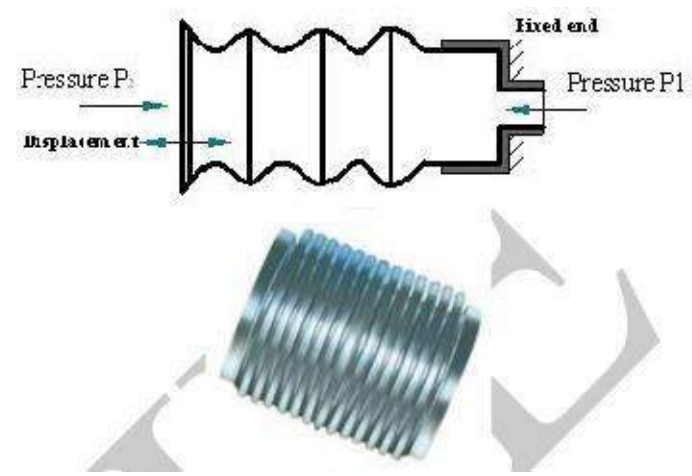


Figure 7 Metallic Bellow

8. 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,

$$R \cdot \quad \cdot \; \underline{\cdot \; L}$$

A

where R = resistance in ohms, = Resistivity of the material in ohm-cm, L= length of the conductor in cm, A= cross sectional area in m^2. Any method of varying one of the quantities involved may be the design criterion for the transducer. Following are some types:

Sliding contact devices:

- Such system consist of voltage/current supply through a conductor.
- mechanical displacement is convert into either change in the effective length of the resistance wire (in turn change in resistance)
- Thereby change in output current or voltage output is achieved.
- The slide or contactor maintains electrical contact with the element ·

slide is a measure of the linear/angular displacement.

Eg: 1. Potentiometers (for linear measurement)**:**

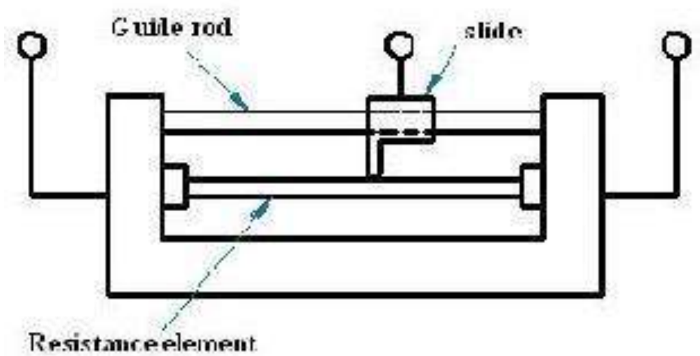


FIGURE 4.11 POTENTIOMETERS

- The resistance elements may be formed by wrapping a resistance wire around a card as shown in fig.
- Slide is moved along guide rode. Slide has electrical contact over the wrapped wire.
- Electrical supply circuit is completed through any one ends of the terminal of wrapped resistance wire and the terminal provided on slide.
- Known voltage is supplied through the circuit and the voltage drop and curret are measure. The resistance is calculated out it. Using the above formula, the length can be measured.

2. Potentiometers (for angular measurement)

The same principle is applied here also except the guide is moving in angular manner to facilitate angular measurement.

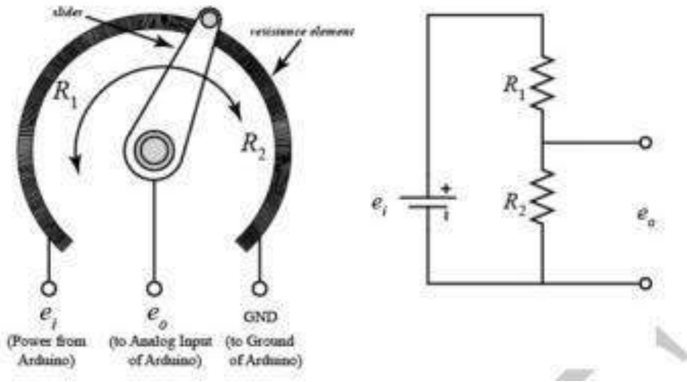


FIGURE 4.12 ANGULAR MOTION POTENTIOMETER

Thermister

A thermistor is a special type of resistor whose resistance changes with the change in its body temperature.

When the ambient temperature of a thermistor increases, its resistance decreases significantly. Typically, for every 1°C rise in temperature, there will be a 5% decrease in their resistance. So their sensitivity is very high.

In simple words we can say, they can observe even a very small change in temperature which could not be observed by a thermocouple or an RTD. This makes them very useful for precision measurement of temperature, control and compensation. These can be used in the temperature range of - 60°C to 300°

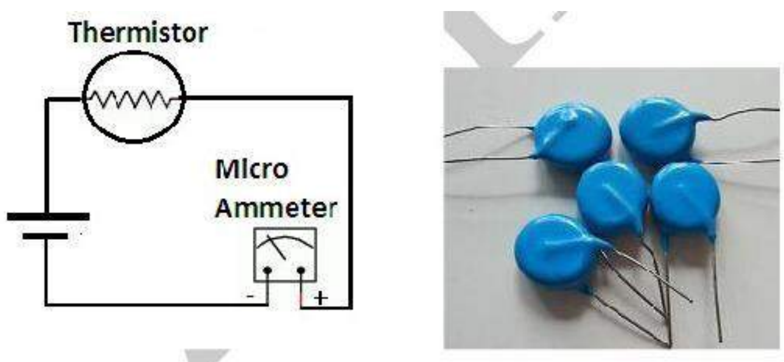


Figure 8 Thermistor as temperature detector

Inductance Transducers

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 (eg: Tranformer).

Magnetic reluctance

- Magnetic reluctance or magnetic resistance, is analogous to resistance in an electrical circuit.
- The obstruction offered by a magnetic circuit to the magnetic flux is known as **reluctance.**
- Resistance in an electrical circuit dissipates the electric energy and the reluctance in magnetic circuit stores the magnetic energy.

$$Reluctance\ (S) = \frac{l}{\mu_0 \mu_r A}$$

Where, l - the length of the conductor

μ_o - permeability of vacuum which is equal to 4π X10_7 Henry/metre. μ_r

- relative permeability of the material.

A - cross-section area of the conductor.

Permeance is the reciprocal of reluctance

VARIABLE SELF INDUCTANCE TRASDUCER (Single Coil)

Principle:

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.

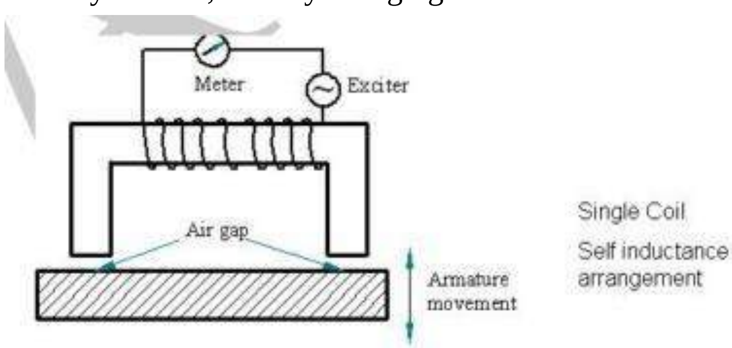


FIGURE 4.13 SINGLE COIL TRANSDUCER

Working

- Inductance, $L = N^2/S$, where, N - no of turns, S- reluctance.

- By changing the air gap permeability will be changed hens the reluctuns. •
  This in turn changes the inductance.

This change can be measured by a suitable circuit, indicating the value of the input. As shown in fig 4.13, the flux path may be changed by a change in the air gap.

Construction and working:

A coil is wounded over a C shaped ferromagnetic core.

Open side of the core is closed by a armature with small air gap.

The measuring probe is connected to armature (as shown in fig).

The displacement of vibration sensed by the probe make the armature to displace/vibrate.

This changes the air gap changes the permeance (permeability) of the circuit.

This change in permeability (in turn reluctance) is measure using suitable electronic circuit suitably calibrated to measure mechanical displacement.

Eg: Talysurf

VARIABLE SELF INDUCTANCE TRASDUCER (Two Coil)

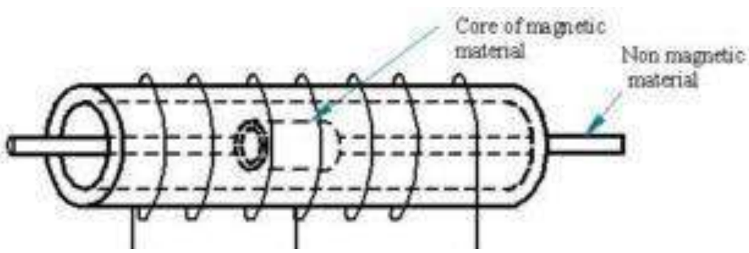


FIGURE 4.14VARIABLE SELF INDUCTANCE -TWO COIL •

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.

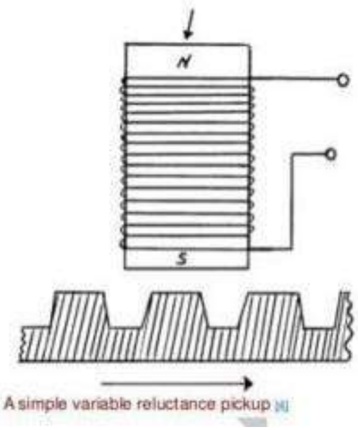
- These transducers are incorporated in inductive bridge circuit in which variation in inductance ratio between the two coils provides the output.
- This is used as a secondary transducer for pressure measurement.

VARIABLE MUTUAL INDUCTANCE TRASDUCER (Two Coil)

(Refer LVDT section - two coil - mutual induction - secondary coil - center core - net generated emf represents displacement.)

VARIABLE RELUCTANCE TRANSDUCERS

- Are used for dynamic applications,
  - The variable reluctance sensor consists of a wire wrapped around a permanent magnet - form the probe.
  - The element whose displacement to be measure should be made of ferromagnetic material.
  - When the element move near/away from the permanent magnet, there will be a change in flux.
  - The magnetic field displacement generate AC voltage, the amplitude and frequency of which depends on the speed of displacement.



Capacitance Transducer

Generally it consists of two plates separated by a dielectric medium

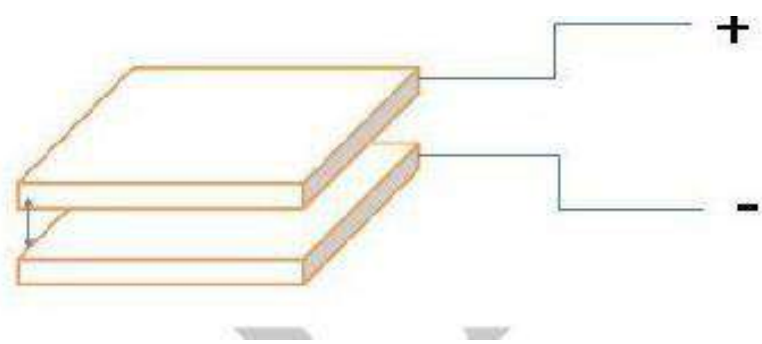


FIGURE: 4.15 CAPACITANCE TRANSDUCERS

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

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

*****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

Capacitance Pickup to measure liquid level (Changing dielectric constant)

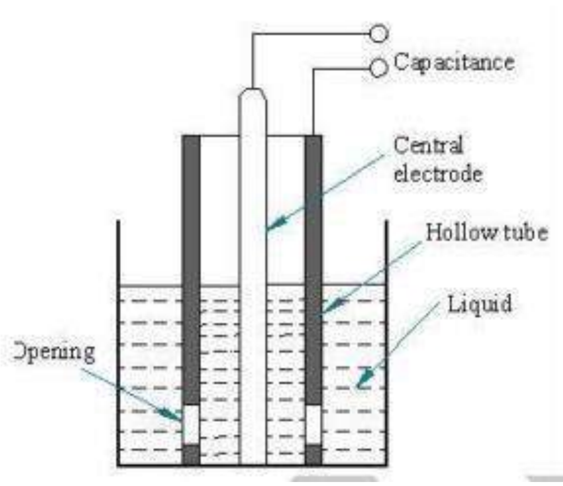


FIGURE 4.16 CAPACITANCE PICKUP TO MEASURE LIQUID LEVEL

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

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.4.17
- 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.

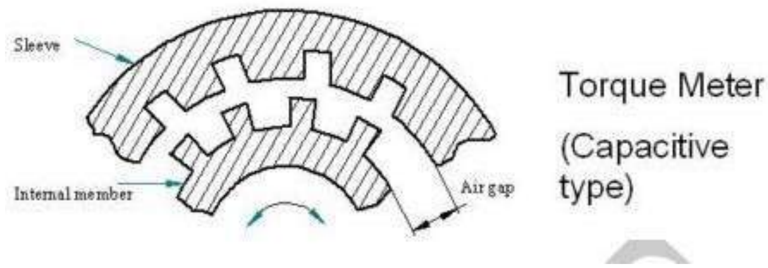


FIGURE 4.17Capacitive Transducer-Changing distance

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.

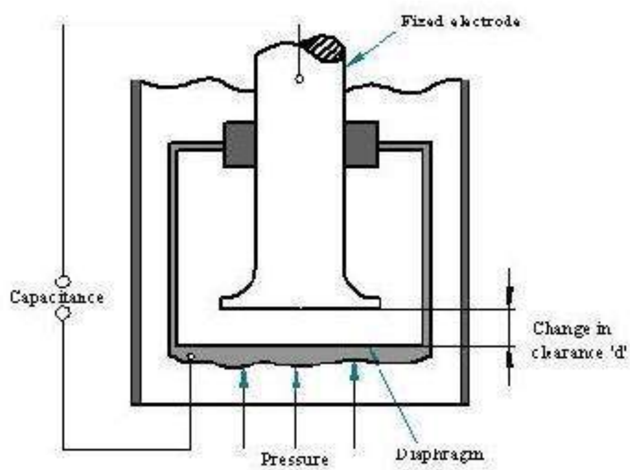


FIGURE 4.18 CAPACITIVE TYPE PRESSURE TRANSDUCERS

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.

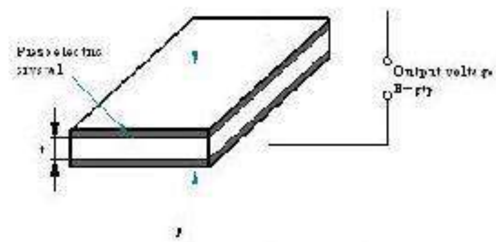


Figure 9 PIEZOELECTRIC EFFECT

Piezoelectric materials

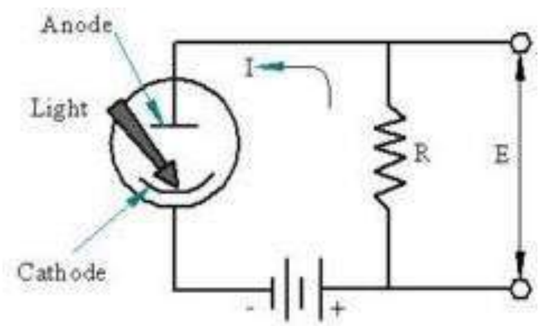
The common piezoelectric materials are quartz, Rochelle salt (Potassium sodium tartarate), ammonium dihydrogen phosphate and ordinary sugar. The desirable properties are stability, high output, insensitivity to temperature and humidity and ability to be formed into desired shape. Quartz is most suitable 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 45^{o}C. 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.

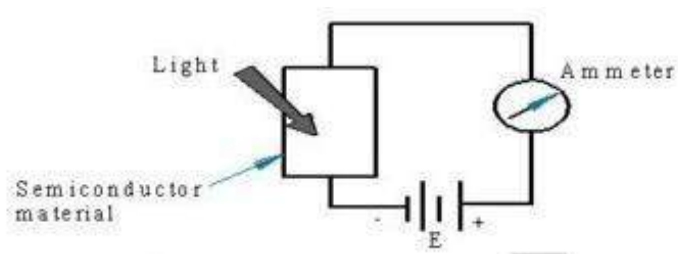


Photoelectric tubes are useful for counting purposes through periodic interruption of a light source

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.

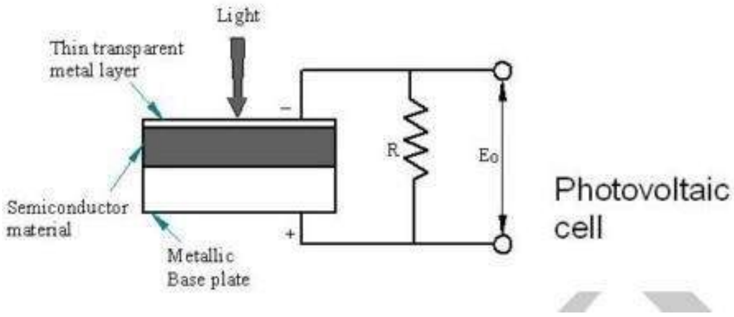


Photoconductive Transducer

PHOTOCONDUCTIVE TRANSDUCERS

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.
-



PHOTOVOLATIC CELL

Ionization Transducers

- Ionization Transducers consist of a glass or quartz envelope with two electrodes A & Band 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 electrodesA & B detect a potential difference in the gas plasma.
- It depends on the electrode spacing and the capacitive coupling between the RF platesand 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%.

9. Intermediate Modifying Devices

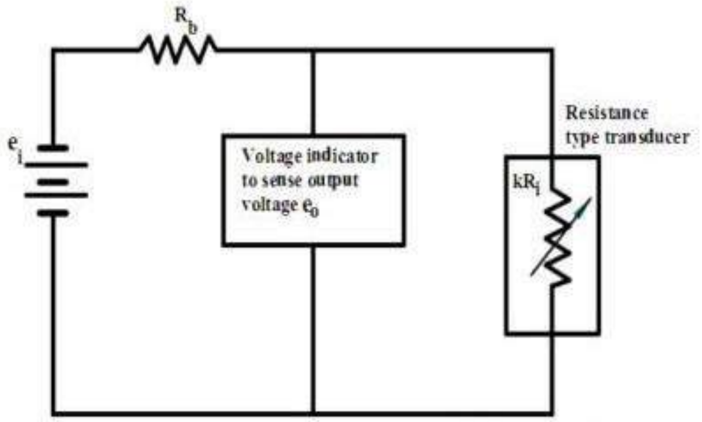
- In most cases, the mechanical quantity which is detected will be transduced into an „*electrical form'*.
- The output of the first stage has to be modified *(signal conditioning)* before it is fed to the third or terminating stage such as indicators, recorders or control elements.
- So, the modifications are carried out in the intermediate stage commonly called as the signal conditioning stage.
- *Signal conditioning* equipment used may be of mechanical, electrical or electronic.
- Mechanical types (using elements such as linkages, gearing, cams, etc.) have many limitations such as friction, inertia, non linearity, backlash, elastic deformation, etc. ·

Hence electrical & electronic systems are used which are free from these drawbacks. ·
Also they give large voltage & power amplifications required to drive the recording

10. Ballast Circuit

A *ballast circuit* is only a simple variation of the current sensitive circuit. In this case a voltage sensitive device is connected across the transducer as shown in fig. It is also called as „voltage sensitive circuit‟.

- A ballast resistor *Rb* is the resistance of the measuring circuit excluding the transducer.
- In the absence of a ballast resistor, the voltage indicator will always record the full source
- voltage *ei* & hence some value of resistance Rb is always necessary for proper functioning of the circuit.
- In order to analyze a ballast circuit, we assume that the voltage indicator has an infinite
- resistance such that it does not draw any current



SCHEMATIC OF BALLAST CIRCUIT

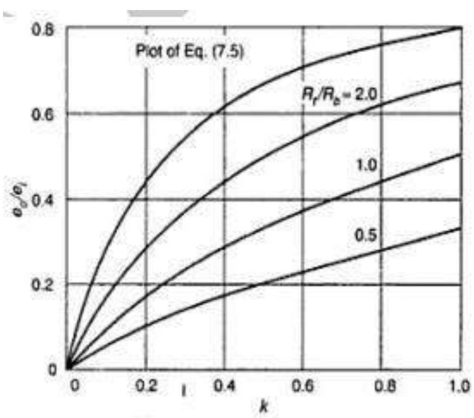
By Ohm's law, the output current is ,

$i_0 = e_i /(R_b+kR_t)$ If e_o *is* the voltage across kR_t, which is indicated by the voltage indicator, then the output voltage indicated is,

$$\frac{e_o}{e_i} = \frac{kR_t}{R_b + kR_t} = \frac{k\,R_t/R_b}{1+\left(\frac{kR_t}{R_b}\right)}.$$

For a ballast circuit,e_o *is a meausure* of the output

• Fig shows the input-output relationships for a ballast circuit.
• It may be noted that a percentage in supply voltage ei results in greater change in output than does a similar percentage change in k, hence very careful voltage regulation must be employed.
• Further the relationship between input & output is not linear



INPUT-OUTPUT RELATIONSHIP FOR BALLAST CIR

CATHODE RAY OSCILLOSCOPE (CRO)

CRO is the most versatile readout device and display device for mechanical measurements. It is used for measurement and analysis of waveforms and other phenomenon in electrical & electronic circuits. CRO is a voltage sensitive instrument with an electron beam striking the fluorescent screen. The extremely low inertia beam of electrons enables it to be used for following the rapidly varying voltages.

The heart of the CRO is the Cathode ray tube (CRT), whose important parts are;

(1) Electron gun assembly: The electron gun assembly produces a sharply focused beam of electrons which in turn are accelerated to high velocity. This beam of electrons strikes the fluorescent screen with sufficient energy to cause a luminous spot on the screen.

(2) Electron gun: An electron gun emits electrons and makes them into a beam. It consists of a heater, cathode, grid, focusing and accelerating anodes. Electrons are emitted from an indirectly heated cathode. These pass through a small hole in the control grid. The grid controls the electrons emitted from the cathode and hence the intensity of the beam. The electrons are then accelerated by accelerating anodes.

(3) Deflection plates: These are two pairs of electrostatic plates. A voltage applied to a pair of vertical plates moves the electron beam vertically up or down. And if the voltage is applied to the pair of horizontal plates, the electron beam moves horizontally from one end to other end of the screen. The CRT is evacuated so that the emitted electrons can move freely from one end of the tube to the other.

• Usually in CRO‟s, the horizontal voltage is internally developed where as the vertical voltage is the voltage under investigation (input).

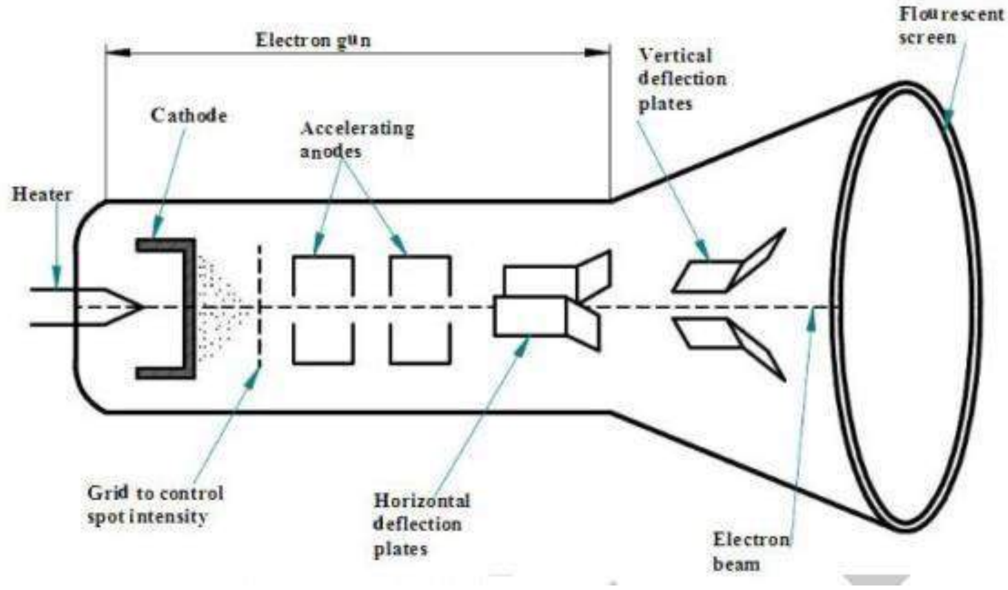
• This voltage moves the luminous spot up & down in accordance with the instantaneous value of voltage. In other words, it traces the „*waveform'* of the input voltage w.r.t. time.

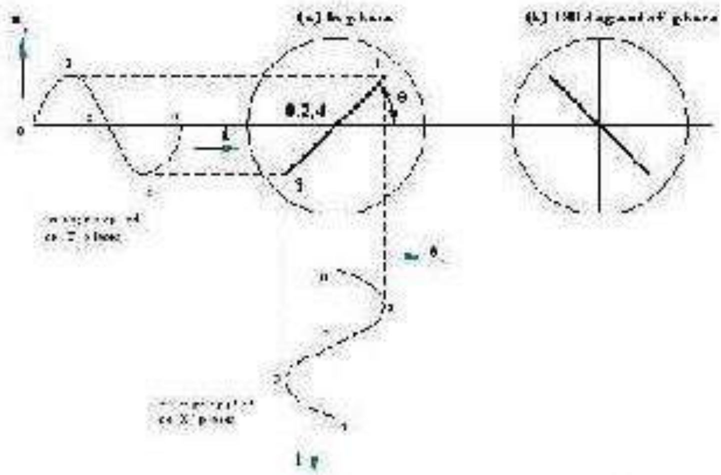
• CRO‟s can also be used to visualize various quantities such as current, strain, acceleration, pressure if they can be converted into voltages.

Applications of CRO

(1) To observe waveform of voltage: In order to observe waveform on a CRO, the voltage under test is applied to vertical or „Y‟ deflection plates and a voltage obtained from a saw tooth oscillator is applied to horizontal or „X‟ deflection plates.
(2) To measure voltage & current: The deflection of the electron beam is proportional to the voltage on the deflection plates. The CRT screen is calibrated in terms of voltage (Volt/cm).
(3) The value of current can be obtained by measuring the voltage drop across a known resistance connected in the circuit.
(4) To measure phase relations & frequency: „Lissajous patterns‟ may be used for this purpose. „Lissajous patterns‟ are the characteristic patterns obtained on the CRT screen when sinusoidal voltages are simultaneously applied to horizontal & vertical deflection plates.

Important parts of a Cathode ray tube





CONSTRUCTION OF CRO

In phase relations: When the two voltages are in phase, then as X voltage increases, so also does the Y voltage. The resulting trace will be a line diagonally passing across the tube. 180 degrees out of phase: The trace will be similar but of the opposite direction.

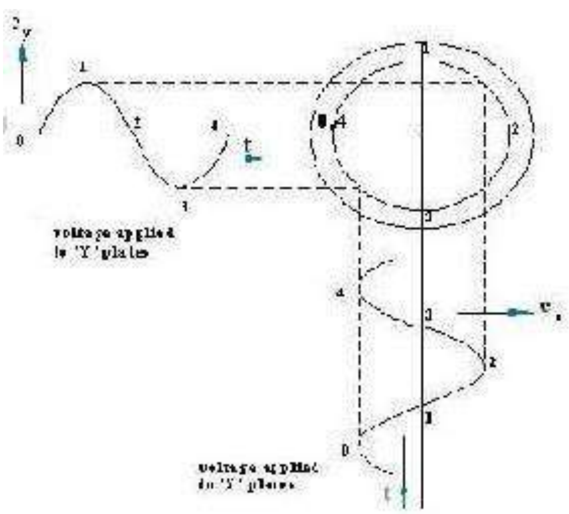


FIGURE 4.23 PHASE RELATIONS

90 degree out of phase relations: When the voltages are 90 degrees out of phase, then as one voltage passes through the zero line, the other will be at maximum and vice versa. The resulting trace will then be an ellipse

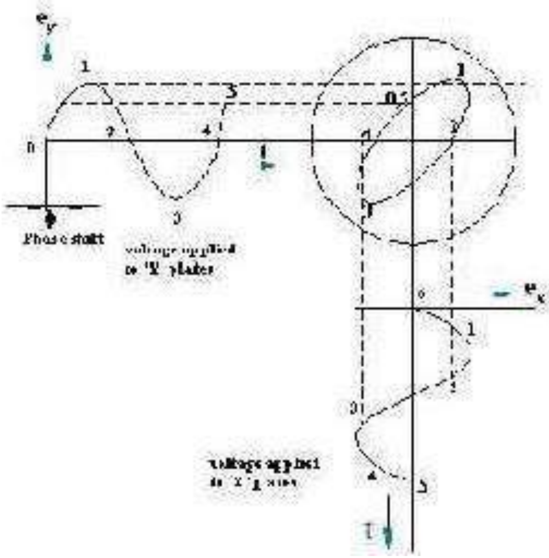


FIGURE 4.24: PHASE RELATIONS

The resulting elliptical trace of the beam provides a means of finding the phase difference between the two applied voltages. From the fig, the sine of the phase angle between the applied voltages is given by, sin f=(X1/X2)=(Y1/Y2) from which phase angle can be calculated.

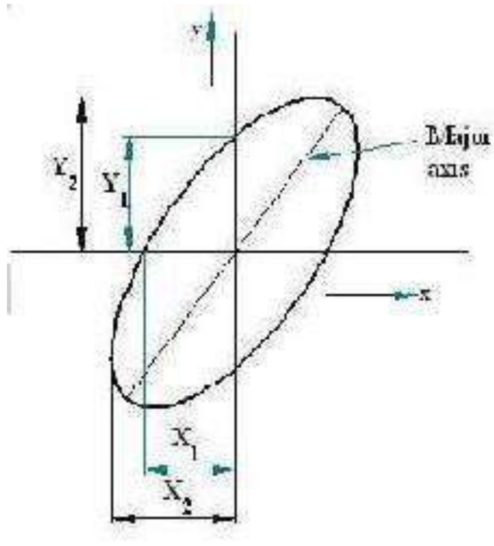


FIGURE 4.25 MEASUREMENT OF FREQUENCY

Measurement of frequency

• Lissajous patterns may be used for measurement of frequency.

• The signal whose frequency has to be measured is applied to the „Y‟ plates, while a standard variable frequency source is connected to the „X‟ plates.

• The standard frequency is adjusted until the pattern appears as a circle, or an ellipse indicating that both signals are of same frequency.

If it is not possible to adjust the standard signal frequency to the exact frequency of the input signal, then it can be adjusted to a *multiple* of unknown frequency such that the pattern appears stationary. By observing the Lissajous patterns, a relation may be used to determine the unknown frequency.

15. Oscillographs

Oscillographs are basically writing instruments unlike CRO which is a display device. These are current sensitive devices. Oscillographs work on the principle of D‟Arsonval meter movement.

They are available in two types:
(1) *Direct writing stylus type*: This employs some form of stylus which directly contacts a moving paper.

(2) Various forms of stylus may be used , depending on whether the recording is accomplished through the use of ink, or by a heated stylus on a treated paper, or by means of a stylus & pressure sensitive paper.

(3) The fig illustrates direct writing stylus consisting of a current sensitive movement and a paper drive mechanism

• As the stylus is deflected by the input signal, the paper is moved under it at a known rate, thereby recording the time function of the input.

• The frictional drag between the paper & pen of the stylus requires considerably more driving torque. These types may have as many as 8 channels.

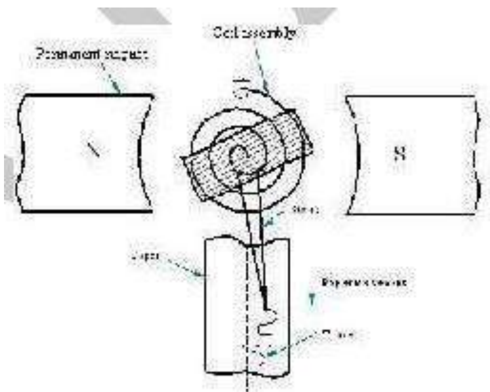


FIGURE 4.26 STYLUS TYPE OSCILLOGRAPH

(2) Light beam or Mirror type:
This type employs a light beam for writing on a photographic film or paper as shown in fig.4.26. It consists of a current sensitive coil assembly, a paper transport mechanism and an optical system for transmitting coil assembly rotation to a displacement on the photographic or photosensitive paper.

• An important parameter in oscillograph is the magnitude of the magnetic flux from the permanent magnet. This requires relatively a large & heavy magnet.

• As the magnitude of the input signal varies, current flows in the moving coil and the mirror deflects. This rotation of mirror deflects these beam (reflected beam) in to photosensitive paper to get the output.

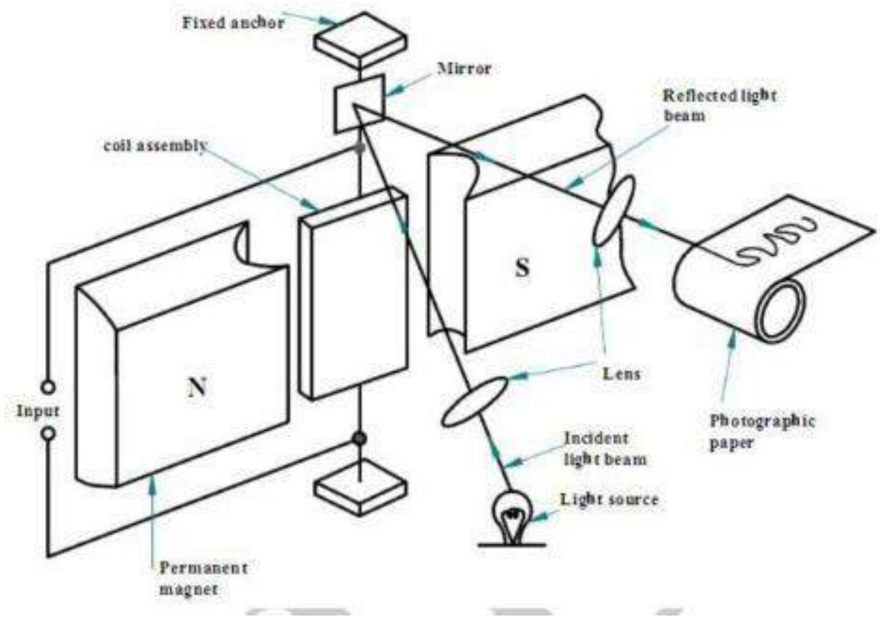


FIGURE 4.27 Light beam or Mirror type Oscillograph

16. QUESTION BANK

1. Explain the significance of measurement. **(Dec 2018, June.2014)**
2. Explain generalised measurement systems **(June. 2014, June 2013, Jan 2016)**
3. Define the following: accuracy, precision, calibration, threshold, sensitivity, hysteresis, repeatability, linearity, loading effect, system response-time delay. **(Dec. 2016, Dec 2018)**
4. Write a note on errors in measurement **(June. 2012, Jan. 2015, Feb 2003)**
5. Explain the classification of error **(May 2009, Dec. 2007)**
6. Explain transducers and write a note on transducer efficiency **(Dec. 2011)**
7. Explain with an example primary transducers (**Jan 2017)**
8. Explain with an example secondary transducers (**Jan 2011)**
9. Name the different ttpes of mechanical trasnducers, explain any two. (**Jan 2017)**
10. Explain pressive sensitive transducing elements (**Dec 2018, Jan 2009)**
11. Explain with a neat skect the use of diaphragms and bellows **(Jan 2012)**
12. Write the advantages of electrical transducers **(Dec. 2008, Jan 2013)**
13. With a neat sketch explain the working principles of sliding contact transducers
14. Explain magnetic reluctance and variable reuctance transducers **(June.2014)**
15. Explain the working principle of capacitance transducers with a neat sketch **(Dec. 2006)**
16. Explain with a neat sketch the working principle of capacitance pick up **(Dec. 2008)**
17. Explain the working principle of pieze electric transducers **(Jan. 2006, Dec. 2009, Jun 2013)**
18. Explain the working principle of photoconductive transducers (**Jan 2015)**
19. Explain the working principle of photovoltaic cell **(Jan. 2009)**
20. Explain the working principle of ionisation transducers (**Jan 2015)**
21. Explain the working principle of electrokinetic **Transducers (Dec. 2005, Jan 2007, Jan 2014, Jan 2012)**
22. Write a note of inherent problems in mechanical systems **(June.2014)**
23. Write a note on electrical intermediate modifying devices **(Dec. 2008, Jan 2013)**
24. Write a note on input circuitry for electrical systems **(June.2014)**
25. Explain the principle of ballast circuit (**Jan 2015**)

26. Explain with a neat sketch electronic amplifiers **(June.2014)**

27. Write a note on terminating devices **(Dec. 2014)**

28. Explain the working principle of cathode ray oscilloscope with a neat sketch **(June.2014)**

29. Explain the working principle of stylus type oscillographs **(Dec. 2017)**
30. Explain the working principle of mirror type oscillographs **(June.2014)**
31. Define Measurement. Differentiate between direct method and indirect method of Measurement. Briefly explain generalized measuring system with the aid of a blockdiagram. (10 Marks, Dec 2019)
32. Classify transducers, giving examples in each category. (10 Marks, Dec 2019)

33. Explain thc following term
(i) Sensitivity (ii) Repeatability (m) Linearity (iv) Threshold (v) Least count. (10 Marks, Dec2019)
34. Explain the working of cathode ray oscilloscope. (10 Marks, Dec 2019)

Assignment questions
Explain the working principle of stylus type oscillographs
Primary and secondary transducer
Inherent problem with mechanical systems

Module-5

MEASUREMENT OF FORCE ,TORQUE,PRESSURE TEMPERATURE

Force-Static balance, equal and unequal balance and Platform balance, Torque- Absorption dynamometer, Prony brake and rope brake dynamometer, Pressure-Elastic members, Bridgeman gauge, McLeod gauge, Pirani gauge.Temperature-Thermocouple, law of thermocouple, materials used for construction of thermocouple, pyrometer and types

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.

Measurement of acceleration of a body of known mass which is subjected to force. Measurement of resultant effect (deformation) when the force is applied to an elastic member.

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.

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 is as shown in Fig.

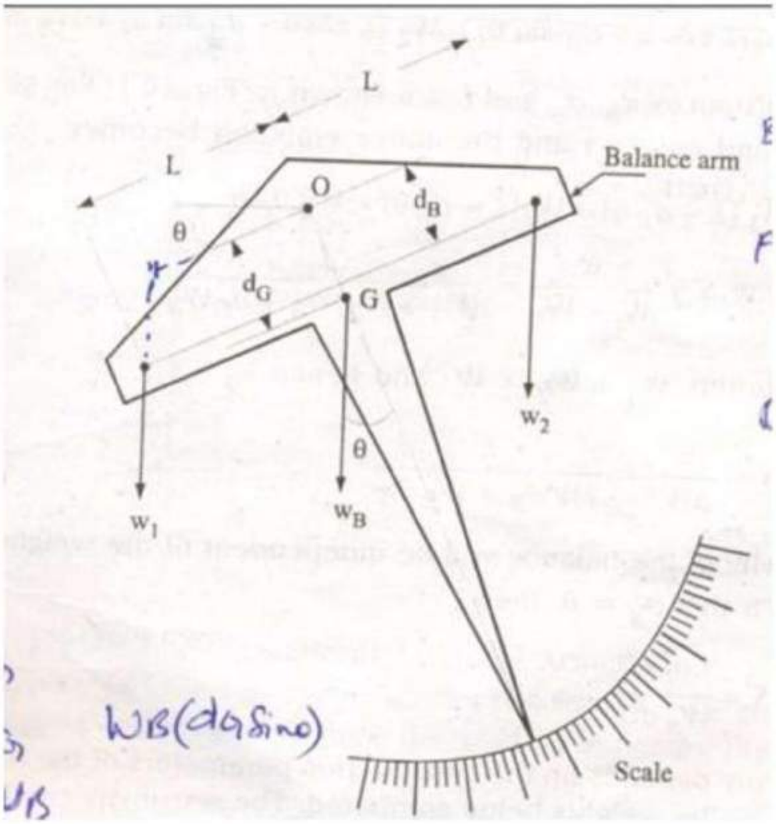


Fig: Analytical balance

The balance arm rotates about the point "O" and two forces W_1 and W_2 are applied at the ends of the arm. W_1 is an unknown force and W_2 is the known force due to a standard mass. Point G is the centre of gravity of the balance arm, and W_B 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 W_1 and W_2 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

$$S = \frac{\theta}{W_1 - W_2} = \frac{\theta}{\Delta W}$$

where, W 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

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

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

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

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

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.

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 x *g*. This force acts as counterposing force against the load which may be a test force F_t.

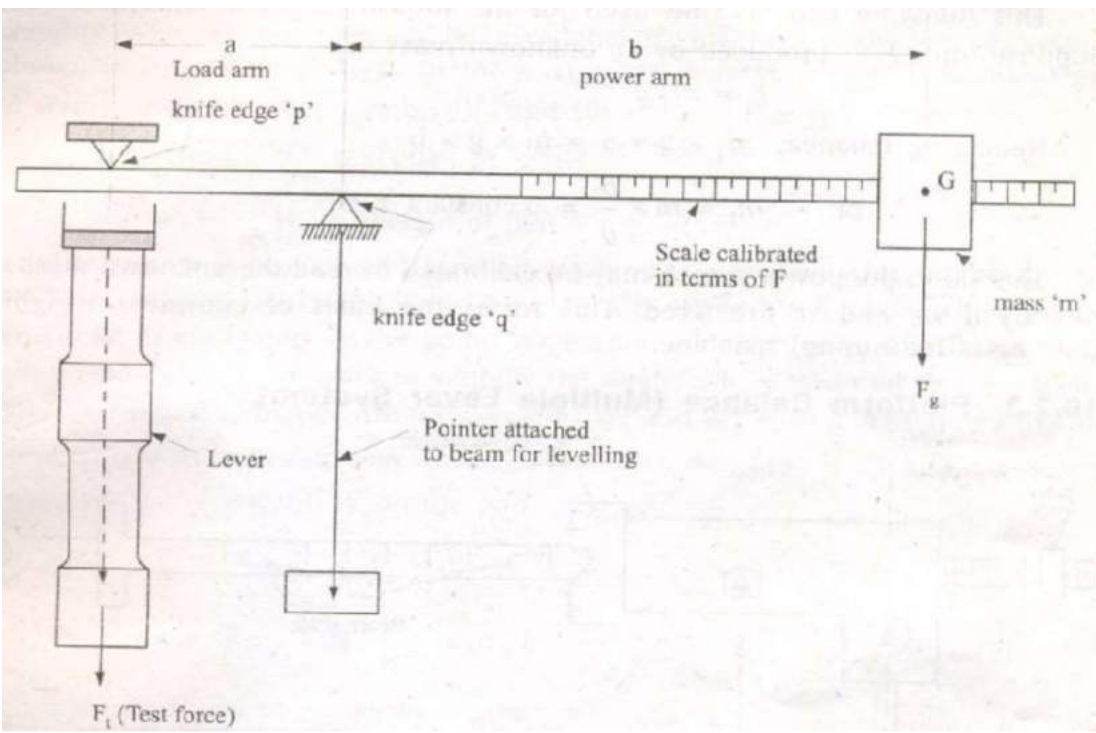


Fig. Schematic of Unequal Arm Balance

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, $F_t \times a = F_g \times b$
or test force $F_t = F_g \times b/a$

= m x g x 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

Platform Balance (Multiple Lever System)

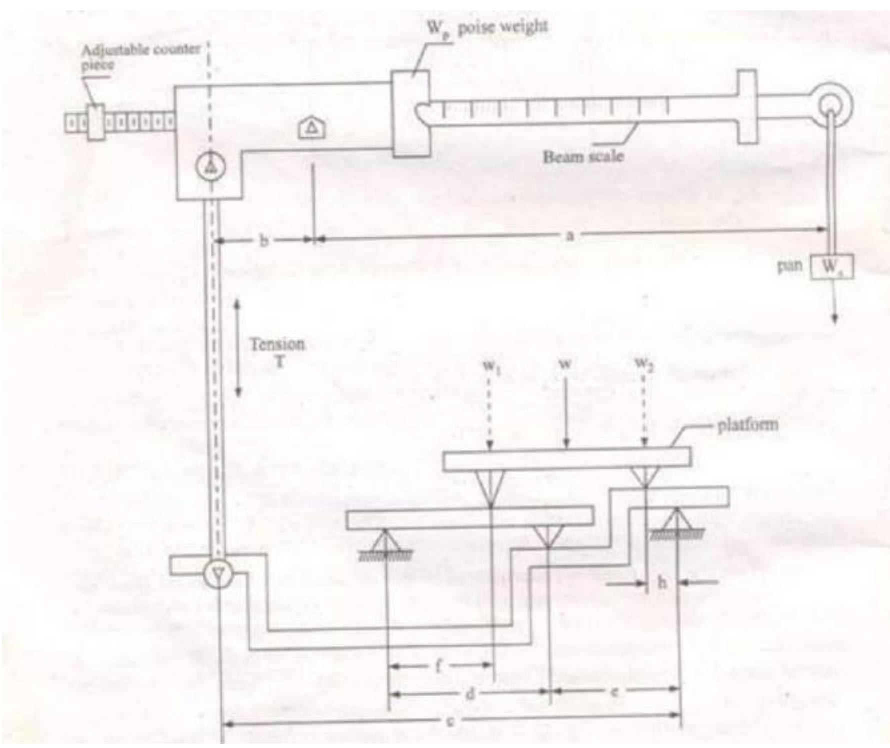


Fig: Schematic of Multiple Lever System

An equal and unequal arm balances are not suited for measurement of large weights. When measurement of large weights are 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 $T \times b = W_S \times a$ ....(1)

and $T \times c = W_1\, f/d\; e + W_2\, h$ ...(2)

If the links are so proportioned that

$$h/e = f/d$$

We get : $T \times c = h (W_1 + W_2)\, hW$ ....(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

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

$$\text{Unknown weight } W = \frac{a\,c}{b\,h} W_S$$

where $m = \frac{a\,c}{b\,h}$ *is called themultiplication 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

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 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.

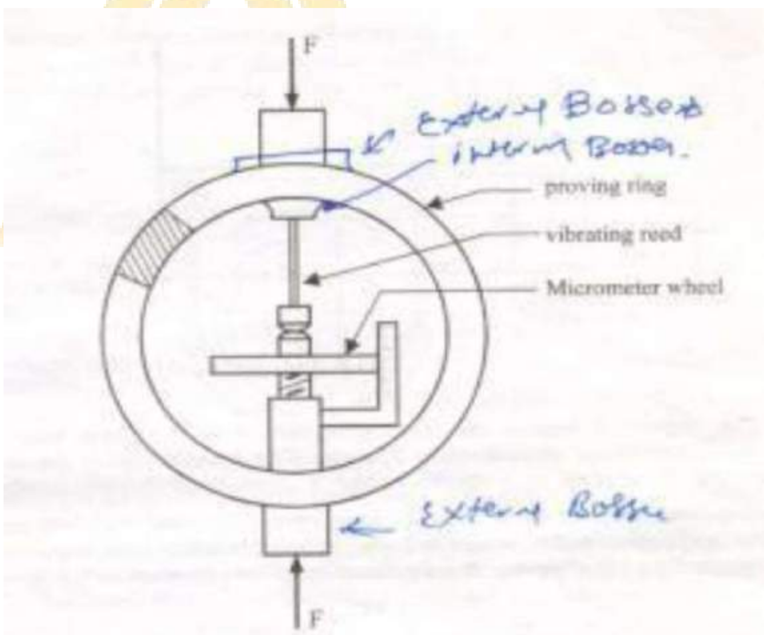


Fig: Proving Ring

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.

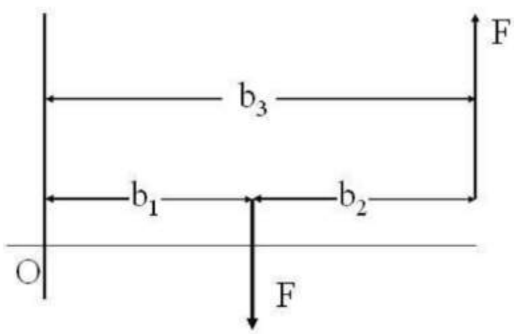
Proving rings are normally used for force measurement within the range of 1.5 KN to 1.5 MN. The maximum deflection is typically of the order of 1% of the outside diameter of the ring.

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.

- **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.

- **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

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.

Mechanical Dynamometer (Prony Brake)

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

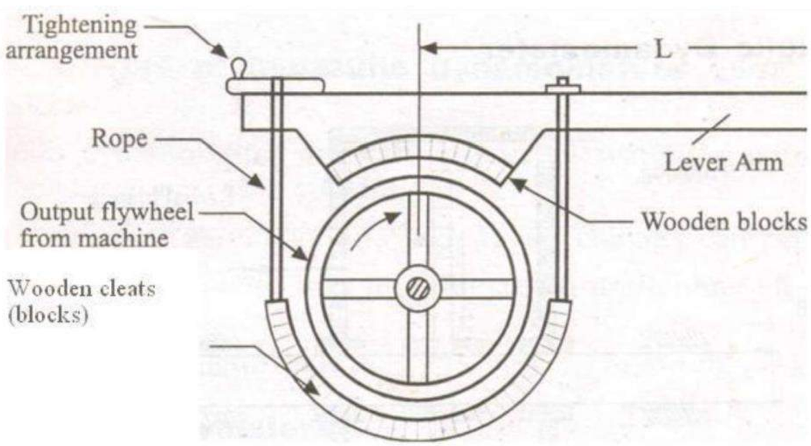


Fig. Schematic of Prony Brake

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
• 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.

• 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

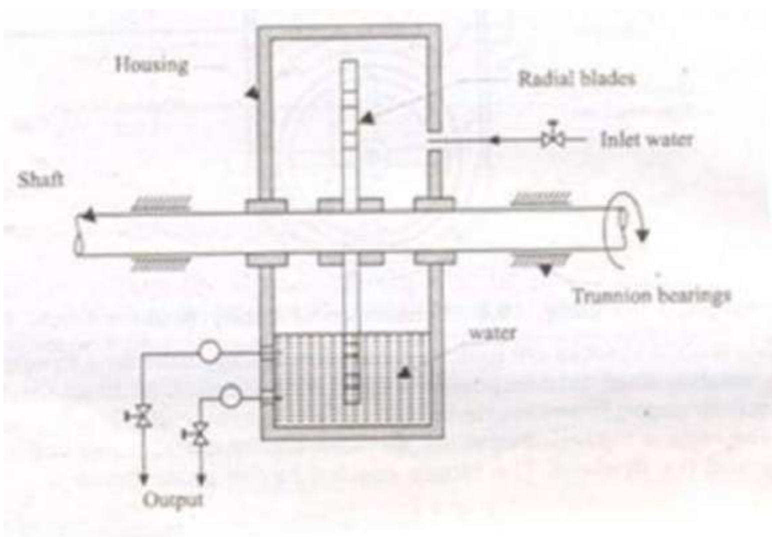


Fig. Section through a typical water brake

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 *r*. 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 a dashpot damper.
- In hydraulic dynamometer there is a flexibility in controlling the operation

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:

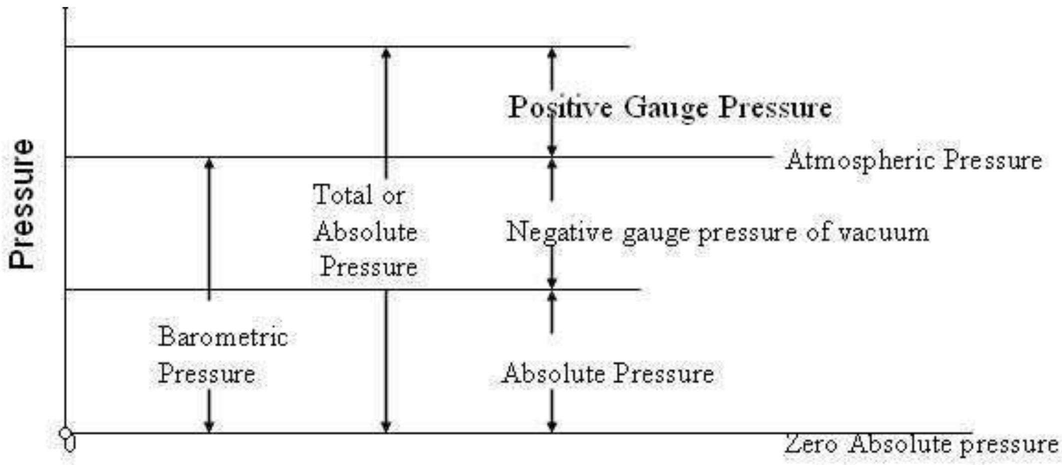
$$P=F/A$$

Units of Measure

System	Length	Force	Mass	Time	Pressure
MKS	Meter	Newton	Kg	Sec	N/M2 = Pascal
CGS	CM	Dyne	Gram	Sec	D/CM2
English	Inch	Pound	Slug	Sec	PSI

Absolute Pressure.

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



Relationship between Pressure Terms

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

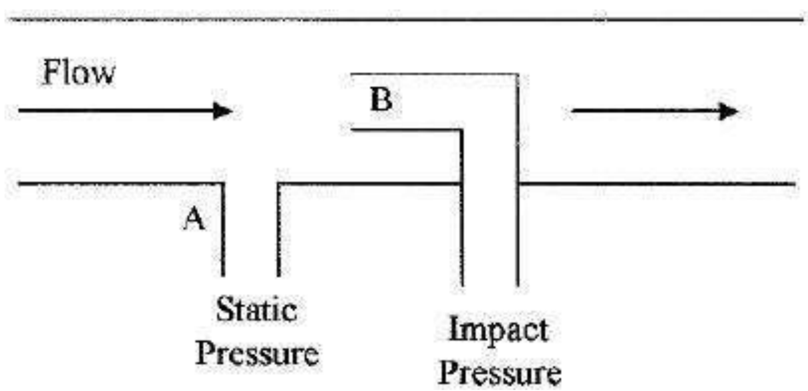
Vacuum

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.

Static, dynamic, and impact pressures



Static pressure is the pressure of fluids or gases that are stationary or not in motion. Dynamic pressure is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow. In Fig., the dynamic pressure is (B − A).Impact pressure (total pressure) is the sum of the static and dynamic pressures on a surface or object. Point B in Fig. depicts the impact pressure.

Types of Pressure Measuring Devices

- 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.

- Electro-mechanical Instruments: this instrument employs a mechanical means for detecting the pressure and electrical means for indicating or recording the detected pressure.

- Electronic Instruments: These instrument depends on some physical change which can be detected and indicated or recorded electronically.

Pressure- Measuring Transducer

Pressure is measured by transducing its effect to a deflection with the help of following types of transducers.

1. Gravitational types

Liquid columns
Pistons or loose diaphragms, and weights.

2. Direct-acting elastic types

Unsymmetrically loaded tubes
Symmetrically loaded tubes
Elastic diaphragms
Bellows

Bulk compression

3 **Indirect-acting elastic type**

Piston with elastic restraining member

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.

1. Bourdon tube,
2. Diaphragms and
3. Bellows

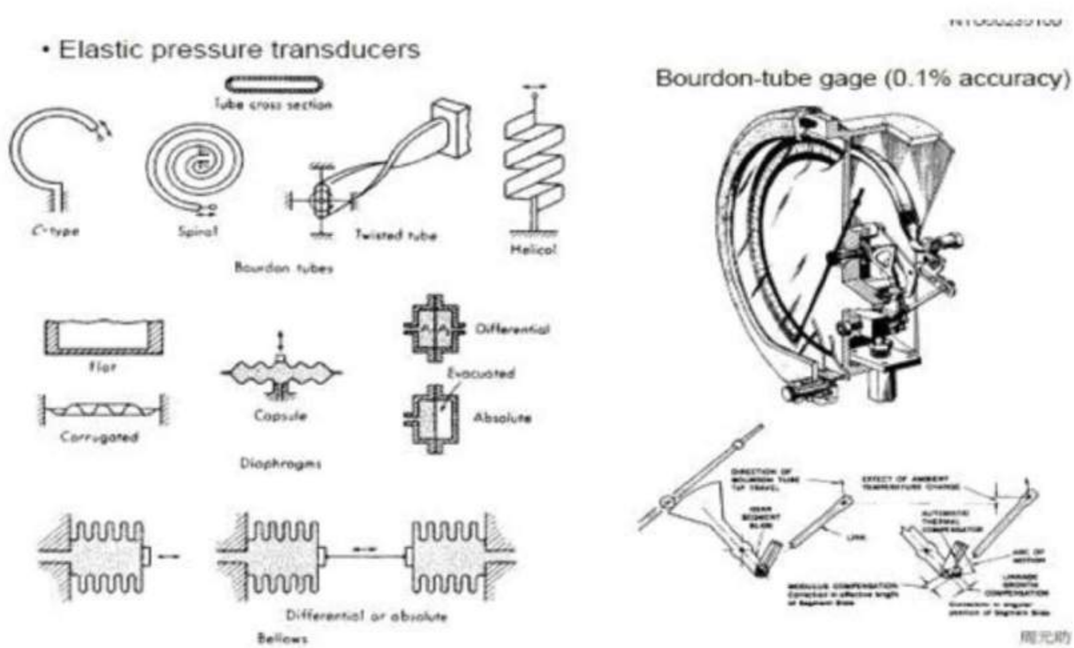
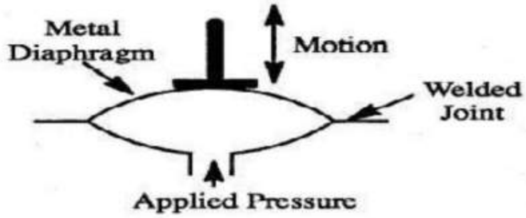
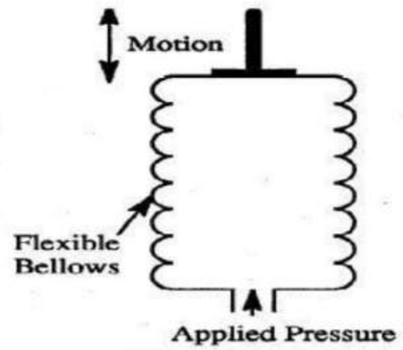


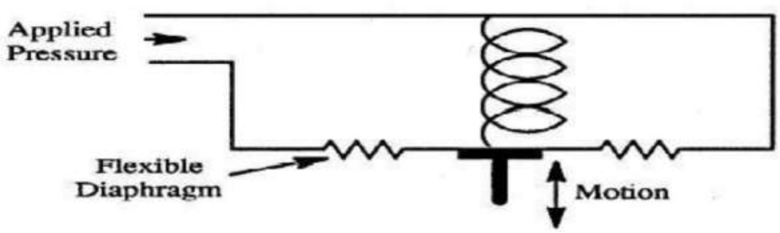
Fig: Primary Pressure Elements Capsule, Bellows & Spring Opposed Diaphragm



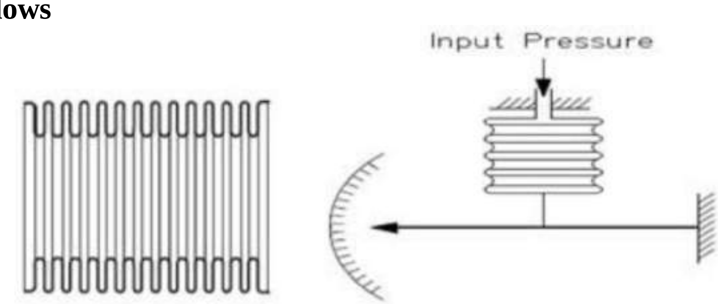
Pressure Capsule



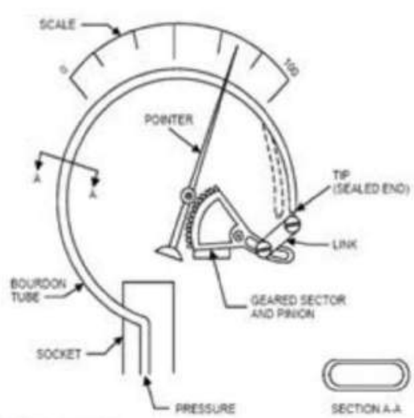
Pressure Bellows

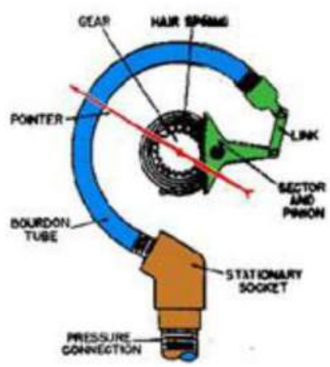


Bellows



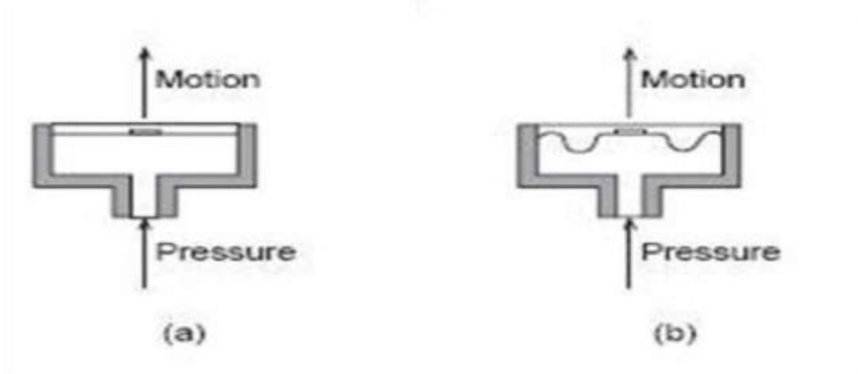
Bourdon Tube





Diaphragm

Diaphragm



A diaphragm usually is designed so that the deflection-versus-pressure characteristics are as linear as possible over a specified pressure range, and with a minimum of hysteresis and minimum shift in the zero point.

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

7. Pressure coefficient of resistance in ohms/100 KN M-2

pgage 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.

The Mcleod Gage

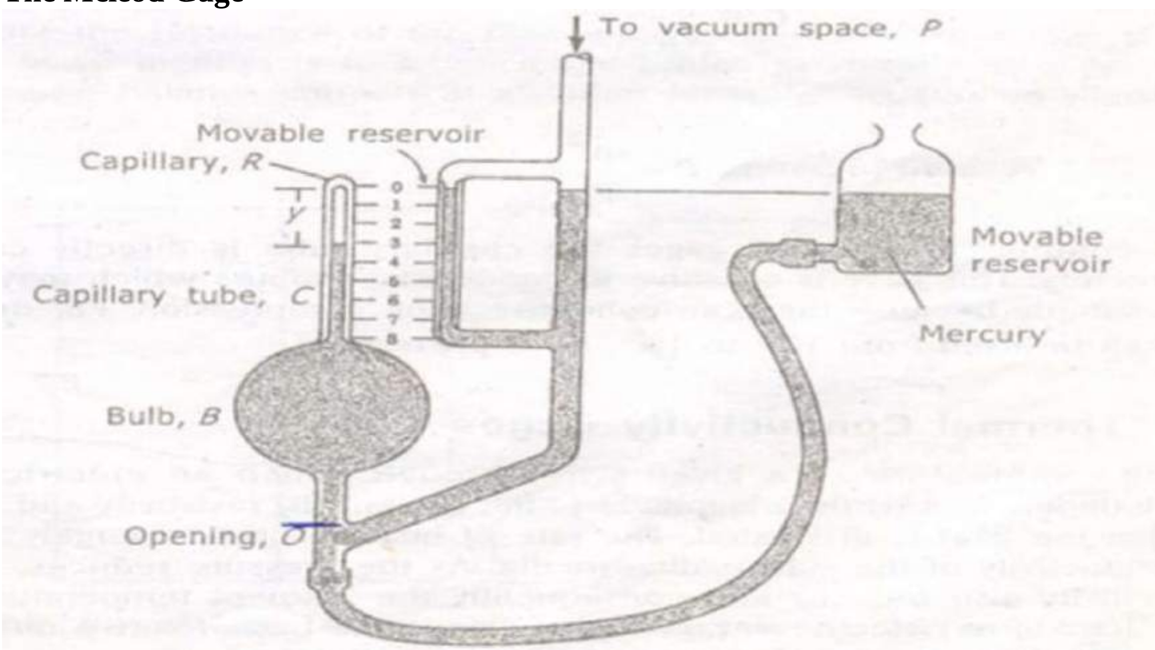
The operation of McLeod gage is based on Boyle's law.

$$p_1 = \frac{p_2 v_2}{v_1}$$

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 Mcleod Gage



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.

$$V_c = ay \text{------------------------} (1)$$

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

$$P_C = P \frac{V_B}{V_C} \text{ -------------------- (2)}$$

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

$$8) \; Vacuumpressur, P = \frac{ay^2}{V_B}$$

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

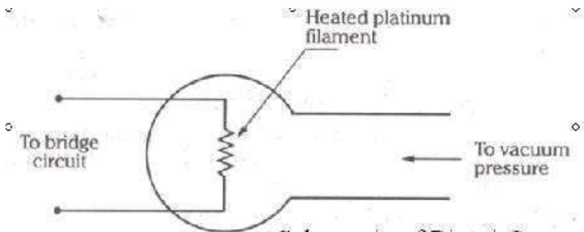
The temperature of a given wire through which an electric current is flowing depend, on (i) the magnitude of the current (ii) resistivity and (iii) the rate at which the heat is dissipated. The rate of heat dissipation largely depends on the conductivity of the surrounding media.

As the pressure reduces, the thermal conducitivity 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.

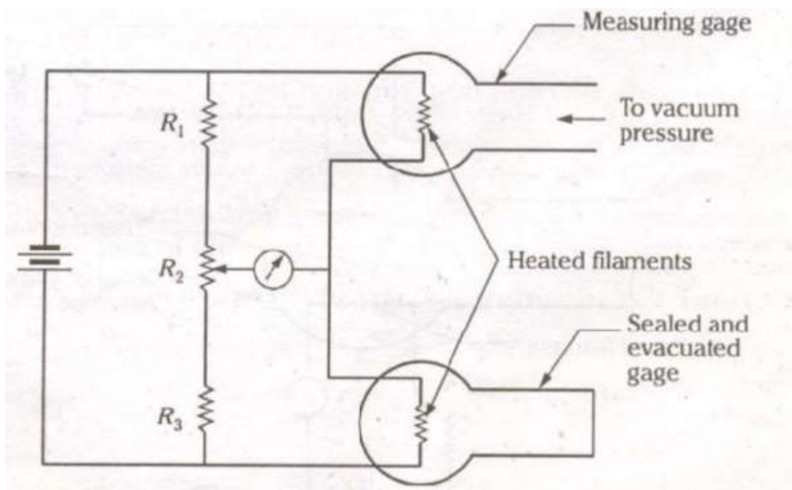


Fig: Pirani gage arrangement to compensate for ambient temperature Changes

The heat loss from the filament is also a function of ambinet 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 differ in the means for measuring the filament temperature. In this gage the filament temperature is measured directly by mc;ans 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.

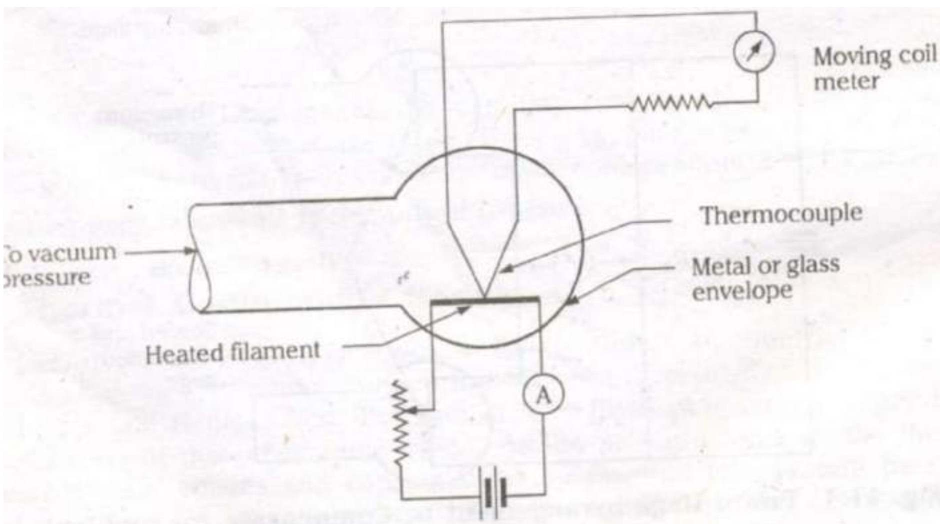


Fig: Thermocouple Vacuum Gage

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:

1. Change in physical state,
2. Change in chemical state,

   Change in physical dimensions,

   Change in electrical properties and

   Change in radiating ability.

And any of these effects may be used to measure the temperature

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 are 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-lineartemperatureresistance 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:

- The material should permit fabrication in convenient sizes.
- Its thermal coefficient of resistivity should be high and constant
  They must be corrosion-resistant and should not undergo phase changes with in the temperature ranges
  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.

$$R_t = Ro\,(1 + aT + bT^2)$$

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.

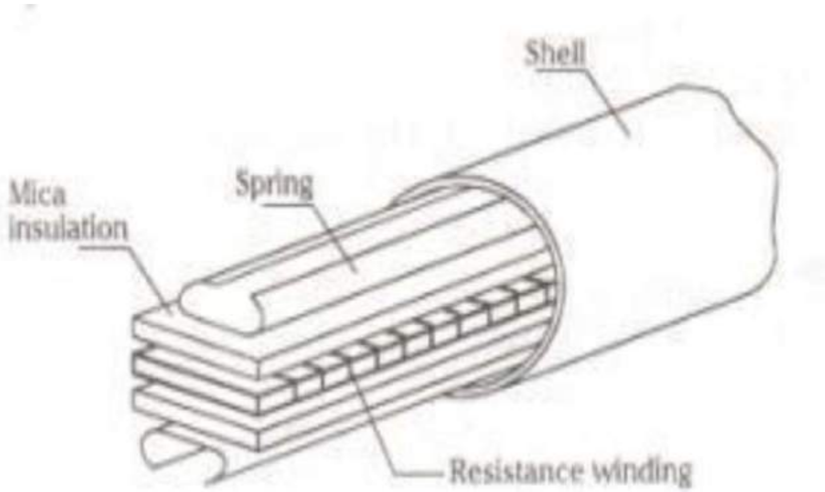


Fig: Resistance Thermometer

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.

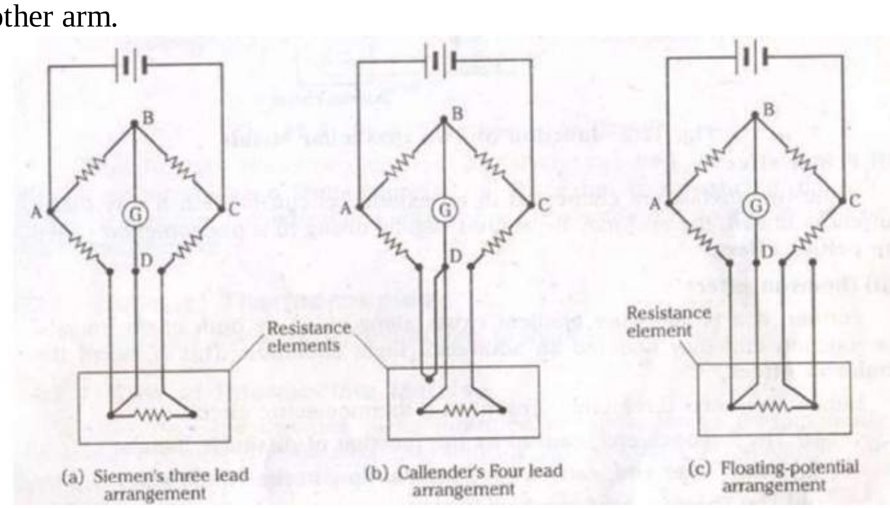


Fig: Methods of Compensating Lead Resistance Error

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.**

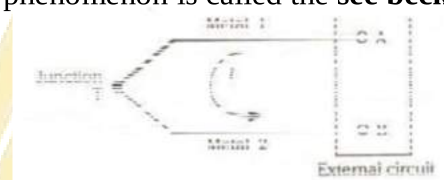


Fig: Junction of Two Dissimilar Metals

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.

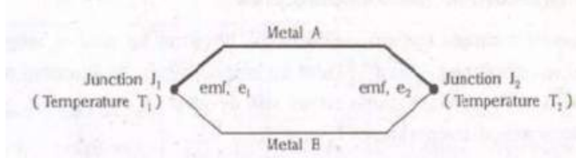


Fig: Basic Thermocouple Circuit

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

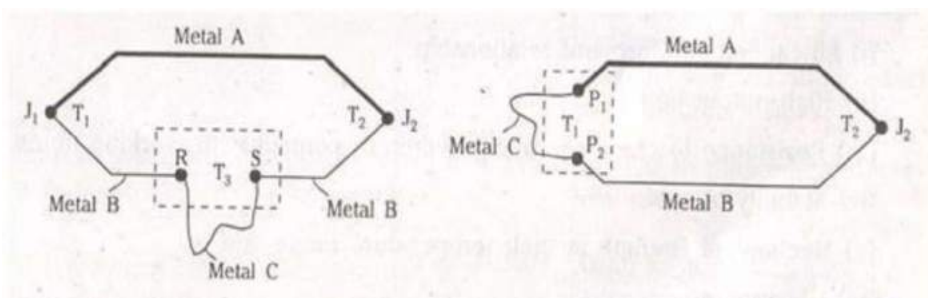


Fig: Circuits illustrating the Law of Intermediate Metals

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.

Fig: 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.

Thermocouple materials and Construction

Any two dissimilar metals can be used to form thermocouple, but certain metals and combinations are better than others. The desirable properties of thermocouple materials are:

- Linear temperature-emf relationship
  High output emf,
  Resistance to chemical change when in contact with working fluids,
  Stability of emf,
  Mechanical strength in their temperature range and
  Cheapness.

The thermocouple materials can be divided into two types

(a) Rare-metal types using platinum, rhodium, iridium etc and
(b) Base-metal types as given in the table.

Table Thermocouple Ranges and Characteristics

Type	ANSI Standards	Temperature Range °C	Characteristics
A. Base-metal type			
1. Copper-constantan (40% Ni 60%Cu)	Type – T	-250 to + 400	Resists oxidizing and reducing atmospheres, and requires protection from acid fumes.
2. Iron Constantan	-	-200 to + 850	Low cost, corrodes in the presence of moisture, oxygen and sulphur bearing gases, suitable for reducing atmospheres
3. Chromel (90% Cr, 10% Ni) - Alumel (94% Ni, 2%Al + Si and Mn)	Type K	-200 to + 1100	Resistant to oxidizing but not to reducing atmospheres. Susceptible to attack by carbon-bearing gases, sulphur and cyanide fumes.
4. Chromel – Constantan	Type – E	-200 to + 850	Similar to Chromel Alumel

A. Rare-metal type 1) Platinum 90% rhodium 10% - Platinum	Type – S	0 to + 1400	Law emf, good resistance to oxidizing atmospheres, poor with reducing atmospheres. Calibration is affected by metallic vapours and contact with metallic oxides
2. Rhodium iridium – Iridium	Type - R	0 to + 2100	Similar to Platinum / rhodium - platinum
3. Tungsten (95%) rhenium (5%) Tungsten (72%) rhenium (26%)	–	0 to + 2600	Used in non-oxidising atmospheres only. The 5% rhenium arm is brittle at room temperature
4. Platinum, rhodium (30%) Platinum, rhodium (6%)	Type - B	+ 850 to + 1800	Not for reducing atmosphere or vacuum. Generates high emf per degree.

The size of thermocouple wire is important because higher the temperature to be measured, heavier should be the wire. As the wire size increases, the time response of the thermocouple to temperature change increases. Hence some compromise between time response and life of the thermocouples is required.

Thermocouples may be prepared by twisting the two wires together and brazed or welded as shown in the Fig.

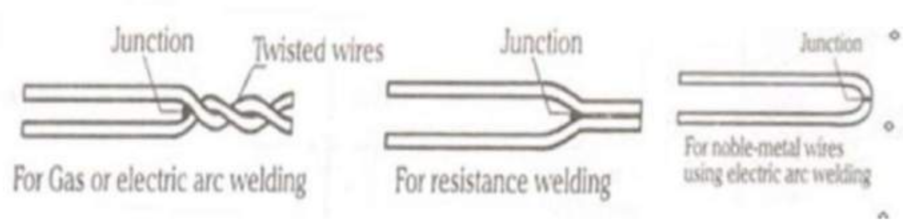


Fig: Forms of Thermocouple Construction

Bare elements without any protector can be used for low-temperature thermocouples. But some form of protection is required for higher temperatures Fig. shows the common methods of providing insulation to the thermocouple wires.

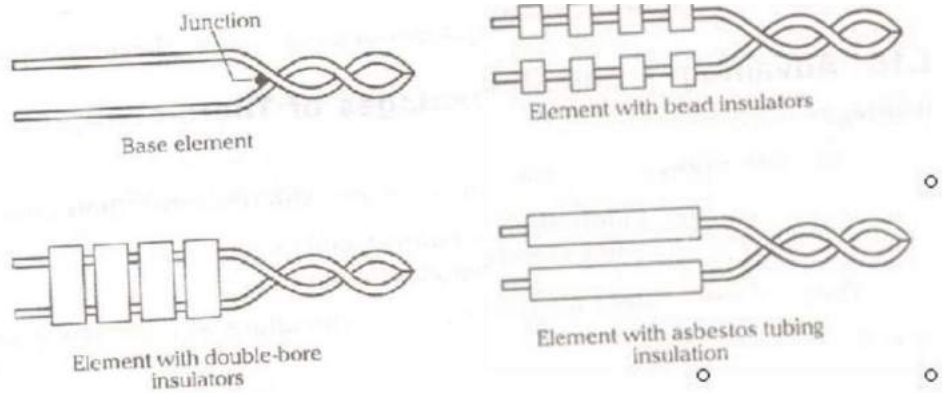


Fig: Methods of Insulating Thermocouple Leads

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.

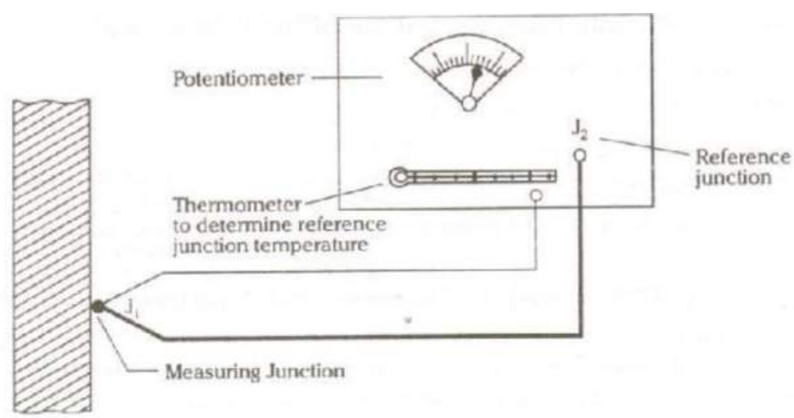


Fig. Temperature measuring Arrangement using Thermocouple

Advantages and Disadvantages of Thermocouples

Advantages

(a) Thermocouples are cheaper than the resistance thermometers.
(b) Thermocouples follow the temperature changes with small time lag thus suitable for recording rapidly changing temperatures.
(c) They are convenient for measuring the temperature at a particular point.

Disadvantages

- Possibility of inaccuracy due to changes in the reference junction temperature hence they cannot be used in precision work.

For long life, they should be protected to prevent contamination and have to be chemically inert and vacuum tight.

- 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.

Theory of Radiation Pyrometers

When temperatures to be measured are very high and physical contact with the medium to be measured is impossible, then thermal radiation methods or optical pyrometers are used. These pyrometers are used when corrosive vapours or liquids would destroy thermocouples and resistance thermometers which come in contact with the measuring medium .

Radiation pyrometers measures the heat emitted or reflected by a hot object. Thermal radiation is the electromagnetic radiation emitted as a result of temperature. The operation of thermal radiation pyrometers are based on black body concept. The total thermal radiation emitted by a black body per unit area is given by Stefen - Boltzmann law as.

$q_b = \sigma T^4$ W/m2

where, σ is the Stefen-Boltzmann constant = 56.7×10^{-9} $W/m^2\text{-}k^4$, and T is the absolute temperature of the surface in kelvin.

Prevost's theory of exchange states that, for two block bodies in sight, each will radiate energy to the other and hence the net energy transfer per unit area from one to the other is given by.

$$q_b = \sigma \left(T_1^4 - T_2^4\right) \quad \mathrm{W/m^2}$$

Where, T_1 and T_2 are the absolute surface temperatures and $T_1 > T_2$. If T_1 is much higher than T_2 it can be assumed that the radiation is proportional toT_1^4 as the term T_2^4 becomes insignificant.

A rough black surface radiates more heat than a smooth bright surface. This effect is called emissivity and is expressed as.

€ = q / qb

The energy is radiated over a range of frequencies of the electromagnetic spectrum, the distribution for any particular wavelength (λ) is given by plank's radiation law as,

$$qb\lambda = C_1 / \{\lambda^5 \left(eC^{C2/\lambda T} - 1\right)\}$$

where, $qb\lambda$ is the energy radiated at wavelength λ and C1 and C2 are constants.

Energy distribution curves calculated from this equation are shown in Fig. for three temperature values and the small visible band of the range is indicated. If a vertical line is drawn at a particular frequency value, then the radiated energy has a particular intensity at each temperature. If a vertical band representing a range of frequencies is drawn, the energy radiated at a particular temperature is given by the area in the band under that temperature curve. The values given in the figure are for perfect black bodies. These values should be multiplied by emissivity in order to get values for actual surfaces. Actual surfaces exhibit highly variable emissivities over the wavelength spectrum. And for the purpose of analysis, the actual surfaces are approximated as grey bodies

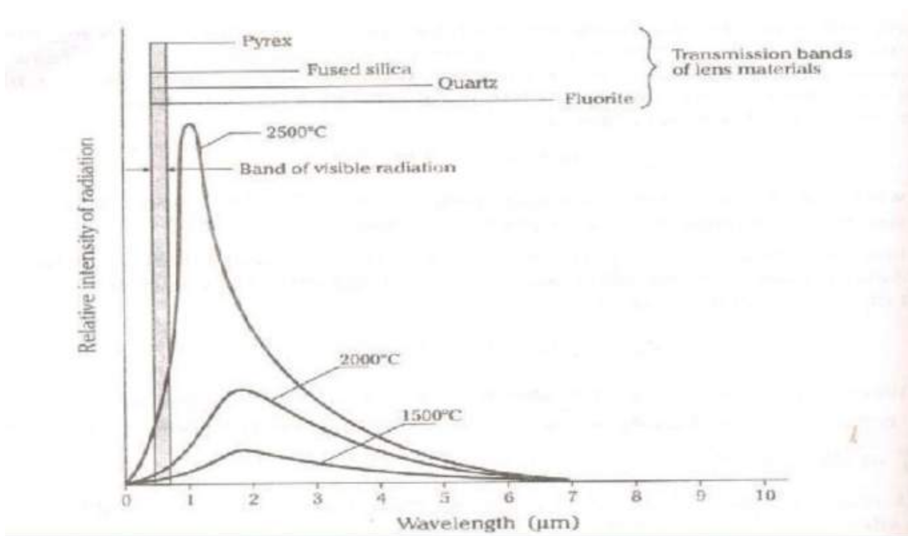


Fig. Distribution of Radient Energy for Black Bodies

It is apparent that the intensity of radiation varies appreciably with wavelength. Also it is observed that the point of maximum radiant intensity shifts to the shorter wavelengths as the temperature increases. This is a common phenomenon observed in the change of colour of a body being heated. A metal gradually heated changes its colour from red, which has a long wavelength to yellow and white as the intensity of radiation increases at the shorter wavelengths of the visible spectrum.

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.

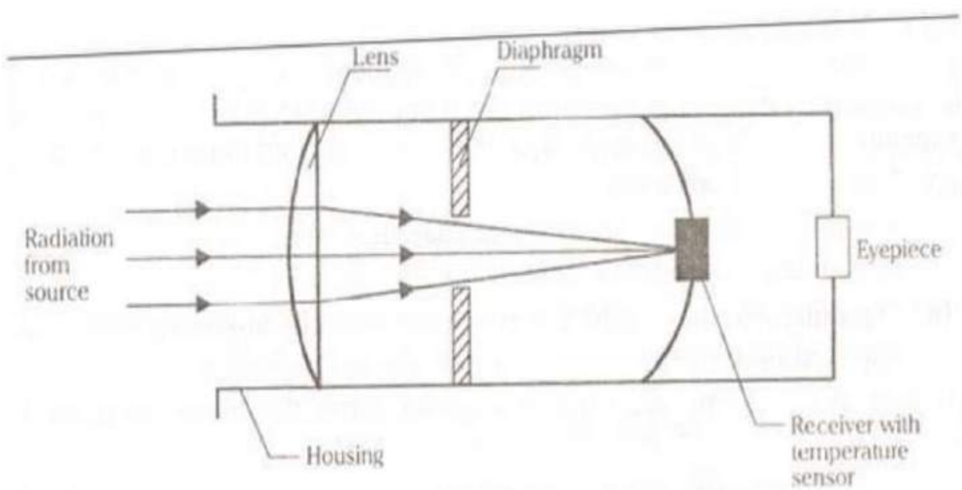


Fig. Schematic of Lens Type Radiation Receiving Device

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.

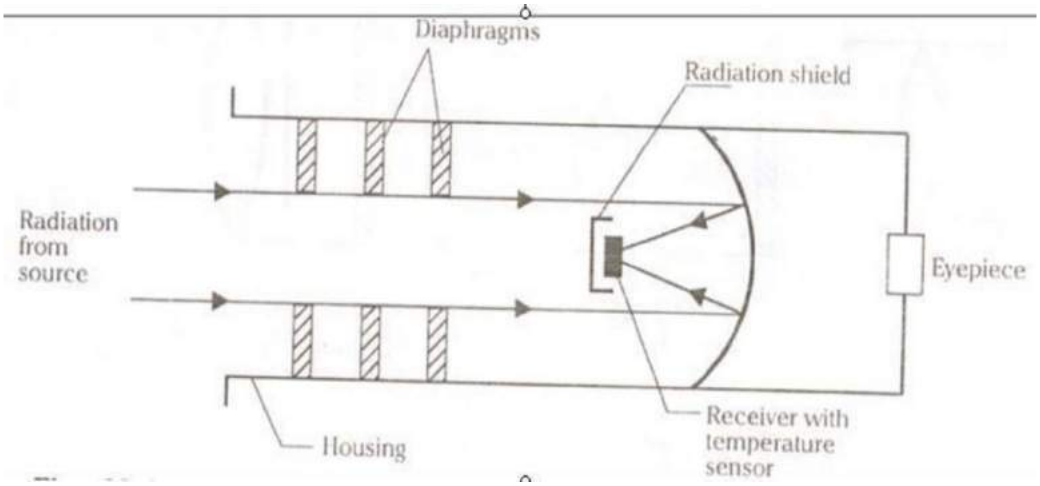


Fig. Mirror Focussing Type Radiation Receiving Device

Although radiation pyrometers may theoretically be used at any reasonable distance from a temperature source, there are practical limitations.

- 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.

- 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 :

- The current through the filament may be controlled electrically with the help of resistance adjustment or
- 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.

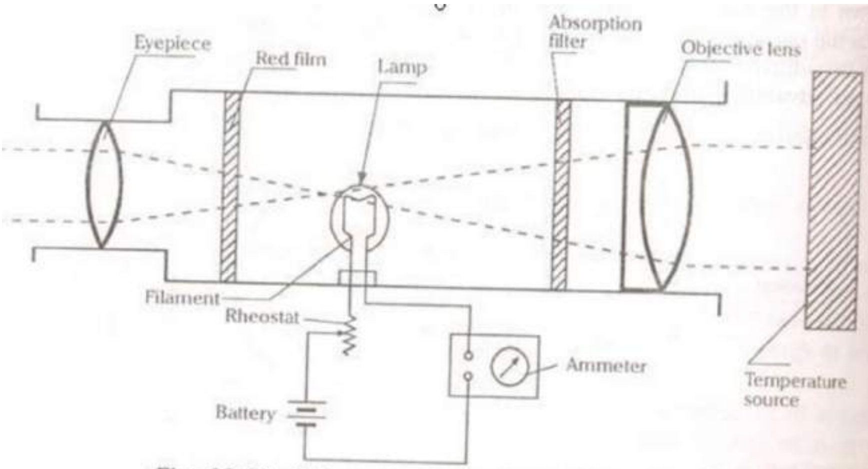


Fig. 12.13 Schematic of an Optical Pyrometer

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.

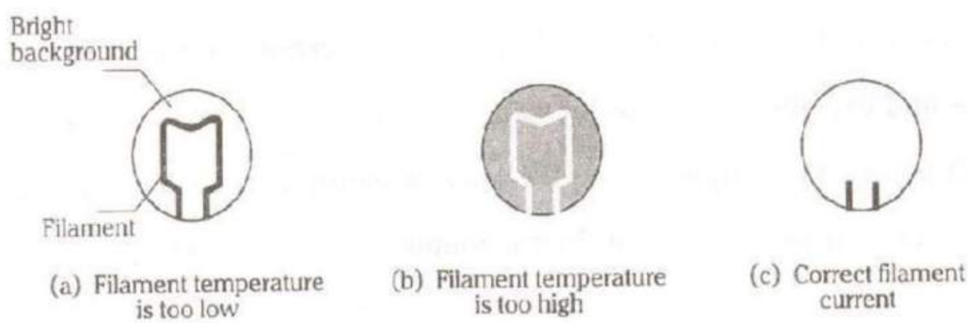


Fig Filament Appearance

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. l2.14(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.

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 $\epsilon = \delta l / l$ 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 train"**

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:

1. Mechanical strain gauges
2. Optical strain gauges
3. Electrical strain gauges

Mechanical Strain Gauges

This type of strain gauges involves mechanical means for magnification. Extensometer employing compound levers having high magnifications were 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.

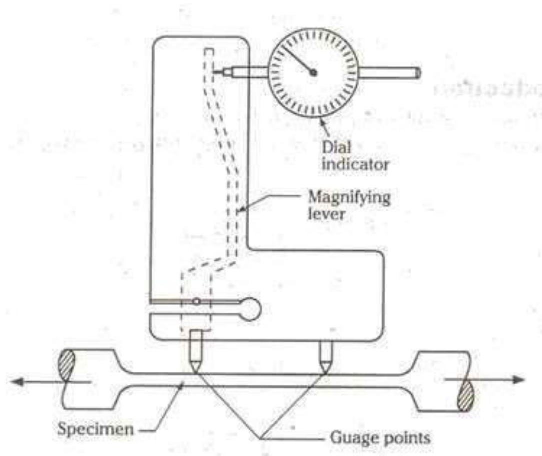


Fig. Mechanical Strain Gauge (Berry Extensometer)

Advantages

- It has a self contained magnification system.
- No auxiliary equipment is needed as in the case of electrical strain gauges.

Disadvantages

- Limited only to static tests.
- The high inertia of the gauge makes it unsuitable for dynamic measurements and varying strains.
- The response of the system is slow and also there is no method of recording the readings automatically.
- There should be sufficient surface area on the test specimen and clearance above it in order to accommodate the gauge together with its mountings

Optical Strain Gauges

The most commonly used optical strain gauge was developed by Tuckerman as shown in the figure It combines mechanical and optical system consisting of an extensometer and an autocollimator. The nominal length of the gauge is the distance from a knife edge to the point of contact of the lozenge. The lozenge acts like a mirror. The distance between the fixed knife edge and lozenge changes, due to loading. Then, the lozenge rotates and if any light beam is falling on it, will be deflected. The function of the auto callimator is to send parallel rays of light and receive back the reflected light beam from the lozenge on the optical system. The relative movement of the reflected light as viewed through the eye-piece of the auto collimator is calibrated to measure the strain directly. This gauge can be used for dynamic measurements of up to 40 Hz using a photographic recorder, and strains as small as 2 µm/m can be resolved. Gauge lengths may vary from 6 mm to 250 mm.

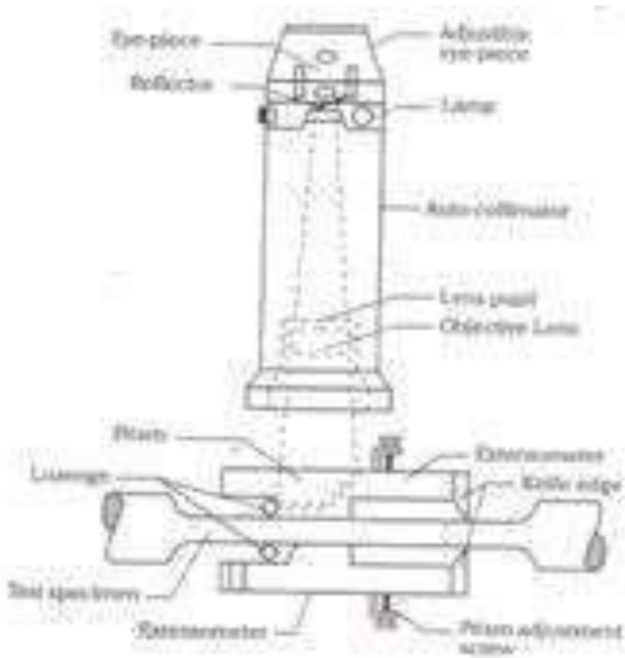


Fig. Tuckerman Optical Extensometer

Advantages:

a. The position of autocolllimator need not be fixed relative to the extensometer, and reading can be taken by holding the autocollimator in hand.

Disadvantages :

- Limited only for static measurements.
- Large gauge lengths are required.
- Cannot be used where large strain gradients are encountered

Electrical Strain Gauges

In electrical strain gauges, a change in strain produces a change in some electrical characteristic. This electrical output can be magnified by some electronic equipment. The electrical methods of measuring strain possess the advantage of high sensitivity and ability to respond to dynamic strains. The electrical strain gauges are classified according to the particular electrical property affected by straining as follows:

- Capacitance gauges
- Inductance gauges
- Piezoelectric gauges
- Resistance gauges

The resistance type gauges are by far the most 1 popular, and they have advantages, primarily of size and mass over the other types of electrical gauges. On the other hand, strain-sensitive gauging elements used in calibrated devices for measuring other mechanical quantities are often of the inductive type, whereas the capacitive kind is used more for special-purpose applications. Inductive and capacitive gauges are generally more rugged than resistive one and better able to maintain calibration over long period of time. Inductive gauges are used for permanent installations, such as rolling mill frames for the measurement of rolling loads. Piezoelectric gauges are extremely sensitive to strain but have the disadvantages of non-linearity and relatively high temperature sensitive. They are mainly used for studying dynamic inputs.

Electrical Resistance Strain Gauges

Electrical resistance strain gauges are very widely used for strain measurement. Its operation is based on the principle that the electrical resistance of a conductor changes when it is subjected to a mechanical deformation. Typically an electric conductor is bonded to the specimen with an insulating cement under no-load conditions. A load is then applied, which produces a deformation in both the specimen and the resistance element. This deformation is indicated through a measurement of the change in resistance of an element as follows:

Resistance of a conductor, R= p L/A
where L = Length of the electrical conductor
A = Cross sectional area of the conductor
p = Resistivity of the conductor material.

In other words when the conductor is stretched, its length *(*L*)* will increase, area *(*A*)* will decrease and hence the resistance *(*R*)* will increase. Similarly, when the conductor is compressed resistance *(*R*)* will decrease.

The electrical resistance strain gauges are classified as follows

- Unbonded type strain gauge,
- Bonded type strain gauge
  a) Wire type b) Foil type.

3. Semi conductor or Piezoresistive strain gauge.

Un bonded Resistance-strain Gauge

In un bonded type of strain gauge, the gird is unsupported. A fine wire is stretched out between two or more points which may form part of a rigid base which itself is strained as shown in Fig. Movement of the points A and B causes tensile strain in the resistance wire, and the change in its resistance is measured by a suitable circuit, to give a signal which is a function of strain. Generally four separate filaments are connected electrically to form a wheatstone bridge and arranged mechanically. so that filaments in adjacent bridge arms are subjected to strains of opposite sign as shown in Fig. (b) and (c). The resistance filaments under tension, are wrapped around electrically insulated pins. When movable platform is moved relative to fixed base, filament tensions are either increased or decreased and the corresponding resistance changes can be calibrated in term of strain. The assembly must provide a built-in prestrain in the grids greater than the maximum compressive strain to be sensed

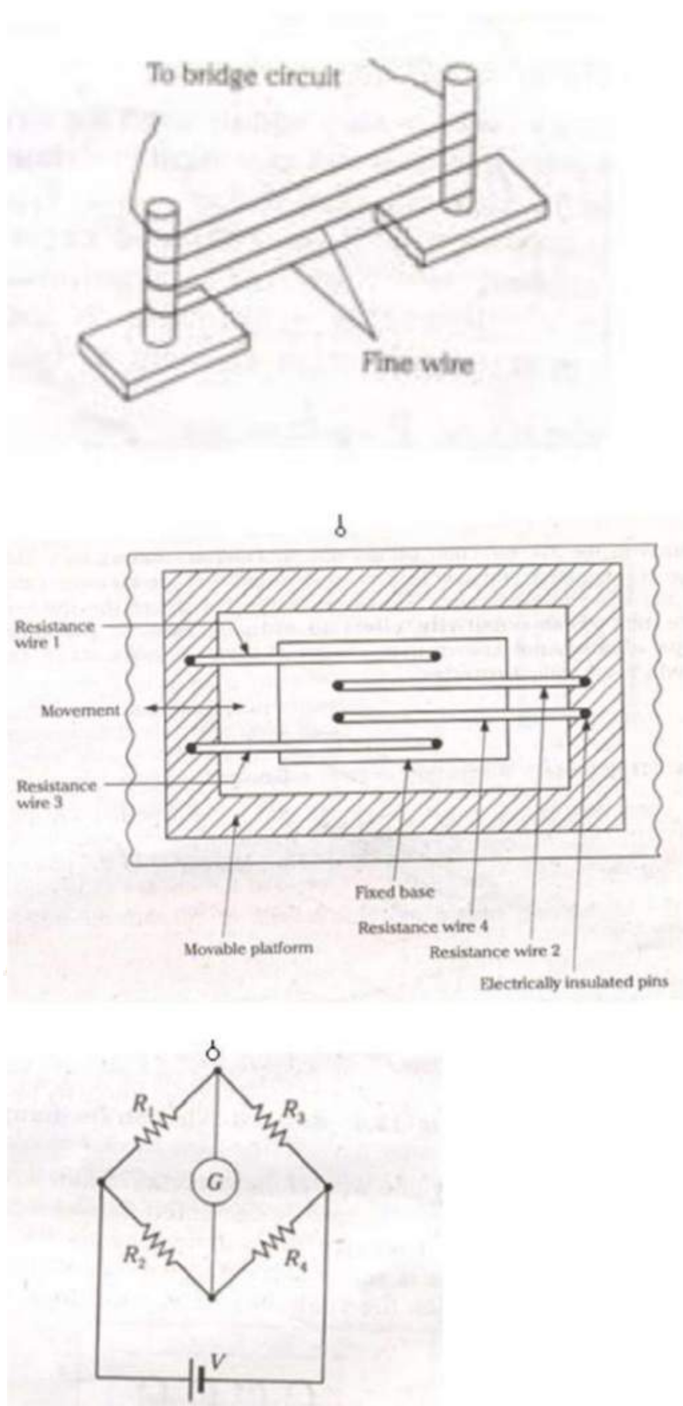


Fig: Unbounded Strain Gauges

Bonded Resistance-strain Gauge

The bonded gauge is a suitably shaped piece of resistance metal which is bonded close to the surface whose strain is to be measured. The exploded view Fig. shows a thin wire shaped into a grid pattern, which is cemented between thin sheets of insulating material such as paper or plastic. The grid can also be made from thin metal foil. The assembled gauge is bonded to the surface with a thin layer of adhesive and finally waterproofed with a layer of wax or lacquer. The grid experiences the same strain as the material to which it is bonded. The gauge is most sensitive to the stain along its axial direction *X-X* while the strain in the *Y-Y* direction occurs due to Poisson's ratio effect. This causes change of resistance, and may lead to an error of 2% in the measured strain when using the wire bonded gauge. However, in the foil gauge the thickened ends reduce this cross-sensitivity effect to virtually zero. If the direction of principal strain is not known then cluster of three or more strain gauges are used ,which are called **rosettes.**

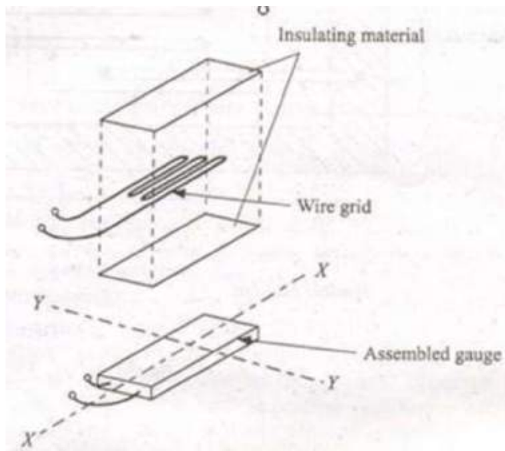


Fig.Bonded Wire strain Gauge

a). Wire type

It consists of a very fine wire of diameter 0.025 mm wounded into a grid shape as shown in fig 13.5 and the grid is cemented between two pieces of thin paper with plastic or ceramic backing. This is done in order that the grid of the wire may be easily handled. This is securely bonded with a suitable cement to the surface of the member in which the strain has to be measured

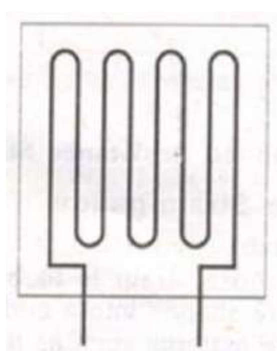


Fig. Wire Type Resistance-strain Gauge

b). Foil type resistance strain gauge

These gauges usually employs a foil less than 0.005 mm thick. The common form of foil type gauge consists of a metal foil grid element on a thin epoxy support. Epoxy filled with fiber glass is used for high temperatures. These foil type gauges are manufactured by printing on a thin sheet of metal alloy with an acid-resistant ink, and then the unprinted portion is etched away. Foil gauges have the advantages of improved hysteresis, better fatigue life and lateral strain sensitivity. It is thinner and more flexible, thus permitting it to be applied to fillets and sharply curved surfaces. The common wire or foil gauges are called metallic gauges.

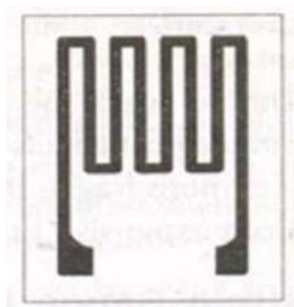


Fig. Single Element. Foil Type Resistance Strain Gauge

Semiconductor or Piezoresistive strain gauge

Semiconductor gauges are cut from single crystals of silicon or germanium in which are combined exact amounts of impurities such as boron which impart certain desirable characteristics. The same types of backing, bonding materials, and mounting techniques as those used for metallic gauges can be used for semiconductor gauges. When the gauge is bonded to a member which is strained, causes changes of current in the semi conductor material. The advantages of semiconductor gauges is their high strain sensitivity which allows very small strains to be measured accurately. A gauge whose electrical resistance increases in response to tensile strain is known as **positive or p-type** semiconductor gauge. On the other hand when the resistance decreases in response to tensile strain then it is known as **negative or n-type** semiconductor gauge.

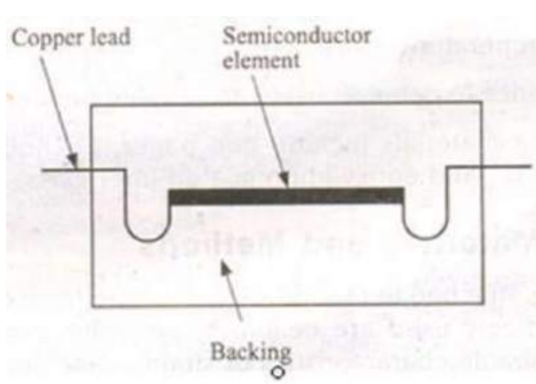


Fig. Semiconductor Strain Gauge

The semiconductor gauge consists of a rectangular filament of about 0.05 mm thick by 0.25

- wide and gauge length varies from 1.5 to 12 mm as shown in Fig. They are made as thin as possible as the breaking stress of the material rises the cross sectional area decreases and also the gauge can be bent to much smaller radius of curvature without fracture. In addition these gauges have very high temperature coefficients of resistance. The disadvantages of semiconductor gauges are:

- The output of the gauge is nonlinear with strain
2. Strain-sensitivity is dependent on temperature.
3. It is more fragile than the corresponding wire or foil element.
4. More expensive than ordinary metallic gauges

Strain Gauge Metals

The most common metals used for the manufacture of metallic strain gauges are: alloys of copper and nickel or, alloy of nickel, chromium and iron with other elements in small percentages. Gauges with resistances varying from 60 Ω to 5000 Ω are available. The current carried by the gauges for long periods is around 25 mA to 50 mA.

Strain Gauge Backing Materials

The strain-gauges are normally supported on some form of **backing** material. This provides not only the necessary electrical insulation between the grid and the tested material, but also a convenient carriage for handling the unmounted gauge. Certain types of gauges intended for high temperature applications use a **temporary** backing which will be removed when the grid is mounted. In this case, at the time of installation the grid is embedded in a special ceramic material that provides the necessary electrical insulation and high-temperature adhesion.

The desirable characteristics for backing materials are as follows :

- Minimum thickness consistent with other factors
- High mechanical and dielectric strength
- Minimum temperature restrictions
- Good adherence to cements used, and should be non-hygroscopic in nature.

Common backing materials include thin paper, phenolic-impregnated paper, epoxy-type plastic films, and epoxy-impregnated fiber glass.

Bonding Materials and Methods

Strain gauges are attached to the test item by some form of cement or adhesive. The adhesives commonly used are cellulose, phenolic, epoxy, cyanoacrylate, or ceramic etc. The desirable characteristics of strain-gauge adhesives are as follows:

- High mechanical and dielectric strength
- High creep resistance
- Minimum temperature restrictions and moisture absorption
- Good adherence with ease of application
- The capacity to set fast

Treatment Regarding Preparation and Mounting of Strain Gauges

The following steps should be stricltly followed for proper mounting of the strain gauges:

0. The surface on which the strain gauge has to be mounted must be properly cleaned by an emery cloth and bare base material must be exposed.
1. Various traces of grease or oil etc must be removed by using solvent like acetone.
2. The surface of the strain gauge coming in contact with the test item should also be free from grease etc.
3. Sufficient quantity of cement is applied to the cleaned surface and the cleaned gauge is then simply placed on it. Care should be taken to see that there should not be any air bubble in between the gauge and the surface. The pressure applied should not be heavy so that the cement may puncture the paper and short toe grid

4. The gauges are then allowed to set for at least eight or ten hours before using it. If possible a slight weight may be placed by keeping a sponge or rubber on the gauge.

5. After the cement is fully cured, the electrical, continuity of grid must be checked by ohm meter and the electrical leads may be welded.

Problems Associated with Strain-gauge Installations

The problems associated with strain-gauge installations generally fall into three categories.

(1) Temperature effects: Temperature problems arise because of differential thermal expansion between the resistance element and the material to which it is bonded. Semiconductor gauges offer the advantage that they have lower expansion coefficient than either wire or foil gauges. In addition to the expansion problem, there is a change in resistance of the gauge with temperature, which must be adequately compensated

(2) Moisture absorption: Moisture absorption by the paper and cement can change the electrical resistance between the gauge and the ground potential and thus affect the output resistance readings.

(3) Wiring Problems : This problem arise because of faulty connections between the gauge-resistance element and the external read out circuit. These problems may develop from poorly soldered connections or from inflexible wiring, which may pull the gauge loose from the test specimen or break the gauge altogether.

Gauge Factor or Strain Sensitivity

The electrical resistance of a metallic conductor varies directly as its resistivity and length and inversely as its cross-sectional area i.e.,

$$R = pL/A$$

The metallic crystal lattice forms a regular atomic pattern and the particular form of bonding between the atoms-metallic bonding-involves mutual sharing of all the valency electrons by all the atoms in the metal. Thus, current passes along a conductor in the form of directional motion of the electrons, called electron flow. The increased length and decreased area of a gauge under tensile strain. Accounts for part of the increase in resistance as the metallic lattice will suffer distortion but these changes alone do not fully account for the total resistance change, thus other changes in the metal lattice must also occur bringing about a change in the resistivity of the metal. This latter effect is an important consideration as it is well known that the resistivity of metals also changes with temperature.

The gauge factor G_F is the ratio of change of resistance *dR/R* to the change of gauge length *dL/L*, thus

$$G_F = \frac{dR / R}{dL / L}$$ where *R* is the nominal resistance of the gauge.

The gauge factor is supplied by the manufacturer and may range from 1.7 to 4 depending on the length of the gauge. Thus, provided that a means is available for measuring the change of resistance, strain can be determined and hence stress. An increase in gauge factor increases the sensitivity, but it is limited in metal gauges, largely because of the relatively low resistivity of metals, a limitation which is overcome in semiconductor strain gauges which have gauge factors of the order of ± 100 or more

Basic Wheatstone Resistance Bridge and Methods of Strain Measurement

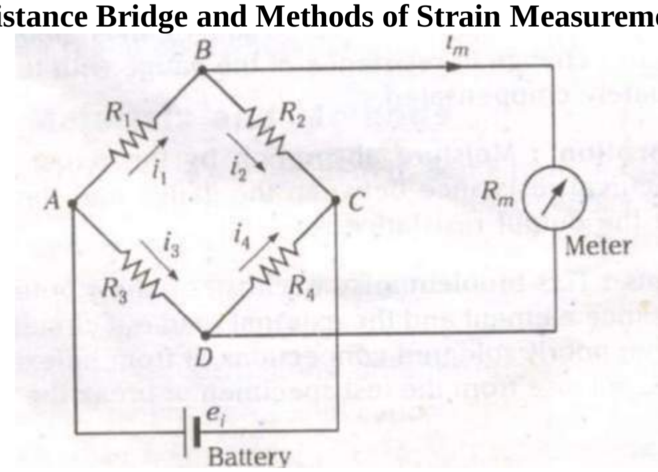


Fig. Basic Wheatstone Bridge Circuit

Electrical resistance type of strain gauges uses highly sensitive wheatstone bridge circuit for the measurement of strain. It consists of four resistance arms with a source of energy (battery) and a detector (meter) as shown in Fig. The basic principle of the bridge may be applied in two different ways the **null method** and the **deflection method.** Let us assume that the resistances have been adjusted so that the bridge is balanced (i.e $e_{BD} = 0$). In order for the bridge to balance, the ratio of resistances of any two adjacent arms must be equal to the ratio of resistances of the remaining two arms, taken in the same sense (i.e., $R_1 / R_3 = R_2 / R_4$). Suppose if anyone of the resistance say R_1 changes, it will unbalance the bridge, and a voltage will appear across *BD* causing a meter reading. The meter reading is an indication of the change in R_1 and actually can be utilized to compute this change. This method of measuring the resistance change is called the **deflection method,** since the meter deflection indicates the resistance change.

In the **null method,** one of the resistors is adjusted manually. Thus, if R_1 changes, causing a meter deflection, R_2 can be adjusted manually until its effect just cancels that of R_1 and the bridge is returned to its balanced condition.

The adjustment of R_2 is guided by the meter reading, R_2 is adjusted so that the meter returns to its null or zero position. In this case the numerical value of the change in R_1 is related directly to the change in R_2 required to effect balance.

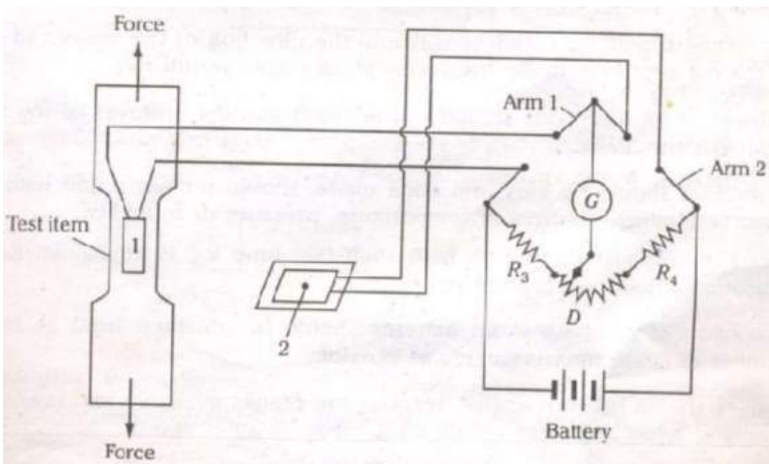


Fig. Wheatston Bridge Arrangement for strain Measurement

A wheatston resistance-bridge arrangement is particularly convenient for use with strain gauges because it may be easily adjusted to a null for zero strain, and it provides means for effectively reducing or eliminating the temperature effects. The Fig. shows a simple resistance bridge arrangement for strain measurement. In which an arm 1 consists of a strain-sensitive gauge mounted on the test item. Arm 2 is formed by a similar gauge mounted on a piece of unstrained material as that of the test item and placed near the test location so that the temperature will be same. Arms 3 and 4 contains fixed resistors selected for good stability and portions of slide-wire resistance, *D* is required for balancing the bridge.

In the deflection method of strain measurement continuous reading from one change of strain to another without rebalancing. This is convenient but less accurate as the bridge output tends to non-linearity if the strain is successively increased or decreased.

In the null balance method after each successive change in strain, the bridge is rebalanced. As the strain indicator will be calibrated under null balance conditions this method offers the highest accuracy while maintaining linear bridge output.

Requirements for Accurate Strain Measurement

Ideally the gauges used for strain measurement should conform to the following requirements :

- The gauge should be small in size and easy to mount on the component.
- The profile should be as low as possible so that it will respond in close agreement with the changes in the surface to which it is fixed.
- The gauge should be highly sensitive in the direction of the measured strain but of low sensitivity in the transverse plane (cross-sensitivity).
- Stiffness in all directions should not be such that the stiffness of the tested surface is modified.
- Calibration should be easy and once made, should remain stable with time, dynamic loading, changes of temperature, pressure or humidity.
- Speed of response should be high such that time log is negligible. Remote indication should not present difficulties.
- Evaluation of complex strain patterns should be obtained from as small a number of strain measurements as possible.
- Gauges should be inexpensive, reliable and readily available and available in variety of types and sizes to suit wide range of applications.
- Immersion in liquids should not modify performance.

A bonded resistance strain gauges satisfy many of these requirements.

Temperature Compensation

Resistance type strain gauges are sensitive to temperature changes. Any variation in the temperature influences the strain gauge readings as follows :

- The gauge factor of the strain gauge is affected by temperature owing to creep.
- The resistance of the strain gauge element varies with a change in the temperature.
- Strain may be induced in the gauge due to the differential expansion between· the test member and the strain gauge bonding material.

These temperature effects may be compensated by

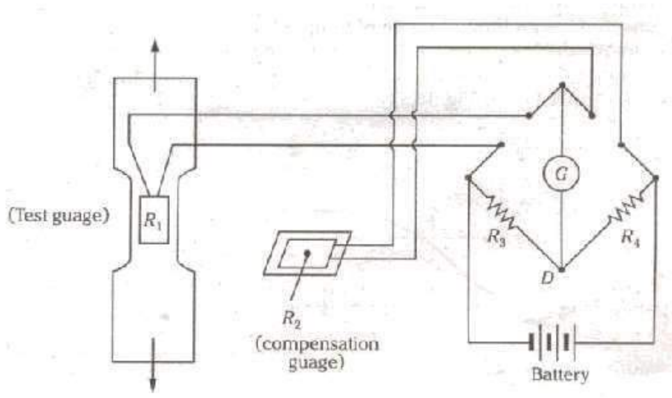
- Adjacent - arm compensating gauge
- Self - temperature compensation

a). Adjacent - Arm compensating gauge

Consider the bridge arrangement for strain measurement as shown in the

Fig. The condition for the bridge balance is given by

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$



If the strain gauges in arms 1 and 2 are alike and mounted on similar materials, and if both gauges experience the same resistance shift Rt, caused by temperature change, then

$$\frac{R_1 + \Delta R_t}{R_2 + \Delta R_t} = \frac{R_3}{R_4}$$

It is clear that any changes in the resistance of gauge 1 due to temperature is cancelled by similar changes in the resistance of gauge 2 and the bridge remains in balance and the output is unaffected by the change in temperature.