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COLLEGE OF ENGINEERING

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Department of Mechanical Engineering

Subject Code: ME-54

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Year &Semester: III - V

Subject Name: Engineering Metrology and Measurements

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UNIT I CONCEPT OF MEASUREMENT:

General concept – Generalised measurement system-Units and standards-measuring instruments- sensitivity, readability, range of accuracy, precision-static and dynamic response-repeatability-systematic and random errors-correction, calibration, interchangeability.

General concept – Generalised measurement system:

Measurement is a comparison of a given quantity with one of its predetermined standard values opted as a unit.

There are **two important requirements of the measurement:**

- The standards used for comparison must accurate and internationally accepted
- The apparatus or instrument and the process used for information must be provable

Need for measurement:

- To ensure that the part to be measured conforms to the established standard.
- To meet the interchangeability of manufacture.
- To provide customer satisfaction by ensuring that no faulty product reaches the customers.
- To coordinate the functions of quality control, production, procurement & other departments of the organization.
- To judge the possibility of making some of the defective parts acceptable after minor repairs.

Methods of Measurement:

1) **Method of direct measurement:** The value of the quantity to be measured is obtained directly without the necessity of carrying out supplementary calculations based on a functional dependence of the quantity to be measured in relation to the quantities actually measured.
Example: Weight of a substance is measured directly using a physical balance.

2) **Method of indirect measurement:** The value of the quantity is obtained from measurements carried out by direct method of measurement of other quantities, connected with the quantity to be measured by a known relationship. *Example:* Weight of a substance is measured by measuring the length, breadth & height of the substance directly and then by using the relation

$$\text{Weight} = \text{Length} \times \text{Breadth} \times \text{Height} \times \text{Density}$$

- 3) **Method of measurement without contact**: The sensor is not placed in contact with the object whose characteristics are being measured.
- 4) **Method of combination measurement closed series**: The results of direct or indirect measurement or different combinations of those values are made use of & the corresponding system of equations is solved.
- 5) **Method of fundamental measurement**: Based on the measurements of base quantities entering into the definition of the quantity.
- 6) **Method of measurement by comparison**: Based on the comparison of the value of a quantity to be measured with a known value of the same quantity (direct comparison), or a known value of another quantity which is a function of the quantity to be measured (indirect comparison).
- 7) **Method of measurement by substitution**: 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 (a type of direct comparison).
- 8) **Method of measurement by transposition** : The value of the quantity to be measured is in the beginning, balanced by a first known value A of the same quantity, then the value of the quantity to be measured is put in place of this known value and is again balanced by another known value B. If the position of the element indicating equilibrium is the same in both the cases, the value of the quantity measured is equal to A & B.
- 9) **Method of differential measurement**: Based on the comparison of the quantity to be measured with a quantity of the same kind, with a value known to be slightly difference from that of the quantity to be measured, and the measurement of the difference between the values of these two quantities.
- 10) **Method of measurement by complement**: The value of the quantity to be measured is complemented by a known value of the same quantity, selected in such a way that the sum of these two values is equal to a certain value of comparison fixed in advance.
- 11) **Method of measurement by interpolation** : It consists of determining value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying between two known values.
- 12) **Method of measurement by extrapolation** : It consists of determining the value of the quantity measured on the basis of the law of correspondence & known values of the same quantity, the value to be determined lying outside the known values.

Generalized measuring system:

The generalized measuring systems consist of the following common elements:

1. Primary sensing element
2. Variable conversion element
3. Variable manipulation element
4. Data transmission element
5. Data processing element
6. Data presentation element

Basic units in SI system:

1) For Length : Metre (m) which is equal to 1650763.73 wavelengths in vacuum of the red-orange radiation corresponding to the transition between the levels $2p_{10}$ & $5d_5$ of the krypton-86 atom. (Definition by wavelength standard)

By Line standard, Metre is the distance between the axes of two lines engraved on a polished surface of the Platinum – Iridium bar 'M' (90% platinum & 10% iridium) kept at Bureau of Weights & Measures (BIPM) at Sevres near Paris at 0°C, the bar kept under normal atmospheric pressure, supported by two rollers of at least 1 cm diameter symmetrically situated in the same horizontal plane at a distance of 588.9 mm (Airy points) so as to give minimum deflection.

2) For Mass: Kilogram (kg) which is equal to the mass of International prototype of the kilogram.

3) For Time : Second (s) which is equal to the duration of 9192631770 periods of the radiation corresponding to the transition between the hyper fine levels of the ground state of the Caesium 133 atom.

4) For Current : Ampere (A) is that constant current which, if maintained in two straight parallel conductors of infinite length of negligible circular cross section & placed one metre apart in vacuum would produce between these conductors, a force equal to 2×10^{-7} Newton per unit length.

5) For Temperature: Kelvin (K) is the fraction $1/273$ of thermodynamic temperature of the triple point of water.

6) For Luminous intensity: Candela (cd) is the luminous intensity in the perpendicular direction of a surface of $1/6,00,000 \text{ m}^2$ of a black body at the temperature of freezing platinum under a pressure of 101325 N/m^2 .

7) For amount of substance: Mole (mol) is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of Carbon-12.

Supplementary SI units:

1) For Plane angle: Radian (rad)

2) For Solid angle: Steradian (sr)

Derived SI units:

1) For Frequency: Hertz ($1 \text{ Hz} = 1 \text{ cycle per second}$)

2) For Force: Newton ($1 \text{ N} = 1 \text{ kg-m/s}^2$)

3) For Energy: Joule ($1 \text{ J} = 1 \text{ N-m}$)

4) For Power: Watt ($1 \text{ W} = 1 \text{ J/s}$)

Classification of Standards:

1) Line & End Standards: In the Line standard, the length is the distance between the centres of engraved lines whereas in End standard, it is the distance between the end faces of the standard. *Example:* for Line standard is Measuring Scale, for End standard is Block gauge.

2) Primary, Secondary, Tertiary & Working Standards:

Primary standard: It is only one material standard and is preserved under the most careful conditions and is used only for comparison with Secondary standard.

Secondary standard: It is similar to Primary standard as nearly as possible and is distributed to a number of places for safe custody and is used for occasional comparison with Tertiary standards.

Tertiary standard: It is used for reference purposes in laboratories and workshops and is used for comparison with working standard.

Working standard: It is used daily in laboratories and workshops. Low grades of materials may be used.

Measuring instruments:

A broad classification of the instruments based on the application mode of operation, manner of energy conversion and the nature of energy conversion and the nature of output signal is given below

1. Deflection and null type instruments
2. Analog and digital instruments
3. Active and passive instruments
4. Automatic and manually operated instruments
5. Contacting and non contacting instruments
6. Absolute and secondary instruments
7. Intelligent instruments.

Performance of instruments:

All instrumentation systems are characterized by the system characteristics or system response.

It consists of two basic characteristics such as static and dynamic. If the instrument is required to measure a condition not varying with time characteristics are called static while for a time varying process variable measurement, the dynamic characteristics are more important.

Static response:

The static characteristics of an instrument are considered for instruments which are used to measure an unvarying process conditions.

Dynamic response:

The behaviors of an instrument under such time varying input – output conditions called dynamic response of an instrument. The instrument analysis of such dynamic response is called dynamic analysis of the measurement system.

Dynamic quantities are two types

1. steady state periodic
2. Transient

Terms in Measurement:

Sensitivity:

Sensitivity of the instrument is defined as the ratio of the magnitude of the output signal to the magnitude of the input signal.

- It denotes the smallest change in the measured variable to which the instruments responds.
- Sensitivity has no unique unit. It has wide range of the units which dependent up on the instrument or measuring system.

Readability:

Readability is a word which is frequently used in the analog measurement. The readability is depends on the both the instruments and observer.

- Readability is defined as the closeness with which the scale of an analog instrument can be read.

The susceptibility of a measuring instrument to having its indications converted to a meaningful number. It implies the ease with which observations can be made accurately.

- For getting better readability the instrument scale should be as high as possible.

Accuracy:

Accuracy may be defined as the ability of instruments to respond to a true value of a measured variable under the reference conditions. It refers to how closely the measured value agrees with the true value.

Precision:

Precision is defined as the degrees of exactness for which an instrument is designed or intended to perform. It refers to repeatability or consistency of measurement when the instruments are carried out under identical conditions at a short interval of time.

It can also defined as the ability of the instruments to reproduce a group of the instruments as the same measured quantity under the same conditions.

Correction:

Correction is defined as a value which is added algebraically to the uncorrected result of the measurement to compensate to an assumed systematic error.

Calibration:

Calibration is the process of determining and adjusting an instruments accuracy to make sure its accuracy is with in manufacturing specifications.

It is the process of determining the values of the quantity being measured corresponding to a pre-established arbitrary scale. It is the measurement of measuring instrument. The quantity to be measured is the 'input' to the measuring instrument.

The 'input' affects some 'parameter' which is the 'output' & is read out. The amount of 'output' is governed by that of 'input'. Before we can read any instrument, a 'scale' must be framed for the 'output' by successive application of some already standardized (inputs) signals. This process is known as 'calibration'.

Interchangeability:

A part which can be substituted for the component manufactured to the small shape and dimensions is known a interchangeable part. The operation of substituting the part for similar manufactured components of the shape and dimensions is known as interchangeability.

Constant of a measuring instrument: The factor by which the indication of the instrument shall be multiplied to obtain the result of measurement.

Nominal value of a physical measure: The value of the quantity reproduced by the physical measure and is indicated on that measure.

Conventional true value of a physical measure: The value of the quantity reproduced by the physical measure, determined by a measurement carried out with the help of measuring instruments, which show a total error which is practically negligible.

Standard: It is the physical embodiment of a unit. For every kind of quantity to be measured, there should be a unit to express the result of the measurement & a standard to enable the measurement.

Types of Errors:**A) Error of Measurement:**

1) Systematic error: It is the error which during several measurements, made under the same conditions, of the same value of a certain quantity, remains constant in absolute value and sign or varies in a predictable way in accordance with a specified law when the conditions change.

The causes of these errors may be known or unknown. The errors may be constant or variable. Systematic errors are regularly repetitive in nature.

2) Random error: This error varies in an unpredictable manner in absolute value & in sign when a large number of measurements of the same value of a quantity are made under practically

identical conditions. Random errors are non-consistent. Random errors are normally of limited time duration.

3) Parasitic error: It is the error, often gross, which results from incorrect execution of measurement.

B) Instrumental error:

1) Error of a physical measure: It is the difference between the nominal value and the conventional true value reproduced by the physical measure.

2) Error of a measuring mechanism: It is the difference between the value indicated by the measuring mechanism and the conventional true value of the measured quantity.

3) Zero error: It is the indication of a measuring instrument for the zero value of the quantity measured.

4) Calibration error of a physical measure: It is the difference between the conventional true value reproduced by the physical measure and the nominal value of that measure.

5) Complementary error of a measuring instrument: It is the error of a measuring instrument arising from the fact that the values of the influence quantities are different from those corresponding to the reference conditions.

6) Error of indication of a measuring instrument: It is the difference between the measured values of a quantity, when an influence quantity takes successively two specified values, without changing the quantity measured.

7) Error due to temperature: It is the error arising from the fact that the temperature of instrument does not maintain its reference value.

8) Error due to friction: It is the error due to the friction between the moving parts of the measuring instruments.

9) Error due to inertia: It is the error due to the inertia (mechanical, thermal or otherwise) of the parts of the measuring instrument.

C) Error of observation:

1) **Reading error**: It is the error of observation resulting from incorrect reading of the indication of a measuring instrument by the observer.

2) **Parallax error**: It is the reading error which is produced, when, with the index at a certain distance from the surface of scale, the reading is not made in the direction of observation provided for the instrument used.

3) **Interpolation error:** It is the reading error resulting from the inexact evaluation of the position of the index with regard to two adjacent graduation marks between which the index is located.

D) Based on nature of errors:

1) Systematic error: (already discussed)

2) Random error: (already discussed)

3) Illegitimate error: As the name implies, it should not exist. These include mistakes and blunders, computational errors and chaotic errors. Chaotic errors are random errors but unlike the latter, they create chaos in the final results.

E) Based on control:

1) **Controllable errors:** The sources of error are known and it is possible to have a control on these sources. These can be calibration errors, environmental errors and errors due to non-similarity of condition while calibrating and measuring.

Calibration errors: These are caused due to variation in the calibrated scale from its normal value. The actual length of standards such as slip gauges will vary from the nominal value by a small amount. This will cause an error of constant magnitude.

Environmental (Ambient /Atmospheric Condition) Errors: International agreement has been reached on ambient condition which is at 20°C temperature, 760 mm of Hg pressure and 10 mm of Hg humidity. Instruments are calibrated at these conditions. If there is any variation in the ambient condition, errors may creep into final results. Of the three, temperature effect is most considerable.

Stylus pressure errors: Though the pressure involved during measurement is generally small, this is sufficient enough to cause appreciable deformation of both the stylus and the work piece. This will cause an error in the measurement.

Avoidable errors: These errors may occur due to parallax in the reading of measuring instruments. This occurs when the scale and pointer are separated relative to one another.

The two common practices to minimise this error are:

i) Reduce the separation between the scale and pointer to minimum.

ii) A mirror is placed behind the pointer to ensure normal reading of the scale in all the cases.

These avoidable errors occur also due to non-alignment of work piece centers, improper location of measuring instruments, etc.

2) **Non-controllable errors:** These are random errors which are not controllable.

UNIT II LINEAR AND ANGULAR MEASUREMENT:

Definition of metrology-Linear measuring instruments: Vernier, micrometer, interval measurement, Slip gauges and classification, interferometry, optical flats, limit gauges-Comparators: Mechanical, pneumatic and electrical types, applications.

Angular measurements: - Sine bar, angle dekor, Optical bevel protractor

Comparator:

It is a precision instrument employed to compare the dimension of a given component with a working standard (generally slip gauges). It does not measure the actual dimension but indicates how much it differs from the basic dimension (working standard).

Uses of Comparator:

- For calibrating the working gauges
- Used as working gauges
- Used as final inspection gauges
-

Essential characteristics of a good Comparator:

- Robust design and construction
- Linear characteristics of scale
- High magnification
- Quick in results
- Versatility
- Minimum wear of contact point
- Free from back lash
- Quick insertion of work piece
- Provision for compensation from temperature effects
- Provision for means to prevent damage during use.

Classification of comparators:

- 1) **Mechanical comparator**
 - a) Dial indicator
 - b) Johansson 'Mikroktor' comparator
 - c) Sigma comparator
 - d) Reed type mechanical comparator
- 2) **Optical comparator:**
 - a) Zeiss Ultra optimeter
 - b) Zeiss optotest comparator
- 3) Mechanical – Optical comparator

- 4) Electrical comparator
- 5) Fluid displacement comparator
- 6) Pneumatic comparator
 - a) Back pressure comparator
 - b) Flow – velocity Pneumatic comparator

In addition, the comparators used in standards room for calibration of gauges are:

- 7) Brookes Level comparator
- 8) Eden-Rolt 'Millionth' Comparator

Slip gauges:

These gauges are other wise called as Gauge blocks or Block gauges and are universally accepted as end standards of length in industry. Slip gauges are rectangular blocks of high grade steel (or tungsten carbide) with less co-efficient of thermal expansion. These blocks are highly hardened (more than 800 HV) through out to ensure maximum resistance to wear and are then stabilised by heating and cooling successively in stages so that the hardening stresses are removed. After hardening, they are subjected to lapping to a high degree of finish, flatness and accuracy. The cross sections of these gauges are 9 x 30 mm for sizes up to 10 mm and 9 x 35 mm for larger sizes. The dimension (height) is marked on one of the measuring faces of gauge blocks.

Wringing of Slip gauges:

The slip gauges are wrung together by hand through a combined sliding and twisting motion. The air gap between the gauge faces is expelled out and the adhesion is caused partly by molecular attraction and partly by atmospheric pressure. The gap between the two wrung slip gauges is only of the order of 0.00635 μ m which is negligible.

Selection of Slip gauges for required dimension:

Always start with the last decimal place and deduct this from the required dimension. Select the next smallest figure in the same way, find the remainder and continue this until the required dimension is completed. Minimum number of slip gauges should be selected to build up the given dimension.

Roller gauges:

Cylindrical rollers with their lengths equal to their diameters may be used as gauges, secondary to block gauges (slip gauges). These are produced to fine tolerances.

Limit gauges:

These are inspection tools for rigid design, without a scale, which serve to check the dimensions of manufactured parts. Gauges do not indicate the actual value of the inspected dimension on the

work. They can only be used for determining as to whether the inspection parts are made within the specified limits. These gauges are made up of suitable wear resisting steel and are normally hardened to not less than 750 HV and suitably stabilized and ground and lapped.

The 'Go' and 'No Go' gauges may be in the form of separate single ended gauge, or may be combined on one handle to form a double ended gauge. Progressive gauge is the single ended gauge with one gauging member having two diameters to the 'Go' and 'No Go' limits respectively.

Gauge Design:

Every gauge is a copy of the part which mates with the part for which the gauge is designed. For example, a bush is made which is to mate with a shaft; in this case, the shaft is the mating part. The bush is checked by a plug gauge which in so far as the form of its surface and its size is concerned, is a copy of the mating part (shaft).

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

'Go' limit: This is applied to upper limit of a shaft and lower limit of a hole.

'No Go' limit: This is applied to lower limit of a shaft and the upper limit of a hole.

Taylor's principle states that the 'Go' gauges should check all the possible elements of dimensions at a time (roundness, size, location, etc.) and the 'No Go' gauge should check only one element of the dimension at a time.

Based on Taylor's principle, 'Go' gauge is designed for maximum material condition and 'No Go' gauge is designed for minimum material condition.

Types of Limit Gauges:

The various types of limit gauges used for gauging internal diameters of holes are:

- 1) **Full form cylindrical plug gauge:** The gauging surface is in the form of an external cylinder. Generally a small circumferential groove is cut near the leading end of the gauge and the remaining short cylindrical surface is slightly reduced in order to act as a pilot.
- 2) **Full form spherical plug or disc gauge:** The gauging surface is in the form of a sphere from which two equal segments are cut off by planes normal to the axis of the handle.
- 3) **Segmental cylindrical bar gauge:** The gauging surface is in one of the two forms: one form; external cylindrical form from which two axial segments are made by lowering down surface at other places. the other form; external cylindrical form in which segments are formed by removing remaining material.
- 4) **Segmental spherical plug gauge:** It is similar to full form spherical plug gauge but has two equal segments cut off by planes parallel to the axis of the handle in addition to the segments cut off by planes normal to the axis of the handle.

- 5) **Segmental cylindrical bar gauge with reduced measuring faces**: It is similar to the segmental cylindrical bar gauge but has reduced measuring faces in a plane parallel to the axis of the handle.
- 6) **Rod gauge with spherical ends**: It has spherical end surfaces which form part of one single sphere.

The various types of limit gauges used for gauging external diameters of shaft are:

- 1) **Full form cylindrical ring gauge**: The gauging surface is in the form of an internal cylinder and whose wall is thick enough to avoid deformation under normal conditions of use.
- 2) **Gap gauge**: It has one flat surface and one cylindrical surface, the axis of the two surfaces being parallel to the axis of the shaft being checked. The surfaces constituting the working size may both be flat or both cylindrical also.

The gauges (for internal taper) are marked with a ring on the gauge planes another ring to indicate the minimum depth of internal taper. The distance between the two ring marks 'Z' corresponds to the permissible deviation of the gauge plane for particular taper. For testing the external taper of the tapered end shank, the ring gauge is inserted, as far as it goes with light pressure. At the extreme position, no part of the tang under test should extend beyond the surfaces A, B and C. The shank surfaces may however, lie flush with these surfaces.

Autocollimator:

It is an optical instrument used for the measurement of small angular differences. It is essentially an infinity telescope and a collimator combined into one instrument.

Principle of Autocollimator:

If a point source of light O is placed at the principal focus of a collimating lens, it will be projected as a parallel beam of light. If this parallel beam now strikes a plane reflector which is normal to the optical axis, it will be reflected back along its own path and refocused at the source O.

If the plane reflector is now tilted through some small angle ' δ ', the reflected parallel beam will turn through 2δ , and will be brought to a focus at O_1 , in the focal plane, a distance x from O. . If the ray passing through the geometric centre of the lens is considered, as it is, unaffected by refraction, it can be seen that $x = 2 \delta f$ mm, where f is the focal length of the lens.

The important points about this collimation of a beam of light are:

- a) The distance between the reflector and the lens has no effect on the separation x between source and image.
- b) For high sensitivity, i.e., a large value of x for a small angular deviation δ , a long focal length is required.

c) Although the distance of the reflector does not affect the reading x , if, at given value of δ , it is moved too far back, all of the reflected rays will miss the lens completely, and no image will be formed. Thus, for a wide range of readings, the minimum distance between lens and reflector is essential.

Angle Dekor:

In this system, an illuminated scale is set in the focal plane of the collimating lens outside the field of view of a microscope eyepiece. It is then projected as a parallel beam and strikes a plane reflector below the instrument. It is reflected, and refocused by the lens so that its image is in the field of view of the eyepiece. The image falls, not across a simple datum line, but across a similar fixed scale at right angles to the illuminated image. Thus, the reading on the illuminated scale measures angular deviations from one axis at 90° to the optical axis, and the reading on the fixed scale gives the deviation about an axis mutually at right angles to the other two. This feature enables angular errors in two planes to be dealt with or more important, to ensure that the reading on a setting master and on the work is the same in one plane, the error being read in the other. Thus, induced compound angle errors are avoided. The setup consists of a lapped flat and reflective base above which the optical details are mounted in a tube on an adjustable bracket.

In use, a master, either a sine bar or a group of combination angle gauges is set up on the base plate and the instrument is adjusted until a reading on both sides is obtained. It is now replaced by the work, a gauge block to give a good reflective surface being placed on the face to be checked. The gauge block can usefully be held in place with elastic bands. The work is now slowly rotated until the illuminated scale moves across the fixed scale, and is adjusted until the fixed scale reading is the same as on the setting gauge. The error in the work angle is the difference in the two readings on the illuminated scale.

Sine bar:

It is a precision measuring instrument and is an excellent example of combination of linear measurement and angular measurement when used in conjunction with gauge blocks (slip gauges). It consists of a bar carrying a suitable pair of rollers set a known centre distance. It is made of high carbon, high chromium corrosion resistant steel, suitably hardened, precision ground and stabilised. Relief holes are provided for easy handling of sine bar and for reducing the weight of the sine bar. It should be used on a grade A surface plate.

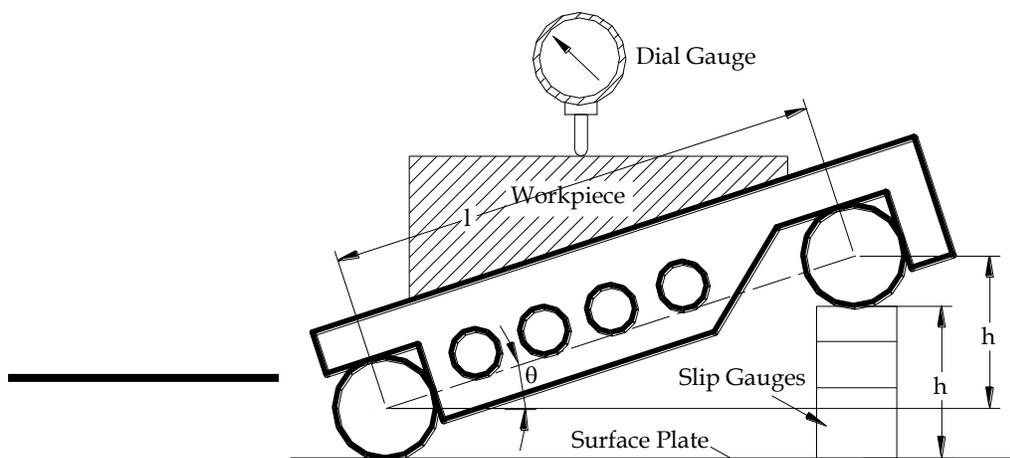


Fig. 2.24 Sine bar

If l is the linear distance between the axes of the rollers and h is the height of the slip gauges, then $\sin \theta = h/l$

The design requirements of a sine bar are as follows, and unless these are carefully maintained the order of accuracy of angular measurement will fall:

- i) The rollers must be of equal diameter and true geometric cylinders.
- ii) The distance between the roller axes must be precise and known, and these axes must be mutually parallel.
- iii) The upper surface of the beam must be flat and parallel with the roller axes, and equidistant from each.

Working principle of Sine bar:

The sine bar is first kept on the surface plate. The work piece is then placed on the sine bar such that the surface whose taper angle is to be measured is facing upwards. Place the set of slip gauges under one end of the roller of sine bar such that the upper surface of the work piece is approximately parallel with the table surface. Place the plunger of the dial gauge on the upper surface of the work piece. Take readings with the dial gauge at both ends and note their difference, noting which end of the work is low. Assuming that the end nearest the high end of the sine bar is low, then the slip gauges height must be increased by an amount equal to the difference in the dial gauge readings multiplied by the proportion of sine bar length to work length. For example, assuming that the end of a workpiece was 0.01mm low, the sine bar being 250 mm long and the work 100 mm long, then the required increase in height of slip gauge set will be $0.01 \times 250/100 = 0.025$ mm. This will not give an immediately correct setting from a first approximation, but it is much quicker than a trial and error method.

Note:

- a) No sine bar should be used to set off angles greater than 45° , as beyond this angle, the errors due to the centre distance of rollers, and slip gauges, being in error are much magnified.
- b) Slip gauges should be kept beneath the setting roller attached to the end which is with taper shape but not beneath the hinge roller. This is to enable the slip gauges not to hit the bottom surface of sine bar.

- c) If the work piece is of large size, then the sine bar is kept upside down on the surface of the work piece as shown below.
- d)

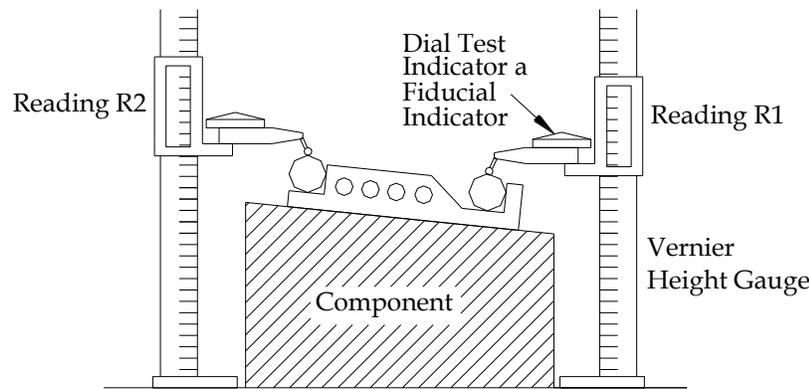


Fig. 2.25 Use of Sine bar with large work piece

The height over the rollers can be measured by a vernier height gauge; using a dial test gauge mounted on the anvil of height gauge to ensure constant measuring pressure.

Sine Centre:

It is the Sine bar carrying centres to hold conical work piece. A typical Sine centre set up is shown in next page.

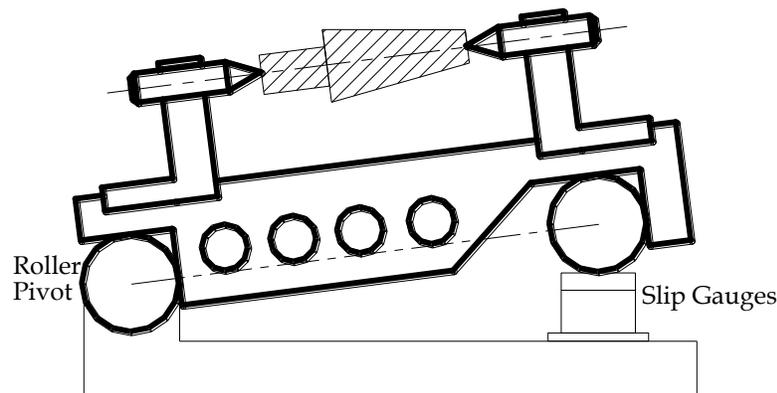


Fig.2.26 Sine Centre

The principle of setting is the same as in the sine bar, although a hazard to be avoided is of the work and centres not being co-axial. To overcome this, the work piece should be rotated on the centres until the maximum dial gauge reading is at the top. The angle is calculated from the slip gauges set in this condition, and then the work piece turned through 180° and the process is repeated. The mean of the two angles determined will be the semi-angle of the work piece, although it must be pointed out that any work which runs out to a measurable extent would probably be considered as sub-standard in quality and be rejected on this account.

Sine table:

It is the most convenient and accurate design for heavy work piece. The equipment consists of a self contained sine bar hinged at one roller and mounted on its datum surface. The table is quite rigid one and the weight of unit and work piece is given fuller and safer support. The sine bar may be safely swung to any angle from 0° to 90° by pivoting it about its hinged end.

Bevel Protractor:

It is the simplest angle measuring instrument. A simple vernier bevel protractor with its various elements is shown in fig.2.27. The body of the bevel protractor is designed in such a way that its back is flat and there are no projections beyond its back. The base plate is attached to the main body and an adjustable blade is attached to a circular plate containing vernier scale. The main body carries a main scale graduated in degrees. The adjustable blade which is capable of rotating freely about the centre of the main scale engraved on the body of the instrument can be locked in any position. An acute angle attachment is provided at the top. The base of the base plate is made flat so that it could be laid flat upon the work piece. The blade can be moved along throughout its length and can also be reversed. The acute angle attachment can be readily fit into the body and clamped in any position.

Universal Bevel protractor: The protractor dial is slotted to hold a blade which can be rotated with the dial to the required angle. It can also be adjusted independently to any desired length. The blade can be locked in any position. This instrument is capable of readings precisely within 5 minutes.

Optical Bevel protractor: This instrument is capable of taking readings within 2 minutes of an arc. The interval circular scale is graduated in divisions of 10 minutes of arc. Readings are taken with the help of optical magnifying system which is an integral part of the instrument.

Uses of Bevel protractor:

The bevel protractors can be used to test the flatness, squareness, parallelism, straightness, angular measurements, etc.

Types of bevel protractors:

As per IS practice, there are two bevel protractors, namely;

- 1) Mechanical Bevel protractor

- a) with vernier and acute angle attachment
 - b) without vernier and acute angle attachment
- 2) Optical Bevel protractor

UNIT III FORM MEASUREMENT:

Measurement of screw threads- Thread gauges, floating carriage micrometer- measurement of gears- tooth thickness-constant chord and base tangent method- Gleason gear testing machine- radius measurement- surface finish, straightness, flatness and roundness measurements.

SCREW THREAD MEASUREMENT:**Introduction:**

Screw threads have to perform two functions namely

- Transmission of power and motion
- Acts as a temporary fastener
- External threads
- Internal thread

Terminology of screw threads:

- Screw thread
- Crest
- Root
- Flank
- Depth of thread
- Lead
- Pitch
- Helix angle
- Flank angle
- Included angle
- Major diameter
- Minor diameter
- Addendum
- Dedendum

Error in screw thread:

- Major diameter error
- Minor diameter error
- Effective diameter error

- Flank angle error
- Pitch error.
 1. Progressive error
 2. Periodic error
 3. Drunken error
 4. Irregular errors
 5. Effect of pitch error.

MEASUREMENT OF VARIOUS ELEMENTS OF THREAD:

Measurement of major diameter:

- Micrometer
- Bench micrometer

Measurement of minor diameter:

- Using taper parallels
- Using rollers

Measurement of effective diameter:

- Thread micrometer method
- One wire method
- Two wire method
- Three wire method

Pitch measurement:

1. Pitch measuring machine
2. Tool maker's microscope
3. Screw pitch gauge

Thread form and flank angle measurement:

THREAD GAUGES:

Introduction:

Thread geometry procedure cannot be used in normal production work

Hence gauges are used where the basis is mating of surfaces.

Thread gauge classification:

- First group
- Second group

Form of thread gauges:

- Plug ring gauges
- Ring screw gauges
- Caliper screw gauges

Gauge wear:**Screw thread gauge tolerance:****Adjustable thread gauges:**

- The Wick man Adjustable thread gauge
- Roller type Adjustable thread gauges.

GEAR MEASUREMENT:**Introduction:**

- Gears are mechanical drives.
- Gears are used to transmit power. Gear in the form of a toothed wheel.

Types of gears:

- Spur gear
- Helical gear
- Spiral gear
- Bevel gear
- Worm and Worm wheel
- Rack and pinion

Gear terminology:

- Tooth Profile
- Base circle
- Pitch circle diameter
- Pitch
- Addendum
- Dedendum
- Pressure angle (α)

- Circular pitch
- Clearance(C)
- Blank diameter
- Face, Flank, Top land
- Back lash
- Module (m)
- Pitch point
- Tooth thickness.

Gear errors:

- Adjacent pitch error
- Cumulative pitch error
- Profile error
- Cyclic error
- Periodic error
- Run out
- Radial run out
- Axial run out

Gear measurement (Spur gear):

- Concentricity
- Alignment
- Hardness

- **Pith:**
 1. Point to point measurement
 2. Direct angular measurement
- Run out
- Lead
- Backlash

- **Profile:**
 1. Optical projection method
 2. Involute measuring machine
 3. Tooth displacement method.

- **Tooth thickness:**
 1. Constant chord method
 2. Base tangent method

Gleason gear testing machine:**RADIUS MEASUREMENT:****Radius measurement methods:**

- Radius measurement using surface plate and rollers. (external radius)
- Radius measurement of concave surface (internal radius)

Radius measurement using surface plate and rollers (external radius):

1. Surface plate
2. Two rollers
3. Vernier caliper
4. C- Clamp

Radius measurement of concave surface (internal radius):

1. Depth micrometer
2. Slip gauges

SURFACE FINISH MEASUREMENT:**Introduction:**

Contain degree of surface finish is required for the proper functioning of the working surface.

Types of surface finish:

- Nominal surface
- Rough surface
- Wavy surface

Elements of surface texture:

- Surface roughness
- Profile
- Flaw, Law, Waviness
- Cut off length

Datum of surface finish measurement:

The M system (The mean line system)

The E system (The envelope system)

Numerical value for surface finish:

1. Peak –to- valley height
2. The depth of smoothness
3. The mean depth
4. Centre line average
5. Root mean square.
- 6.

Methods of measuring surface finish:

- Visual inspection
- Touch method
- Scratch method

Comparative or qualitative methods of surface finish measurement:

Direct methods:

- Stylus probe instrument
- Tomlinson surface meter
- Taylor Hobson "Talysurf"
- Profilometer

STRAIGHTNESS MEASUREMENT:

Straightness:

Is a geometrical shape.

Straightness measuring instrument:

- Straight edge
- Spirit level
- Auto – Collimator

FLATNESS MEASUREMENT:

Flatness:

A surface is said to be flat within a given range of measurement.

Flatness testing:

If the test surface is large, then it is tested for flatness using a spirit level or an auto collimator.

Procedure to determine flatness:

A surface can be considered to be a collection of a large number of lines.

Flatness testing by interferometry:

Monochromatic light source and a set of optical flats are used.

ROUNDNESS MEASUREMENT:**Roundness or circularity:**

Is the radial uniformity of work surface measured from the centre line of the work piece.

Methods of measuring roundness:

- V- block and dial indicator method
- Roundness measuring machine

UNIT IV LASER AND ADVANCES IN METROLOGY:

Precision instruments based on laser – principle- laser interferometer- application in linear, angular measurements and machine metrology- Coordinate measuring machine (CMM)- constructional features- types, applications- digital devices- computer aided inspection.

PRECISION INSTRUMENT BASED ON LASER:**Introduction:**

“Light Amplification by Stimulated Emission of Radiation”.

- Laser metrology
- Laser telemetric system
- Laser and led based distance measuring instruments
- Scanning laser gauge
- Photodiode array imaging

- Diffraction pattern technique
- Laser triangulation sensors
- Two frequency laser interferometer
- Gauge wide diameter from the diffraction pattern formed in a laser.

Principle of laser:

The principle involved in laser is when the photon emitted during stimulated emission has the same energy, phase and frequency as the incident photon.

- Interferometry
- Uses laser in Interferometry

Laser Interferometry:

Two frequency laser source

Optical elements:

Beam splitters

Beam benders

Retro reflectors.

Laser heads measuring receiver

Measurement display

- **Types of AC Laser interferometer (ACLI)**

Standard interferometer

Single beam Interferometry

Laser interferometer:

- AC laser interferometer
-

Other types of interferometers:

Dual frequency laser interferometer

Twyman-Green Interferometer.

Applications:

- Linear instruments
- Angular measurements

Machine tool metrology:

- introduction
- Geometrical test
 - Static test
 - Dynamic test
- Practical test

Various geometrical checks:

Straightness

Flatness

Parallelism, equidistance and coincidence

Squareness of straight line and plane

Rotations

Movement of all the working components

Spindle test

- Machine tool test
- Alignment tests on lathe
- Alignment tests on milling machine
- Alignment tests for pillar type drilling machine
- Acceptance tests for surface grinders

COORDINATE MEASURING MACHINE (CMM):**Types of measuring machines:**

- Length bar measuring machine
- Newall measuring machine
- Universal measuring machine
- Co-ordinate measuring machine
- Computer controlled Co-ordinate measuring machine

Types of CMM:

- Cantilever type
- Bridge type
- Horizontal boring type
- Vertical boring type

Features of CMM:**Causes of errors in CMM:****Calibration of Three CMM:****Performance of CMM:****Application of CMM:**

- Is ideally suited
- Determine dimensional accuracy of the components
- It can be used for sorting tasks
- Suited for economic viability
- Suited for development of new products

Advantages of CMM:

- Increase inspection rate
- Uniform inspection quality
- Reduction in setup time
- Reduction in off line

Disadvantages of CMM:

- The probe may have run out
- Errors in digital systems.

CNC -- CMM:

- Stationary granite measuring table
- Length measuring machine
- Air bearing
- Control unit
- Software
-

Digital Devices:**Computer based inspection:****Computer aided inspection using robots:**

UNIT V MEASUREMENT OF MECHANICAL PARAMETERS:

Force, torque, power ; - Pneumatic, hydraulic and electrical type – Pressure measurement-
Flow measurement : Venturi, Orifice, Rota meter, Pitot tube

Temperature: Bimetallic strip, pressure thermometers, thermocouples, pyrometers, electrical resistance thermistor

MEASUREMENT OF FORCE:**Introduction:**

“Force is a basic engineering parameter”.

Direct methods:

- Equal arm balance
- Analytical balance
- Unequal arm balance
- Multiple level system
- Pendulum scale

In-Direct methods:

- Accelerometers
- Electromagnetic balance

Load cells:

“Load cells are the force transducer for weighing purposes”

Elastic load members:

- Coil springs
- Proving rings
- Load cell type
- Bourdon tube
- Bellows
- Shear type load cell
- Hydraulic load cell
- Pneumatic load cell
- Strain gauge load cell
- Pressductor

- Electronic Weighing System

MEASUREMENT OF TORQUE:

- **Torque reaction methods**

Cradled power source

Cradled power absorber

- Proney Brake

Torque measurement using Torsion bars:

- Optical method
- **Capacitive method:**
Cross section through shaft and sensor
Longitudinal method
- Laser- optic method
- Proximity method
- Stroboscope method
- Magnetostrictive method
- SAW method

MEASUREMENT OF POWER:

“Power is generally done by dynamometers”

Types of dynamometers:

- Absorption **dynamometers**
- Driving **dynamometers**
- Transmission **dynamometers**

Mechanical Dynamometers:

“Mechanical energy is converted in to heat through dry friction between the

Wooden brake blocks and the flywheel of the machine.

D.C. Dynamometers:

“Is usable as an absorption as well as transmission dynamometers”

Eddy current:

- Hydraulic dynamometer
- Diaphragm
- Typical diaphragm pressure gauge

Capsule pressure sensor:**Bellows pressure sensors:****Bourdon tube pressure sensors:****Performance of CMM:**

- Spiral coil
- Helical coil

Piezoelectric sensors:**Tactile sensors:****MEASUREMENT OF POWER:****Types of flow meters:**

- Mechanical flow meters
- Electrical flow meters

Kinds of instrument (Flow):

- Quantity meters
- Flow meters

Types of Flow meters:**Obstruction meters:**

- Orifice
- Venturi
- Nozzle
- Variable area meters

Velocity Probes:

- Static pressure probes
- Total pressure probes

Special methods:

- Turbine type meters
- Magnetic flow meters
- Sonic flow meters
- Vortex shedding phenomenon
- Hot wire anemometers
- Pitot tube
- **Ultrasonic flow meters:**
 - Doppler frequency method
 - Transit time method

Other flow measurements:

- Current Meter
 - Cup type
 - Screw or propeller
- Floats
- LDA

MEASUREMENT OF TEMPERATURE:

“Is a measure of velocity of fluid particles”

- Standard temperature and pressure (STP)
- Normal temperature and pressure (NTP)
- Temp.Scale

Instruments to measure temperature:

- Filled system in temperature measurement
- Bimetallic strip
- Pressure thermometers
- Thermocouples
- Calibration of temp measuring devices
- Electrical resistance thermometer
- Pyrometer
 - Total radiation pyrometer
 - Optical pyrometer

Computer based inspection:**Computer aided inspection using robots:**

