

SCAD ENGINEERING COLLEGE  
ME6504 Metrology and Measurements

*Unit 1*  
**Basic Concepts of  
Measurements**

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*Metrology* is the name given to the science of pure measurement. *Engineering Metrology* is restricted to measurements of length & angle.

**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.

**Precision & Accuracy of Measurement**

*Precision* : It is the degree which determines how well identically performed measurements agree with each other. It is the repeatability of the measuring process. It carries no meaning for only one measurement. It exists only when a set of observations is gathered for the same quantity under

identical conditions. In such a set, the observations will scatter about a mean. The less is the scattering, the more precise is the measurement.

**Accuracy** : It is the degree of agreement between the measured value and it's true value. The difference between the measured value & the true value is known as '*Error of measurement*'. Accuracy is the quality of conformity.

To distinguish the Precision from Accuracy, the following simple example can be said. A repaired needle-watch will give Precision readings (same time) all the times, but will give Accurate readings (correct time) only 2 times in a day.

Of the two, Precision & Accuracy, only the former is required though the latter is usually sought for in a measuring process. Achieving high precision is easier & cheaper than achieving high accuracy. If the measuring instrument is of high precise & is calibrated for its error, then the true value can be easily obtained from the measured average value after deducting the instrument error. So, high precision - instrument is required rather than the high accurate - instrument, considering cost and reliability of the measuring instrument.

However, of the two, precision & accuracy, which one is more vital, depends on the situation. For example, for a carpenter entrusted with the job of fitting a shelf into cupboard, precision is more important. This can be achieved only when he uses the same scale to measure the cupboard & the board for shelf. It hardly matters whether his scale is accurate or not. If however, such a board is ordered for purchase from a pre-cut board from outside, accuracy becomes more vital than precision. He must measure the size of the cupboard very accurately before placing the order.

'Interchangeability' is the call of the day. Not only a nut from its lot should fit on any bolt of its lot, both

manufactured in the same plant by same men, but also, it should fit on a bolt from some other manufacturer. The simplest way to maintain compatibility of parts for interchangeable manufacture is by adopting accuracy in measurement everywhere.

### **Factors affecting the accuracy of measuring system**

a) Factors affecting the standard of measurement:

- ❖ co-efficient of thermal expansion
- ❖ elastic properties
- ❖ stability with time
- ❖ geometric compatibility

b) Factors affecting the work piece to be measured:

- ❖ co-efficient of thermal expansion
- ❖ elastic properties
- ❖ arrangement of supporting work piece
- ❖ hidden geometry
- ❖ surface defects such as scratches, waviness, etc.

c) Factors affecting the inherent characteristics of instrument:

- ❖ repeatability & readability
- ❖ calibration errors
- ❖ effect of friction, backlash, etc
- ❖ inadequate amplification for accuracy objective
- ❖ deformation in handling or use

d) Factors affecting person:

- ❖ improper training / skill
- ❖ inability to select proper standards / instruments
- ❖ less attitude towards personal accuracy measurements

e) Factors affecting environment:

- ❖ temperature, humidity, atmospheric pressure, etc.
- ❖ cleanliness
- ❖ adequate illumination
- ❖ heat radiation from lights / heating elements

## Reliability of Measurement

If a measuring instrument is not precise, it will give different values for same dimension, when measured again and again. Such an instrument thus is considered non-trust worthy. The first and fundamental requirement of any good measuring instrument to be effective is that it should have adequate repeatability or precision. The measuring instrument which gives precise (same) values all the times is far reliable than the instrument which gives accurate (true) values rarely but not precise values all the times. The precise value can be easily converted into accurate value by taking the constant error of precision instrument into account.

If the precision measuring instrument is highly calibrated for its error of measurement & the constant error of measurement is known in advance, then the accurate (true) value can be obtained as follows ;

$$\text{True value} = \text{Measured value} \pm \text{Error}$$

Hence, calibrated & precision measuring instrument is more reliable and hence is used in metrological laboratories.

## 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.

### **Terms in Measurement**

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

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

3) 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.

4) 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.

5) Calibration: 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 standardised (inputs) signals. This process is known as 'calibration'.

6) Sensitivity of instrument: The ability of the instrument to detect small variation in the input signal.

7) Readability of instrument: 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.

## **Standards of Measurement**

a) FPS System: In this system, the units of length, mass, time, temperature are Foot (or Yard), Pound (or Slug), Second, Rankine (or Fahrenheit) respectively. It is common in English speaking countries and is developed by Britain.

b) Metric System: It is a decimal system of weight & measurement is based on the Metre as the unit of length. It was first used in France. Its basic unit is Metre.

CGS prescribes Centimetre, Gram, Second for length, weight & time respectively.

MKS prescribes Metre, Kilogram, Second for length, weight & time respectively.

MKSA (Giorgi) system added Ampere, the unit of electrical current to MKS system.

c) SI system: In 1960, General Conference on Weights & Measures (CGPM) formally gave the MKSA, the title "Systems International d' unites" with the abbreviation 'SI' (also called as International System of units). In SI, the main departure from the traditional metric system is the use of 'Newton' as the unit of Force. India by Act of Parliament No.89, 1956 switched over to SI system.

### **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  $0^{\circ}\text{C}$ , 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  $2 \times 10^{-7}$  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  $101325 \text{ N/m}^2$ .

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  $0.012 \text{ kg}$  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.

### **Errors in Measurement**

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 as an absolute error or as a relative error.

1) Absolute error: It is the algebraic difference between the measured value and the true value of the quantity measured. It is further classified as;

a) True absolute error: It is the algebraic difference between the measured average value and the conventional true value of the quantity measured.

b) Apparent absolute error: It is the algebraic difference between one of the measured values of the series of measurements and the arithmetic mean of all measured values in that series.

2) Relative error: It is the quotient of the absolute error and the value of comparison (which may be true value, conventional true value or arithmetic mean value of a series of measurements) used for the calculation of that absolute error.

*Example :* If the actual (true) value is 5,000 and estimated (measured) value is 4,500, find absolute and relative errors.

*Solution :* Absolute error = True value - Measured value  
= 5,000 - 4,500  
= 500 units

Relative error = Absolute error / Measured value  
= 500 / 4,500  
= 0.11 (11%)

## 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 centres, improper location of measuring instruments, etc.

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

### **Causes of Errors**

1) **Errors due to deflection (Errors of supports):** When long bars are supported as beam, they get deformed or deflected. This elastic deformation occurs because long bars, supported as to ends sags under their own weight. The amount of deflection depends upon the positions of the supports. This problem was considered by Sir G.B. Airy, who showed that the positions of the supports can be arranged to give a minimum error. Slope and deflection at any point can be calculated from the theory of bending.

Two conditions are considered, as follows; For a bar of length L, supported equidistant from the centre on supports by distance 'l' apart, then for no slopes at the ends,  $l = 0.577 L$  (suitable for line standards and end bars). For minimum deflection of the beam,  $l = 0.544 L$  (suitable for straight edges)

2) Errors due to misalignment: Abbe's principle of alignment should be followed in measurements to avoid cosine errors, sine errors, etc. According to Abbe's principle, "*the axis or line of measurement of the measured part should coincide with the line of measuring scale or the axis of measurement of the measuring instrument*".

The combined Cosine and Sine error occurs if the micrometer axis is not truly perpendicular to the axis of the work piece as shown below.

Similarly, the same error occurs when measuring an end gauge in the horizontal comparator. If the gauge is not supported so that its axis is parallel to the axis of measuring anvils, or if its ends, though parallel to each other, are not square with the axis. This is shown below.

The above combined Cosine & Sine errors can be avoided by using gauges with spherical ends. If the axis of the two spherical end gauges are not aligned, the error in length will occur this is equal to (a+b) as shown below.

From the above figure, it is known that

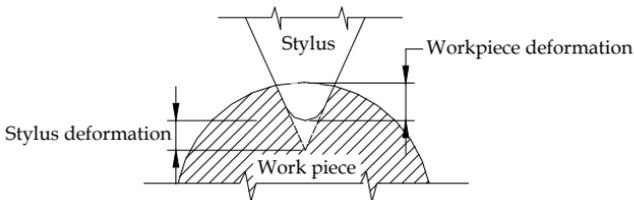
$$\begin{aligned}
 a &= R_1 (1 - \cos \theta) \\
 &= R_1 (1 - \sqrt{1 - \sin^2 \theta}) \\
 &= R_1 \left[ 1 - \sqrt{1 - \frac{h^2}{(R_1 + R_2)^2}} \right] \\
 &= R_1 \left[ 1 - 1 + \frac{h^2}{2(R_1 + R_2)^2} \right]
 \end{aligned}$$

$$= \frac{R_1 h^2}{2(R_1 + R_2)^2} \text{ very nearly}$$

$$\text{Similarly, } b = \frac{R_2 h^2}{2(R_1 + R_2)^2}$$

$$\begin{aligned} \text{Therefore, } (a+b) &= \frac{(R_1 + R_2)h^2}{2(R_1 + R_2)^2} \\ &= \frac{h^2}{2(R_1 + R_2)} \end{aligned}$$

3) Error due to contact pressure: The variations in the contact pressure between the anvils of the instrument and the work piece being measured produce considerable difference in reading. The deformation of the work piece and the anvils of instrument depend upon the contact pressure and the shape of the contact surfaces.



4) Error due to vibrations: The errors due to vibrations can be avoided by

- a) locating the laboratory away from the sources of vibration
- b) keeping slipping cork, felt, rubber pads under the gauge
- c) mounting the gauge pedestal or floor sections on tar mastic
- d) putting a gauge on a surface plate resting in turn on a heavy plate.

5) Error due to dirt: 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.

6) Error due to poor contact: To avoid this type of error, the gauge with lesser area of contact should be used while measuring irregular or curved surface and correct pressure should be applied while making the contact.

7) Error due to wear in gauges: Wear of measuring surfaces of instrument occurs due to repeated use. This error can be avoided by hardening the surfaces or by using chrome plated parts for contact surfaces.

8) Error due to looseness : Looseness can be tested by setting the gauge contact on gauge anvil and zeroing the meter; and then applying finger pressure or a light tap to each location, where looseness might be expected and noting the reading again.

9) Error due to location: Figure drawn below shows how imperfect location of surface causes errors.

$$\text{Reading} = a + b = c \tan \theta + t \sec \theta$$

$$\text{Error} = a + b - t = c \tan \theta + t (\sec \theta - 1)$$

10) Error due to parallax effect: Parallax error occurs when;

- i) the line of vision is not directly in line with the measuring scale.
- ii) the scale and the pointer are separated from each other.

In the figure shown below,  $d$  = separation of scale and pointer

$D$  = distance between pointer and observer's eye

$\theta$  = angle which the line of sight makes with the normal to scale

## *Unit 2*

# Linear & Angular Measurements

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### Measurement of Engineering Components

Gauges are used mainly to check the Engineering Components produced on mass scale, where the job is usually handled by semi-skilled workers. This type of measurement cannot be relied upon where accuracy is more important. The different methods and instruments used for precision & accurate (linear & angular) measurements are discussed in this unit.

### 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 'Mikrokator' 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

### **Basic principle of operation of comparator**

The comparator is first adjusted to zero on its dial or recording device with a gauge block in position. The gauge block (slip gauges) is of dimension which the work piece

should have. The work piece to be checked is then placed in position and the comparator gives the difference in dimension in relation to the gauge block. The dimension of the work piece may be less than, equal to, or greater than the standard dimension. The difference in the dimension will be shown in the dial or in the recording device of the comparator.

**Mechanical Comparators:** Various mechanical comparators are discussed next.

### **Dial indicator**

It is the simplest type of mechanical comparator. It consists of a base with a rigid column and an arm carrying dial gauge (dial indicator). The arm can be adjusted vertically up and down along the column. The arm can be swivelled and the dial gauge also can be locked in any position along its arm. The whole set up is placed on the surface plate which is used as a datum surface.

### **Johansson 'Mikrokator'**

A thin metal strip carries at the centre of its length a very light glass tube pointer. From the centre, the strip is permanently twisted to form right and left hand helices. One end of the strip is fixed to the adjustable cantilever strip, the other being anchored to the spring strip elbow, one arm of which is carried on the measuring plunger. As the measuring plunger moves, either upwards or downwards, the elbow acts as a bell crank lever and causes the twisted strip to change its length and thus further twist, or untwist. Hence, the pointer at the centre of the twisted strip rotates an amount proportional to the change in length of the strip. It can be shown that the ratio

$$\frac{d\theta}{d\ell} = \text{amplification} = -\frac{9.1 \ell}{W^2 n}$$

where

$l$  is the length of twisted strip, measured along its neutral axis.

$W$  is the width of twisted strip

$n$  is the number of turns

$\theta$  is the twist of mid point of strip with respect to end.

The setup is diagrammatically shown below

## **Sigma comparator**

The plunger, mounted on a pair of slit diaphragms to give a frictionless linear movement, has mounted upon it a knife edge which bears upon the face of the moving member of a cross strip hinge. It consists of the moving component and a fixed member, connected by thin flexible strips alternately at right angles to each other. It can be shown that if an external force is applied to the moving member, it will pivot, as would a hinge, about the line of intersection of the strips. Attached to the moving member is an arm which divides into a 'Y' form. If the effective length of this arm is  $L$  and the distance from the hinge pivot to the knife edge is  $x$ , then the first stage of the magnification is  $L/x$ . To the extremities of the 'Y' arm is attached a phosphor-bronze strip which is passed around a drum of radius ' $r$ ' attached to the pointer spindle. If the pointer is of length ' $R$ ' then the second stage of magnification is  $R/r$  and the magnification is  $LR/(xr)$ .

## **Sigma Mechanical Comparator**

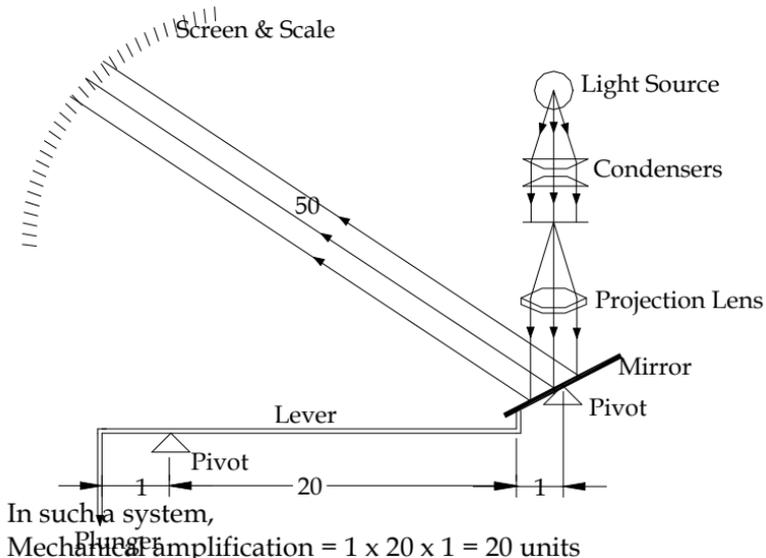
The magnification can be adjusted by slackening one and tightening the other screw attaching the knife edge to the plunger and thus adjusting distance 'x', while a range of instruments of differing magnifications can be produced by having drums of different radii 'r' and suitable strips.

The other interesting features of this instrument are:

- a) More safety
- b) Dead beat readings can be obtained
- c) Fine adjustment is possible
- d) Parallax error is avoided
- e) Constant measuring pressure by the use of magnet plunger.

### Mechanical - Optical Comparator

In this system, a small displacement of the measuring plunger is amplified first by a mechanical system consisting of pivoted levers. The amplified mechanical movement is further amplified by a single optical system involving the projection of an image. The setup is shown below.



**Fig. 2.4 Principle of Optical Comparator**

Optical amplification =  $50 \times 2 = 100$  units  
Total amplification =  $20 \times 100 = 2000$  units

### **Pneumatic Comparator**

In this system, no physical contact is made either with the setting gauge or the part being measured, and that internal dimensions may be readily measured, not only with respect to tolerance boundaries, but also geometric form. Further, the system lends itself to the inspection of a single, or a number of dimensions simultaneously, either during or immediately after the operating cycle of a machine tool.

### **Pneumatic Comparator**

Back-pressure (Pneumatic) comparator: It uses a water manometer for the indication of back pressure. It consists of a vertical metal cylinder filled with water upto a certain

level and a dip tube immersed into it upto a depth corresponding to the air pressure required. A calibrated manometer tube is connected between the cylinder and control orifice as shown in fig. 2.5.

The air from its normal source of supply is filtered and passes through a flow valve. Its pressure is then reduced and maintained at a constant value by a dip tube into a water chamber, the pressure value being determined by the head of the water displaced, excess air escaping to atmosphere. The air at reduced pressure then passes through the control orifice, and escapes from the measuring orifice. The back pressure in the circuit is indicated by the head of water displaced in the manometer tube. The tube is graduated linearly to show changes of pressure resulting from changes in dimension 'd'. Amplifications of up to 50000 are obtainable with this system.

### **Slip gauges**

These gauges are otherwise 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 coefficient of thermal expansion. These blocks are highly hardened (more than 800 HV) throughout 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  $0.00635 \mu\text{m}$  which is negligible.

*When taking the slip gauges apart, the gauges are slid apart.*

Procedure for wringing:

- i) The slip gauges are first cleaned using a lint free cloth or chamois leather or a cleansing tissue.
- ii) One slip gauge is then placed at  $90^\circ$  to other by using light pressure and then it is rotated until the blocks are brought in one line.

Indian Standards on Slip gauges:

Grade II : Workshop grade for rough checks.

Grade I : Used for setting up sine bars, checking gap gauges and setting dial test indicators to zero.

Grade 0 : Used in tool room and inspection department.

Grade 00 : Kept in standard room and used for high precision work such as checking Grade I and Grade II slip gauges.

Applications of Slip gauges:

- Direct precise measurement
- For calibration of vernier callipers, micrometers, and other measuring instruments.
- For setting up a comparator to a specific dimension
- For angular measurement in conjunction with sine bar
- For checking gap between parallel locations such as in gap gauges or between two mating parts.

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 stabilised 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.

A typical limit plug gauge and limit snap gauge are shown in the next page.

## **Limit Plug Gauge**

## **Limit Snap Gauge**

### **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.

**Problem :** Design a general type GO and NO GO gauge for components having 20H7f8 fit. Given :

- (i)  $i$  (micron) =  $0.45 (D)^{1/3} + 0.001 D$
- (ii) fundamental deviation of 'f' shaft =  $-5.5 (D)^{0.41}$  (D is in mm)
- (iii) 20mm falls in the diameter step of 18mm to 30 mm.
- (iv)  $IT_7 = 16 i$
- (v)  $IT_8 = 25 i$

**Solution :** From the standard table, it is found that 20 lies between 18 & 30 Hence,  $D = \sqrt{D_1 \times D_2} = \sqrt{18 \times 30} = 23.2379$  mm

$$\begin{aligned} i &= 0.45 (D)^{1/3} + 0.001 D \text{ microns} \\ &= 0.45 (23.2379)^{1/3} + 0.001 (23.2379) \\ &= 1.3074 \text{ microns} \end{aligned}$$

$$\begin{aligned} IT_7 &= 16 i \text{ microns} \\ &= 16 \times 1.3074 \text{ microns} \\ &= 20.918 \text{ microns} = 0.021 \text{ mm} \end{aligned}$$

$$\begin{aligned} IT_8 &= 25 i \text{ microns} \\ &= 25 \times 1.3074 \text{ microns} \\ &= 33 \text{ microns} = 0.033 \text{ mm} \end{aligned}$$

$$\begin{aligned}
 \text{fundamental deviation of shaft} &= -5.5 D^{0.41} \text{ microns} \\
 &= -5.5 \times 23.2379^{0.41} \\
 &= -20 \text{ microns} = -0.02 \text{ mm}
 \end{aligned}$$

Lower deviation of H - hole = zero

$$\text{Hence, Limits for hole } 20 H_7 = 20 + 0.021, + 0.000 \text{ mm}$$

Limits for shaft 20 f<sub>8</sub> :

$$\begin{aligned}
 \text{Higher Limit of shaft} &= 20 + \text{fundamental deviation} \\
 &= 20 - 0.02 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 \text{Lower Limit of shaft} &= 20 + \text{funda deviation} - IT_8 \\
 &= 20 - 0.02 - 0.033 \\
 &= 20 - 0.053 \text{ mm}
 \end{aligned}$$

$$\text{Hence, Limits for shaft } 20 f_8 = 20 - 0.02, -0.053 \text{ mm}$$

Gauge tolerance for plug gauge = 10% of work tolerance (hole)

$$= 0.1 \times 0.021 = 0.0021 \text{ mm}$$

Wear allowance for plug gauge = 10% of gauge tolerance (hole)

$$= 0.1 \times 0.0021 = 0.00021 \text{ mm}$$

Gauge tolerance for snap gauge = 10% of work tolerance (shaft)

$$= 0.1 \times 0.033 = 0.0033 \text{ mm}$$

Wear allowance on snap gauge = 10% of gauge tolerance (shaft)

$$= 0.1 \times 0.0033$$

$$= 0.00033 \text{ mm}$$

*For Hole :*

$$\begin{aligned}
 \text{Upper limit of Go plug gauge} &= 20 + 0.0021 + 0.00021 \\
 &= 20 + 0.00231 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 \text{Lower limit of Go plug gauge} &= 20 + 0.00021 \text{ mm} \\
 &= 20 + 0.00021 \text{ mm}
 \end{aligned}$$

$$\text{Now, upper limit of No-Go plug gauge} = 20.021 + 0.0021 = 20.0231 \text{ mm}$$

$$\text{lower limit of No-Go plug gauge} = 20.021 \text{ mm}$$

For Shaft :

$$\begin{aligned}\text{Upper limit of Go snap gauge} &= 20.00 - 0.02 - 0.00033 \\ &= 20 - 0.02033 \text{ mm}\end{aligned}$$

$$\begin{aligned}\text{Lower limit of Go snap gauge} &= 20.00 - 0.02 - 0.0033 - 0.00033 \\ &= 20.00 - 0.02363 \text{ mm}\end{aligned}$$

$$\begin{aligned}\text{Now, upper limit of No-Go snap gauge} &= 19.947 = 19.947 \text{ mm} \\ &= 20 - 0.0530 \text{ mm}\end{aligned}$$

$$\begin{aligned}\text{lower limit of No-Go snap gauge} &= 19.947 - 0.0033 \text{ mm} \\ &= 20 - 0.0563 \text{ mm}\end{aligned}$$

### Types of Limit Gauges

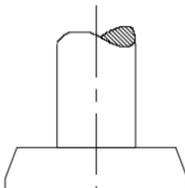
The various types of limit gauges used for gauging internal diameters of holes are:

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.

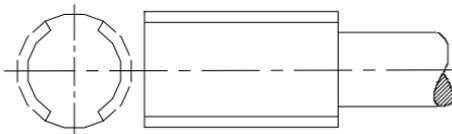


**Fig. 2.8 Full form cylindrical plug gauge**

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.

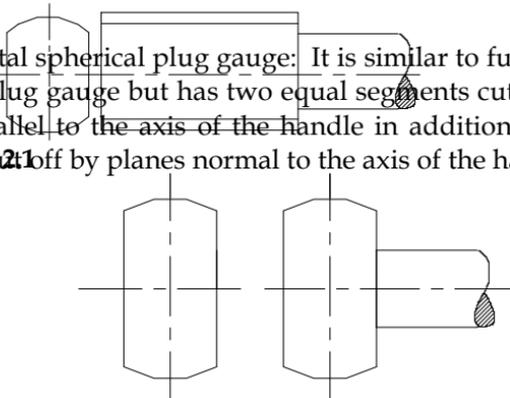


3) Segmental cylindrical bar gauge: The gauging surface is in one of the two forms: one form; external cylindrical form from which two axial segments are made by lowering down surface at other places. (Fig.2.10) the other form; external cylindrical form in which segments are formed by removing remaining material. (Fig. 2.11).



**Fig.2.10 Segmental cylindrical bar gauge**

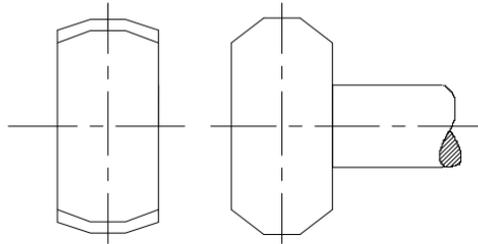
4) Segmental spherical plug gauge: It is similar to full form spherical plug gauge but has two equal segments cut off by planes parallel to the axis of the handle in addition to the segments cut off by planes normal to the axis of the handle.



**Fig. 2.12 Segmental Spherical plug gauge**

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.



**Fig.2.13 Segmental cylindrical bar gauge**

6) Rod gauge with spherical ends: It has spherical end surfaces which form part of one single sphere.



**Fig. 2.14 Rod gauge with spherical ends**

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.

### **The 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 as in fig.2.17. 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 ' $\delta$ ', the reflected parallel beam will turn through  $2\delta$ , and will be brought to a focus at  $O_1$ , in the focal plane, a distance  $x$  from O. This effect is shown in fig.2.18. 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.

## **Point source of light in focal plane of a collimating 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  $\delta$ , a long focal length is required.
- c) Although the distance of the reflector does not affect the reading  $x$ , if, at given value of  $\delta$ , 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.

## **Projection of a point source being reflected form an inclined reflector**

## The Microptic Auto-Collimator

The concept of projecting the image of a point source of light is not practical, so in this instrument a pair of target wires in the focal plane of the collimating lens is illuminated from behind and their images are projected. Fig.2.19 shows the optical arrangement of the instrument, the projected image striking a plane reflector and the reflection of the image being brought to a focus in the plane of the target wires.

The wires and their images are viewed simultaneously in an eyepiece, which also contains a pair of adjustable setting wires and a scale. The setting wires are adjusted by a micrometer until they straddle the reflected image (not the target wire). The scale is read to the nearest  $\frac{1}{2}$  min, and the micrometer drum which moves the wires  $\frac{1}{2}$  min per revolution, is divided into 60 equal parts. Thus, 1 division of the micrometer drum represents an angular deflection of the reflector of one  $\frac{1}{2}$  sec of arc. With care, and given a rigid mounting for the instrument, repeat readings of 0.2 sec are possible. The instrument normally has a range of readings of 10 min of arc up to a range of 10 m. It is invaluable in machine tool alignment testing or for any large scale measurement involving small angular deviations.

## **The Microptic Auto-collimator**

### **The Angle Dekkor**

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  $90^\circ$  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. The optical system and the view in the eyepiece are shown in next page

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.

### **Optical system of Angle dekkor**

To check the squareness of the work piece, no master is necessary. If gauge blocks are held against both faces and the angle dekkor adjusted to give a reading, it will be found to consist of two mirror images (due to double reflection) of the illuminated scale, superimposed on each other. The misalignment of the readings of these images will be double the error in the right angle. The type of view obtained in the eyepiece when the angle dekkor is used in this manner is shown below. Initially, it is difficult to read, but with practice, the method provides a quick and accurate means of testing squareness. Although this instrument is not so sensitive as the auto-collimator, it is extremely useful for a wide range of angular measurements at short distances. It is used in tool room inspection. Readings direct to 1 min over a range of 50 min may be taken, and by estimation, readings down to about 0.2 min are possible.

## **View in Angle dekkor eye piece**

Combination angle gauges:

These combination angle gauges are used as master in angle-dekkor. They are simply blocks, hardened and lapped to precise angles so that they can be wrung together. Unlike gauge blocks, it must be realised that angular blocks can be added or subtracted as shown below.

### **Addition & Subtraction of combination angle gauges.**

The values of the angles used are arranged in a modified geometric progression with a common ratio of 3 as shown

below in a table. These thirteen gauges, along with a square block, each of whose angles are calibrated, enable any angle between  $0^\circ$  and  $90^\circ$  to be realised in increments of 3 sec. The gauges are used either in combination with each other or may be subtracted from the square block.

The gauges, which are manufactured to the same high standards as gauge blocks, are stabilised, have 'wringing' characteristics, and are calibrated to a high degree of precision. The reflective properties of their lapped surfaces make them particularly suitable for use with collimating type of instruments.

**Table: Nominal values of combination angle gauges.**

Degrees	Minutes	Decimal minutes
1	1	0.05
3	3	0.1
9	9	0.3
27	27	0.5
41		

### **The Alignment Telescope**

It consists of two units, a collimating unit and a focusing telescope, the body of each of which is ground truly cylindrical and to a precise outside diameter. Further, the optical axis and the mechanical axis are coincident. Thus, each unit may be fit directly or by precision bushing into two bearings, a considerable distance apart, and sightings taken from the telescope unit to the collimating unit.

The collimating unit contains a light source and condensers, in front of which is placed an angular graticule in the focal plane of the collimating lens. This graticule scale is thus projected as a parallel beam of light. If the telescope is focussed at infinity, it will bring to a focus the parallel rays and the angular scale is seen against the datum lines in the

telescope. Thus, angular misalignment in both planes is determined. The collimating unit also contains, in front of the collimating lens, a second graticule also having two scales at right angles to each other. If the focus of the telescope is now shortened, this graticule is seen against the datum lines of the telescope and linear displacements are measured directly. In this case, the collimating lens is simply providing even illumination for the displacement graticule, and the angular misalignment graticule cannot be seen because it is so far out of focus. A line diagram of the collimating unit and the view in the telescope eyepiece at both conditions of focus is shown in fig. 2.23.

## **The Alignment Telescope**

It should be noted that distance has no effect on the angular misalignment readings, as these are taken using the collimating principle. However, this is not so with the linear displacement scale. The telescope only magnifies the apparent size of the scale as seen by the eye. Thus, as the distance is increased, the size of the displacement scale is reduced and its 'readability' is also reduced. Thus, the accuracy of this reading diminishes with distance.

### 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.

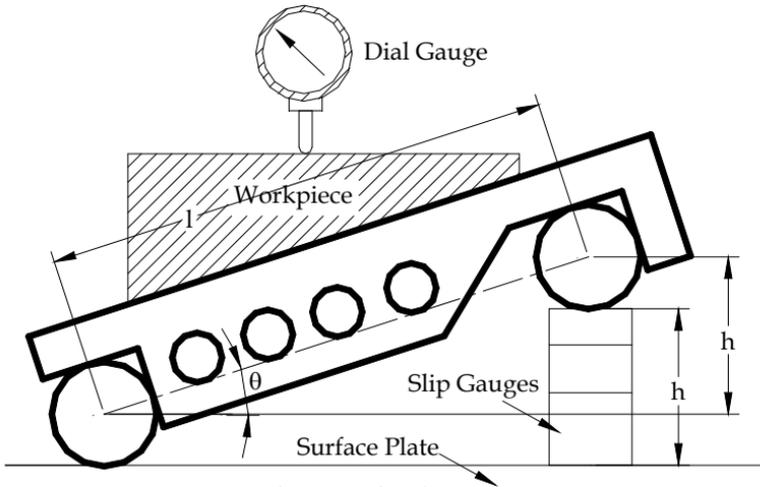


Fig. 2.24 Sine bar

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:

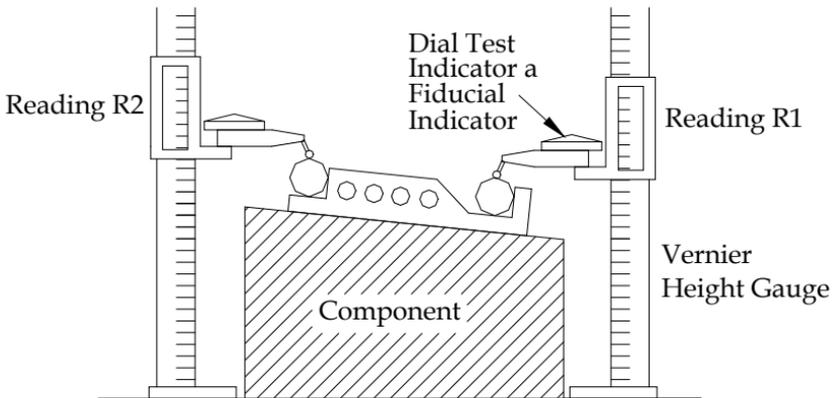
- i) The rollers must be of equal diameter and true geometric cylinders.
- ii) The distance between the roller axes must be precise and known, and these axes must be mutually parallel.
- iii) The upper surface of the beam must be flat and parallel with the roller axes, and equidistant from each.

### **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  $45^\circ$ , 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)

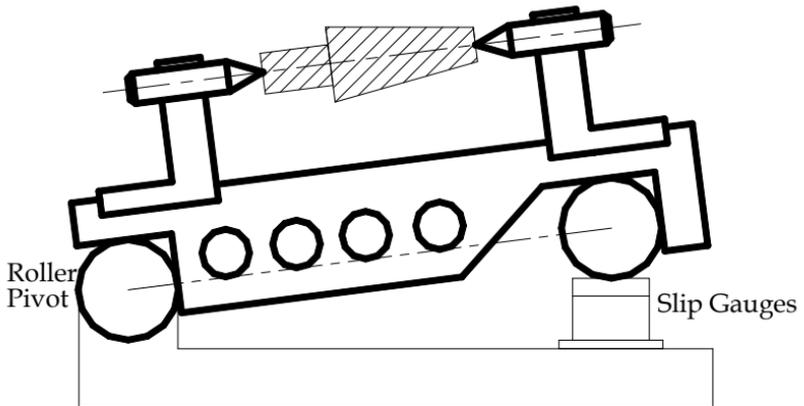


**Fig. 2.25 Use of Sine bar with large work piece**

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  $180^\circ$  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  $0^\circ$  to  $90^\circ$  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.

### **Vernier Bevel Protractor**

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