# MODULE 1

## INTRODUCTION TO METROLOGY AND LINEAR MEASUREMENT AND ANGULAR MEASUREMENTS



## OBJECTIVES

Students will be able to

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

# 1. Introduction to Metrology

## 1.1 Definition of Metrology

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

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

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

## 1.2 Objectives of Metrology

The basic objectives of metrology are;

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

## 1.3 Need of Inspection

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

## Fundamental methods of Measurement

Two basic methods are commonly employed for measurement.

(a) Direct comparison with primary or secondary standard.

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

## Direct comparison

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

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

• It is easy and quick.

## Drawbacks of Direct comparison methods

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

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

• Also measurements by direct methods are not always possible, feasible and practicable. Example: Measurement of temperature, Measurement of weight.

## Indirect comparison

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

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

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

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

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

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

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

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

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

## 1.4 Classification of measuring instruments and system

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

They are;

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

### Primary measurement

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

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

### Secondary measurement

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

### Tertiary measurement

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

### Accuracy

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

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

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

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

Va =Actual value

Vr = max or min result value.

Vfs = full scale reading

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

## Precision

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

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

## 1.5 Errors in Measurements

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

## Error classification

Classified in different ways

- Systematic error
- Random errors
- Illegitimate errors

## Systematic errors

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

• May result from improper condition or procedures employed.

## Calibration errors

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

## Human errors

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

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

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

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

**(1) Systematic or fixed errors:**

(a) Calibration errors

(b) Certain types of consistently recurring human errors

(c) Errors of technique

(d) Uncorrected loading errors

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

**(2) Random or Accidental errors:**

(a) Errors stemming from environmental variations

(b) Certain types of human errors

(c) Due to Variations in definition

(d) Due to Insufficient sensitivity of measuring system.

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

**(3) Illegitimate errors:**

(a) Blunders or Mistakes

(b) Computational errors

(c) Chaotic errors

## 1.6 Definition of Standards

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

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

## Role of Standards

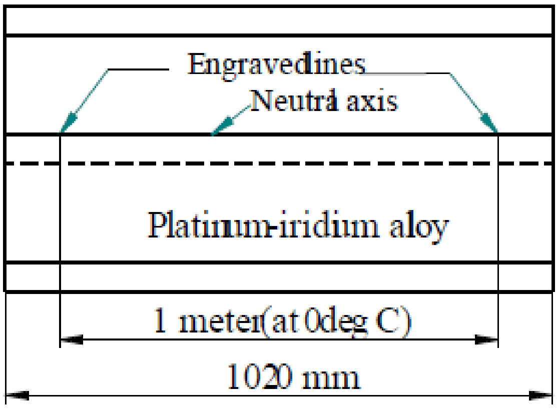
The role of standards is to achieve uniform, consistent and repeatable measurements throughout the world. Today our entire industrial economy is based on the interchangeability of parts the method of manufacture. To achieve this, a measuring system adequate to define the features to the accuracy required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

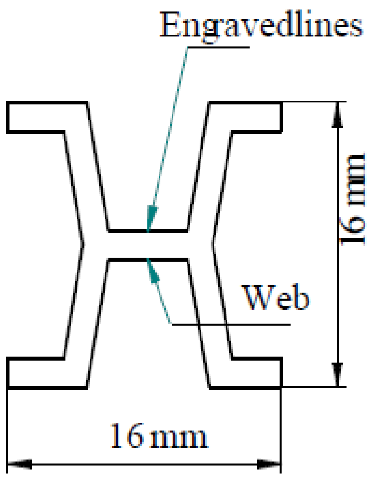
## STANDARDS OF LENGTH

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

## International Prototype meter

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






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

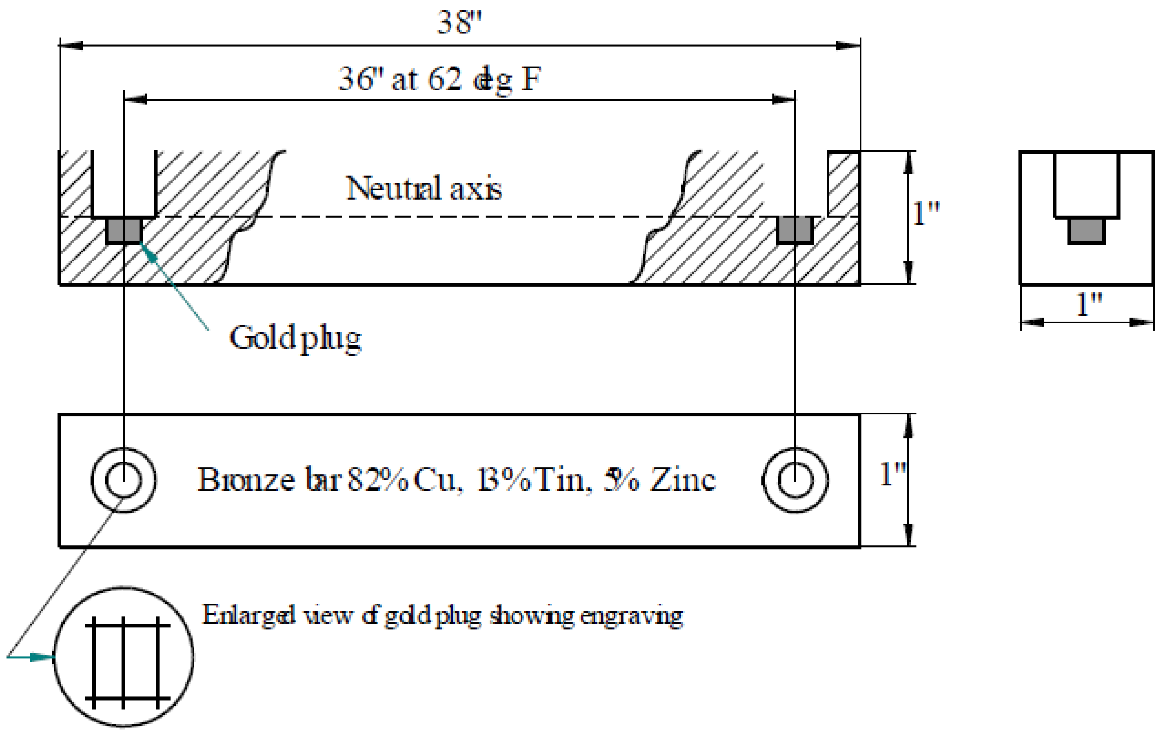
## Imperial Standard yard

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

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

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

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




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

## Disadvantages of Material length standards

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

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

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

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

## Light (Optical) wave Length Standard

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


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

## Advantages of using wave length standards

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

## 1.7 Subdivision of standards

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

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

## Primary standards

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

## Secondary standards

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

### Teritiary standards

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

### Working standards

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

Sometimes, standards are also classified as;

- Reference standards (used as reference purposes)
- Calibration standards (used for calibration of inspection & working standards)
- Inspection standards (used by inspectors)
- Working standards (used by operators)

## 1.8 LINE STANDARDS

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

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

### Characteristics of Line Standards

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

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

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

## END STANDARDS

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

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

## Characteristics of End Standards

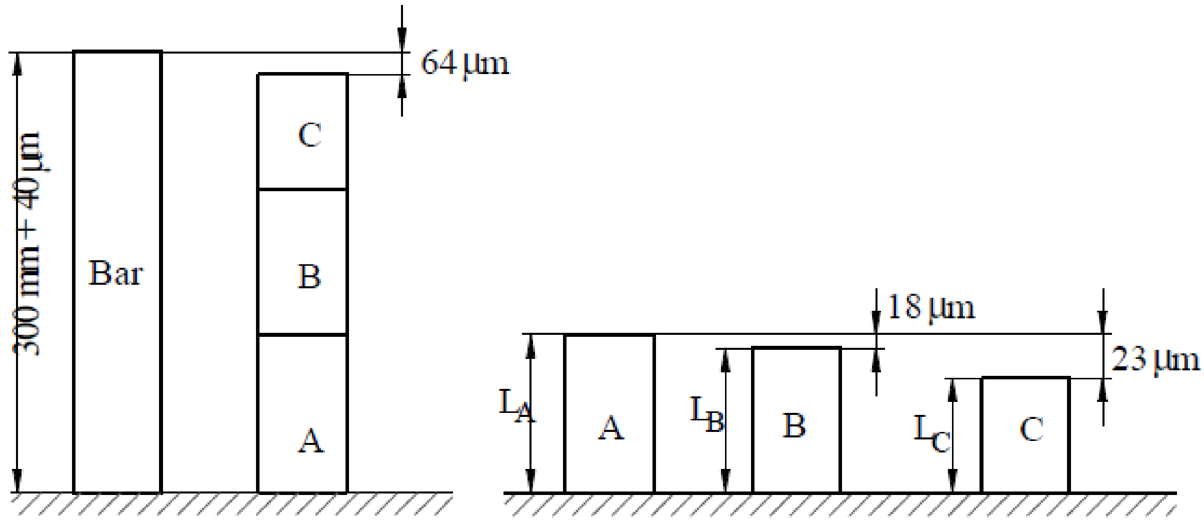
1. End standards are highly accurate and are well suited for measurements of close tolerances as small as 0.0005 mm.
2. They are time consuming in use and prove only one dimension at a time.
3. End standards are subjected to wear on their measuring faces.
4. End standards have a 'built in' datum, because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

## 1.9 CALIBRATION OF END BARS

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

## Numerical problem-1

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




**Numerical problem-2**

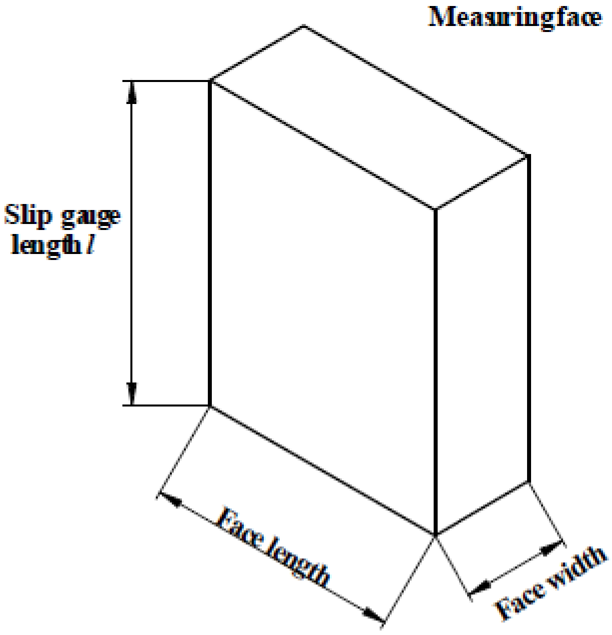
Four end bars of basic length 100 mm are to be calibrated using a standard bar of 400 mm whose actual length is 399.9992 mm. It was also found that lengths of bars B,C & D in comparison with A are +0.0002 mm, +0.0004 mm and -0.0001 mm respectively and the length of all the four bars put together in comparison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

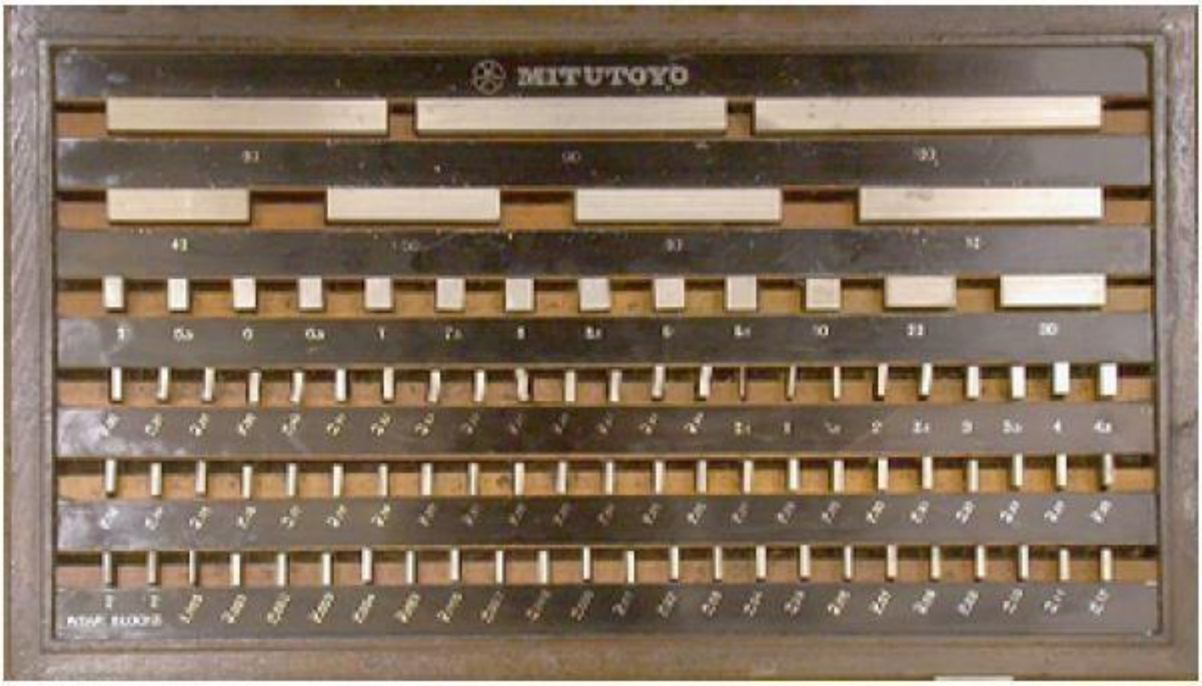
## LINEAR MEASUREMENT AND ANGULAR MEASUREMENTS

## LINEAR MEASUREMENT

## SLIP GAUGES OR GAUGE BLOCKS (JOHANSSON GAUGES)

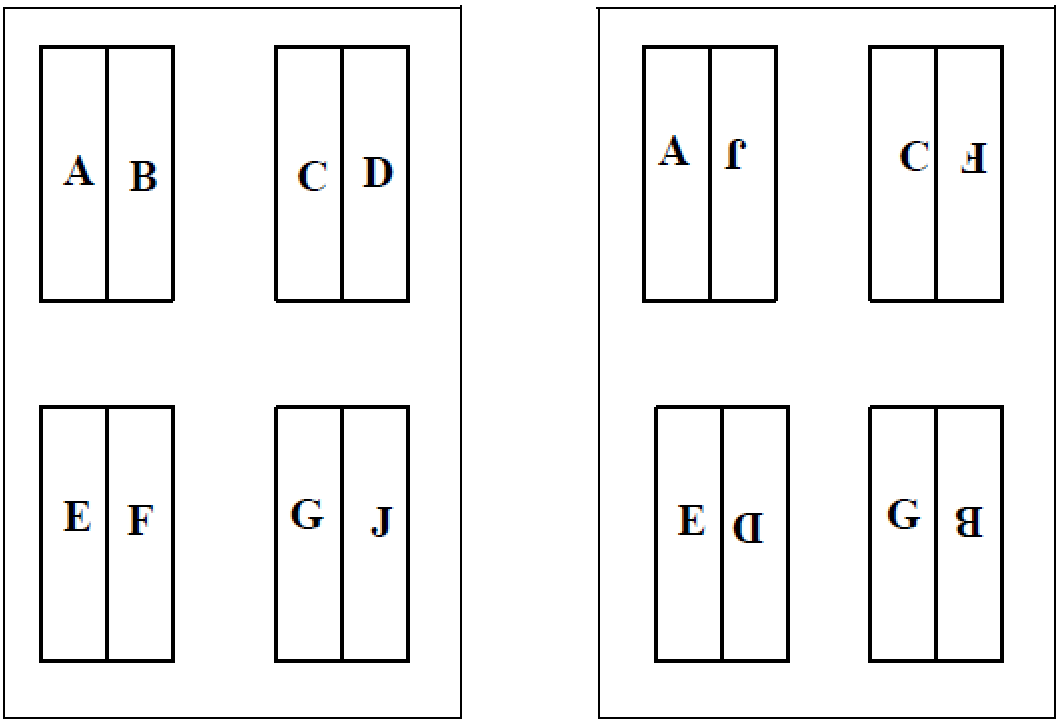
Slip gauges are rectangular blocks of steel having cross section of 30 mm face length & 10 mm face width as shown in fig.




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

**Manufacture of Slip Gauges**




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

## Protector Slips

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

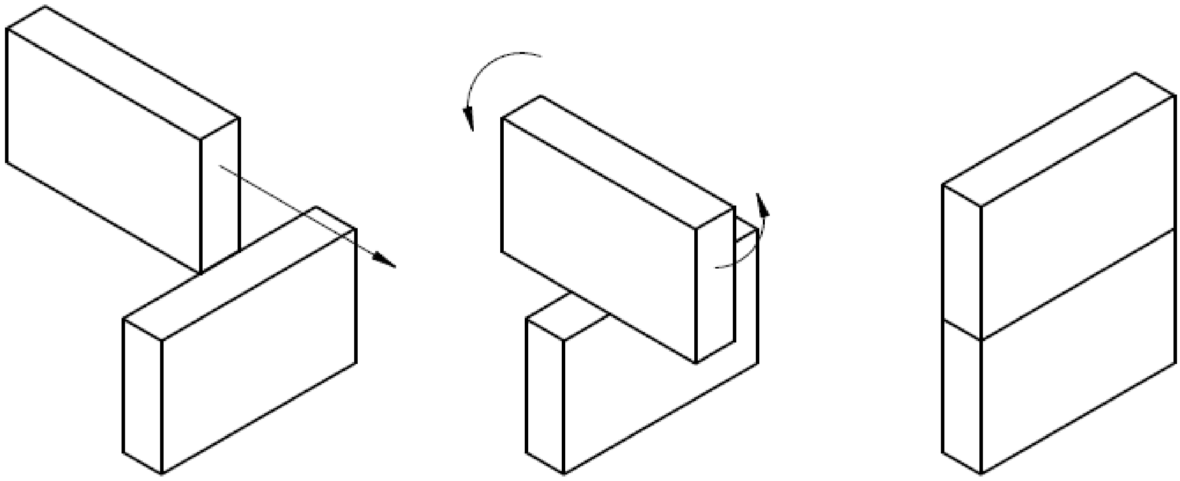
### Wringing of Slip Gauges

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

• Use the minimum number of blocks.

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

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



Wringing of Slip Gauges

**INDIAN STANDARD ON SLIP GAUGES (IS 2984-1966)**

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

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

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

## M-87 set of slip gauges

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

## M-112 set of slip gauges

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

**Important notes on building of Slip Gauges**

• Always start with the last decimal place.

• Then take the subsequent decimal places.

• Minimum number of slip gauges should be used by selecting the largest possible block in each step.

• If in case protector slips are used, first deduct their thickness from the required dimension then proceed as per above order.

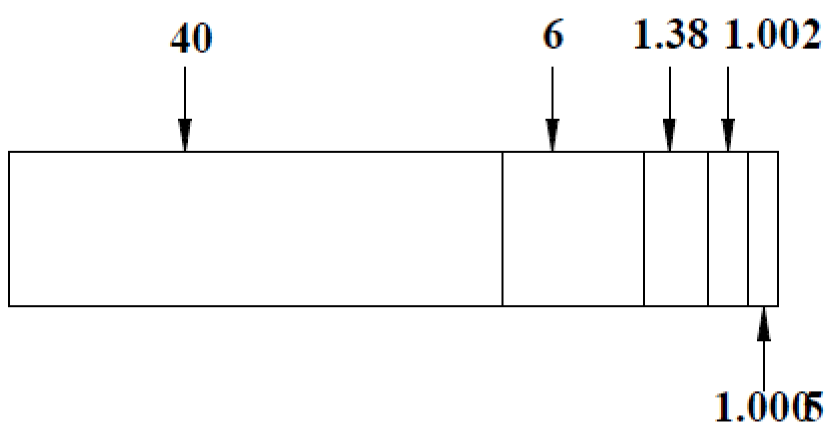
**Numerical problem-1**

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

**Solution**

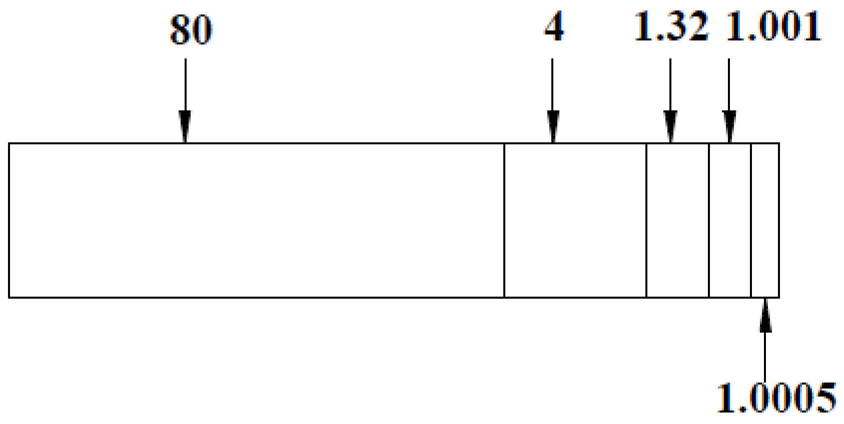
**(i) To build 49.3825 mm**

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



## (ii) To build 87.3215 mm

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

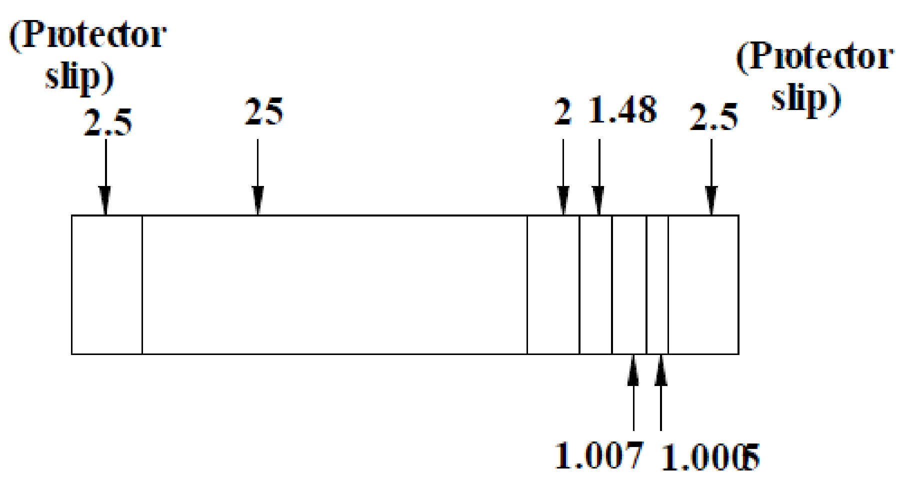



## Numerical problem-2

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

**Solution:**

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



## 1.10 Angular Measurements

## Introduction

## Definition of Angle

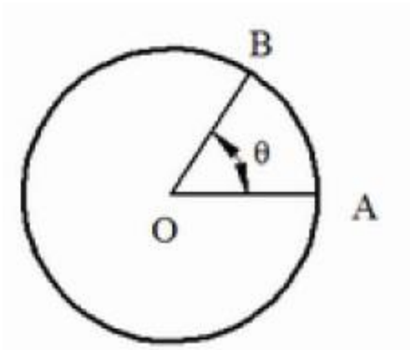
• Angle is defined as the opening between two lines which meet at a point.

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

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

The unit 'Radian' is defined as the angle subtended by an arc of a circle of length equal to

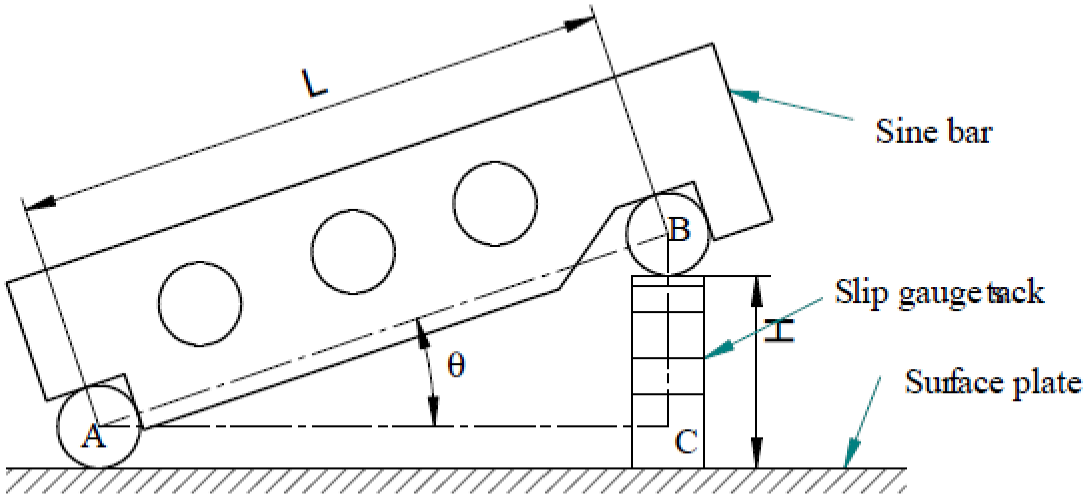
radius. If arc AB = radius OA, then the angle q = 1 radian.




## Sine bar

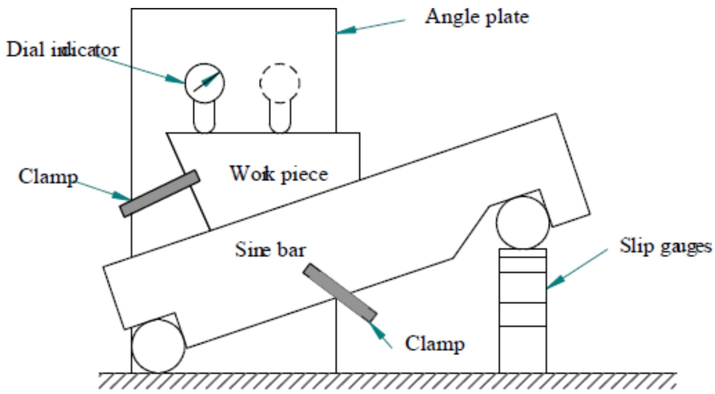
Sine bars are made from high carbon, high chromium, corrosion resistant steel which can be hardened, ground & stabilized. Two cylinders of equal diameters are attached at the ends as shown in fig. The distance between the axes can be 100, 200 & 300 mm. The Sine bar is designated basically for the precise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

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

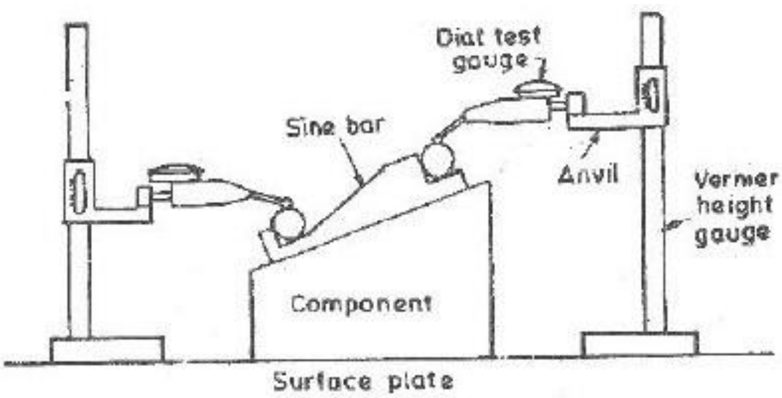



## (1) For checking unknown angles of a component

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




## (2) Checking of unknown angles of heavy component



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

## Advantages of sine bar

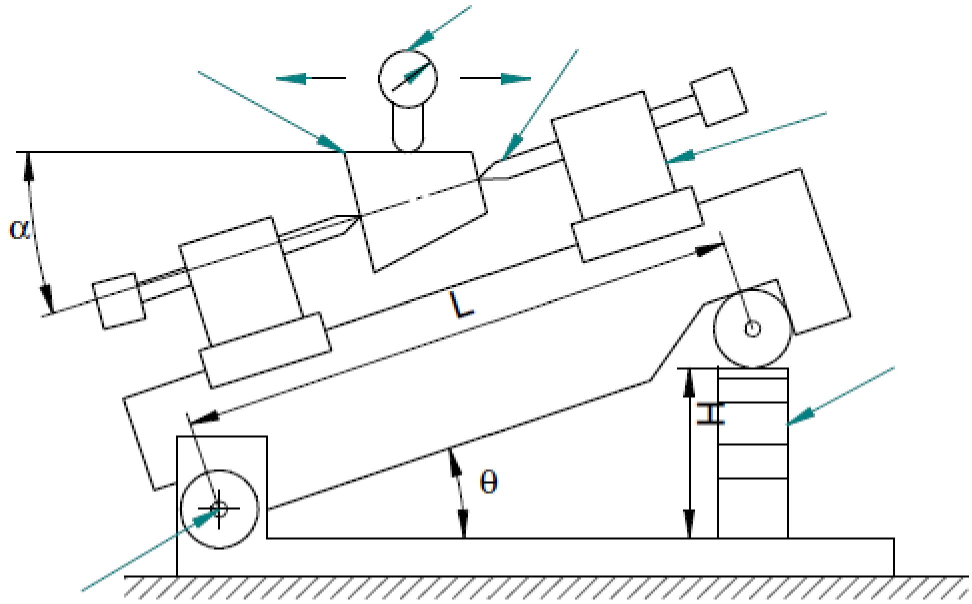
1. It is used for accurate and precise angular measurement.
2. It is available easily.
3. It is cheap.

## Disadvantages

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

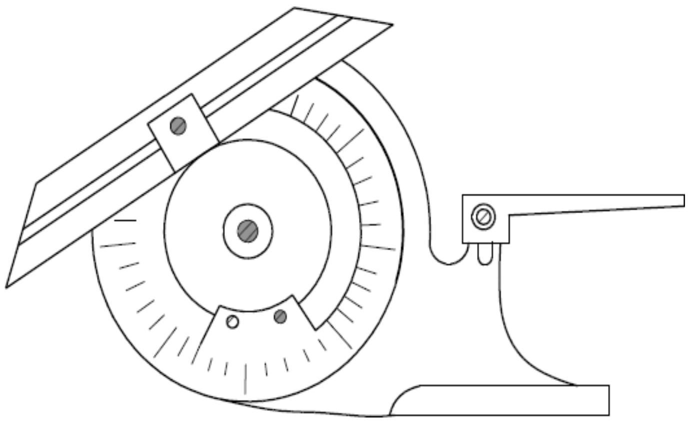
## Sine Centers

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




## Vernier Bevel Protractor (Universal Bevel Protractor)

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



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

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

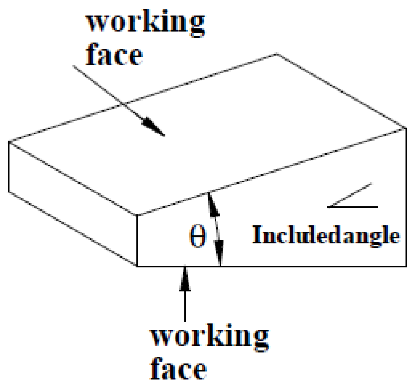
The main scale is graduated in degrees. The vernier scale has 12 divisions on either side of the center zero. They are marked 0-60 minutes of arc, so that each division is 1/12$^{th}$ of

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

## Angle Gauges

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

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




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

Nominal angles of combination angle gauges

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

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

## 1.11 Numericals on building of angles

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

**Numerical 1:**

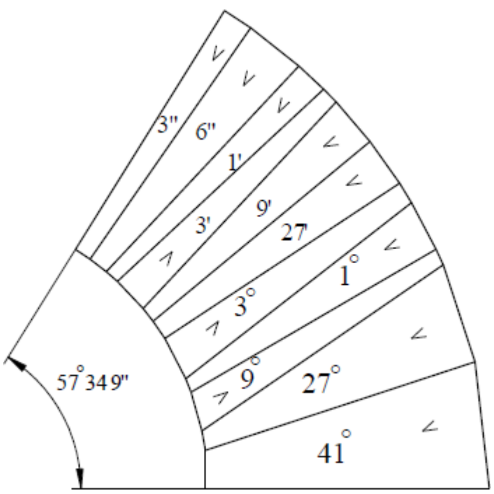
Build an angle of 57°34' 9"

**Solution:**

Degree = 41° +27° -9°+1°-3°=57°

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

Seconds = 6"+ 3" =9"




**Numerical 2:**

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

**Solution:**

Degree: 90°+9° +3° =102°

Minutes: 9’-1’ = 8’

Seconds 30”+ 18”- 6” =42”

## Clinometer

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

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

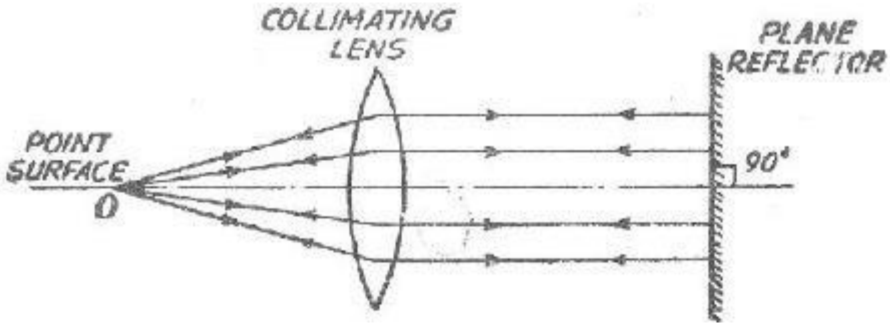
These can also be used for setting inclinable table on jig boring; machines and angular work on grinding machines etc.

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

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

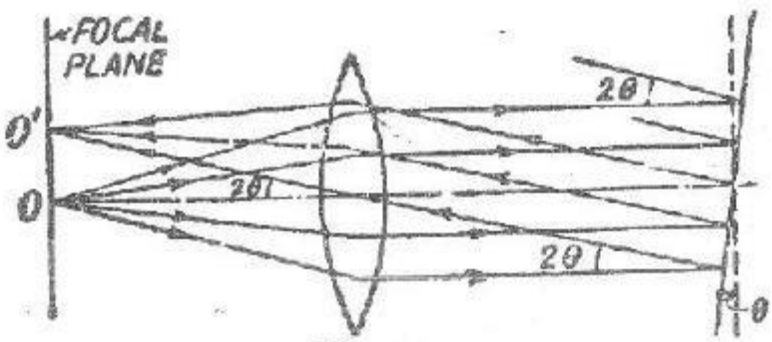
## 1.12 Autocollimators

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




There are certain important points to appreciate here:

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




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

## Principle of the Autocollimator

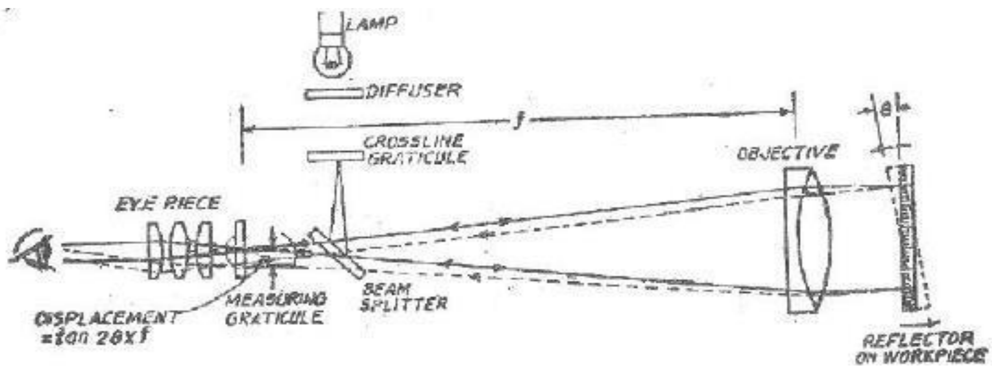
A crossline "target" graticule is positioned at the focal plane of a telescope objective system with the intersection of the crossline on the optical axis, i.e. at the principal focus.

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

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

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

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




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

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

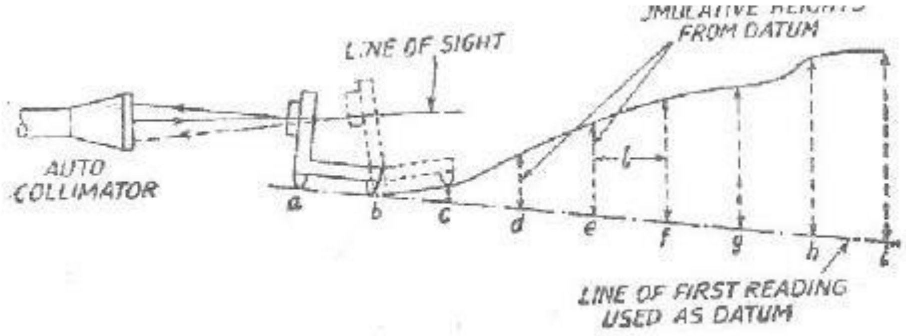
When both the autocollimator and the target mirror gauge can remain fixed, extremely close readings may be taken and repeatability is excellent. When any of these has to be moved, great care is required.

## Tests for straightness

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

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

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




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

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

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

## OUTCOMES

Students will be able to

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

# Questions

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