Chapter 2
Linear measurement, Angular measurement
Taper measurement, Limit gauges

2.1 Introduction:

The main objective of studying this chapter is known that any quantity can be measured by some or the other unit and it should be universal acceptable. So, linear and angular measurement is helpful to measure these quantities.

STANDARDS OF MEASUREMENT

Functional: We have to do the measurement

Non Functional: where we have to estimate the unit like, Weight of the component

2.2 Standard system for linear measurement:

Length can be measured as distance between 2 lines or as distance between 2 faces.

Instruments categories are of two types:

(a)Line standard

(b)End Standard

(a)Line Standard:

Length is measured as the distance b/w centers of two engraved lines.

Eg: Steel Rule

Characteristics of line standard:

- Scales are engraved to high accuracy but they posses some thickness , so measurement is not accurate
- Scale is quick and easy to use over a wide range
- Scale marking is not subjected to wear. However ends are subjected to wear, which leads to undersize measurement.
- Parallax error will be there.
- For higher accuracy magnifying glass should be used

(b)End Standard:

Length is expressed as the distance between two flat parallel faces/surfaces.

Eg: Micrometer

Characteristics of line standard:

- Standards are if high accuracy and measurement can be made for low tolerances
- More time taken process for measurement
- Subjected to wear on the end faces
- No parallax error

2.3 Universally accepted line standard:

They are two types of universally accepted line standards.

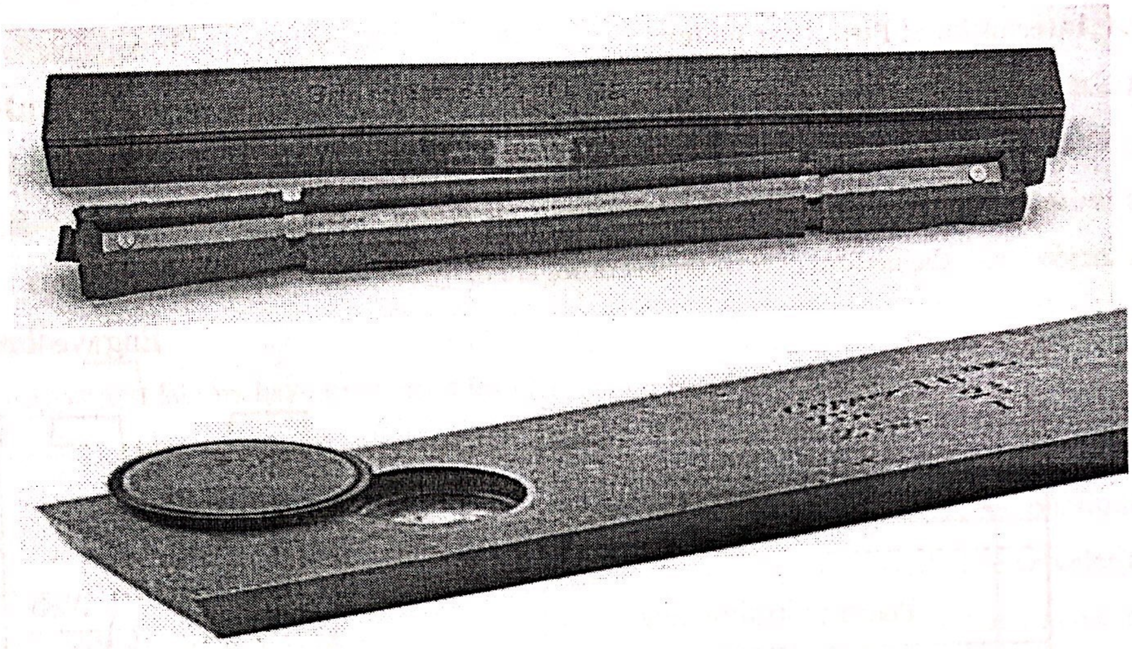
a) YARD (English System) (Length Standard)

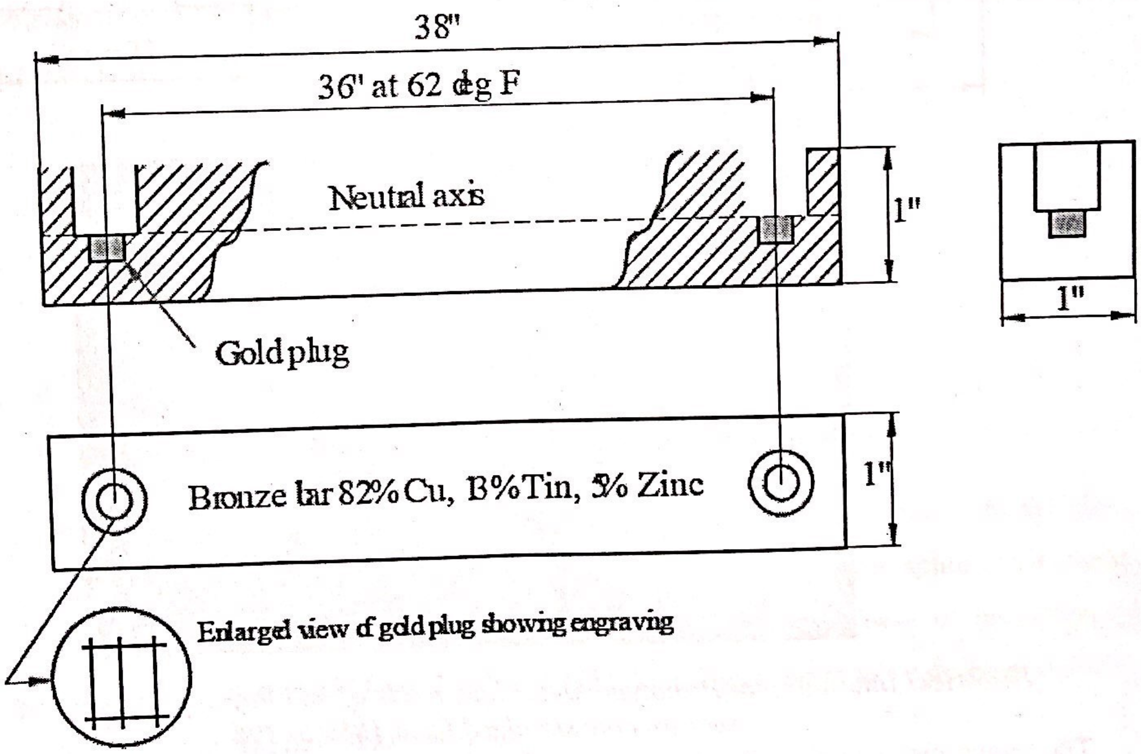
b) METER (Metric System),(International Standard)

a) Imperial Standard Yard: Standard yard made by Trough ton & Simms, London, 1855. Parliamentary Copy No. 34 of the British standard yard of 1854.Bronze bar in wooden case. The yard is measured between fine lines marked on a gold pin in the well at each end of the bar Primary standard yard for Victoria, 1856 to 1966. This standard yard was placed in the custody of Robert Ellery, Government Astronomer, in 1860

1 yard is approximately 91cm.

The Imperial Standard Yard is a bronze bar of one inch square cross-section and 38 inches long (Fig.) and up to central plane of the bar. A gold plug 1 / 10 diameter having three lines engraved transversely, and two lines longitudinally is inserted into these holes so that the lines are in neutral plane. Yard is then defined as the distance between the two central transverse lines of the plug at 62°F.



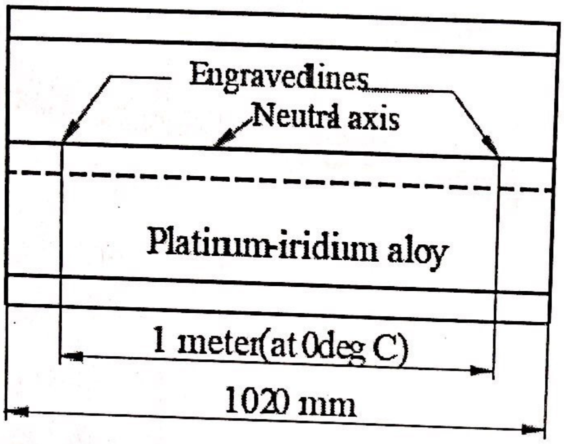


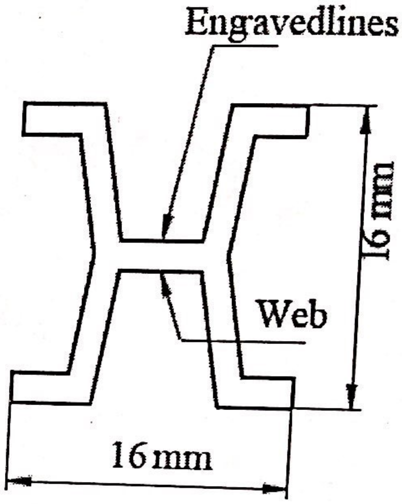
Figure's shows imperial standard Yard

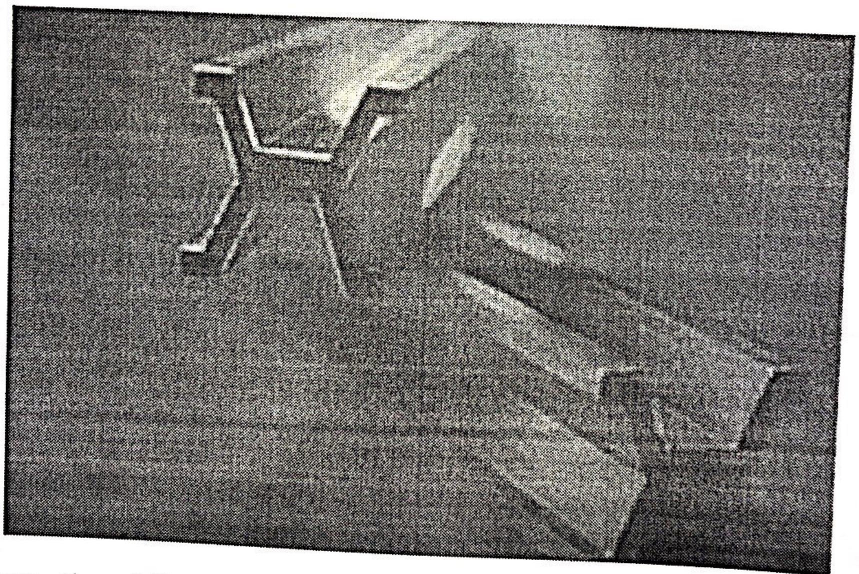
Bronze Yard was the official standard of length for the United States between 1855 and 1892, when the US went to metric standards. 1 yard = 0.9144 meter. The yard is used as the standard unit of field-length measurement in American, Canadian and association football, cricket pitch dimensions, swimming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

2.4 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.







Historical International Prototype Meter bar, made of an alloy of platinum and iridium, that was the standard from 1889 to 1960.

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.

Disadvantages of Material length standards:

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

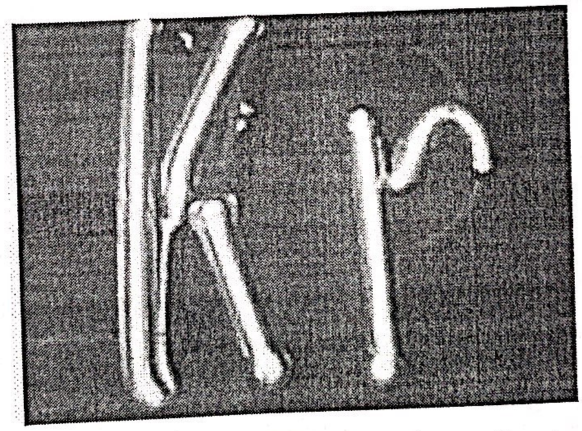
2. The exact replicas of material length standards were not available for use somewhere else.

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.

2.5 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.

Meter as on Today: In 1983, the 17th general conference on weights & measures proposed the use of speed of light as a technically feasible & practicable definition of meter. Meter is now defined as the length of path of travelled by light in vacuum in (1/299792458) second. The light used is iodine stabilized helium-neon laser.

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.

2.6 Subdivision of standards:

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

a. Primary Standards
b. Secondary standards
c. Teritiary standards
d. Working standards

a. 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.

b. 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.

c. 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.

d. Working standards:

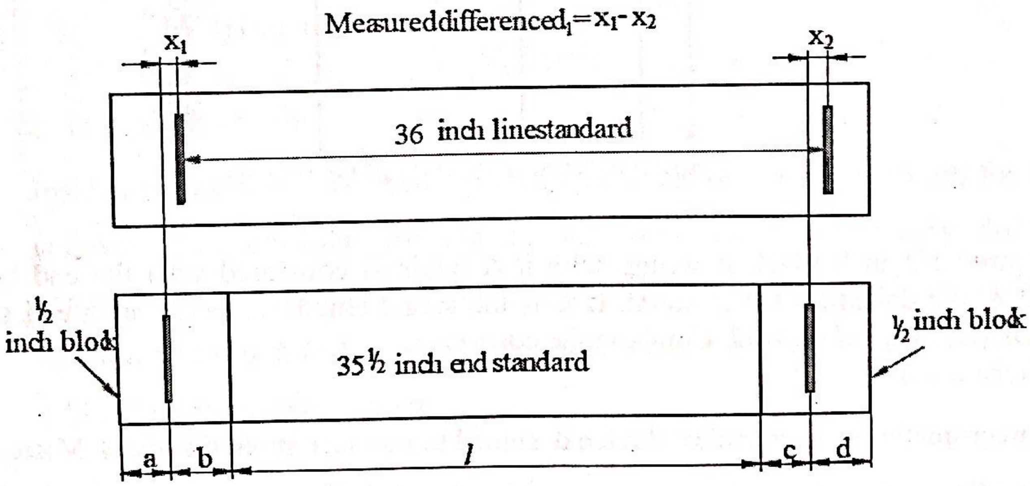
These standards are similar in design to primary, secondary & tertiary standards. But being less in cost and are made of low grade materials, they are used for general applications in metrology laboratories.

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)

2.7 **Transfer from line standard to end standard** (NPL method of deriving End standard from line standard)

Line Standard Comparator:



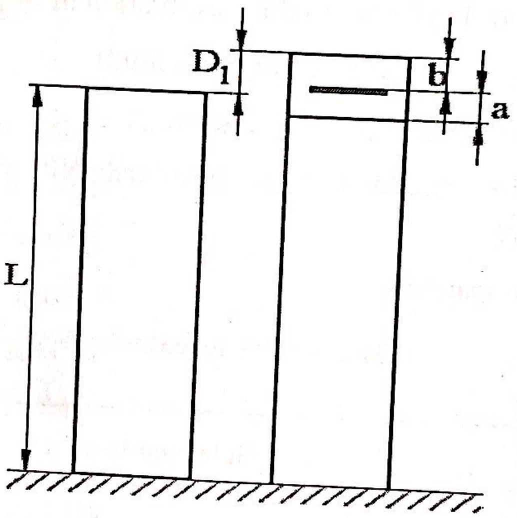
A line standard comparator is used to transfer the line standard correctly to the ends of a bar. It consists of two microscopes mounted about a yard apart over a table. An end standard about 351/2 inch in length is produced with flat & parallel faces. Two 1/2 inch blocks with centrally engraved lines are 'wrung' to the ends of this end standard, such that the distance between the center lines is approximately 36 inches. The difference of readings between the lines on the line standard & the lines on the end standard are noted every time, by arranging the end blocks in different ways to eliminate errors in wringing & of marking of center lines. If the actual length of the end standard is *l*, then for the four different ways of wringing the end blocks, we can write;

$$l+b+c=36+d_1 \qquad l+b+d=36+d_2$$

$$l+a+c=36+d_3 \qquad l+a+d=36+d_4$$

Where d1, d2, d3 & d4 are the differences noted for the successive positions of the 1/2 inch blocks respectively.
Take mean,

Next the 351/2 inch end standard wrung with one of the 1/2 inch blocks is compared with 36 inch end bar (to be calibrated) on a Brooke's level comparator & the deviation D1 may be noted.



Then the other 1/2 inch block is wrung with it & again is compared with the end bar (to be calibrated) & the deviation D2 is noted. If L is the actual length of the 36 inch end bar, then; $l+a+b=L+D1$, $l+c+d=L+D2$. Combine the equations.

2.8 Micrometer

A micrometer is a mechanical device designed to measure small distances Micrometers are only one inch long.The micrometer is used with different types and sizes of frames to provide precise measurements of many different objects.

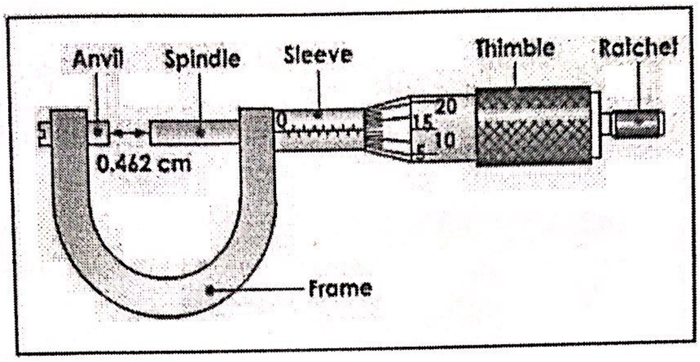
Reading micrometer caliper-parts:

The first step in being able to read a micrometer is learning the names of the parts.

- The face of the anvil and the face of the spindle are the contact surfaces.
- The spindle and thimble turn together.
- The ratchet/friction stop improves the repeatability of measurements for beginners.

- A micrometer caliper is read at the point where the edge of the thimble crosses the barrel scale

Insure the lock is released before trying to turn the thimble..

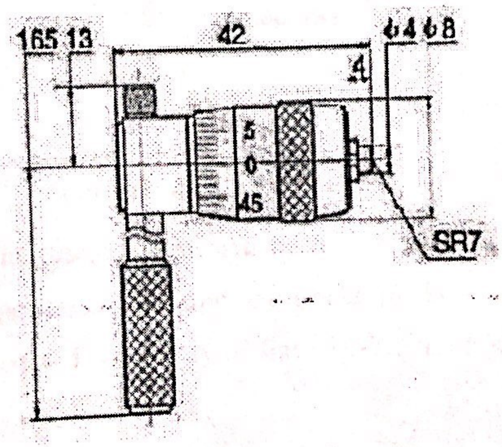


Three types of micrometers:

a) Micrometer caliper
b) Inside micrometer
c) Depth gauge micrometer

b) Inside Micrometer

Inside micrometers have been replaced by dial calipers and other tools for small gas engines. The principles for reading are the same. The primary difference is determining the smallest whole unit. The physical size of the micrometer limits the smallest whole unit to 1 or 1-1/2 inch. Extensions are added to set the minimum size to the desired range as shown.



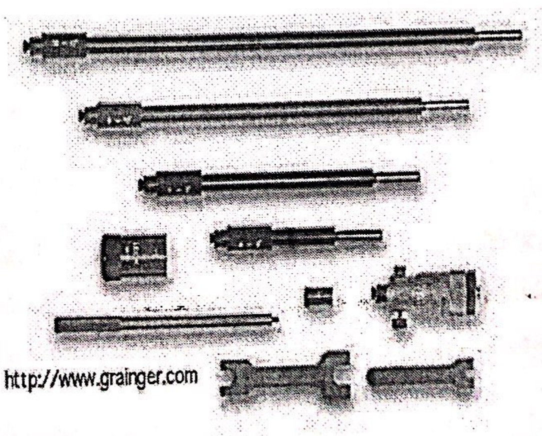
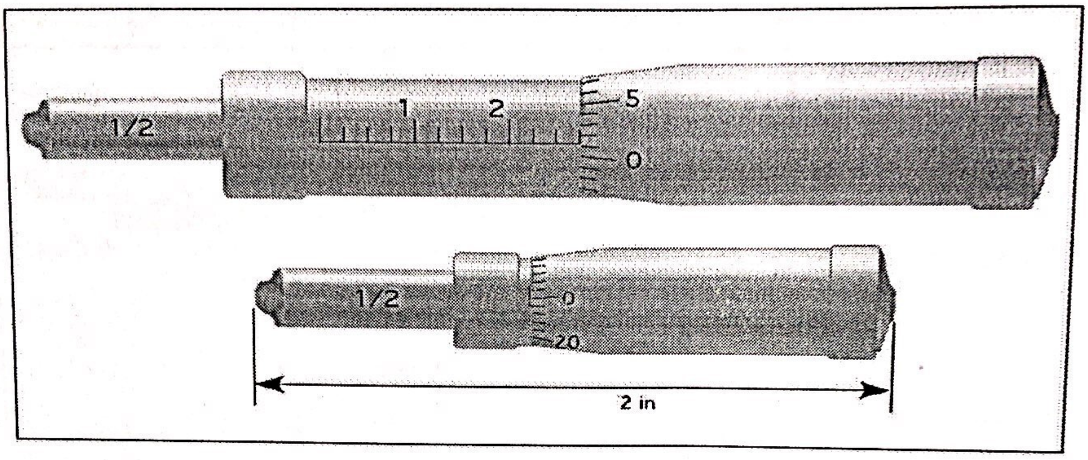


Figure shows insider micrometer

Inside micrometers use extensions to change the range of measurements. Adding an extension increases the minimum measurement. In this example a 1/2 inch extension has been added.



Note: when the zero on the thimble is close to the reference line and a 25 thousands line is close to the edge of the thimble, it may be difficult to determine if the last line that should be counted. If the thimble zero is above the reference line the line is not counted. If it is below it should be counted.

c) Depth gauge micrometer

Depth gauge micrometers are used to measure the depth of blind holes, slots, key ways, etc. The spindle length can be changed to set the micrometer for the desired range of measurement. To read a depth gauge micrometer you must visualize the distance that has been covered by the thimble.

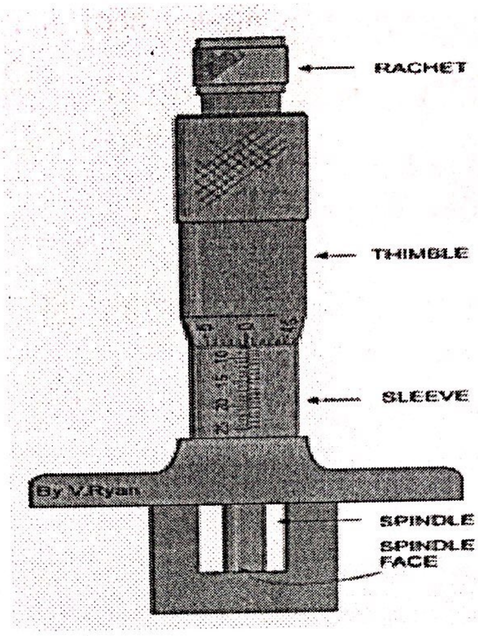


Figure shows depth micrometer

2.9 Vernier Caliper.

Vernier calipers are an old tool that has been mostly replaced by dial and digital calipers. They are manufactured with decimal scales, metric scales and fractional scales. The Vernier scale is still used on many mechanical measuring tools.

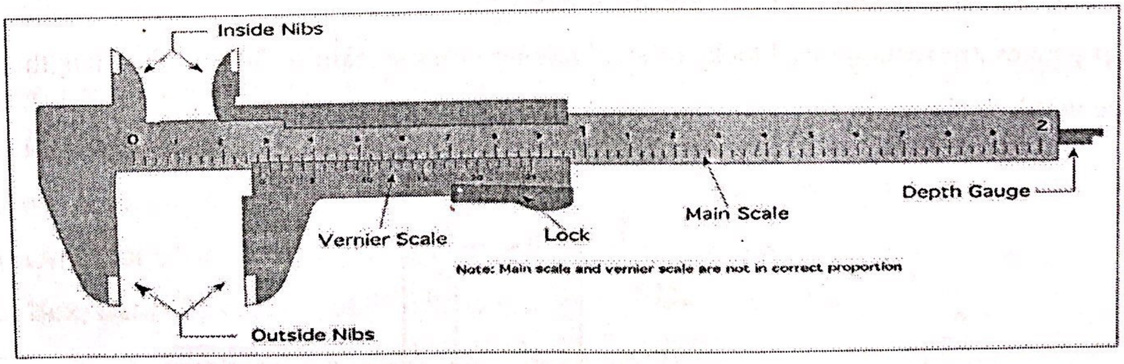
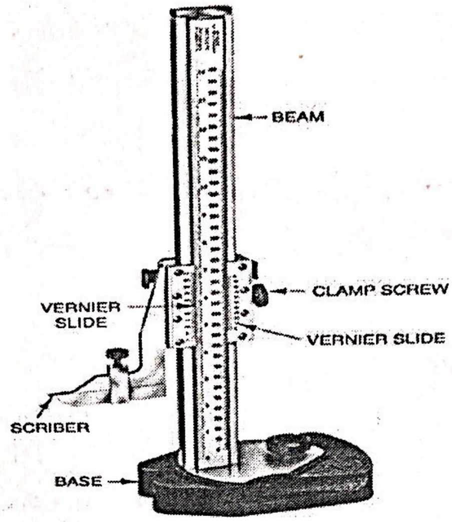


Figure shows vernier caliper

2.10 Vernier Height Gauge:

A height gauge is a measuring device used either for determining the height of something, or for repetitious marking of items to be worked on. Vernier height gauge a Precision instrument. Has variety of sizes 12-72 in. or 300-1000 mm. Height within .001 in (0.02 mm)

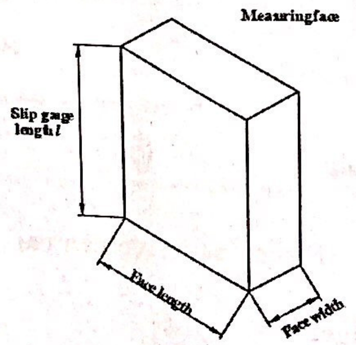
Digital height gage zero function, display .0001 in. Offset scriber: Attachment that permits setting heights from face of plate and Depth gage attachment.



2.11 Slip gauges:

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.

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



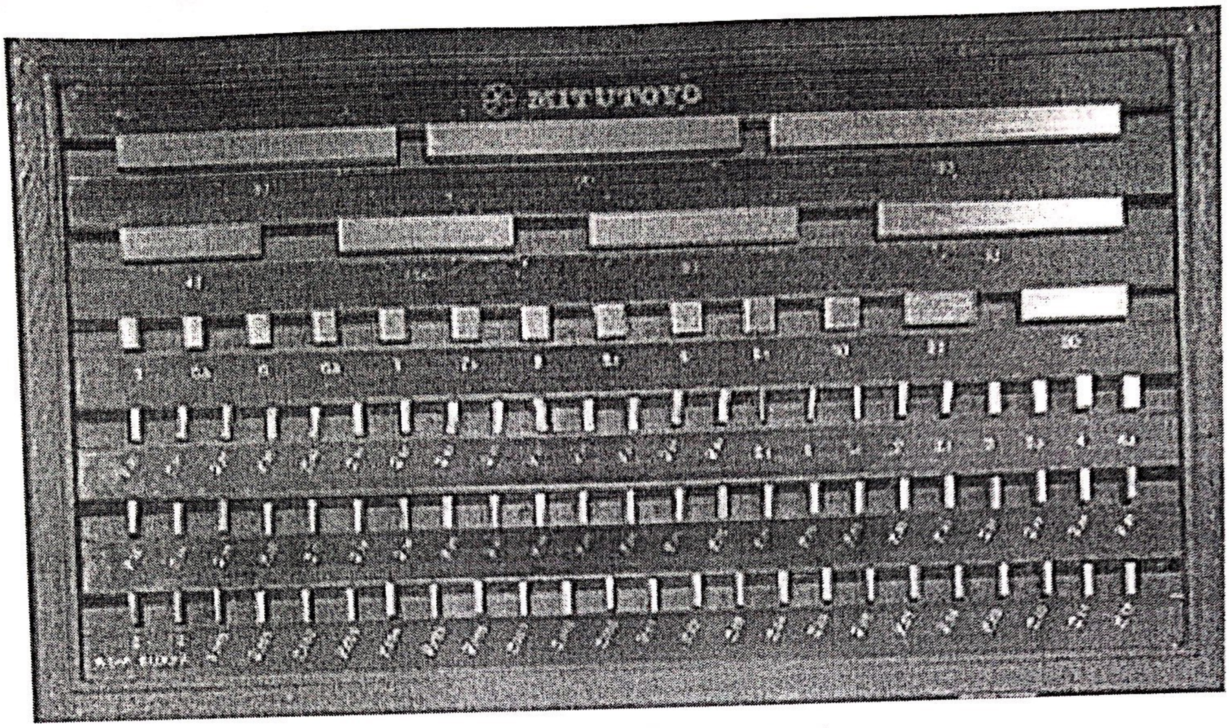


Figure shows slip gauge block.

Types of slip gauges:

INDIAN STANDARD ON SLIP GAUGES (**IS 2984-1966**), these are available in three standard sets:

M45, M112, M87.

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.

M45 Set Box: Basically consists of 45 Slip gauges in it as shown in table

Range (in mm)	Step	No. of pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.1	9
1 to 9	1	9
10 to 90	10	9

M87 Set Box: Basically consists of 87 Slip gauges in it as shown in table

Range (in mm)	Step	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

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-45 53.975

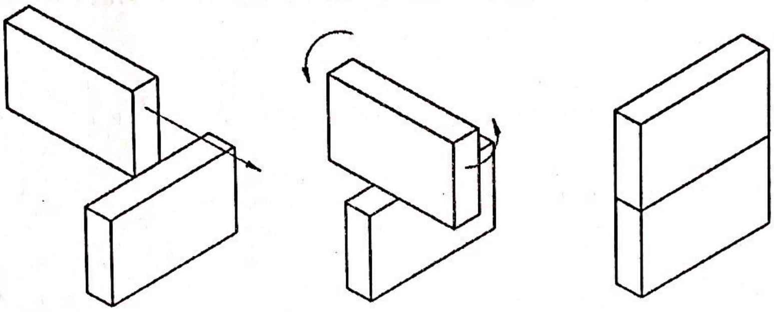
Solution:

Form last decimal place	1 slip=1.005
Form second last decimal place	2 slip=1.07
Form third last decimal place	3slip=1.9
Form fourth	4slip=50.00
	53.975

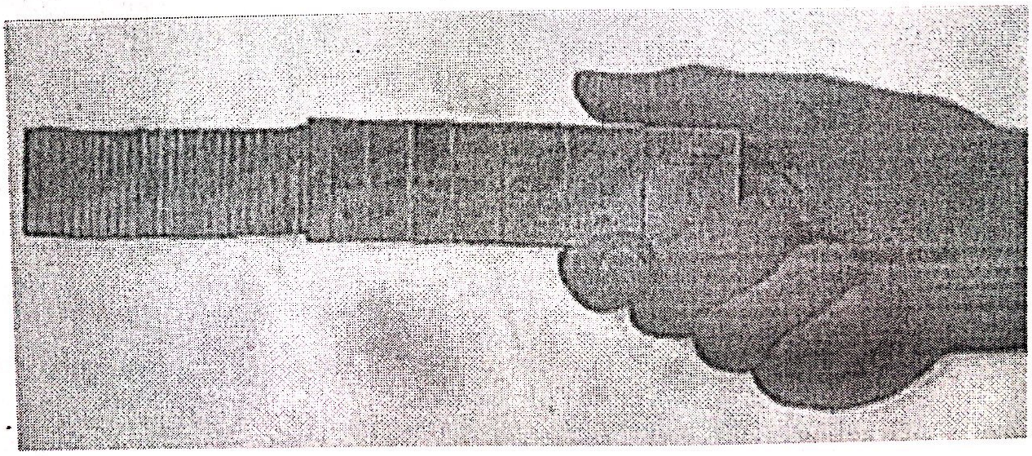
Wringing of Slip Gauges:

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



36 Johansson gauge blocks wrung together easily support their own weight

2.12 Methods of Manufacturing Slip Gauges:

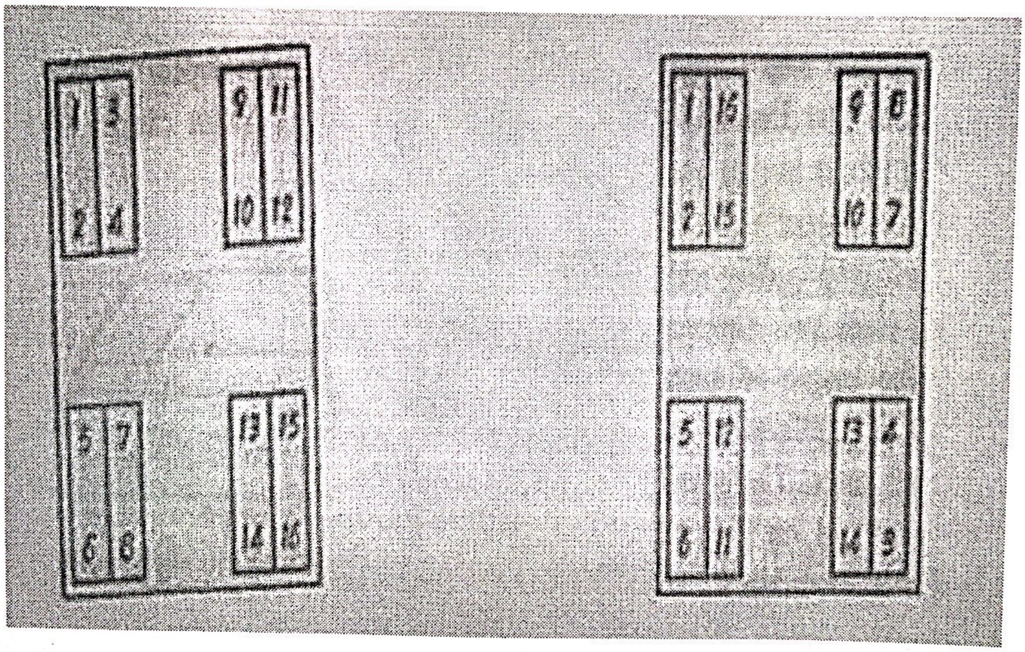
They are two different methods for manufacturing

a) National physics laboratory method

b) Mechanical method of lapping

a) National physics laboratory method:

In NPL method magnetic chucks are used. All the slip gauges in chuck and grinding will be done and lapping process will be done in order to have good surface finish. Next they will reverse all the slip gauges so that they have same parallelism and flatness as shown.



Manufacturing procedure:

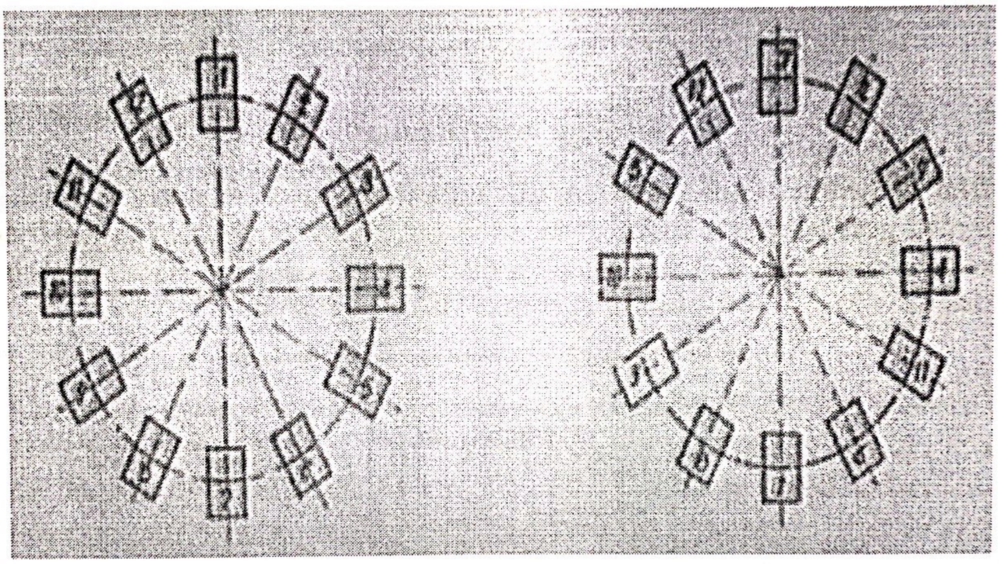
- Machining
- Heat treatment
- Grinding
- Lapping
- Reversing slip gauges
- Final Lapping

b) Mechanical method of lapping:

Three different types

- Upper lap
- Central lap
- Bottom lap

Upper lap can be moved in any angle and does not have any rotary motion. It will be like a simple pendulum. The central lap contains slots. The slip gauges are held in this lap by means of screws. This lap has a rotary motion. Bottom lap is rigidly placed on the base.



Manufacturing procedure:

- Machining
- Heat treatment
- Grinding
- Lapping
- Reversing slip gauges
- Final Lapping

2.13 Dial-Indicator: The dial indicator is a precision measuring tool that measures relative distances. Use it to measure the difference in distance to two or more locations. The dial indicator is great for checking alignment and run out.

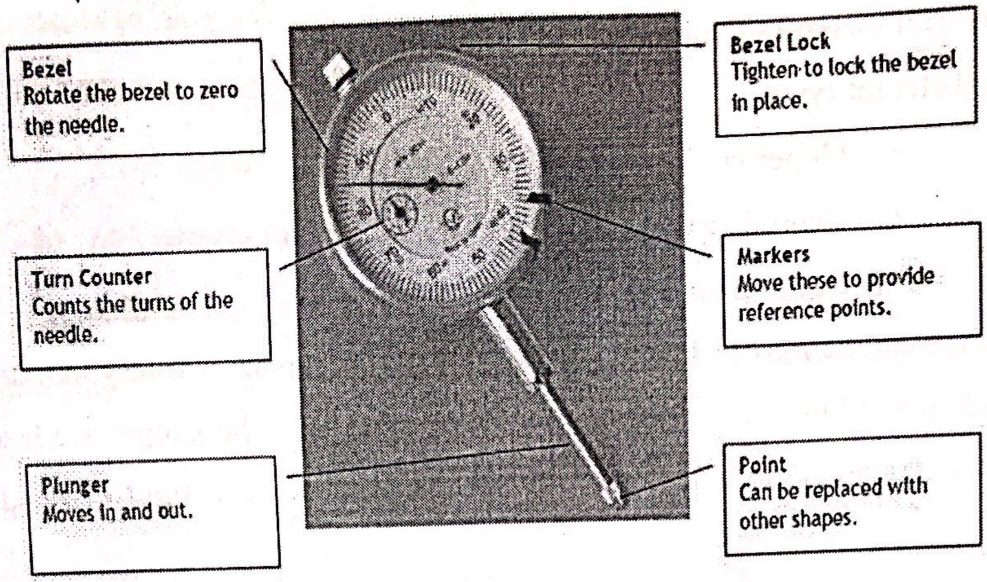


Figure shows the parts of dial indicator.

Dial Indicator Application: A dial indicator is used to measure shaft run out, shaft thrust, gear backlash, flywheel face run out, flywheel housing concentricity, and valve seat concentricity. You can mount a dial indicator on a test stand or, with clamps and a magnetic base, directly on the equipment to be measured.

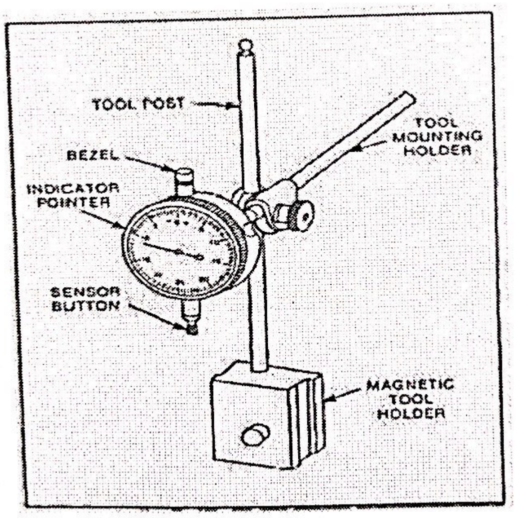


Figure shows a typical dial indicator with mounting accessories, most dial indicators have components such as a bezel, indicator pointer, tool post and clamp, magnetic tool holder, and sensor button that are used in taking measurements.

Advantages of Dial Indicator:

1. Ease of reading a dial indicator is the biggest advantage over other conventional types of linear measuring
2. This is extremely useful for quality control in the inspection room and unskilled labor can be employed for its use

3. This is best suited for precision dimensional control
4. Dimensions can be easily controlled in mass production.
5. This is not subjected to problems of gauge wear and temperature variations etc
6. There's speed, adaptability, and positive visibility of dial indicator gauges, in addition to their accuracy
7. One can use it for many different measurements by means of a few simple attachments, thus making it more versatile.
8. Maintenance cost is less

Characteristics of Dial Indicator:

- Robust in design
- Mechanical stop should be provided for the plunger
- Plunger should show both positive and negative values

2.14 Angular Measurement: For measuring the angle, no absolute standard is required. The measurement is done in degrees, minutes and seconds. The measurement of angular and circular divisions is an important part of inspection. It is concerned with the measurement of individual angles, angular changes and deflections on components, gauges and tools. For precision measurement of angles more skill is required. Like linear measurement, angular measurements have their own importance. The basic difference between the linear and angular measurement is that no absolute standard is required for angular measurement. There are several methods of measuring angles and tapers. The various instruments used are angle gauges, clinometers, bevel protractor, sine bar, sine centers, taper plug and ring gauges

Definition:

Angle is the difference as the gap in between two straight lines which are meeting at a single point.

Standards of Measuring Angle:

(a)Sexagesimal System

Assume that there is a Circle where the Circle is divided into 360 equal parts and each part is called as a Degree (^{0}).

One Degree =60 minutes;

1 Minute =60 seconds.

(b)Radians

Angle subtended at the centre by an arc of circle of length equal to its radius is called Radian

2π radians= 360^0

1 Radian = 57.2958 degrees.

2.15 Instruments for Angular Measurement:

a. Vernier bevel protractor

b. Sine bar

c. Angular gauges

a.) Vernier bevel protractor:

It is used to measure angles accurately to 5 minutes. It is finely made tool with dial, graduated in degrees, a base and a sliding blade. The blade can be locked against dial by tightening the blade clamp nut. The blade and dial can be rotated as one unit to any position and locked by tightening the dial clamp nut for accurate measurement, a vernier or a fine adjustment device is fitted on the dial. The dial is graduated into, I thread, the vernier scale is divided into twelve equal parts on each side of zero, every third division is numbered 0, 15, 30, 45, 60 representing minutes.

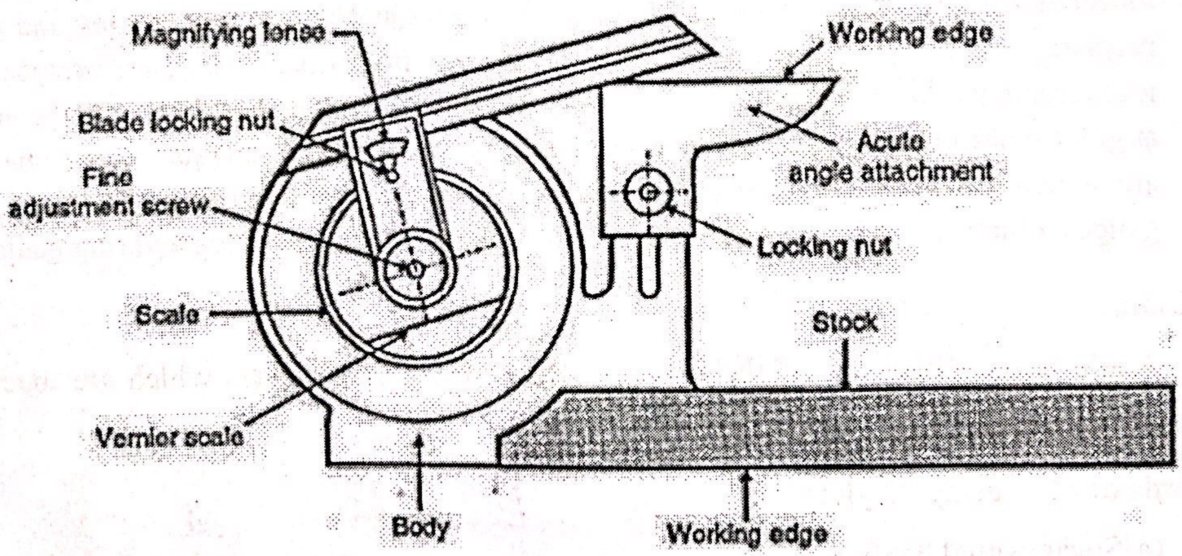
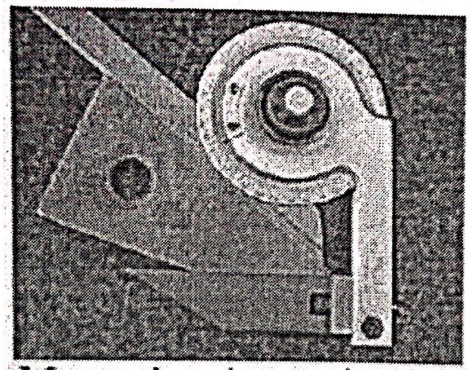


Figure indicates Bevel Protractor



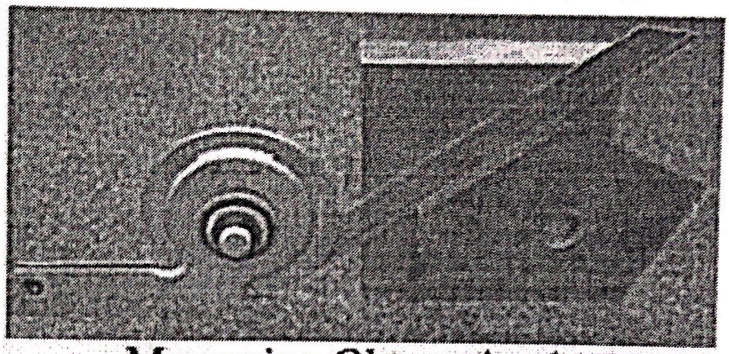
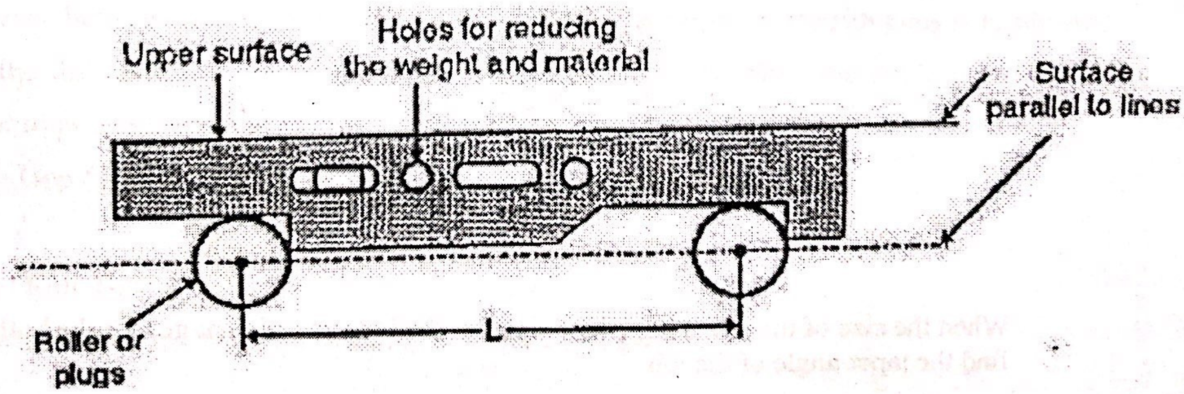


Figure shows ways in which a bevel can be used to measure angles

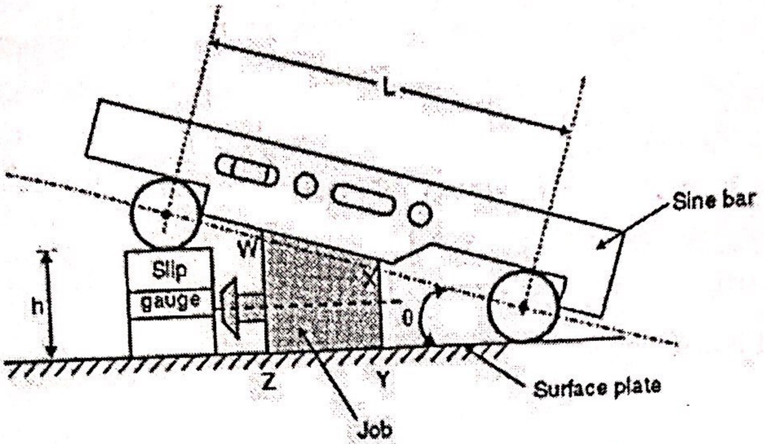
b.) Sine bar:

It is used for measurement of an angle of a given job or for setting an angle. They are hardened and precision ground tools for accurate angle setting. It can be used in conjunction with slip gauge set and dial gauge for measurement of angles and tapers from horizontal surface. As shown in Figure, two accurately lapped rollers are located at the extreme position. The center to center distance between the rollers or plugs is available for fixed distance i.e. l = 100, 200, 250, 300 mm. The diameter of the plugs or roller must be of the same size and the center distance between them is accurate. The important condition for the sine bar is that the surface of sine bar must be parallel to the center lines of the plug



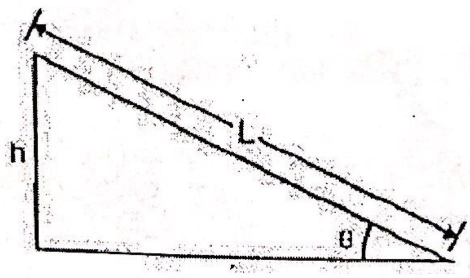
Principle of Working:

As shown in Figure the taper angle θ of the job WX YZ is to be measured by the sine bar. The job is placed over the surface plate. The sine bar is placed over the job with plug or roller of one end of the bar touching the surface plate. One end of the sine bar is rested on the surface plate and the other end is rested on the slip gauges

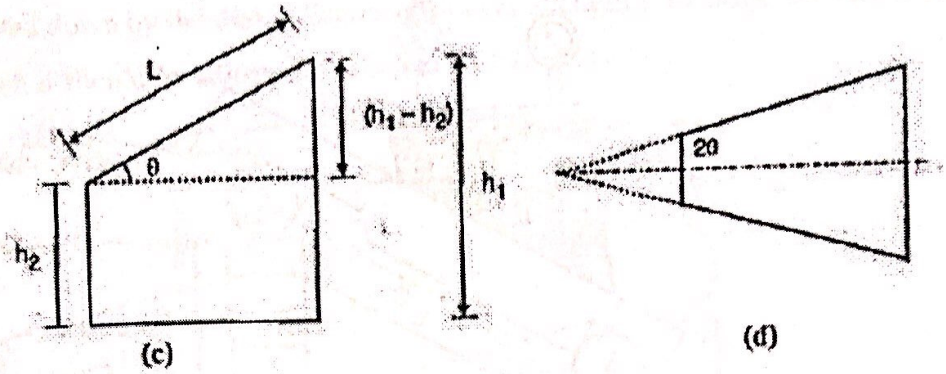


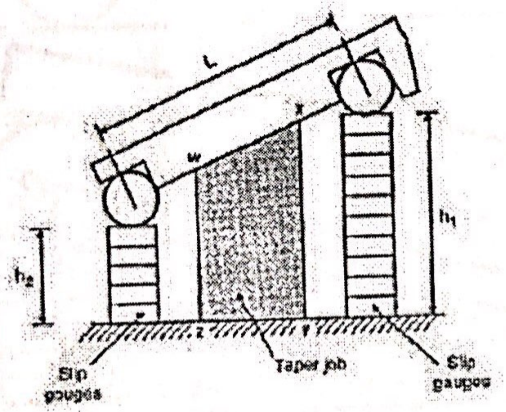
The angle of the job is then first measured by some non-precision instrument, such as bevel protector. That angle gives the idea of the approximate slip gauges required, at the other end of sine bar. Finally the exact number of slip gauges are added equal to height h, such that, the top most slip gauges touches the lower end of the roller. The height of the slip gauges required is then measured. Then the taper angle can be measured by making sine bar as a hypotenuse of right angle triangle and slide gauge as the opposite side of the triangle as shown in Figure

h = Height in mm
L = Center distance in mm
$\sin\theta = Opp / Hyp = (h/ L)$



When the size of the job is large having taper then we use slip gauges for the both the side to find the taper angle of the job



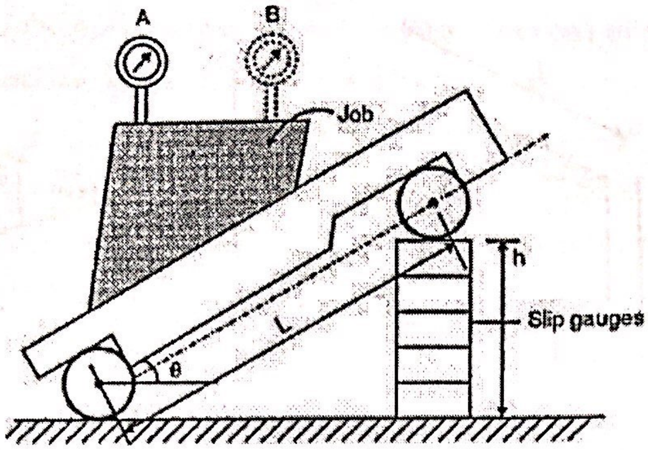


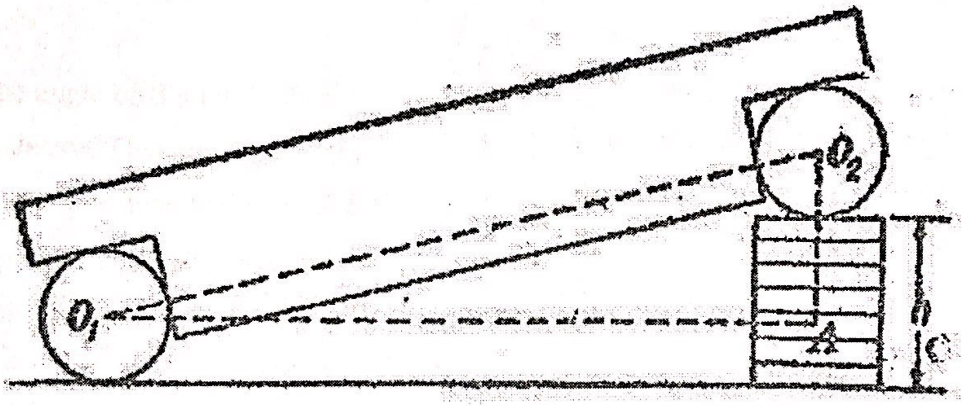
For a small component, the component or work piece can be placed over a sine bar as shown in Figure. The job is held on the sine bar with some suitable accessories. The dial indicators are provided at the top position and the reading is taken at A position. The dial indicator is then moved to the right hand side and the reading is taken at position B. If there is a difference between reading at position A and B, then the height of the slip gauges is adjusted until the dial indicator shows the same reading at A and B. Then the angle is calculated similar to previous method as

Sinθ = Opp / Hyp = (h/ L)

Use of Sine Bar:

(1)Measuring known angles or locating any work to a given angle





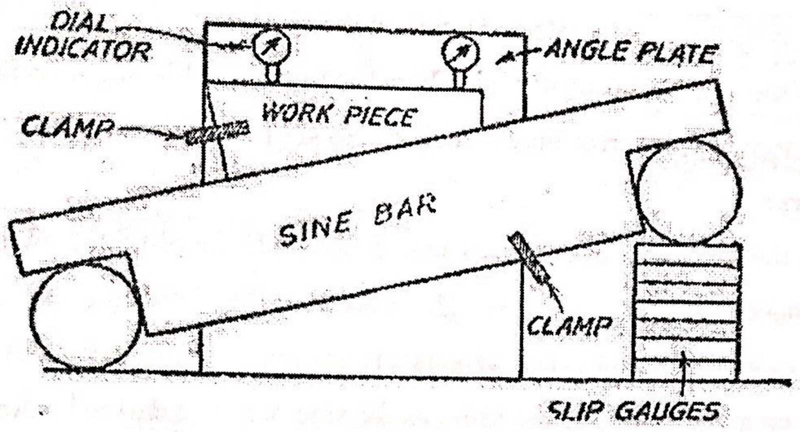
For this purpose the surface plate is assumed to be having a perfectly flat surface, so that its surface could be treated as horizontal. One of the cylinders or rollers of sine bar is placed on the surface plate and other roller is placed on the slip gauges of height h. Let the sine bar be set at an angle θ. Then $\sin\theta = h/l$, where l is the distance between the centres of the rollers. Thus knowing θ, h can be found out and any work could be set at this angle as the top face of sine bar is inclined at angle θ to the surface plate. The use of angle plates and clamps could also be made in case of heavy components. For better results, both the rollers could also be placed on slip gauges, of height h_1 and h_2 respectively.

Then $\sin\theta = (h_2 - h_1)/l$

(2) Checking of unknown angles.

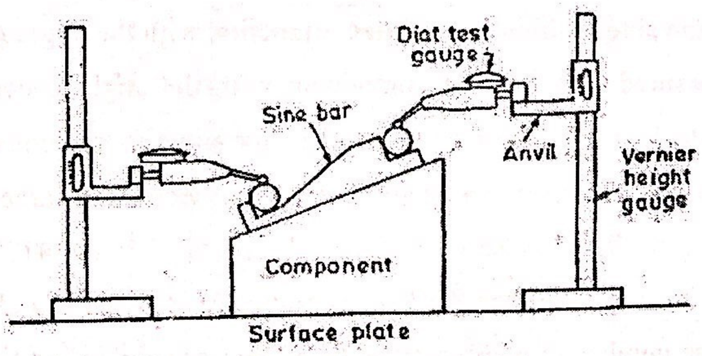
Many a times, angle of a component to be checked is unknown. In such a case, it is necessary to first find the angle approximately with the help of a bevel protractor. Let the angle be θ. Then the sine bar is set at an angle θ and clamped to an angle plate. Next, the work is placed on the sine bar and clamped to the angle plate as shown in Fig. and a dial indicator is set at one end of the work and moved to the other, and deviation is noted. Again slip gauges are so adjusted (according to this deviation) that dial indicator reads zero across the work surface.

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



(3) 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:

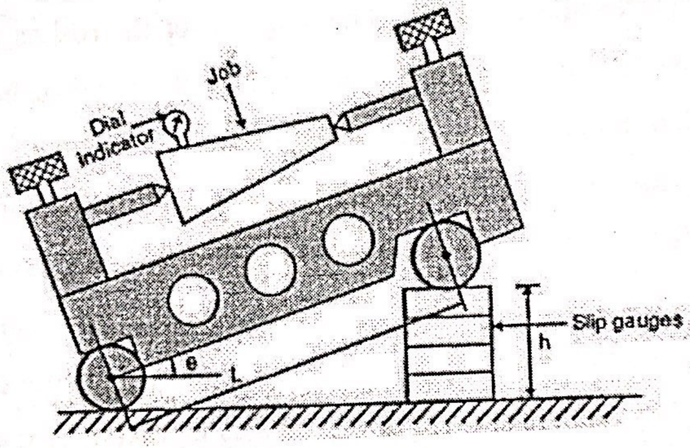
1. It is used for accurate and precise angular measurement.
2. It is available easily.
3. It is cheap.

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.

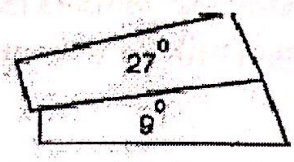
Sine Centers:

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)

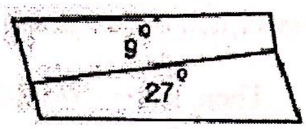


c.) **Angular gauges:**

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.



(a) Addition



(b) Subtraction

2.16 TAPER MEASUREMENT

External taper measurement: Place the smaller end of the tapered plug gauge on the surface plate. Place equal height of slip gauge combinations (h1) on either side of gauge and measure M1 using a micrometer. Increase height of slip gauge combinations (h2 > h1) on either side of gauge and measure M2 using micrometer.

Then, $\tan \alpha = (M2-M1) / 2 (h2- h1)$,

Where M1 = Distance between two rollers at lower position

M2 = Distance between two rollers at upper position

h1 = Slip gauge combination height at lower position

h2 = Slip gauge combination height at upper position

α = Half taper angle

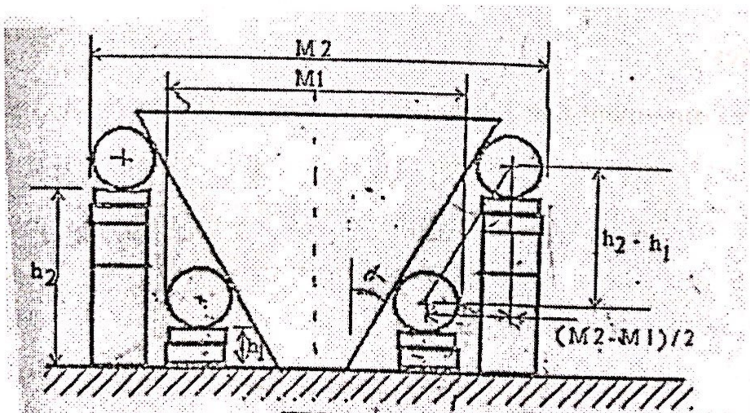


FIG. 2

Internal taper measurement: Place one end of the tapered ring gauge on the surface plate. Place suitable slip gauge combinations (M1) in between two balls such that both balls arc in contact with internal side of the ring gauge. Place the reverse end of the tapered ring gauge on the surface plate and repeat the above procedure for reading M2. Measure the height (H) of ring gauge with a Vernier height gauge. Measure the diameter of balls (d) with a micrometer.

Then, tan α = (M 2-M1) /2 (H- d)

M1 = Distance between two balls at upright position

M2 = Distance between two balls at upside down position

H = Height of the tapered part

d=Diameter of the ball

α = Half taper angle

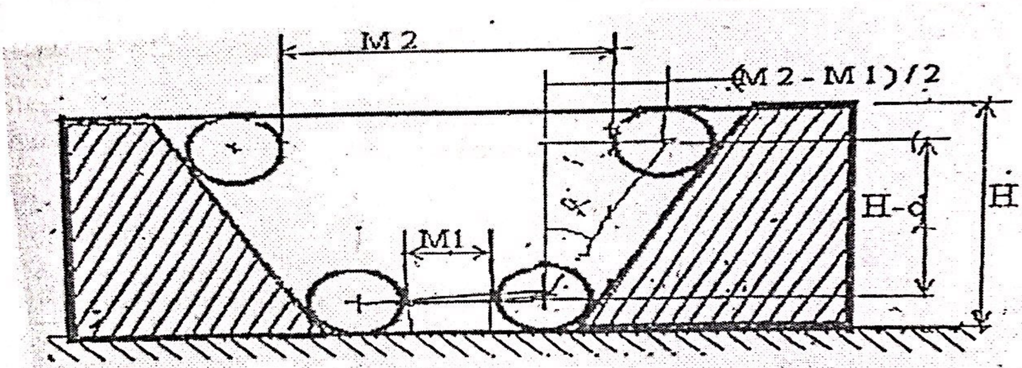


FIG 3

CHAPTER-3

OPTICAL MEASURING INSTRUMENTS

FLAT SURFACE MEASUREMENT

INTRODUCTION

Today, it is an accepted fact that light waves provide the best standard for length. The significance of light waves as the length standard was first explored by Albert A. Michelson and W.L. Worley, although indirectly. They were using an interferometer to measure the path difference of light that passed through a tremendous distance in space. In their experiment, they measured the wavelength of light in terms of metre, the known standard then. They soon realized that the reverse was more meaningful—it made more sense to define a metre in terms of wavelengths of light. This aspect was soon recognized, as scientists began to understand that the wavelength of light was stable beyond any material that had hitherto been used for the standard. Moreover, they realized that light was relatively easy to reproduce anywhere.

Optical measurement provides a simple, easy, accurate, and reliable means of carrying out inspection and measurements in the industry. This chapter provides insights into some of the important instruments and techniques that are widely used. Although an autocollimator is an important optical instrument that is used for measuring small angles, it is not discussed here..

Since optical instruments are used for precision measurement, the projected image should be clear, sharp, and dimensionally accurate. The design of mechanical elements and electronic controls should be compatible with the main optical system. In general, an optical instrument should have the following essential features:

1. A light source
2. A condensing or collimating lens system to direct light past the work part and into the optical system
3. A suitable stage or table to position the work part, the table preferably having provisions for movement in two directions and possibly rotation about a vertical axis
4. The projection optics comprising lenses and mirrors
5. A viewing screen or eyepiece to receive the projected image
6. Measuring and recording devices wherever required

When two light waves interact with each other, the wave effect leads to a phenomenon called *interference* of light. Instruments designed to measure interference are known as *interferometers*. Application of interference is of utmost interest in metrology. Interference makes it possible to accurately compare surface geometry with a master, as in the case of optical flats. Microscopic magnification enables micron-level resolution for carrying out inspection or calibration of masters and gauges. Lasers are also increasingly being used in interferometers for precision measurement. The first part of this chapter deals with a few prominent optical instruments such as the tool maker's microscope and optical projector. The latter part deals with the principle of interferometry and related instrumentation in detail.

3.1 Tool Maker's Microscope

We associate microscopes with science and medicine. It is also a metrological tool of the most fundamental importance and greatest integrity. In addition to providing a high degree of magnification, a microscope also provides a simple and convenient means for taking readings. This enables both absolute and comparative measurements. Let us first understand the basic principle of microscopy, which is illustrated in Fig. 3.1.

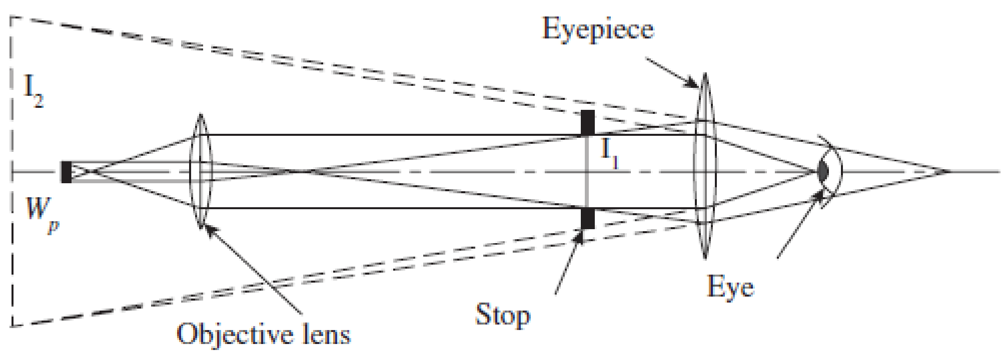


Fig. 3.1 Principle of microscopy

A microscope couples two stages of magnification. The *objective lens* forms an image of the work piece at I1 at the *stop*. The stop, frames the image so that, it can be enlarged by the *eyepiece*. Viewed through the eyepiece, an enlarged virtual image I2 is obtained. Magnification at each stage multiplies. Thus, a highly effective magnification can be achieved with only moderate magnification at each stage.

Among the microscopes used in metrology, we are most familiar with the tool maker's microscope. It is a multifunctional device that is primarily used for measurement on factory shop floors. Designed with the measurement of work piece contours and inspection of surface features in mind, a tool maker's microscope supports a wide range of applications from shop floor inspection, and measurement of tools and machined parts to precision measurement of test tools in a measuring room. The main use of a tool maker's microscope is to measure the shape, size, angle, and position of small components that fall under the microscope's measuring range. Figure 3.2 illustrates the features of a typical tool maker's microscope.

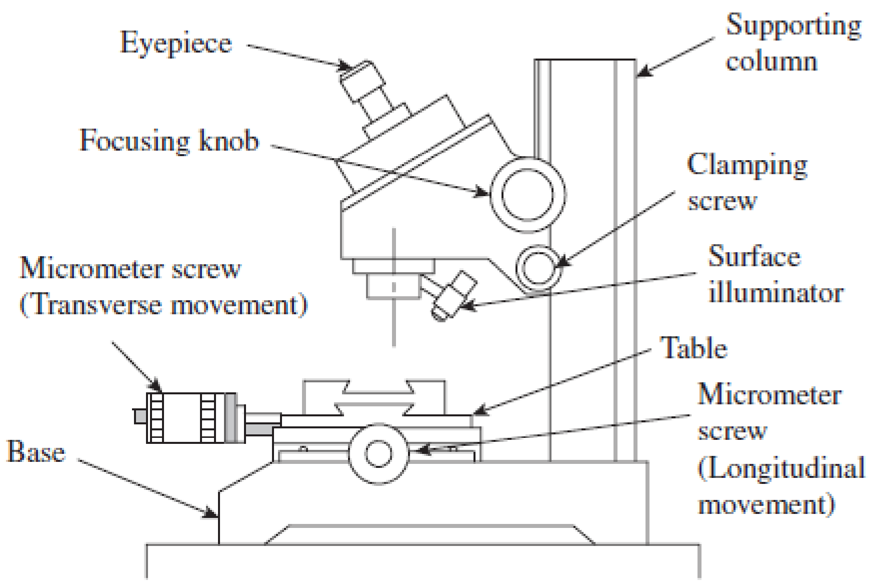


Fig. 3.2 Tool maker's microscope

It features a vertical supporting column, which is robust and carries the weight of all other parts of the microscope. It provides a long vertical working distance. The work piece is loaded on an *XY* stage, which has a provision for translatory motion in two principal directions in the horizontal plane. Micrometers are provided for both *X* and *Y* axes to facilitate linear measurement to a high degree of accuracy. The entire optical system is housed in the measuring head. The measuring head can be moved up and down along the supporting column and the image can be focused using the focusing knob. The measuring head can be locked into position by operating the clamping screw. An angle dial built into the eyepiece portion of the optical tube allows easy angle measurement. A surface illuminator provides the required illumination of the object, so that a sharp and clear image can be obtained.

The element that makes a microscope a measuring instrument is the *reticle*. When the image is viewed through the eyepiece, the reticle provides a reference or datum to facilitate measurement. Specialized reticles have been developed for precise setting. A typical reticle has two 'cross-wires', which can be aligned with a reference line on the image of the work piece. In fact, the term 'cross-wire' is a misnomer, because modern microscopes have cross-wires etched on glass. Figure 3.3 illustrates the procedure for linear measurement.

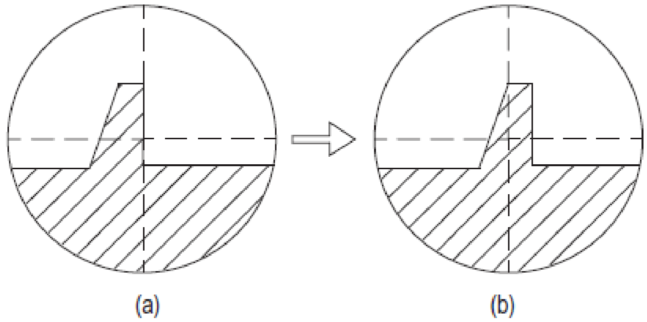


Fig. 3.3 Alignment of cross-wires with the measuring point (a) Reading R1 (b) Reading R2

A measuring point on the work piece is aligned with one of the cross-wires and the reading R1 on the microscope is noted down. Now, the *XY* table is moved by turning the micrometer head, and another measuring point is aligned with the same cross-wire. The reading, R2 is noted down. The difference between the two readings represents the dimension between the two measuring points. Since the table can be moved in two mutually perpendicular directions (both in the longitudinal as well as transverse directions) using the micrometers, a precise measurement can be obtained. In some tool maker's microscopes, instead of a micrometer head, vernier scales are provided for taking readings.

Table 7.1 Lenses used in the Mitutoyo tool maker's microscope

Lens	Magnification	Working distance (mm)
Eyepiece	10×	–
	20×	–
Objective lens	2×	65
	5×	33
	10×	14

Table 3.1 gives the details of lenses available in a 'Mitutoyo' tool maker's microscope. While the eyepiece is inserted in an eyepiece mount, the objective lens can be screwed into the optical tube. For example, an objective lens of magnification 2× and an eyepiece of magnification 20× will together provide a magnification of 40×.

The reticle is also inserted in the eyepiece mount. A positioning pin is provided to position the reticle accurately. A dioptre adjustment ring is provided in the eyepiece mount to bring the cross-wires of the reticle into sharp focus. The measuring surface is brought into focus by moving the optical tube up and down, with the aid of a focusing knob. Looking into the eyepiece, the user should make sure that the cross-wires are kept in ocular focus during the focusing operation.

Positioning of the work piece on the table is extremely important to ensure accuracy in measurement. The measuring direction of the work piece should be aligned with the traversing direction of the table. While looking into the eyepiece, the position of the eyepiece mount should be adjusted so that the horizontal cross-wire is oriented to coincide with the direction of the table movement. Now, the eyepiece mount is firmly secured by tightening the fixing screws. The work piece is placed/ clamped on the table and the micrometer head turned to align an edge of the work piece with the centre of the cross-wires. Then, the micrometer is operated and the moving image is observed to verify whether the work piece pavement is parallel to the measuring direction. By trial and error, the user should ensure that the two match perfectly.

Most tool maker's microscopes are provided with a surface illuminator. This enables the creation of a clear and sharp image. Out of the following three types of illumination modes that are available, an appropriate mode can be selected based on the application:

Contour illumination This type of illumination generates the contour image of a work piece, and is suited for measurement and inspection of work piece contours. The illuminator is equipped with a green filter.

Surface illumination This type of illumination shows the surface of a work piece, and is used in the observation and inspection of work piece surfaces. The angle and orientation of the illuminator should be adjusted so that the work piece surface can be observed under optimum conditions.

Simultaneous contour and surface illuminations Both contour and surface of a work piece can be observed simultaneously.

Some of the latest microscopes are also provided with angle dials to enable angle measurements. Measurement is done by aligning the same cross-wire with two edges of the work piece, one after the other. An angular vernier scale, generally with a least count of 61, is used to take the readings.

Applications of Tool Maker's Microscope

1. It is used in shop floor inspection of screw threads, gears, and other small machine parts.
2. Its application includes precision measurement of test tools in tool rooms.

3. It helps determine the dimensions of small holes, which cannot be measured with micrometers and callipers.

4. It facilitates template matching inspection. Small screw threads and involute gear teeth can be inspected using the optional template reticles.

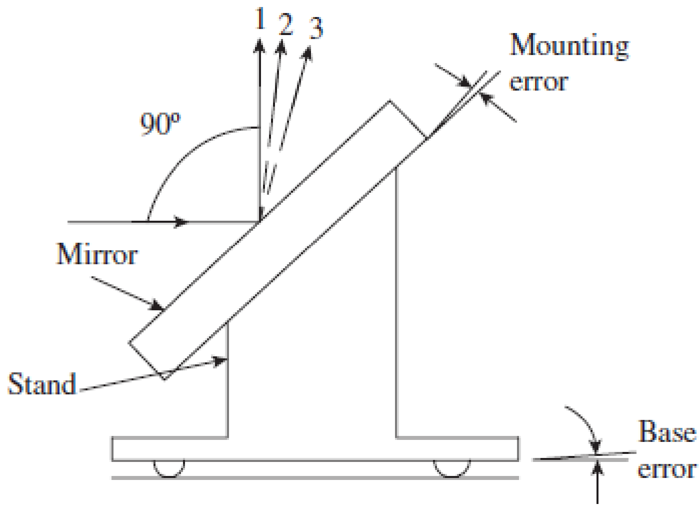
5. It enables inspection of tapers on small components up to an accuracy of 61.

3.2 Profile Projector:

The profile projector, also called the optical projector, is a versatile comparator, which is widely used for the purpose of inspection. It is especially used in tool room applications. It projects a two-dimensional magnified image of the work piece onto a viewing screen to facilitate measurement. A profile projector is made up of three main elements: the projector comprising a light source and a set of lens housed inside an enclosure, a work table to hold the work piece in place, and a transparent screen with or without a chart gauge for comparison or measurement of parts.

3.2.1 Optical Squares

An optical square is useful in turning the line of sight by 90° from its original path. Many optical instruments, especially microscopes, have this requirement. An optical square is essentially a pentagonal prism (pentaprism). Regardless of the angle at which the incident beam strikes the face of the prism, it is turned through 90° by internal reflection. Unlike a flat mirror, the accuracy of a pentaprism is not affected by the errors present in the mounting arrangement. This aspect is illustrated in Figs 3.4 and3.5. It can be seen from Fig. 3.4 that a mirror is kept at an angle of 45° with respect to the incident ray of light, so that the reflected ray will be at an angle of 90° with respect to the incident ray. It is observed that any error in the mounting of the mirror or in maintaining its base parallel, in a fixed reference, to the beam is greatly magnified by the optical lever effect. These two errors in combination may even be greater than the work piece squareness error.



1 — Reflected ray without errors
2 — Reflected ray due to mounting error
2 — Reflected ray due to base error

Fig. 3.4 Mirror reflecting light by 90°

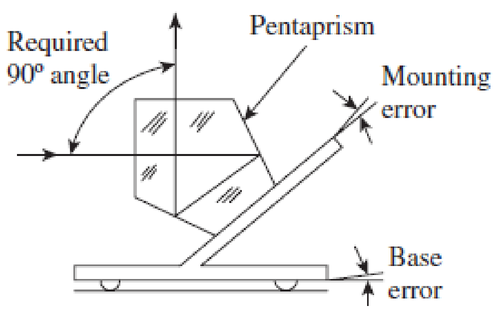


Fig. 3.5 Optical square

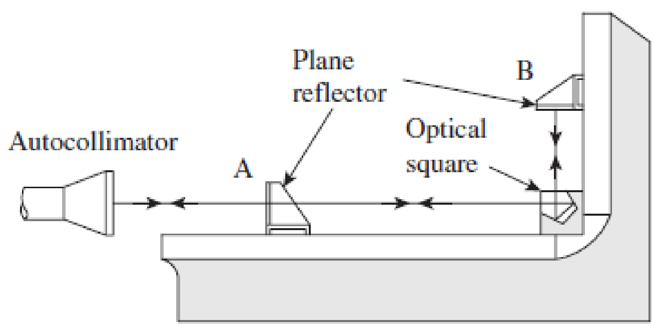


Fig. 3.6 Use of an optical square to test squareness

This problem may be overcome by using an optical square. Figure 3.5 illustrates the optical path through an optical square. The incident ray is reflected internally from two faces and emerges from the square at exactly 90° to the incident light. This is a remarkable property. Any slight deviation or misalignment of the prism does not affect the right angle movement of the light ray. Optical squares are of two types. One type is fitted into instruments like telescopes, wherein an optical square is factory-fitted to ensure that the line of sight is perpendicular to the vertex. The second type comes with the necessary attachments for making adjustments to the line of sight. This flexibility allows optical squares to be used in a number of applications in metrology. Figure 3.6 illustrates the use of an optical square to test the squareness of machine slideways.

Squareness of the vertical slideway with respect to a horizontal slideway or bed is of utmost importance in machine tools. The test set-up requires an autocollimator, plane reflectors, and an optical square. It is necessary to take only two readings, one with the reflector at position A and a second at position B, the optical square being set down at the intersection of the two surfaces when the reading at B is taken. The difference between the two readings is the squareness error.

7.3 OPTICAL INTERFERENCE

A ray of light is composed of an infinite number of waves of equal wavelength. We know that the value of the wavelength determines the colour of light. For the sake of simplicity, let us consider two waves, having sinusoidal property, from two different light rays. Figure 3.7 illustrates the combined effect of the two waves of light.

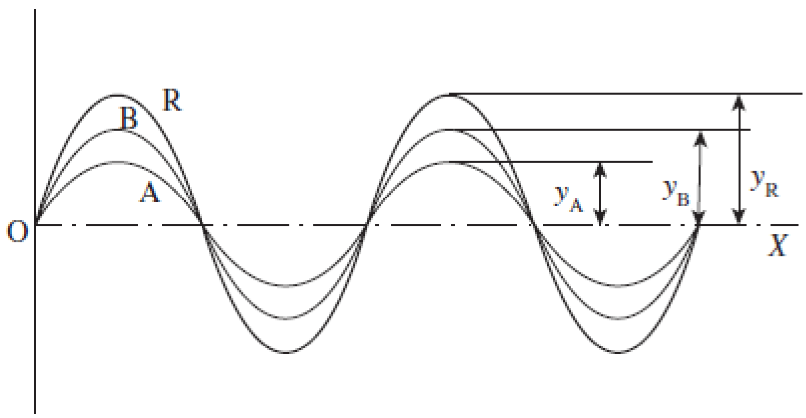


Fig. 3.7 Two waves of different amplitudes that are in phase

The two rays, A and B, are in phase at the origin O, and will remain so as the rays propagate through a large distance.

Suppose the two rays have amplitudes *y*A and *y*B, then the resultant wave will have an amplitude *y*R = *y*A + *y*B. Thus, when the two rays are in phase, the resultant amplitude is maximum and the intensity of light is also maximum. However, if the two rays are out of phase, say by an amount *d*, then the resultant wave will have an amplitude *y*R = (*y*A + *y*B) cos *d* /2. It is clear that the combination of the two waves no longer produces maximum illumination.

Consider the case where the phase difference between the two waves is 180°. The amplitude of the resulting wave, which is shown in Fig. 3.8, is the algebraic sum of *y*A and *y*B. The corollary is that if *y*A and *y*B are equal, then *y*R will be zero since cos(180/2) is zero. This means that complete *interference* between two waves having the same wavelength and amplitude produces darkness.

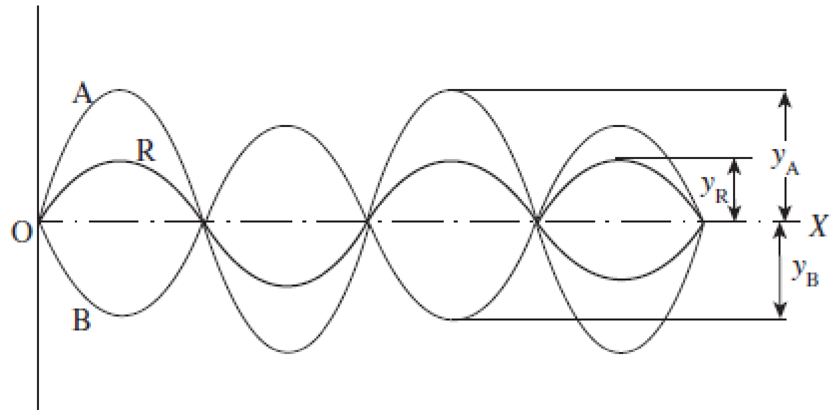


Fig. 3.8 *Two waves of different amplitudes, out of phase by 180°*

One of the properties of light is that light from a single source can be split into two component rays. Observing the way in which these components recombine shows us that the wave length of light can be used for linear measurement. The linear displacement *d* between the wavelengths of the two light rays results in maximum interference when $d = \lambda/2$, where λ is the wavelength of light.

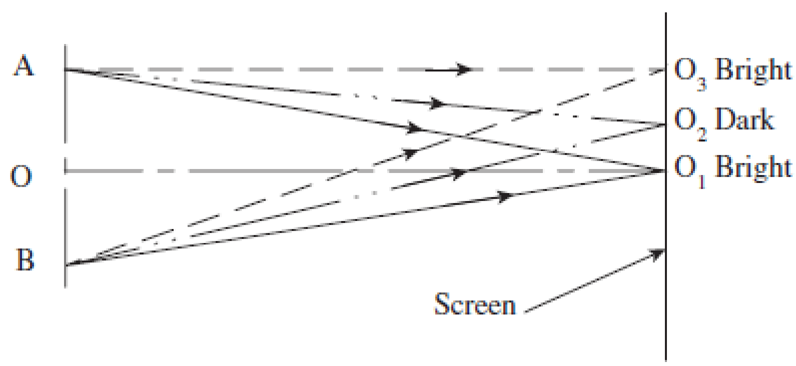


Fig. 3.9 Formation of fringes

Now in what way is this property going to help us in taking linear measurements? Figure 3.9 illustrates how the property of interference of light can be used for linear measurement. Let us consider two monochromatic light rays from two point sources, A and B, which have the same origin. The light rays are made to fall on a flat screen that is placed perpendicular to the axis OO1. The axis OO1 is in turn perpendicular to the line joining the two point sources, A and B.

Since both rays originate from the same light source, they are of the same wavelength. Let us also assume that the distances OA and OB are equal.

Now, consider convergence of two rays at point O1 on the screen. Since the distances AO1 and BO1 are equal, the two rays are in phase, resulting in maximum illumination at point O1. On the other hand, at point O2, the distance BO2 is longer than the distance AO2. Therefore, by the time the two rays arrive at point O2, they are out of phase. Assuming that the phase difference $d = \lambda/2$, where λ is the wavelength of light, complete interference occurs, forming a dark spot.

At point O3 on the screen, the distance BO3 is longer than AO3. If the difference between the two distances, that is, BO3 − AO3, is equal to an even number of half wavelengths, the two light rays arriving at O3 will be in phase, leading to the formation of a bright spot. This process repeats on either side of O1 on the screen, resulting in the formation of alternate dark and bright areas. This pattern of alternate bright and dark areas is popularly known as fringes. The dark areas will occur whenever the path difference of A and B amounts to an odd number of half wavelengths, and the bright areas will occur when the path difference amounts to an even number of half wavelengths.

3.4 INTERFEROMETRY

It is now quite obvious to the reader that the number of fringes that appear in a given length on the screen is a measure of the distance between the two point light sources and forms the basis for linear measurement. This phenomenon is applied for carrying out precise measurements of very small linear dimensions, and the measurement technique is popularly known as *interferometry*. This technique is used in a variety of metrological applications such as inspection of machine parts for straightness, parallelism, and flatness, and measurement of very small diameters, among others. Calibration and reference grade slip gauges are verified by the interferometry technique. The instrument used for making measurements using interferometry technique is called an *interferometer*.

A variety of light sources are recommended for different measurement applications, depending on convenience of use and cost. The most preferred light source is a tungsten lamp with a filter that transmits monochromatic light. Other commonly used light sources are mercury, mercury 198, cadmium, krypton 86, thallium, sodium, helium, neon, and gas lasers. Among all the isotopes of mercury, mercury 198 is one of the best light sources, producing rays of sharply defined wavelength. In fact, the wavelength of mercury 198 is the international secondary standard of length.

Krypton-86 light is the basis for the new basic international standard of length. The metre is defined as being exactly 1,650,763.73 wavelengths of this light source, measured in vacuum. Gas lasers comprising a mixture of neon and helium produce light that is far more monochromatic than all the aforementioned sources. Interference fringes can be obtained with enormous path differences, up to 100 million wavelengths.

While optical flats continue to be the popular choice for measurement using the interferometry technique, a host of other instruments, popularly known as interferometers, are also available. An interferometer, in other words, is the extension of the optical flat method. While interferometers have long been the mainstay of dimensional measurement in physical sciences, they are also becoming quite popular in metrology applications. While they work according to the basic principle of an optical flat, which is explained in the Section 7.4.1 they provide additional conveniences to the user. The mechanical design minimizes time-consuming manipulation. The instrument can be fitted with additional optical devices for magnification, stability, and high resolution. In recent times, the use of lasers has greatly extended the potential range and resolution of interferometers.

3.4.1 Optical Flats

The most common interference effects are associated with thin transparent films or wedges bounded on at least one side by a transparent surface. Soap bubbles, oil films on water, and optical flats fall in this category. The phenomenon by which interference takes place is readily described in terms of an optical flat, as shown in Fig. 3.10.

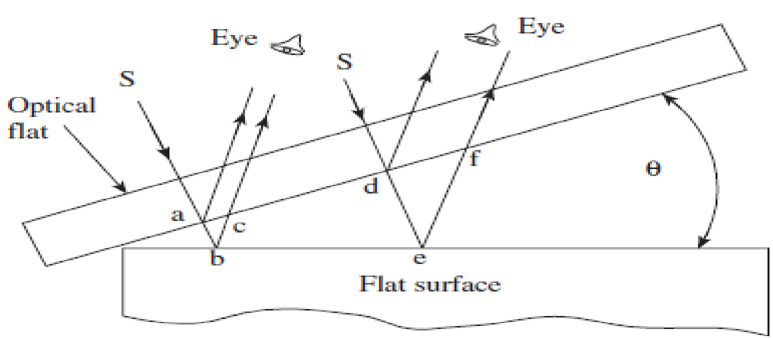


Fig. 3.10 Fringe formation in an optical flat

An optical flat is a disk of high-quality glass or quartz. The surface of the disk is ground and lapped to a high degree of flatness. Sizes of optical flats vary from 25 to 300 mm in diameter, with a thickness ranging from 25 to 50 mm. When an optical flat is laid over a flat reflecting surface, it orients at a small angle θ, due to the presence of an air cushion between the two surfaces. This is illustrated in Fig. 3.10. Consider a ray of light from a monochromatic light source falling on the upper surface of the optical flat at an angle. This light ray is partially reflected at point 'a'. The remaining part of the light ray passes through the transparent glass material across the air gap and is reflected at point 'b' on the flat work surface. The two reflected components of the light ray are collected and recombined by the eye, having travelled two different paths whose length differs by an amount 'abc'.

If 'abc' = $\lambda/2$, where λ is the wavelength of the monochromatic light source, then the condition for complete interference has been satisfied. The difference in path length is one-half the wavelength, a perfect condition for total interference, as explained in Section 3.3. The eye is now able to see a distinct patch of darkness termed a fringe. Next, consider another light ray from the same source falling on the optical flat at a small distance from the first one. This ray gets reflected at points 'd' and 'e'. If the length 'def' equals $3\lambda/2$, then total interference occurs again and a similar fringe is seen by the observer. However, at an intermediate point between the two fringes, the path difference between two reflected portions of the light ray will be an even number of half wavelengths. Thus, the two components of light will be in phase, and a light band will be seen at this point.

To summarize, when light from a monochromatic light source is made to fall on an optical flat, which is oriented at a very small angle with respect to a flat reflecting surface, a band of alternate light and dark patches is seen by the eye. Figure 3.11 illustrates the typical fringe pattern seen on a flat surface viewed under an optical flat. In case of a perfectly flat surface, the fringe pattern is regular, parallel, and uniformly spaced. Any deviation from this pattern is a measure of error in the flatness of the surface being measured.

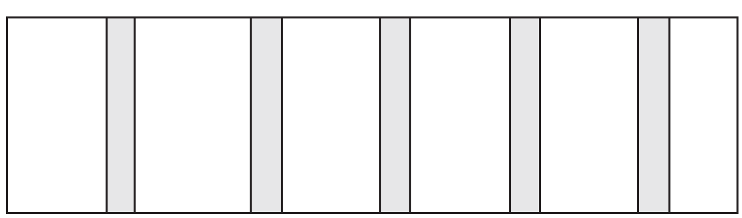


Fig. 3.11 Interference fringes

Fringe patterns provide interest-ing insights into the surface being inspected. They reveal surface conditions like contour lines on a map. Figure 3.12 illustrates typical fringe patterns, and Table 3.2 offers useful hints about the nature of surfaces corresponding to the patterns. Once we recognize surface configurations from their fringe patterns, it is much easier to measure the configurations.

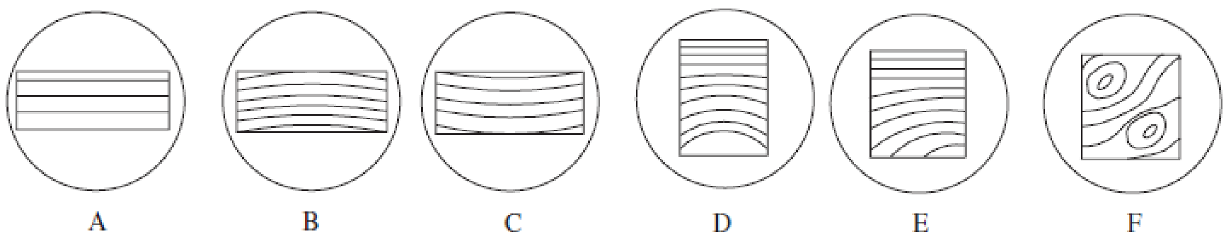


Fig. 7.12 Fringe patterns reveal surface conditions

Comparative Measurement with Optical Flats

One of the obvious uses of an optical flat is to check the heights of slip gauge blocks. The slip gauge that is to be checked is kept alongside the reference gauge on a flat table. An optical flat is then placed on top of both gauges, as shown in Fig. 3.13. Let us assume that A is the standard reference gauge block while B is the gauge block that is being inspected.

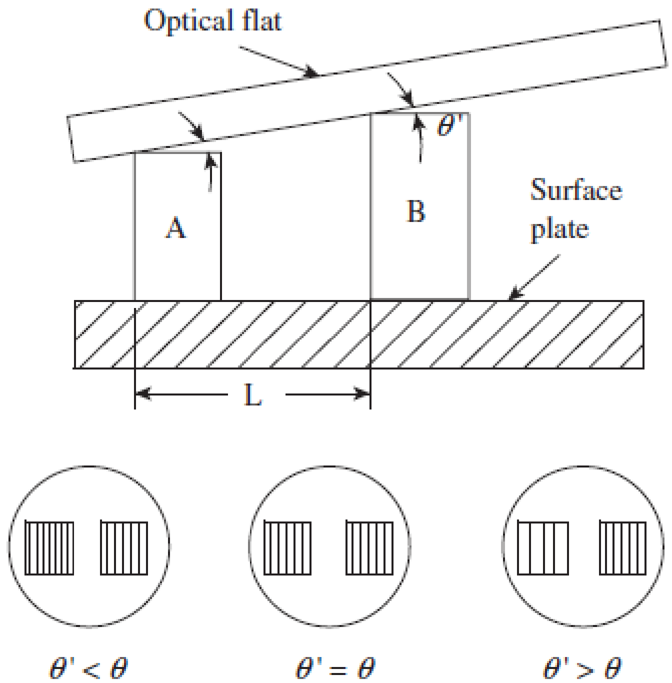


Fig. 3.13 Height measurement using an optical flat

A monochromatic light source is used and the fringe patterns are observed with the help of a magnifying glass. It can be seen from the figure that the optical flat makes inclinations of *q* and *q* ' with the top surfaces of the two slip gauges. Ideally, the two angles should be the same. However, in most cases, the angles are different by virtue of wear and tear of the surface of the slip gauge that is being inspected. This can easily be seen by looking at the fringe pattern that is formed on the two gauges, as seen from the magnified images. The fringes seen on both the gauges are parallel and same in number if both the surfaces are perfectly flat; otherwise, the number of fringes formed on the two gauges differs, based on the relationship between *q* and *q* '.

Now, let the number of fringes on the reference block be *N* over a width of *l* mm. If the distance between the two slip gauges is *L* and λ is the wavelength of the monochromatic light source, then the difference in height *h* is given by the following relation:

h = l*LN* 2*l*

This simple procedure can be employed to measure very small height differences in the range of 0.01–0.1 mm. However, the accuracy of this method depends on the accuracy of the surface plate and condition of the surfaces of the specimen on which the optical flat is resting. It is difficult to control the 'lay' of the optical flat and thus orient the fringes to the best advantage. The fringe pattern is not viewed from directly above, and the resulting obliquity can cause distortion and errors in viewing. A better way of conducting accurate measurement is to use an interferometer. While a variety of interferometers are used in metrology and physical sciences, two types are discussed in the following section: the NPL flatness interferometer and the Pitter–NPL gauge interferometer.

Table 3.2 Fringe patterns and the resulting surface conditions

Fringe pattern	Surface condition
A	Block is nearly flat along its length.
B	Fringes curve towards the line of contact, showing that the surface is convex and high in the centre.
C	Surface is concave and low in the centre.
D	Surface is flat at one end but becomes increasingly convex.
E	Surface is progressively lower towards the bottom left-hand corner.
F	There are two points of contact, which are higher compared to other areas of the block.

3.5 INTERFEROMETERS

Interferometers are optical instruments that are used for very small linear measurements. They are used for verifying the accuracy of slip gauges and measuring flatness errors. Though an interferometer works on the same basic principle as that of an optical flat, it is provided with arrangements in order to control the lay and orientation of fringes. It is also provided with a viewing or recording system, which eliminates measurement errors.

3.5.1 NPL Flatness Interferometer

This interferometer was designed and developed by the National Physical Laboratory of the United Kingdom. It comprises a simple optical system, which provides a sharp image of the fringes so that it is convenient for the user to view them. The light from a mercury vapour lamp is condensed and passed through a green filter, resulting in a green monochromatic light source. The light will now pass through a pinhole, giving an intense point source of monochromatic light. The pinhole is positioned such that it is in the focal plane of a collimating lens. Therefore, the collimating lens projects a parallel beam of light onto the face of the gauge to be tested via an optical flat. This results in the formation of interference fringes. The light beam, which carries an image of the fringes, is reflected back and directed by 90° using a glass plate reflector.

The entire optical system is enclosed in a metal or fibreglass body. It is provided with adjustments to vary the angle of the optical flat, which is mounted on an adjustable tripod. In addition, the base plate is designed to be rotated so that the fringes can be oriented to the best advantage (Fig. 3.14).

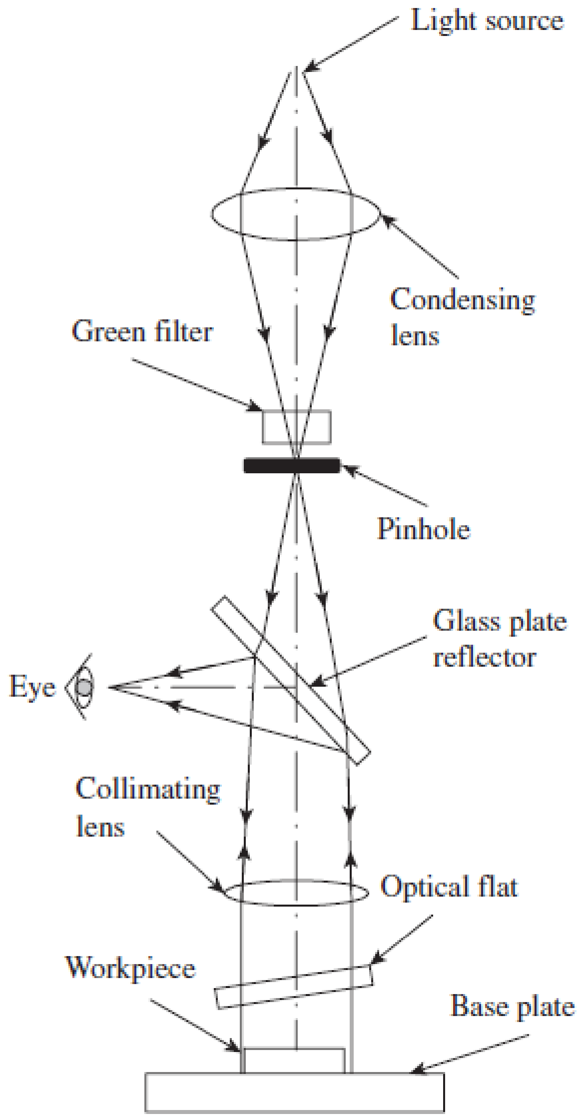
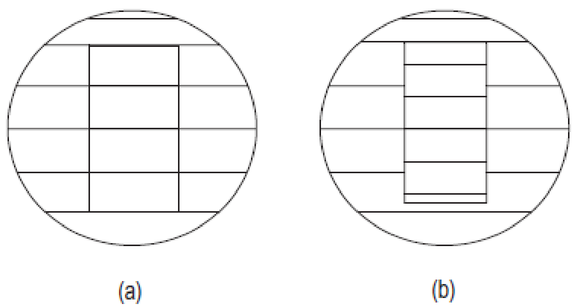


Fig. 3.14 Optical system of an NPL flatness interferometer

Figure 3.15 illustrates the fringe pattern that is typically observed on the gauge surface as well as the base plate. In Fig. 3.15(a), the fringes are parallel and equal in number on the two surfaces. Obviously, the two surfaces are parallel, which means that the gauge surface is perfectly flat. On the other hand, in Fig. 3.15(b), the number of fringes is unequal and, since the base plate surface is ensured to be perfectly flat, the work piece surface has a flatness error. Due to the flatness error, the optical flat makes unequal angles with the work piece and the base plate, resulting in an unequal number of fringes. Most of the times fringes will not be parallel lines, but will curve out in a particular fashion depending on the extent of wear and tear of the upper surface of the work piece. In such cases, the fringe pattern gives a clue about the nature and direction of wear.



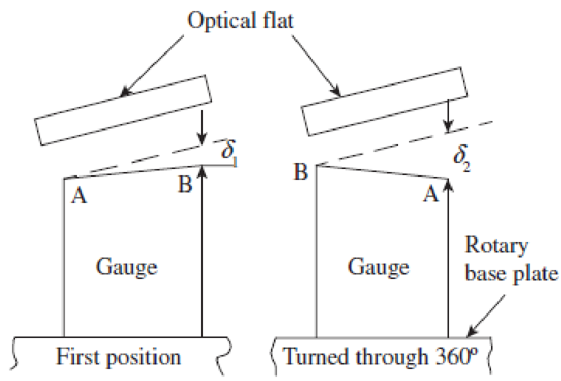


Fig. 3.15 Example of fringe patterns

(a) Equal fringes on parallel surfaces

(b) Unequal fringes due to flatness error

Fig. 3.16 testing parallelism in gauges

Measuring Error in Parallelism

The NPL flatness interferometer is used for checking flatness between gauge surfaces. The gauge to be checked is placed on a base plate that has a high degree of flatness. If the gauge length is smaller than 25 mm, the gauge is placed on the base plate and the fringe pattern is observed. If the gauge being inspected is free from flatness error, then the fringes formed on both the gauge surface and the base plate are equally spaced. For gauges longer than 25 mm, fringe pattern on the base plate is difficult to observe. Therefore, the gauge is placed on a rotary table, as shown in Fig. 3.16. Suppose the gauge surface has flatness error, because of the angle it makes with the optical flat, a number of fringes are seen on the gauge surface. Now the table is rotated through 180°, and the surface of the gauge becomes even less parallel to the optical flat. This results in more number of fringes appearing on the gauge surface.

Let us consider a gauge that shows $n1$ fringes along its length in the first position and $n2$ in the second position. As seen in Fig. 3.16, the distance between the gauge and the optical flat in the first position has increased by a distance $d1$, over the length of the gauge, and in the second position by a distance $d2$. It is clear that the distance between the gauge and the optical flat changes by $\lambda/2$, between adjacent fringes.

Therefore, $d1 = n1 \times \lambda/2$ and $d2 = n2 \times \lambda/2$.

The change in angular relationship is $(d2 - d1)$, that is, $(d2 - d1) = (n1 - n2) \times \lambda/2$.

3.5.2 Pitter–NPL Gauge Interferometer

This interferometer is used for determining actual lengths of slip gauges. Since the measurement calls for a high degree of accuracy and precision, the instrument should be used under highly controlled physical conditions. It is recommended that the system be maintained at an ambient temperature of 20 °C, and a barometric pressure of 760 mmHg with a water vapour pressure of 7 mm, and contain 0.33% by volume of carbon dioxide.

The optical system of the Pitter–NPL interferometer is shown in Fig. 3.17. Light from a monochromatic source (the preferred light source is a cadmium lamp) is condensed by a condensing lens and focused onto an illuminating aperture. This provides a concentrated light source at the focal point of a collimating lens. Thus, a parallel beam of light falls on a constant deviation prism. This prism splits the incident light into light rays of different wavelengths and hence different colours. The user can select a desired colour by varying the angle of the reflecting faces of the prism relative to the plane of the base plate.

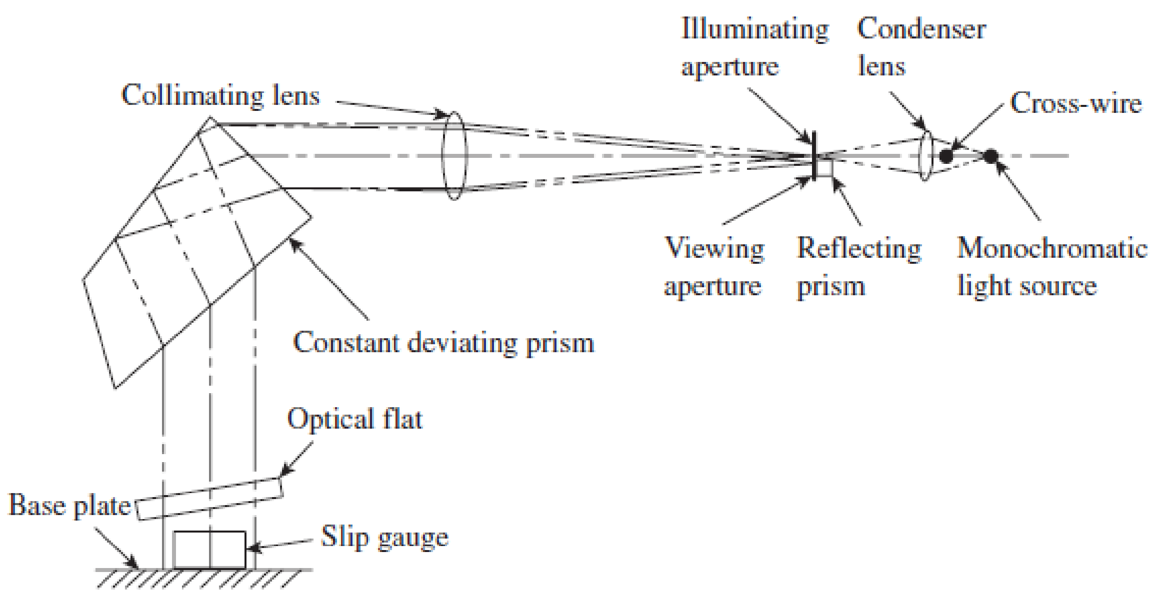


Fig. 3.17 Optical system of the Pitter–NPL gauge interferometer

The prism turns the light by 90° and directs it onto the optical flat. The optical flat can be positioned at a desired angle by means of a simple arrangement. The slip gauge that is to be checked is kept right below the optical flat on top of the highly flat surface of the base plate. The lower portion of the optical flat is coated with a film of aluminium, which transmits and reflects equal proportions of the incident light. The light is reflected from three surfaces, namely the surface of the optical flat, the upper surface of the slip gauge, and the surface of the base plate. Light rays reflected from all the three surfaces pass through the optical system again; however, the axis is slightly deviated due to the inclination of the optical flat. This slightly shifted light is captured by another prism and turned by 90°, so that the fringe pattern can be observed and recorded by the user.

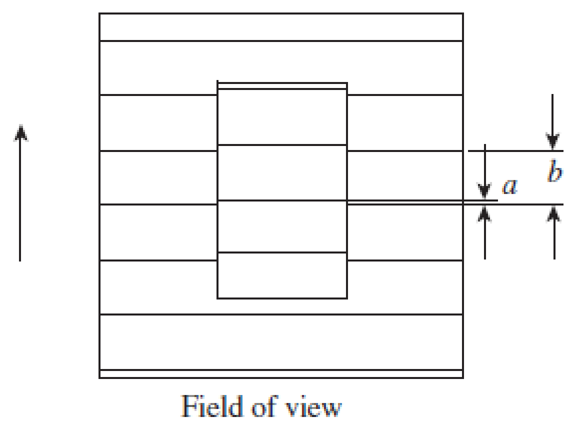


Fig. 7.18 Field of view of fringe pattern

The typical fringe pattern observed is shown in Fig. 3.18. Superimposition of the fringes corresponding to the upper surface of the slip gauge upon those corresponding to the surface of the base plate is shown in Fig. 7.18. It can be seen that the two sets of fringes are displaced by an amount a with respect to each other. The value of a varies depending on the colour of the incident light. The displacement a is expressed as a fraction of the fringe spacing b, which is as follows:

$f = a/b$

The height of the slip gauge will be equal to a whole number of half wavelengths, n, plus the fraction a/b of the half wavelengths of the radiation in which the fringes are observed.

Therefore, the height of the slip gauge, $H = n\,(\lambda/2) + (a/b) \times (\lambda/2)$, where n is the number of fringes on the slip gauge surface, λ is the wavelength of light, and a/b is the observed fraction.

However, practitioners of industrial metrology are not happy with the values thus obtained. The fraction readings are obtained for all the three colours of cadmium, namely red, green, and violet. For each of the wavelengths, fractions *a*/*b* are recorded. Using these fractions, a series of expressions are obtained for the height of the slip gauge. These expressions are combined to get a general expression for gauge height. The Pitter–NPL gauge interferometer is provided with a slide rule, in which the wavelengths of red, green, and violet are set to scale, from a common zero. This provides a ready reckoner to speed up calculations.

COMPARATORS

Introduction:

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

Need for a comparator:

In mass production identical component parts are produced on a very large scale. To achieve inter changeability these parts should be produced to a close dimensional tolerances.

Basic Principle of Operation:

The basic principle of operation of a comparator is:

The comparator is first adjusted to zero on its dial or recording device with a guage block in position. The gauge block is of dimension which the workpiece should have. The workpiece to be checked is then placed in position and the comparator gives the difference in dimension in relation to the gauge block.

Uses of Comparator:

The various Ways in which comparators can be used are:

1. Laboratory Standards: Comparators are used as laboratory standards from which working or inspection gauges are set and correlated.

2. Working Gauges: They are also used as working gauges to prevent work spoilage and to maintain required tolerance at all important stages of manufacture.

3. Final Inspection Gauges: Comparators may be used as final inspection gauges. Where selective assembly, of production parts is necessary.

4. Receiving Inspection Gauges: As receiving inspection gauges comparators are used for checking parts received from outside sources.

5. For checking newly purchased gauges: The use of comparators enables the checking of the parts (components in mass production at a very fast rate.)

Essential characteristics of a good comparator:

1. Robust design and construction: The design and construction of the comparator should be robust so that it can withstand the effects of ordinary uses without affecting its measuring accuracy. [Robust=strong]

2. Linear characteristics of scale: Recording or measuring scale should be linear and uniform (straight line characteristic) and its indications should be clear.

3. High magnification: The magnification of the comparator should be such that a smallest deviation in size of component can be easily detected.

4. Quick in results: The indicating system should be such that the readings are obtained in least possible time.

5. Versatility: Instruments should be designed that it can be used for wide range of measurements.

6. Minimum wear of contact point: The measuring plunger should have hardened steel contact or diamond to minimize wear effects. Further the contact pressure should be low and uniform.

7. Free from oscillations: The pointer should come rapidly to rest and should be free from oscillations.

8. Free from back lash: System should be free from back lash and unnecessary friction and it should have minimum inertia.

9. Quick insertion of workpiece: Means should be provided for lifting the plunger for quick insertion of work.

10. Adjustable Table: The table of the instrument should, preferably, be adjustable in a vertical sense.

11. Compensation from temperature effects: The indicator should be provided with maximum compensation for temperature effects.

12. Means to prevent damage: Suitable means should be provided for preventing damage of the instrument in the event of the plunger moving through a greater distance than that corresponding to the range of its measuring scale.

Classification of comparators:

A wide variety of comparators are commercially available at present. They are classified according to the method used for amplifying and recording the variations measured in to the following types.

1. Mechanical comparators

2. Optical comparators

3. Mechanical-Optical comparators

4. Electrical and Electronics comparators

5. Pneumatic comparators.

6. Fluid displacement comparators

7. Projection comparators

8. Multi check comparators

9. Automatic Gauging Machines

10. Electro-Mech. comparators.

In addition to above, comparators of particularly high sensitivity and magnification, used in standard rooms for calibration of gauges include.

1. The Brookes Level comparator 2. The Eden-Rolt 'millionth' comparator.

- **Mechanical Comparators:**

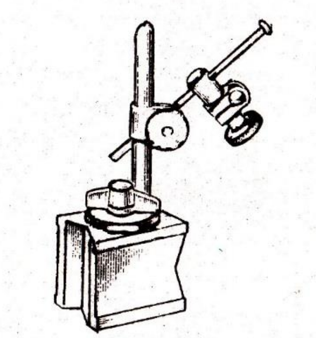
Principle of workings: A mechanical comparator employes mechanical means for magnifying the small movement of the measuring stylus, brought about due the difference between the standard and the actual dimension being checked. In these comparators the magnification of the small stylus movement is obtained by means of levers, gear trains, rack and pinion or a combination. The usual magnification obtained by these comparators ranges from about 250 to 1000. Mechanical comparators are of the following types:

1. Dial indicator (Dial gauge) 2. Johansson Mikrokator 3. Read type mechanical comparator

4. Sigma comparator.

1. Dial indicator (Dial gauge):

The simplest type of mechanical comparator is a dial indicator. It consists of a base with a rigid column risign from its rear. An arm is mounted on this column and it carries a dial gauge at its outer end. The arm can be adjusted vertically up and down along the column. An anvil or a worktable is mounted on the base, which provides a reference on which work pieces are placed during measuring operation. Such a simple comparator is ideal for the checking of components with a tolerance of say $\pm$0.05 millimeters.



Dial gauge

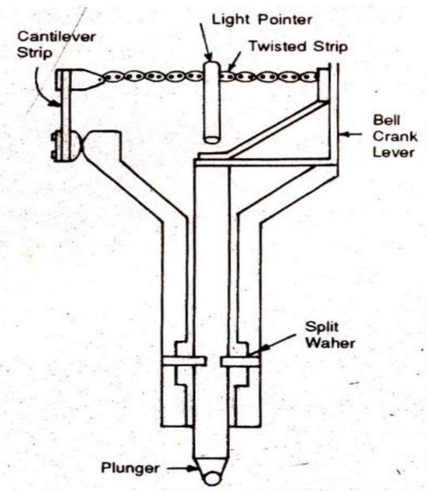
In its operation, the indicator is set to zero by the use of slip gauses representing the basic size of the part. The part to be checked is then placed below the measuring plunger of the indicator. The linear movement of the plunger is magnified by means of a gear and pinion train in to sizable rotation of the pointer. The variation in dimension of the part from the basic size is indicated on the dial.

Dial indicator is generally used for inspection of small precision machined parts. The dial indicator with various attachments may be used for large number of works; with V-block attachment it can be used for checking out of roundness of a cylindrical part.

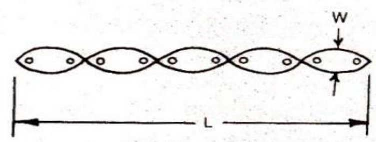
2. Johansson Mikrokator:

This instrument was first devised by m/s C.F. Johansson and hence the name. It uses a twisted strip to convert small linear movement of a plunger into a large circular movement of a pointer. It is therefore, also called as twisted strip comparator. It uses the simplest method for obtaining the mechanical magnification designed by H. Abramson which is known as 'Abramson movement'.

A twisted thin metal strip carries at the centre of its length a very light pointer made of thin glass. One end of the strip is fixed to the adjustable cantilever strip and the other end is anchored to the spring elbow, one arm of which is carried on measuring plunger. The spring elbow acts as a bell crank lever. The construction of such a comparator is shown in Fig.



Johansson Mikrokator



Twisted strip of Mikrokator

A slight upward movement of plunger will make the bell crank lever to rotate.

Due to this a tension will be applied to the twisted strip in the direction of the arrow. This causes the strip to untwist resulting in the movement of the point. The spring will ensure that the plunger returns when the contact pressure between the bottom tip of the plunger and the workpiece is not there, that is, when the workpiece is removed from underneath the plunger.

The length of the cantilever can be varied to adjust the magnification. In order to prevent excessive stress on the central portion, the strip is perforated along the centre line by performation as shown in Fig. 5.3. The magnification of the instrument is approximately equal to the ratio of rate of change of pointer movement to rate of change in length of the strip, *i.e.*, $\frac{dQ}{dL}$. It can be shown that the magnification of the instrument $\frac{dQ}{dL} \propto \frac{L}{w^2 n}$,

where, Q = twist of mid point of strip with respect to the end

L = length of twisted strip measured along its neutral axis

w = width of twisted strip and,

n = number of turns.

It is thus obvious that in order to increase the magnification of the instrument a very thin rectangular strip must be used.

3. Read type mechanical comparator:

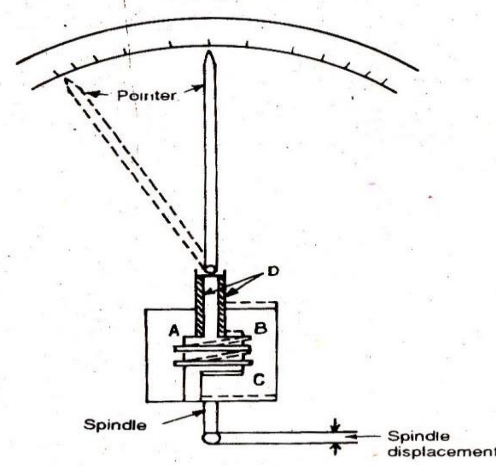
In reed type mechanical comparator, the gauging head is usually a sensitive, high quality, dial indicator. The dial indicator is mounted on a base supported by a sturdy column. Fig. 5.4 shows a read type mechanical comparator.

The reed mechanism is fricti ›nless device for magnifying small motions of the spindle. It consists of a fixed block. A which is rigidly fastened to the gauge head case, and floating block *B*, which carries the gauging spindle and is connected horizontally to the fixed block by reed *C*.

A vertical reed is attached to each block with upper ends joined together.

These vertical reeds are indicated by *D*. Beyond this joint extends a pointer. A linear motion of the spindle moves the free block vertically causing the vertical reed on the floating block to slide past the vertical reed on the fixed block. However, as the vertical reeds are joined at the upper end, instead of slipping, the movement causes both reeds swing through an arc.

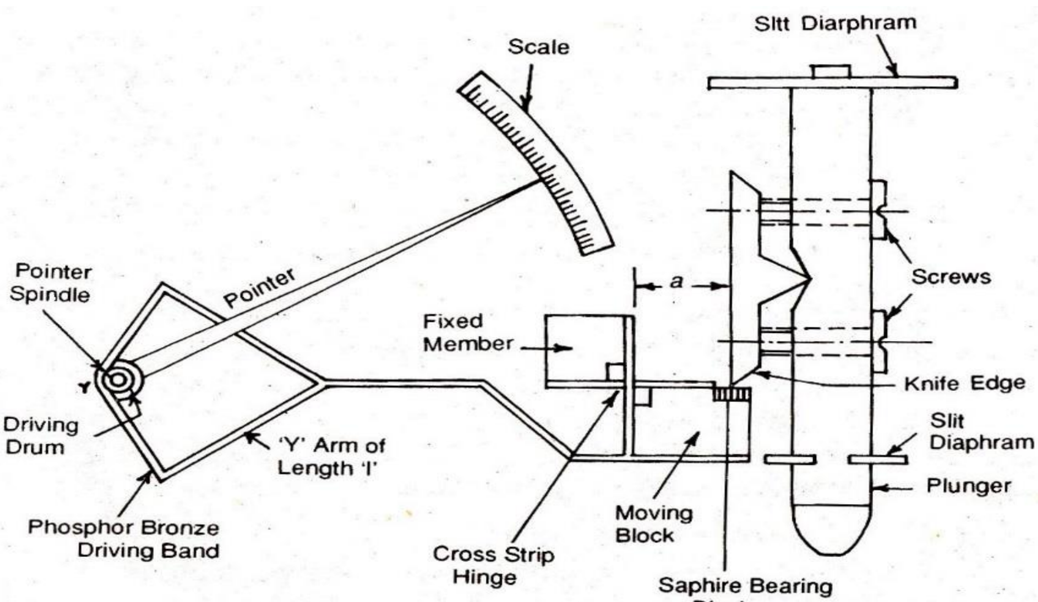
The scale may be calibrated by means of gauge block to indicate any deviation from an initial setting. The mechanical amplification is usually less than 100 but it is multiplied by the optical lens system. It is available in amplification ranging from 500 to 1000.



Reed type mechanical comparator

4. Sigma comparator:

This is a mechanical comparator providing magnification in the range of 300 to 5000. It consists of a plunger mounted on two flat steel strings (slit



Sigma of comparator

diaphrams). this provides a frictionless linear movement for the plunger. The plunger carries a knife edge, which bears upon the face of the mounting block of a cross-strip hinge. The cross strip hinge is formed by pieces of flat steel springs arranged at right angles and is a very efficient pivot for smaller angular movements. The moving block carries a light metal Y-forked arms. A thin phosphor bronze ribbon is fastened to the ends of the forked arms and wrapped around a small drum, mounted on a spindle carrying the pointer.

Any vertical displacement of the measuring plunger and hence that of the knife edge makes the moving block of the cross strip liver to pivot. This causes the rotation of the Y-arms. The metallic band attached to the arms makes the driving drum and hence the pointer to rotate.

The ratio of the effective length (L) of the arm and the distance (a) of the knife edge from the pivot gives the first stage magnification and the ratio of the pointer length (l) and radius (r) of the driving drum gives second stage magnification of the instrument. Total magnification of the instrument is thus $\left(\frac{L}{a} \times \frac{l}{r}\right)$. The magnification of the instrument can be varied by changing the distance (a) of Knife edge of tightening or slackening of the adjusting screws : The range of instruments available provides magnifications of x 300 to X 5000, the most sensitive models allowing scale estimation of the order of 0.0001 mm to be made.

Some important features (advantages) of the sigma comparator are :

1. Safety : As the knife edge moves away from the moving member of the hinge and is followed by it, therefore, if too robust movement of the plunger is made due to shock load, that will not be transmitted through the movement.

2. Dead beat Readings : By mounting a nonferrous disc on the pointer spindle and making it move in field of a permanent magnet, dead beat reading can be obtained.

3. Parallax : The error due to Parallax is avoided by having a reflective strip on the scale

4. Constant pressures. The constant measuring pressure over the range of the instrument is obtained by the use of magnet plunger. On the frame

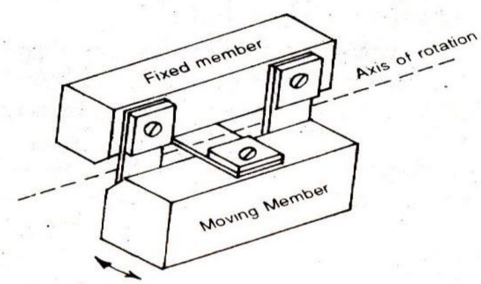


Fig. 5.6. cross strip liver used in sigma comperator.

5. Fine adjustments are possible

Disadvantages 1. Due to motion of the parts there is a wear in the moving parts.

2. It is not sensible as optical comparator due to friction of the morning parts.

Advantages of Mechanical Comparators:

1. Cheaper. Mechanical comparators are less costly as compared to other amplifying devices.

2. No need of external agency. These instruments do not require any external agency such as electricity or air and as such the variations in outside supply do not affect the accuracy.

3. Linear Scale. Usually the mechanical comparators have linear scale.

4. Robust and compact: These instruments are robust and compact in design and easy to handle.

5. Portable: For ordinary workshop conditions, these instruments are very suitable and being portable can be issued from the stores.

Disadvantages of Mechanical Comparators

1. Less accuracy (a) Due to more moving parts, the friction is more which reduces the accuracy

(b) Any slackness in moving parts also reduces the accuracy considerably.

2. Sensitive to vibrations: The mechanisms in mechanical comparators have more inertia and. this may cause them to be sensitive to vibrations.

3. Faults magnified: Any wear backlash or dimensional faults in the mechanical devices used will also be magnified.

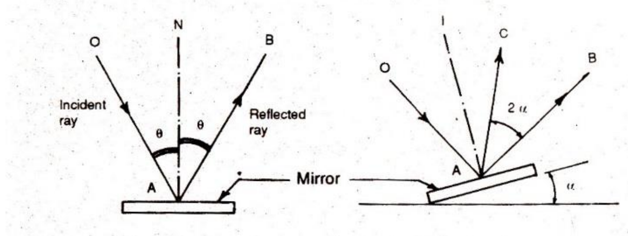
4. Limited range: The range of the instrument is limited as the pointer moves over a fixed scale.

5. Parallax error: Error due to Parallax are more likely with these instruments as the pointer moves over a fixed scale.

- **Optical Comparators:**

Working principle: In these comparators, use is made of a fundamental optical law and instead of a printer, the edge of the shadow is projected on to a curved graduated scale to indicate the comparison measurement. The optical principle adopted is that of 'optical lever' which is shown in Fig. If a ray of light OA strikes a mirror, it is reflected as ray AB such that,

$$\angle OAN = \angle NAB$$



Optical principle

Now, if the mirror is titled through an angle on the reflected ray of light has moved through an angle 2α. In optical comparators, the mirror is tilted by the measuring plunger movement and the movement of the reflected light is recorded as an image on a screen.

Mechanical-optical Comparators:

In mechanical optical comparators, small displacement of the measuring plunger are 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. As shown in fig. The mechanical system causes a plane reflector to tilt about an axis and the image of an index is projected on a scale on the inner surface of a ground glass screen. Magnification as shown in fig:

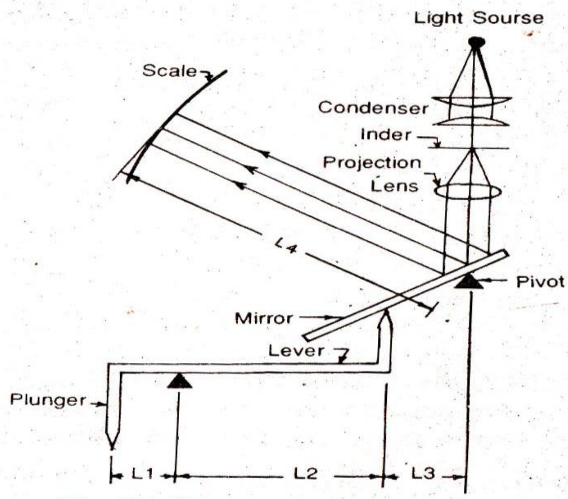


Fig. 5.8. Meeter optical comparator

Mechanical amplification $= \frac{L_2}{L_1}$ (by lever principle)

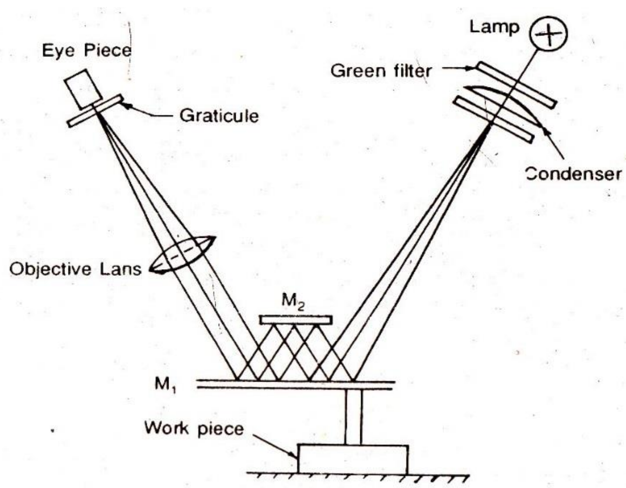
Now, if the movement of the plunger causes the mirror to tilt by an angle α, then the image will be tilted by 2α.

Therefore optical amplification $= 2 \times \frac{L_4}{L_3}$

Thus overall magnification of this system $= 2\frac{L_2}{L_1} \times \frac{L_4}{L_3}$

Zeiss -Ultra Optimeter:

The optical system of zeiss ultra optimeter involves double reflection of light and thus gives higher degree of magnification. Fig. Shows the optical system of this type of comparator. The light rays from the lamp falls on the green filter. The green filter filters all and only green light passes to a condenser, which projects is on to a movable mirror M_1. It is then reflected to another fixed mirror M_2 and then back again to first movable mirror. The objective lens brings the reflected beam from the first mirror to a focus at a transparent graticule containing a precise scale -which is viewed by an eye-piece.



Zeiss ultra optmer.

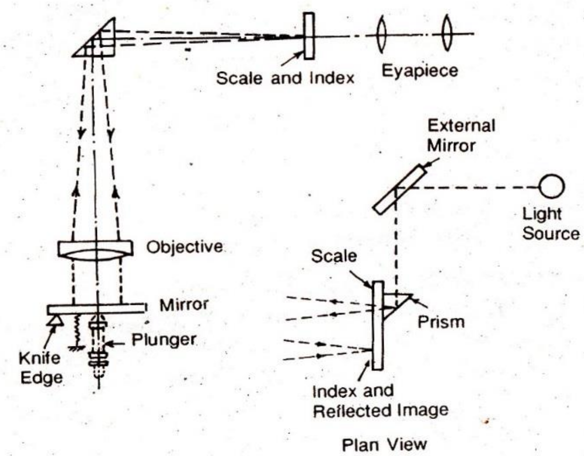
Magnification : If the distance from the plunger centre line to the first mirror pirot is x and the plunger moves a height h, then the angular movement of the mirror $\delta\theta = \frac{h}{x}$. If f be the focal length of the lens, then the movement of the scale is $2f.\ \delta\theta$, *i.e.*, $2f\frac{h}{x}$.

Therefore, magnification $= \frac{2fh}{xh} = \frac{2f}{x}$

overall magnification $= \frac{2f}{x} \times$ Eyepiece magnification.

Zeiss optotest Comporator:

This is a commercial measuring instrument. It consists of a plunger, tilted mirror, objective lens, prism and observing eye piece to provide a high degree of magnification. As shown in Fig. The mirror is mounted on a knife edge and it can be tilted about this fulcrum by any linear vertical movement of the contact plunger.



A beam of light passes through a graticule suitably engraved with a linear scale. The movement of the mirror causes this scale to move up or down past a translucent screen inside the observing hood of the instrument. The eye placed near the eye piece views the image of a small scale engraved on glass after reflection from the plunger-actuated mirror and the prism as shown in the plan view of the figure.

In the focal plane of the eyepiece a fine reference line (index) is provided and the system of lenses is so arranged that the image of the scale is projected in the same focal plane. Thus, only the movement of the scale image can be measured with reference to the fixed line. The division of the scale image opposite the index line indicates the amount of movement of contact plunger. The image of the scale and the index line could also be viewed, through a projection system. The overall magnification of this comparator is given by

$$\frac{2f}{d} \times \text{Eye piece magnification}$$

where f is the focal length of the lens and d is the distance between the knife edge of the planer.

Advantages optical comparators:

1. High accuracy: These comparators have very few moving parts and hence gives higher accuracy.

2. No parallax Error: The scale can be made past a datum line and thus have high range and no parallax error.

3. High magnification: Hence suitable for precision measurements.

4. Optical lever is weightless.

5. Illuminated scale: Since scale is illuminated, it enables readings to be taken irrespective of room lighting conditions.

Disadvantages:

1. As the magnification is high, heat from the lamp, transformers, etc. may cause the setting the drift.

2. Depends on external electrical power supply.

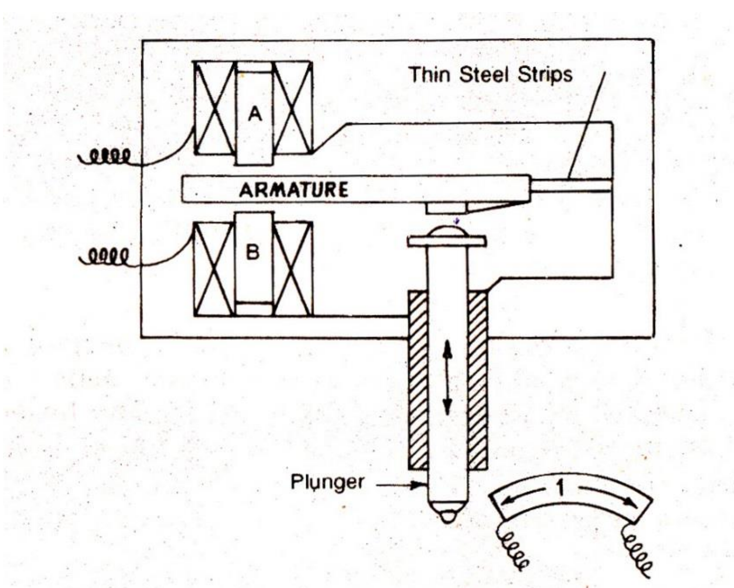
3. Apparatus is usually bulky and expensive.

4. When scale is projected on a screen, the instrument is to be used r in dark room.

5. Instrument is inconvenient for continuous use, because the scale is to be viewed through eyepiece.

- **Electrical Comparators:**

Principle: These comparators depend on their operation on an A.C. Whetstone bridge circuit incorporating a galvanometer. In these comparators, the movement of the measuring contact is converted into an electrical signal. This electrical signal is recorded by an instrument which can be calibrated in terms of plunger movement.



Visual Ganging Heads

The purpose of the visual gausing heads is to give visual inspection, using small coloured signal lamps, of the acceptability of an engineering component with regard to the dimension under test. Clearly an electrical principle is involved, which may be simply described, as follows, with reference to Fig. 5.12. Vertical displacement of an interchangeable plunger causes movement of the rod *C* either to the left or right, as shown in the figure *A* and *B* are electrical contacts, capable of precise adjustment in the direction of the arrows, a micrometer device is available.

In the position shown, that is to say with the rod in mid position between the contacts *A* and *B*, the dimension under test is within the limits. If the dimension is oversize, the rod *C* moves to the right and makes contact with *B*. Immediately the top red lamp is illuminated. Likewise if the dimension is undersize the rod moves to left, making contact with *A* and illuminating the yellow lamp.

It may, however, be noted that the actual magnifying device is not shown in the figure; levers and thin steel strips, together with knife-edge seatings, are employed.

With various detachable plungers, there is practically no limit to the application of this instrument. Fig. 5.12 illustrates the visual gauging of a single dimension, but the same principle can be applied in measuring the several dimensions simultaneously.

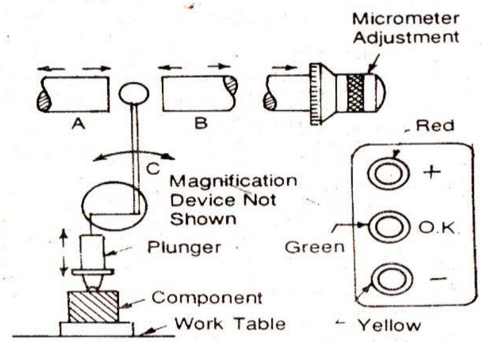


Fig. 5.12. Visual gauging head

<u>**Advantages of electrical and electronic Comparators:**</u>

1. Few number of moving parts: The electric and electronic comparators have few number of moving parts, and these is less friction and wear.

2. High magnification: It has a wide range of magnification.

3. Not sensitive to vibrations: The mechanism carrying the pointer is very light and not sensitive to vibrations.

4. Easy to set up and operate.

5. Less error due to sliding friction: operation of the instrument on AC supply reduces, sliding friction errors.

6. The instrument is small and compact.

7. The indicating' instrument need not be placed close to the measuring unit.

Disadvantages:

1. Fluctuation in the voltage or frequency of the electric supply may affect the results.

2. Heating of coils in the measuring unit may cause zero drift and alter the calibration.

3. When measuring unit is remote from the indicating unit, reliability is lower.

4. Cost is generally more than mechanical comparator.

Solex pneumatic Gauges

This instrument was commercially introduced by solex Air Gauges Ltd. It is generally designed for internal measurement, but with suitable measuring head it can be used for external gauging also.

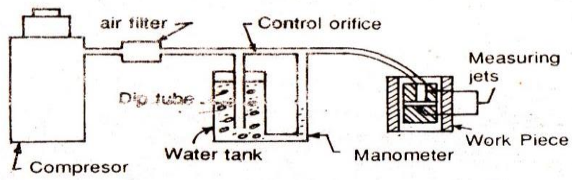


Fig. 5.15. Solex Pneumatic Gauge

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 artifice as shown in Fig. 5.15.

If the pressure of the air supplied is higher than the desired pressure, some air will bubble out from the bottom of the dip tube and air moving to the control volume will be at the desired constant pressure. The constant pressure air then passes through the control orifice and escape from the measuring jets when there is no restriction to the escape of air, the level of water in the manometer tube will coincide with that in the cylinder. But, if there is a restriction to the escape of air through the jets, a back pressure will be induced in the circuit and level of water in the manometer tube will fall. The restriction to the escape of air depends upon the variations in the dimensions to be measured.

Thus the variation in the dimension to be measured are converted into corresponding pressure variations, which can be read from the calibrated scale provided with the manometer.

To find concentricity (roundness of any job at any section). the workpiece may be revolved around measuring gauge. If no change in reading is there, then it is perfectly round hole. Similarly the diameter can be noted down at several places along the length of bore and thus tapering of hole is determined. This method is therefore, best suited for measuring roundness and taperness of cylinder bases and gun barrel bores.

Advantages of pneumatic comparators:

1. The gauging member does not come in contact with the part to be measured and hence practically no wear takes place on gauging member.

2. It is probably the best method to determine the ovality and taperness of circular holes.

3. Single or number of dimensions can be inspects simultaneously.

Disadvantages:

1. Limited range of measurement is available with these comparators

2. It gives low speed of response compared with electrical magnification system.

3. It requires elaborate auxiliary equipment such 'as accurate pressure regulator.

The scale is generally not uniform.

Comparator	Measuring Instrument
1. It is used to compare dimensions of parts with working standards. It does not measure the actual dimension but indicates how much the size of the part differs from the working standards.	1. It is used to measure the actual dimensions of the parts.
2. The readings are magnified by suitable arrangement	2. No magnification system is provided.
3. Measurements can be done rapidly and accurately, so it is suitable in mass production.	3. Measurement is time consuming and therefore not suitable mass production system.
4. Comparators can be used to check dimensions as well as geometric forms.	4. Measuring Instruments can not be used to check geometric forms.
5. There are no chances of errors due to incorrect contact pressure or deformation of-workpiece.	5. Errors are caused due to misalignment or instrument or workpiece, incorrect contact pressure and deformation of instrument or workpice
6. Accuracy is independent of correct feel or operators skill.	6. Accuracy depends on the correct feel and operators skill.

Problem 4. *Differentiate between Comparator and a gauge*

Sol.

Comparator	Gauge
1. They are used to compare the dimensions of parts with working standards.	1. Gauges are used to determine whether the dimensions of parts lies within the given limits of size or not.
2. Determines the difference between the sizes of parts and standards.	2. Determine deviation firm the actual dimensions or form of parts.
3. The readings are magnified by suitable arrangement	3. Magnification system is not provided
4. Indicating device is provided to determine the deviation in dimension, size etc of part from the standard.	4. Indicating device is not provided. It only helps to determine whether the parts is within the given tolerance limit and hence acceptable or otherwise.
5. Comparator can be used to compare dimensions of larger and thin walles parts	5. Gauge is not suitable to gauge the dimensions of larger and thin walled parts.

Problem 5. *Compare between Electrical Comparator and Mechanical Comparator.*

Sol.

	Mechanical comparator		**Electrical Comparator**
1.	Mechanical comparator has more number of moving parts, hence, friction and wear is more, and accuracy is less.	1.	Small number of moving parts, hence less friction, wear, and accuracy is more.
2.	They are independent of any external power supply, so accuracy of the reading is not affected by variations in the power supply.	2.	Fluctuations in the voltage or frequency of the electric power supply may affect the results and accuracy of measurement.
3.	These instruments are portable and cheaper.	3.	Measuring and indicating units being separate and since they require electric supply they are not so easily portable and more costly also.
4.	Inertia of the moving parts makes the instrument sensitive to vibrations.	4.	The mechanism carrying the pointers being very light is not sensitive to vibrations.
5.	Range of the instrument is limited by the range of the fixed scale.	5.	It has wide range of magnification.

Problem 6. *State only the principle of working of mechanical comparator, Electrical comparator, optical comparator and pneumatic comparator.*

Sol. Mechanical comparator : A mechanical comparater employs mechanical means for magnifying the small movement of the measuring styles, brought about due to the difference between the standard and the actual dimension being checked. In these comparators the magnification of the small stylus movement is obtained by means of levers, gear trains, rack and pinion or a combination.

Electrical Compasator : Electrical comparators depend on their operation on an A.C. wheatstone bridge circuit incorporating a galvanometer. In these comparators, the movement of the moving contact is converted into an electrical signal. This electrical signal is recorded by an instrument which can be calibrated in terms of plunger movement.

Optical Comparator : These comparaters, makes use of fundamental optical principle of 'optical lever'.

In optical comparators the mirrors is tilted by the measuring plunger movement and the movement of the reflected light is recorded as an image on the curved graduated scale to indicate the comparison movement.

Pneumatic comparator : These comparators utilize the variation in the air pressure or velocity as an amplifying medium. A jet or jets of air are applied to the surface being measured and the variation in the back pressure or velocity of air caused due to variations in size are used to amplify the output signal.

*****THE END*****