



UNIT-4

SURFACE ROUGHNESS MEASUREMENT

Introduction:-

With the more precise demands of modern engineering products, the control of surface texture together with dimensional accuracy has become more important. It has been investigated that the surface texture greatly influences the functioning of the machined parts. The properties such as appearance, corrosion resistance, wear resistance, fatigue resistance, lubrication, initial tolerance, ability 'to hold pressure, ,load carrying capacity, noise reduction in case of gears are influenced by the surface texture.

Whatever may be the manufacturing process used, it is not possible to produce perfectly smooth surface. The imperfections and irregularities are bound to occur. The manufactured surface always departs from the absolute perfection to some extent. The irregularities on the surface are in the form of succession of hills and valleys varying in height and spacing. These irregularities are usually termed as surface roughness, surface finish, surface texture or surface quality. These irregularities are responsible to a great extent for the appearance of a surface of a component and its suitability for an intended application.

Factors Affecting Surface Roughness:-

The following factors affect the surface roughness:

- (1) Vibrations
- (2) Material of the workpiece
- (3) Type of machining.
- (4) Rigidity of the system consisting of machine tool, fixture cutting tool and work
- (5) Type, form, material and sharpness of cutting tool
- (6) Cutting conditions i.e., feed, speed and depth of cut
- (7) Type of coolant used

Reasons for Controlling Surface Texture:-

- (1) To improve the service life of the components
- (2) To improve the fatigue resistance
- (3) To reduce initial wear of parts
- (4) To have a close dimensional tolerance on the parts
- (5) To reduce frictional wear
- (6) To reduce corrosion by minimizing depth of irregularities
- (7) For good appearance

(8) If the surface is not smooth enough, a turning shaft may act like a reamer and the piston rod like a broach.

However, as already explained perfectly smooth surface is not always required, the requirement of surface texture depends upon the specific application of the part.

Orders of Geometrical Irregularities:-

As we know that the material machined by chip removal process can't be finished perfectly due to some departures from ideal conditions as specified by the designer. Due to conditions not being ideal, the surface produced will have some irregularities, these geometrical irregularities can be classified into four categories.

First Order: The irregularities caused by inaccuracies in the machine tool itself are called as first order irregularities. These include:

- (1) Irregularities caused due to lack of straightness of guide ways on which the tool most moves.
- (2) Surface regularities arising due to deformation of work under the action of cutting forces, and
- (3) Due to the weight of the material itself.

Second Order: The irregularities caused due to vibrations of any kind are called second order irregularities.

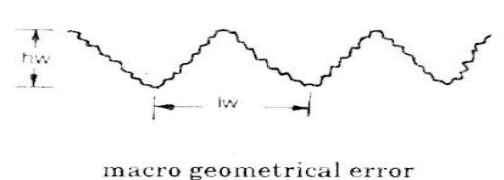
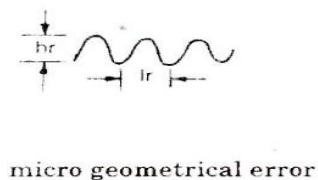
Third order: Even if the machine were perfect and completely free from vibrations some irregularities are caused by machining itself due to the characteristics of the process.

Fourth Order: The fourth order irregularities include those arising from the rupture of the material during the separation of the chip.

Irregularities on the surface of the part:-

The irregularities on the surface of the part produced can also be grouped into two categories:

- (i) Roughness or primary texture, (ii) Waviness or secondary texture.



Micro and macro geometrical errors

(i) Primary texture (Roughness):

The surface irregularities of small wavelength are called primary texture or roughness. These are caused by direct action of the cutting element on the material i.e., cutting tool shape, tool feed rate or by some other disturbances such as friction, wear or corrosion.

These include irregularities of third and fourth order and constitute the micro-geometrical errors. The ratio l_r / h_r denoting the micro-errors is less than 50, where l_r = length along the surface and h_r = deviation of surface from the ideal one.

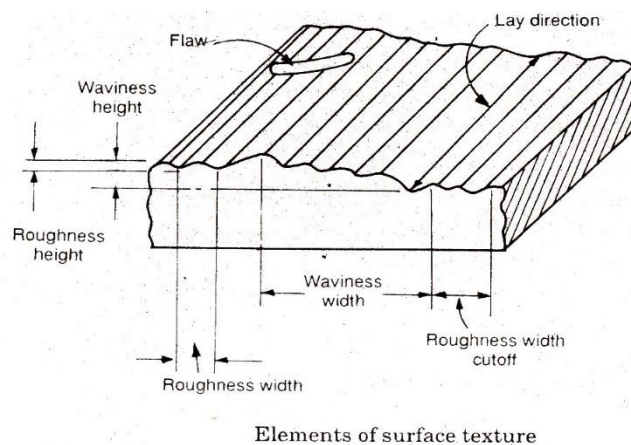
(ii) Secondary texture (Waviness):

The surface irregularities of considerable wavelength of a periodic character are called secondary texture or waviness. These irregularities result due to inaccuracies of slides, wear of guides, misalignment of centres, non-linear feed motion, deformation of work under the action of cutting forces, vibrations of any kind etc.

These errors include irregularities of first and second order and constitute the macro-geometrical errors. The ratio of l_w / h_w denoting the macro-errors is more than 50. Where, l_w = length along the surface and h_w = deviation of surface from ideal one.

Elements of Surface Texture:-

The various elements of surface texture can be defined and explained with the help of fig which shows a typical surface highly magnified.



Surface: The surface of a part 'is confined by the boundary which separates that part from another part, substance or space. Actual surface. This refers to the surface of a part which is actually obtained after a manufacture ring process.

Nominal surface: A nominal surface is a theoretical, geometrically perfect surface which does not exist in practice, but it is an average of the irregularities that are superimposed on it.

Profile: Profile is defined as the contour of any section through a surface, Roughness. As already explained roughness refers to relatively finely spaced micro geometrical irregularities. It is also called as primary texture and constitutes third and fourth order irregularities.

Roughness Height: This is rated as the arithmetical average deviation expressed in micro-meters normal to an imaginary centre line, running through the roughness profile.

Roughness Width: Roughness width is the distance parallel , to the normal surface between successive peaks or ridges that constitutes the predominant pattern of the roughness.

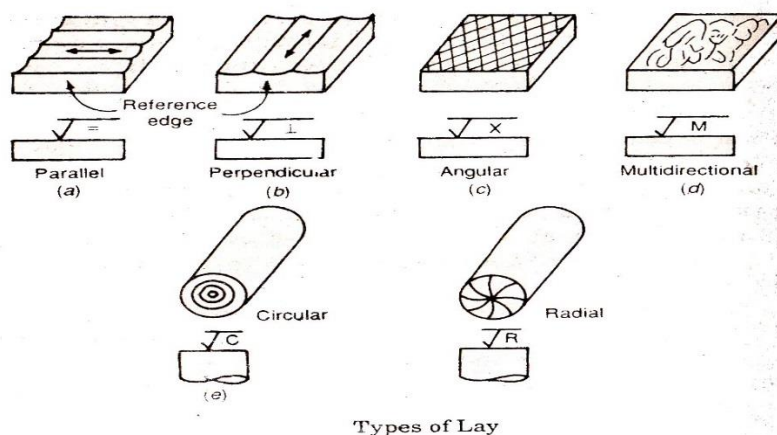
Roughness Width cutoff: This is the maximum width of surface irregularities that is included in the measurement of roughness height. This is always greater than roughness width and is rated in centimetres.

Waviness: Waviness consists of those surface irregularities which are of greater spacing than roughness and it occurs in the form of waves. These are also termed as moon geometrical errors and constitute irregularities of first and second order. These are caused 'due to misalignment of centres, vibrations, machine or work deflections, warping etc.

Effective profile: It is the real center of a surface obtained by using instrument

Lays: Flaws are surface irregularities or imperfections which occur at infrequent intervals and at random intervals. Examples are: scratches, holes, cracks, porosity etc. These may be observed directly with the aid of penetrating dye or other material which makes them visible for examination and evaluation.

Surface Texture: Repetitive or random deviations from the nominal. Surface which forms the pattern on the surface. Surface texture includes roughness, waviness, lays and flaws.



Lay: It is the direction of predominant surface pattern produced by tool marks or scratches. It is determined by the method of production used. Symbols used to indicate the direction of lay are given below:

| | = Lay parallel to the boundary line of the nominal surface that is, lay parallel to the line representing surface to which the symbol is applied e.g., parallel shaping, end view of turning and O.D grinding.

⊥ = Lay perpendicular to the boundary line of the nominal surface, that is lay perpendicular to the line representing surface to which the symbol is applied, e.g. , end view of shaping, longitudinal view of turning and O.D. grinding.

X = Lay angular in both directions to the line representing the surface to which symbol is applied, e.g. traversed end mill, side wheel grinding.

M= Lay multidirectional e.g. lapping super finishing, honing.

C= Lay approximately circular relative to the centre of the surface to which the symbol is applied e.g., facing on a lathe.

R= Lay approximately radial relative to the centre of the surface to which the symbol is applied, e.g., surface ground on a turntable, fly cut and indexed on end mill.

Sampling length: It is the length of the profile necessary for the evaluation of the irregularities to be taken into account. It is also known as cut-off length. It is measured in a direction parallel to the general direction of the profile. The sampling length should bear some relation to the type of profile.

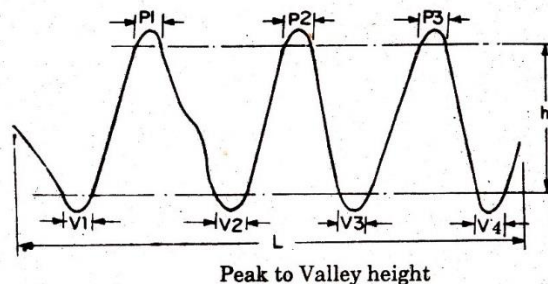
Evaluation of Surface Finish:

A numerical assessment of surface finish can be carried out in a number of ways. These numerical values are obtained with respect to a datum. In practice, the following three methods of evaluating primary texture (roughness) of a surface are used:

- (1) Peak to valley height method
- (2) The average roughness
- (3) Form factor or bearing curve.

(1) Peak to valley height method:

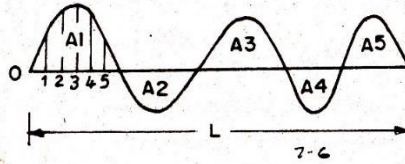
This method is largely used in Germany and Russia. It measures the maximum depth of the surface irregularities over a given sample length, and largest value of the depth is accepted as a measure of roughness. The drawback of this method is that it may read the same h_{max} for two largely different texture. The value obtained would not give a representative assessment of the surface.



To overcome this PV (Peak to Valley) height is defined as the distance between a pair of lines running parallel to the general 'lay' of the trace positioned so that the length lying within the peaks at the top is 5% of the trace length, and that within the valleys at the bottom is 10% of the trace length. This is represented graphically in Fig.

(2) The average roughness: For assessment of average roughness the following three statistical criteria are used:

(a) C.L.A Method: In this method, the surface roughness is measured as the average deviation from the nominal surface.



Centre Line Average or Arithmetic Average is defined as the average values of the ordinates from the mean line, regardless of the arithmetic signs of the ordinates

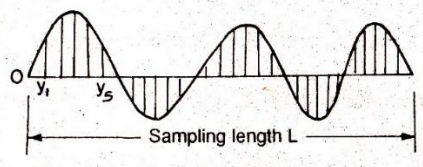
$$\text{C.L.A Value} = \frac{h_1 + h_2 + h_3 + \dots h_n}{n} \quad \dots(i)$$

$$\begin{aligned} \text{Also C.L.A.} &= \frac{A_1 + A_2 + A_3 + \dots A_n}{L} \\ &= \frac{\Sigma A}{L} \quad \dots(ii) \end{aligned}$$

The calculation of C.L.A value using equation (ii) is facilitated by the planimeter.

CLA value measure is preferred to RMS value measure because its value can be easily determined by measuring. The areas with planimeter or graph or can be readily determined in electrical instruments by integrating the movement of the styles and displaying the result as an average.

(b) R.M.S. Method: In this method also, the roughness is measured as the average deviation from the nominal surface. Root mean square value measured is based on the least squares.



R.M.S value is defined as the square root of the arithmetic mean of the values of the squares of the ordinates of the surface measured from a mean line. It is obtained by setting many equidistant ordinates on the mean line ($y_1, y_2, y_3 \dots$) and then taking the root of the mean of the squared ordinates.

Let us assume that the sample length 'L' is divided into 'n' equal parts and $y_1, y_2, y_3 \dots$ are the heights of the ordinates erected at those points.

Then,

$$\begin{aligned} \text{RMS average} &= \sqrt{\frac{y_1^2 + y_2^2 + y_3^2 + \dots + y_n^2}{n}} \\ y_{rms} &= \left(\frac{1}{L} \int_0^L y^2 dL \right)^{1/2} \end{aligned}$$

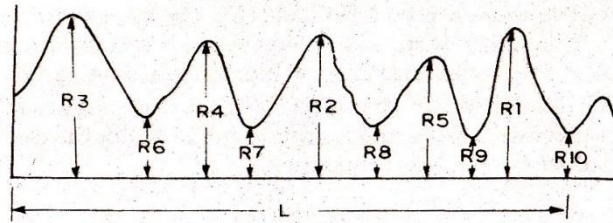
(c) Ten Point Height Method: In this method, the average difference between the five highest peaks and five lowest valleys of surface texture within the sampling length, measured from a line parallel to the mean line and not crossing the profile is used to denote the amount of surface roughness.

Mathematically,

R_2 = ten point height of irregularities

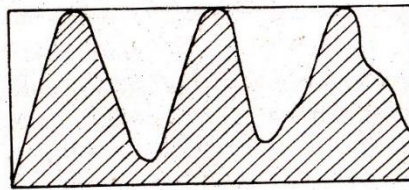
$$= \frac{1}{5} [(R_1 + R_2 + R_3 + R_4 + R_5) - (R_6 + R_7 + R_8 + R_9 + R_{10})]$$

This method is relatively simple method of analysis and measures the total depth of surface irregularities within the sampling length. But it does not give sufficient information about the surface, as no account is taken of frequency of the irregularities and the profile shape. It is used when it is desired to control the cost of finishing for checking the rough machining.



(3) Form factor and Bearing Curves: There are certain characteristic which may be used to evaluate surface texture.

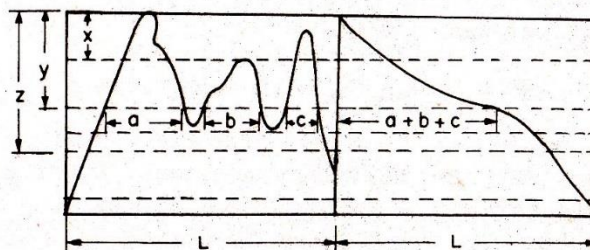
Form Factor: The load carrying area of every surface is often much less than might be thought. This is shown by reference to form factor. The form factor is obtained by measuring the area of material above the arbitrarily chosen base line in the section and the area of the enveloping rectangle. Then,



$$\text{Degree of fullness (K)} = \frac{\text{Area of metal}}{\text{Area of enveloping rectangle}}$$

$$\text{Degree of emptiness} = (K_p) = 1 - K$$

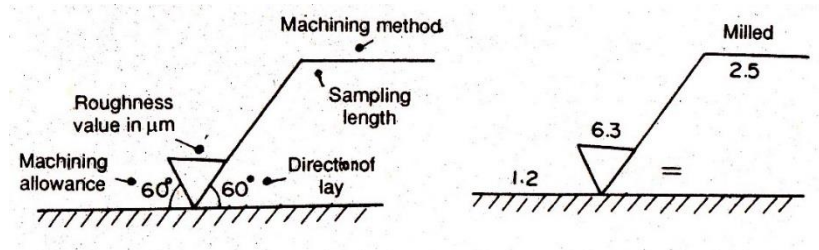
Bearing Area Curve: The bearing area curve is also called as Abbot's bearing curve. This is determined by adding the lengths a, b, c etc. at depths x, y, z etc. below the reference, line and indicates the percentage bearing area which becomes available as the crest area worn away. Fig. indicates the method of determining the bearing curve.



Conventional Method for Designing Surface finish:

As per IS: 696 surface texture specified by indicating the following

- (a) Roughness value i.e., R_a value in μm
- (b) Machining allowance in mm.
- (c) Sampling length or instrument cut-off length in mm.
- (d) Machining production method, and
- (e) Direction of lay in the symbol form as = $\perp$, X, M, C, R



Measurement of surface finish surfaces texture:

The methods used for ensuring the surface finish can be classified broadly into two groups.

1. Inspection by comparison.

2. Direct instrument measurement

1. Inspection by comparison methods. In these methods, the surface texture is assessed by observation of the surface. These are the methods of qualitative analysis of the surface texture. The texture, R_a of the surface W to be tested is compared with that of a specimen of known roughness R_a value and finished by similar machining processes. Though these methods are rapid, the results are not reliable because they can be misleading if comparison is not made with the surface produced by similar techniques. The various methods available for comparison are:

(i) Visual Inspection

(ii) Touch Inspection

(iii) Scratch Inspection

(iv) Microscopic Inspection

(v) Surface photographs

(vi) Micro-Interferometer

(vii) Wallace surface Dynamometer

(viii) Reflected Light Intensity.

(i) Visual Inspection: In this method the surface is inspected by naked eye. This method is always likely to be misleading particularly when surfaces with high degree of finish are inspected. It is therefore limited to rougher surfaces.

(ii) Touch Inspection: This method can simply assess which surface is more rough, it cannot give the degree of surface roughness. Secondly, the minute flaws can't be detected. In this method, the finger tip is moved along the surface at a speed of about 25 mm per second and the irregularities as small as 0.0125 mm can be detected. In modified method a tennis ball is rubbed over the surface and surface roughness is judged thereby.

(iii) Scratch Inspection: In this method a softer material like lead, babbitt, or plastic is rubbed over the surface to be inspected. The impression of the scratches on the surface produced is then visualised.

(iv) Microscopic Inspection: This is probably the best method for examining the surface texture by comparison. But since, only a small surface can be inspected at a time several readings are required to get an average value. In this method, a master finished surface is placed under the microscope and compared with the surface under inspection. Alternatively, a straight edge is placed on the surface to be inspected and a beam of light projected at about 600 to the work. Thus the shadow is cast into the surface, the scratches are magnified and the surface irregularities can be studied.

(v) Surface photographs: In this method magnified photographs of the surface are taken with different types of illumination to reveal the irregularities.

If the vertical illumination is used then defects like irregularities and scratches appear as dark spots and flat portion of the surface appears as bright area. In case of 'oblique illumination, reverse is the case. Photographs with different illumination are compared and the result is assessed.

(vi) Micro Interferometer: In this method, an optical flat is placed on the surface to be inspected and illuminated by a monochromatic source of light. Interference bands are studied through a microscope. The scratches in the surface appear as interference lines extending from the dark bands into the bright bands. The depth of the defect is measured in terms of the fraction of the interference bands.

(vii) Wallace Surface Dynamometer: It is a sort of friction meter. It consists of a pendulum in which the testing shoes are damped to a bearing surface and a predetermined spring pressure can be applied. The pendulum is lifted to its initial starting position and allowed to swing over the surface to be tested. If the surface is smooth, then there will be less friction and pendulum swings for a longer period. Thus, the time of swing is a direct measure of surface texture.

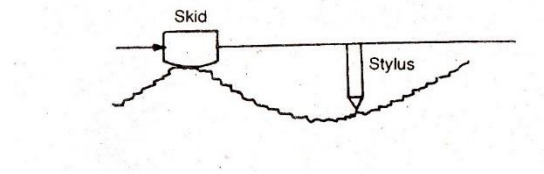
(viii) Reflected Light Intensity: In this method a beam of light of known quantity is projected upon the surface. This light is reflected in several directions as beams of lesser intensity and the change in light intensity in different directions is measured by a photocell. The measured intensity changes are already calibrated by means of reading taken from surface of known roughness by some other suitable method.

2. Direct Instrument Measurement:

These are the methods of quantitative analysis. These methods enable to determine the numerical value of the surface finish of any surface by using instruments of stylus probe type operating on electrical principles. In these instruments the output has to be amplified and the amplified output is used to operate recording or indicating instrument.

Principle, constructive and operation of stylus Probe type surface texture measuring instruments:

If a finely pointed Probe or stylus be moved over the surface of a workpiece, the vertical movement of the stylus caused due to the irregularities in the surface texture can be used to assess the surface finish of the workpiece.



Stylus which is a fine point made of diamond or any such hard material is drawn over the surface to be tested. The movements of the stylus are used to modulate a high frequency carrier current or to generate a voltage signal. The output is then amplified by suitable means and used to operate a recording or indicating instrument.

Stylus type instruments generally consist of the following units:

- (i) Skid or shoe
- (ii) Finely pointed stylus or probe
- (iii) An amplifying device for magnifying the stylus movement and indicator
- (iv) Recording device to produce a trace and ~
- (v) Means for analyzing the trace.

Advantages:

The main advantage of such instruments is that the electrical signal available can be processed to obtain any desired roughness parameter or can be recorded for display or subsequent analysis. Therefore, the stylus type instruments are widely used for surface texture measurements inspite of the following disadvantages.

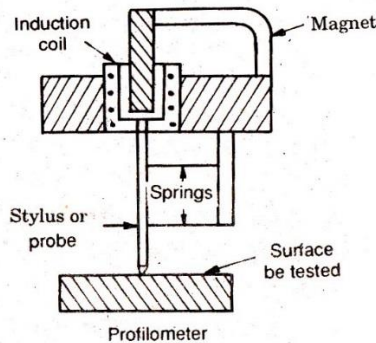
Disadvantages:

- (i) These instruments are bulky and complex.
- (ii) They are relatively fragile.
- (iii) Initial cost is high.
- (iv) Measurements are limited to a section of a surface.
- (v) Needs skilled operators for measurements.
- (vi) Distance between stylus and skid and the shape of the skid introduce errors in measurement for wavy surfaces.

The stylus probe instruments currently in use for surface finish measurement.

- (a) Profilometer
- (b) The Tomlinson surface meter.
- (c) The Taylor Hobson Talysurf
- (d) Profilograph.

(a) Profilometer:

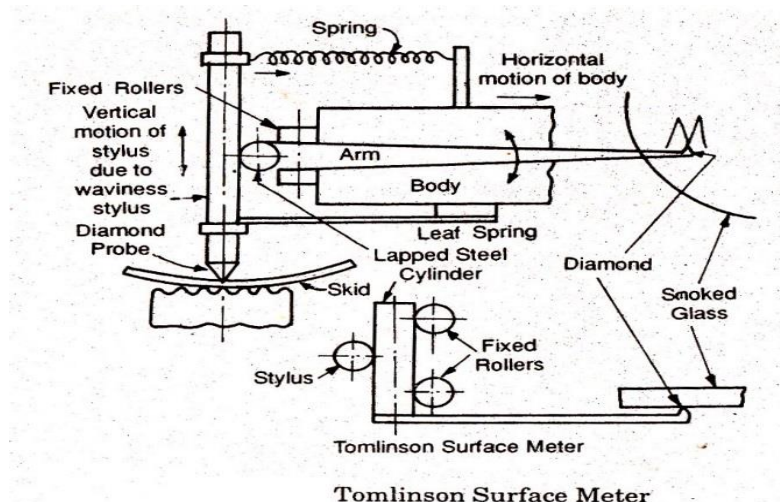


Profilometer is an indicating and recording instrument used to measure roughness in microns. The principle of the instrument is similar to gramophone pick up. It consists of two principal units: a tracer and an amplifier. Tracer is a finely pointed stylus. It is mounted in the pick up unit which consists of an induction coil located in the field of a permanent magnet. When the tracer is moved across the surface to be tested, it is displaced vertically up and down due to the surface irregularities. This causes the induction coil to move in the field of the permanent magnet and induces a voltage. The induced voltage is amplified and recorded.

This instrument is best suited for measuring surface finish of deep bores.

(b) The Tomlinson surface meter:

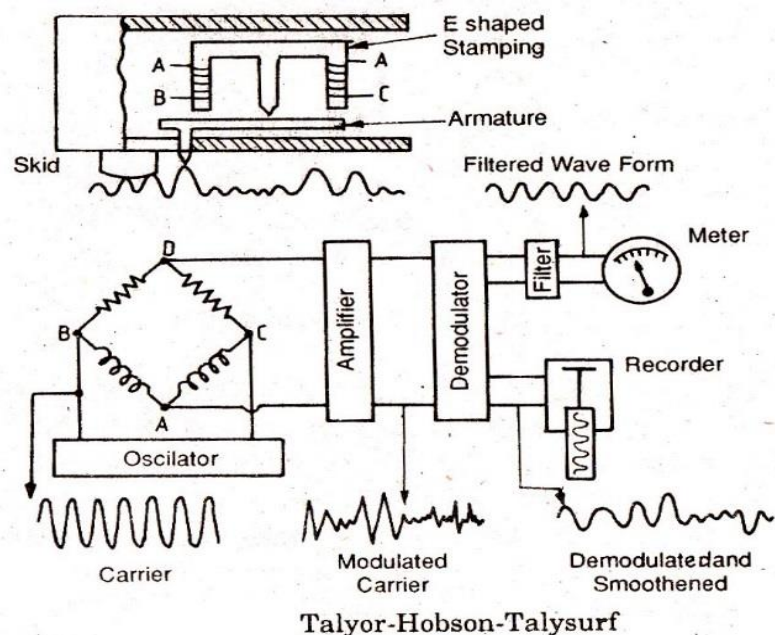
The Tomlinson surface meter is a comparatively cheap and reliable instrument. It was originally designed by Dr. Tomlinson.



It consists of a diamond probe (stylus) held by spring pressure against the surface of a lapped steel cylinder and is attached to the body of the instrument by a leaf spring. The lapped cylinder is supported on one side by the probe and on the other side by fixed rollers. A light spring steel arm is attached to the lapped cylinder. It carries at its tip a diamond scriber which rests against a smoked glass. The motions of the stylus in all the directions except the vertical one are prevented by the forces exerted by the two springs.

For measuring surface finish the body of the instrument is moved across the surface by screw rotated by asynchronous motor. The vertical movement of the probe caused by surface irregularities makes the horizontal lapped cylinder to roll. This causes the movement of the arm attached to the lapped cylinder. A magnified vertical movement of the diamond scriber on smoked glass is obtained by the movement of the arm. This vertical movement of the scriber together with horizontal movement produces a trace on the smoked glass plate. This trace is further magnified at X 50 or X 100 by an optical projector for examination.

(c) The Taylor Hobson Talysurf:

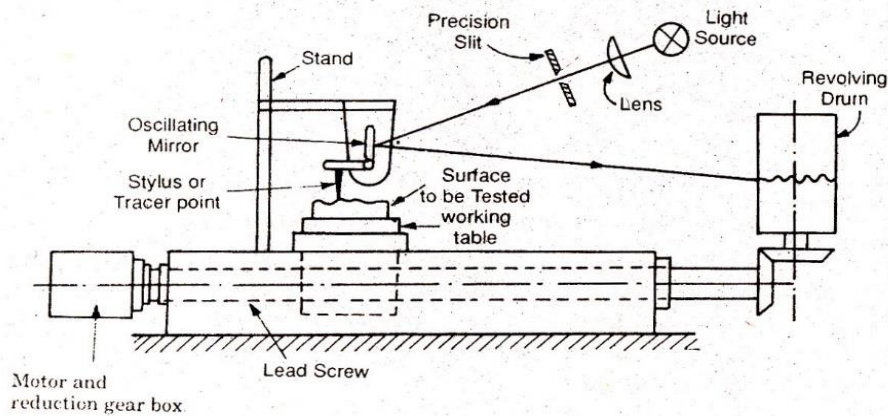


Taylor-Hobson Talysurf is a stylus and skid type of instrument working on carrier modulating principle. Its response is more rapid and accurate as compared to Temlinson Surface Meter. The measuring head of this instrument consists of a sharply pointed diamond stylus of about 0.002 mm tip radius and skid or shoe which is drawn across the surface by means of a motorised driving unit. In this instrument the stylus is made to trace the profile of the surface irregularities, and the oscillatory movement of the stylus is converted into changes in electric current by the arrangement as shown in Fig. The arm carrying the stylus forms an armature which pivots about the centre piece of E-shaped stamping. On two legs of (outer pole pieces) the E-shaped stamping there are coils carrying an a.c. current. These two coils with other two resistances form an oscillator. As the armature is pivoted about the central leg, any movement of the stylus causes the air gap to vary and thus the amplitude of the original a.c. current flowing in the coils is modulated. The output of the bridge thus consists of modulation only as shown in

Fig. This is further demodulated so that the current now is directly proportional to the vertical displacement of the stylus only.

(d) Profilograph:

(i) Profilograph : The principle of Working of a tracer type profilograph is shown in Fig. The work to be tested is placed on the table of the instrument. The work and the table are traversed with the help of a lead screw.



The stylus which is pivoted to a mirror moves over the tested surface. Oscillations of the tracer point are transmitted to the mirror. A light source sends a beam of light through lens and a precision slit to the oscillating mirror. The reflected beam is directed to a revolving drum, upon which a sensitised film is arranged. This drum is rotated through two bevel gears from the same lead screw that moves the table of the instrument. A profilogram will be obtained from the sensitised film, that may be sub-sequently analysed to determine the value of the surface roughness.

Problems:

Problem 3. What do you mean by R_a and R_z values ?

Sol. The Roughness average (R_a) is a quantitative measure of surface roughness. It is the arithmetical mean deviation of the surface profile from the mean line. Thus R_a values are numerical assessment of the average heights of irregularities of surface texture and are usually expressed in microns where one microns = 10^{-3} mm. Fig. 7.21 shows a graph of machined surface. To obtain R_a value, a sampling length is chosen and a return line is drawn so that the sum of the area ($A_2 + A_4 + A_6$) enclosed above the line is equal to the sum of the shaded areas ($A_1 + A_2 + A_3$) enclosed below it. The R_a value is given by, $R_a(CLA) = \frac{\Sigma A}{L}$.

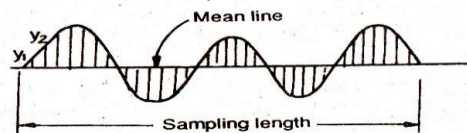


Fig. 7.21

R_z Value : It is ten point height of irregularities and is defined as the average difference between the five height peaks and five lowest valleys on,

the surface profile within the sampling length from a line parallel to the mean line and not crossing the profile. Mathematically,

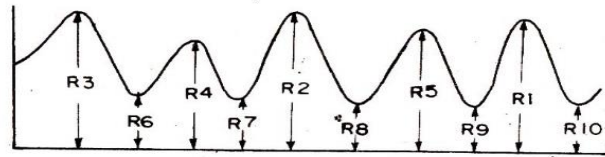


Fig. 7.22.

$$R_2 = \frac{1}{5} [(R_1 + R_2 + R_3 + R_4 + R_5) - (R_6 + R_7 + R_8 + R_9 + R_{10})]$$

where, $R_1, R_2, \dots, R_5$ are five highest peaks

and $R_6, R_7, \dots, R_{10}$ are five lowest valleys.

Problem 4. State how surface finish is designated on drawings.

Sol. The surface roughness is represented as shown in Fig. 7.23.

The following information is furnished with the symbol ∇ .

(1) Surface roughness value in R_a value in microns μm

(2) Machining allowance in mm.

(3) Sampling length in mm.

(4) Method of machining such as milled, ground turned, tapped, shaped etc.

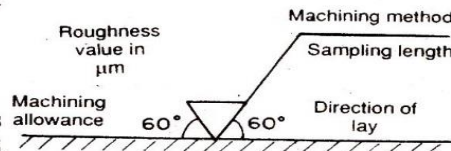


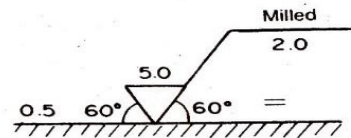
Fig. 7.23.

(5) Direction of lay in the symbol form as :

$=, \perp, X, M, C, R$

Problem 5. The surface finish on the milled surface is not to exceed $5 \mu m R_a$ with a cut-off length 2 mm, machining allowance 0.5 mm. and direction of lay parallel. How will you represent it on a drawing?

Sol.



Problem 7. In the measurement of surface roughness, heights of successive 10 peaks and troughs were measured from a datum and were 33, 25, 30, 19, 22, 18, 27, 29 and 20 microns. If these measurements were obtained on 10 mm length, determine CLA and RMS values of surface roughness.

Sol. CLA value or R_a value = $\frac{y_1 + y_2 + y_3 + \dots + y_n}{n}$

$$= \frac{33 + 25 + 30 + 19 + 22 + 18 + 27 + 29 + 20}{10}$$

$$= 25.5 \text{ microns}$$

RMS value = $\sqrt{\frac{y_1^2 + y_2^2 + y_3^2 + \dots + y_n^2}{n}}$

$$= \sqrt{\frac{33^2 + 25^2 + 30^2 + 19^2 + 22^2 + 18^2 + 27^2 + 29^2 + 20^2}{10}}$$

$$= 26.03 \text{ microns}$$

Problem 10. Calculate the C.L.A. value of a surface for the following data :

The sampling length is 0.8 mm, the graph is drawn to a vertical magnification of 15,000 and horizontal magnification of 100 and the areas above and below the datum line are 160, 90, 180, 50 mm² and 95, 65, 170, 150 mm² respectively.

$$\begin{aligned}\text{Sol. C.L.A.} &= \frac{\Sigma A}{L} \times \frac{1}{\text{vertical scale}} \times \frac{1}{\text{horizontal scale}} \\ &= \frac{(160 \times 95 + 90 + 65 + 180 + 170 + 50 + 150)}{0.8} \times 15000 \times 100 \\ &= 0.8 \mu\text{m.}\end{aligned}$$

Problem 11. In the measurement of surface roughness, heights of 20 successive peaks and valleys measured from a datum are as follows :

45, 25, 40, 25, 35, 16, 40, 22, 25, 34, 25, 40, 20, 36, 28, 18, 20, 25, 30, 38

If these measurements were made over a length of 20 mm, determine the C.L.A and RMS values of the surface.

Sol.

$$\begin{aligned}\text{C.L.A. value} &= \frac{45 + 25 + 40 + 25 + 35 + 16 + 40 + 22 + 25 + 34 + 25 \\ &\quad + 40 + 20 + 36 + 28 + 18 + 20 + 30 + 38}{20} \\ &= 29.35\end{aligned}$$

$$\begin{aligned}\text{RMS Value} &= \sqrt{\frac{45^2 + 25^2 + 40^2 + 25^2 + 35^2 + 16^2 + 40^2 + 22^2 + 25^2 + 34^2 + 25^2 \\ &\quad + 40^2 + 20^2 + 36^2 + 28^2 + 18^2 + 20^2 + 30^2 + 38^2}{20}} \\ &= 930.96\end{aligned}$$

ISI Symbols for Indication of surface Finish

The surface roughness is represented in figure. If the machining method is milling, sampling length is 2.5 mm, direction of lay is parallel to the surface, machining allowance is 3 mm and the representative will be as shown in figure,

Representation of Surface Roughness:

(i) The limits of surface roughness can be represented as,

$$R_{a16.0}^{8.0} \text{ or } R_a^{8.0-16.0}$$

(ii) The surface roughness and sampling length can be represented as,

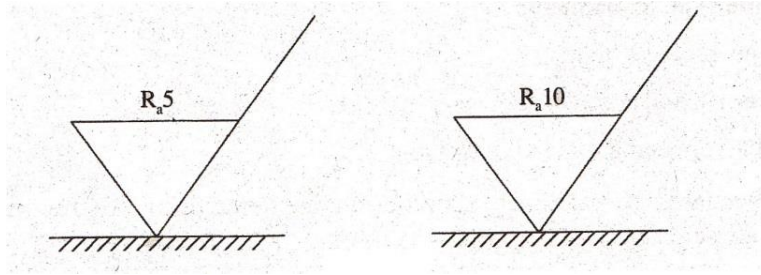
$$R_a^{8.0(2.5)}$$

Here surface sampling length is 2.5 mm

(iii) The surface roughness and lay can be stated as,

$$R_a^{1.6} \text{ lay Circular}$$

However, in most cases, one single piece of information is sufficient which is indicated as follows,



The I.S.O has recommended as series of preferred roughness values and corresponding roughness grade numbers to be used when specifying surface roughness on drawings.

The roughness symbols indicate the practice followed in the industry.

Roughness Values (R_a) (μm)	Roughness Grade Number	IS Roughness Symbol
50	N 12	~
25	N 11	▽
12.5	N 10	
6.3	N 9	
3.2	N 8	▽▽
1.6	N 7	
0.8	N 6	
0.4	N 5	▽▽▽
0.2	N 4	
0.1	N 3	
0.05	N 2	▽▽▽▽
0.025	N 1	

//////////////////////*THE END*//////////////////////



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 interchangeability 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 gauge 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.

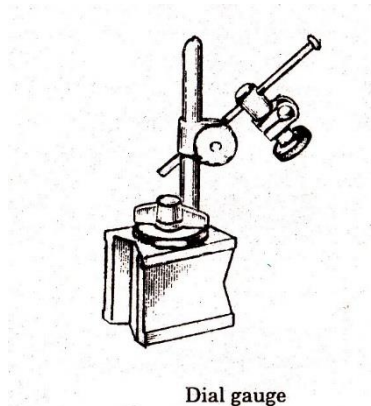
➤ **Mechanical Comparators:**

Principle of workings: A mechanical comparator employs 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 ± 0.05 millimeters.



Dial gauge

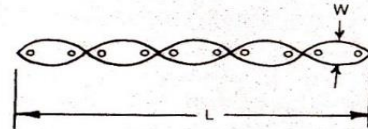
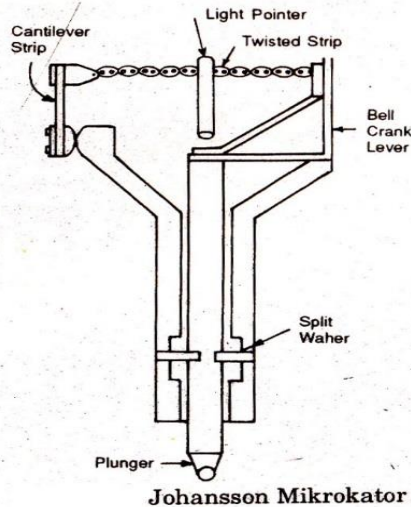
In its operation, the indicator is set to zero by the use of slip gauges representing the basic size of the part. The part to be checked is then placed below the measuring plunger of the indicator. The linear movement of the plunger is magnified by means of a gear and pinion train in to sizable rotation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



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 perforation 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:

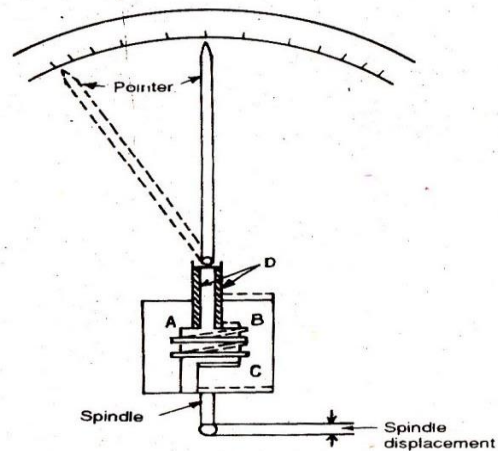
In reed type mechanical comparator, the gauging head is usually a sensitive, high quality, dial indicator. The dial indicator is mounted on a base supported by a sturdy column. Fig. 5.4 shows a read type mechanical comparator.

The reed mechanism is a frictionless 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 to swing through an arc.

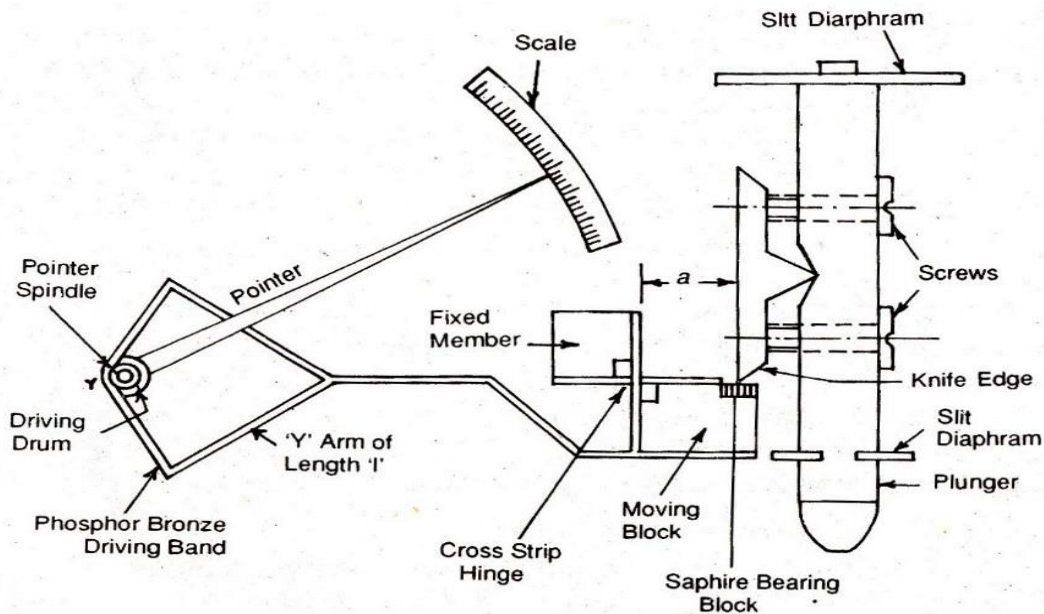
The scale may be calibrated by means of gauge block to indicate any deviation from an initial setting. The mechanical amplification is usually less than 100 but it is multiplied by the optical lens system. It is available in amplification ranging from 500 to 1000.



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

diaphragms). 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 $\times 300$ to $\times 5000$, 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

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.

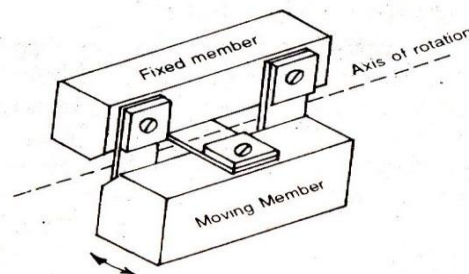


Fig. 5.6. cross strip liver used in sigma comparator.

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.

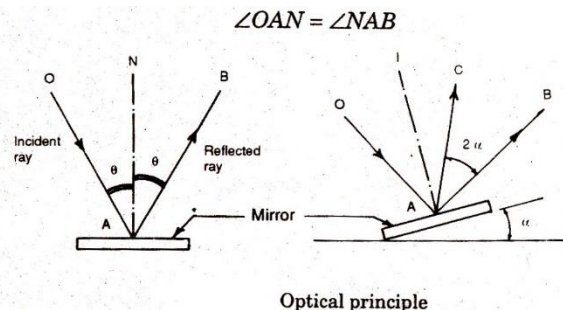
5. Portable: For ordinary workshop conditions, these instruments are very suitable and being portable can be issued from the stores.

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,



Now, if the mirror is tilted through an angle α 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:

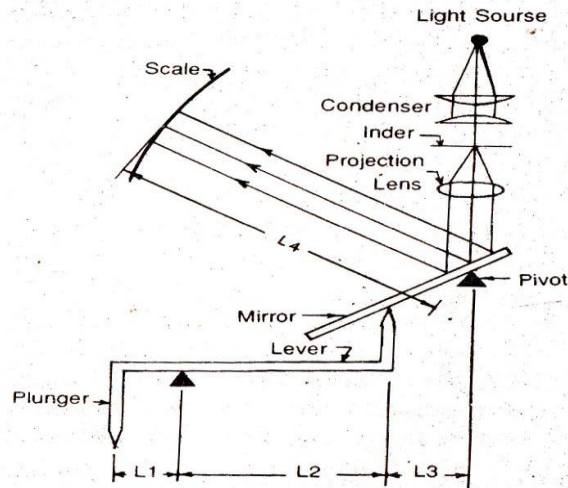


Fig. 5.8. Meeter optical comparator

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

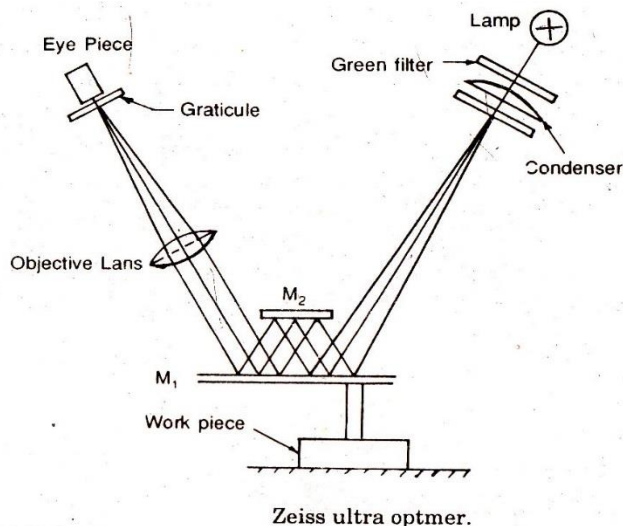
Now, if the movement of the plunger causes the mirror to tilt by an angle α , then the image will be tilted by 2α .

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.



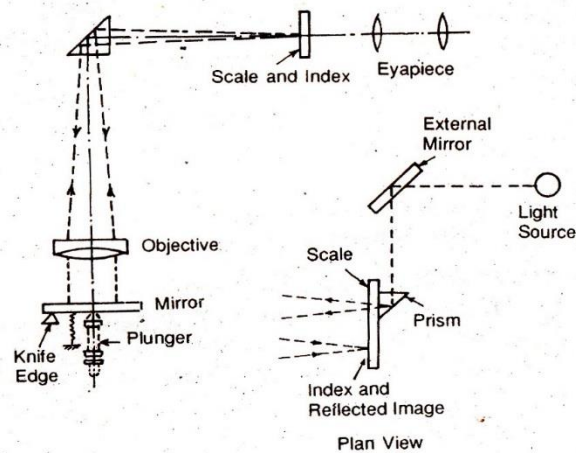
Magnification : If the distance from the plunger centre line to the first mirror pivot is x and the plunger moves a height h , then the angular movement of the mirror $\delta \theta = \frac{h}{x}$. If f be the focal length of the lens, then the movement of the scale is $2f \cdot \delta \theta$, i.e.,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

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

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

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:

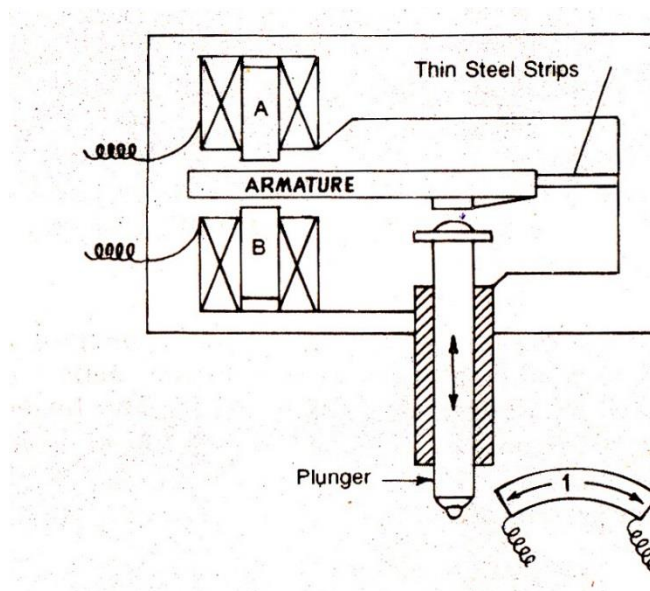
1. High accuracy: These comparators have very few moving parts and hence gives higher accuracy.
2. No parallax Error: The scale can be made past a datum line and thus have high range and no parallax error.
3. High magnification: Hence suitable for precision measurements.
4. Optical lever is weightless.
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 gauging 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.

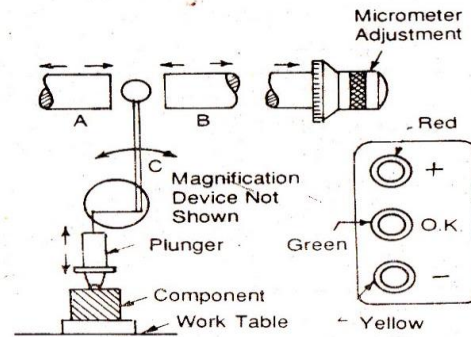


Fig. 5.12. Visual gauging head

Advantages of electrical and electronic Comparators:

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.

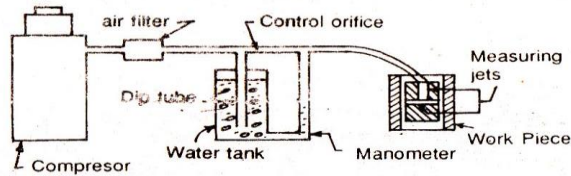


Fig. 5.15. Solex Pneumatic Gauge

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 artifact 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 inspected 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. 2. The readings are magnified by suitable arrangement 3. Measurements can be done rapidly and accurately, so it is suitable in mass production. 4. Comparators can be used to check dimensions as well as geometric forms. 5. There are no chances of errors due to incorrect contact pressure or deformation of-workpiece. 6. Accuracy is independent of correct feel or operators skill.	1. It is used to measure the actual dimensions of the parts. 2. No magnification system is provided. 3. Measurement is time consuming and therefore not suitable mass production system. 4. Measuring Instruments can not be used to check geometric forms. 5. Errors are caused due to misalignment or instrument or workpiece, incorrect contact pressure and deformation of instrument or workpiece 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. 2. Determines the difference between the sizes of parts and standards. 3. The readings are magnified by suitable arrangement 4. Indicating device is provided to determine the deviation in dimension, size etc of part from the standard. 5. Comparator can be used to compare dimensions of larger and thin walled parts	1. Gauges are used to determine whether the dimensions of parts lies within the given limits of size or not. 2. Determine deviation from the actual dimensions or form of parts. 3. Magnification system is not provided 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. 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 comparator 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 Comparasator : 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*****