

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.

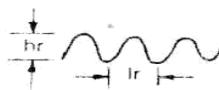
Third order: Even if the machine were perfect and completely free from vibrations some irregularities are caused by machining itself due to the characteristics of the process.

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

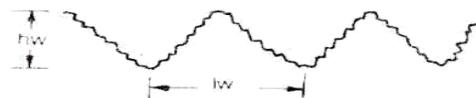
Irregularities on the surface of the part:-

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 geometrical error



macro geometrical error

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.

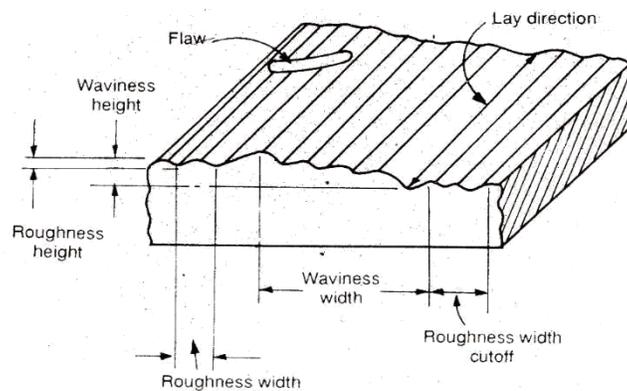
(ii) Secondary texture (Waviness):

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.



Elements of surface texture

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.

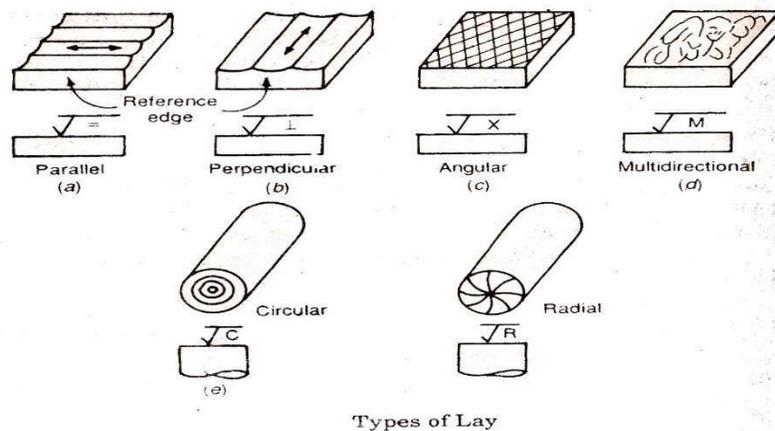
Roughness Width cutoff: This is the maximum width of surface irregularities that is included in the measurement of roughness height. This is always greater than roughness width and is rated in centimetres.

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.

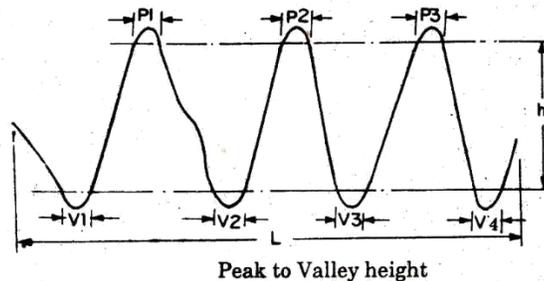
Evaluation of Surface Finish:

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:

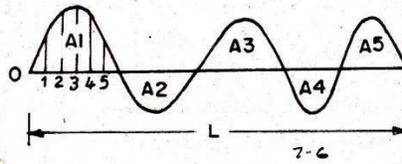
This method is largely used in Germany and Russia. It measures the maximum depth of the surface irregularities over a given sample length, and largest value of the depth is accepted as a measure of roughness. The drawback of this method is that it may read the same h for two largely different texture. 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

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

Also

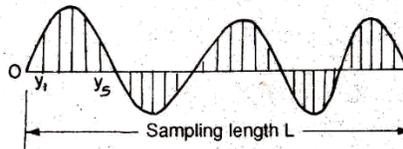
$$\text{C.L.A.} = \frac{A_1 + A_2 + A_3 + \dots + A_n}{L}$$

$$= \frac{\Sigma A}{L} \quad \dots(ii)$$

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 (1, 2, 3 ...) 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 1, 2, 3 ... are the heights of the ordinates erected at those points.

Then,

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

$$y_{rms} = \left(\frac{1}{L} \int_0^L y^2 dL \right)^{1/2}$$

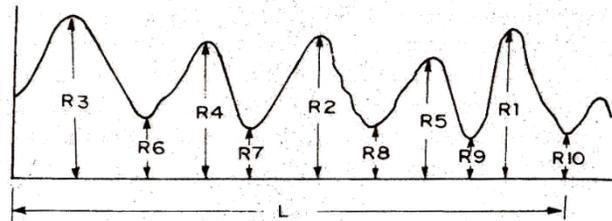
(c) Ten Point Height Method: In this method, the average difference between the five highest peaks and five lowest valleys of surface texture within the sampling length, measured from a line parallel to the mean line and not crossing the profile is used to denote the amount of surface roughness.

Mathematically,

R_2 = ten point height of irregularities

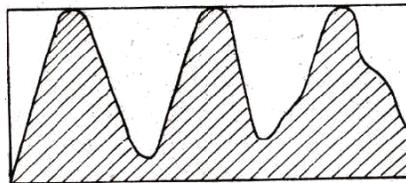
$$= \frac{1}{5} [(R_1 + R_2 + R_3 + R_4 + R_5) - (R_6 + R_7 + R_8 + R_9 + R_{10})]$$

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.

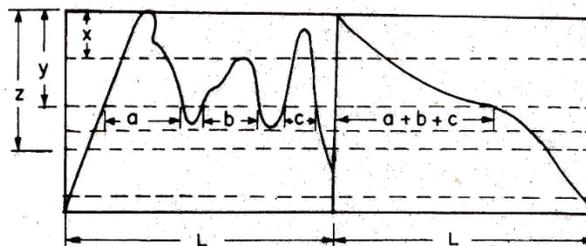
Form Factor: The load carrying area of every surface is often much less than might be thought. This is shown by reference to form factor. The form factor is obtained by measuring the area of material above the arbitrarily chosen base line in the section and the area of the enveloping rectangle. Then,



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

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

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.

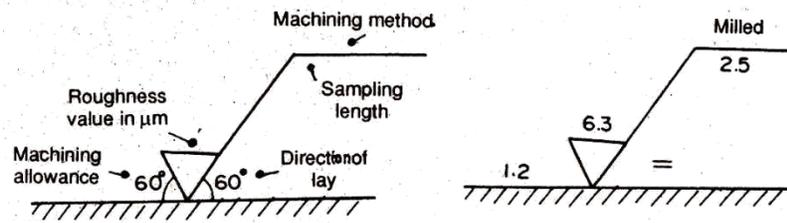


Conventional Method for Designing Surface finish:

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

- (a) Roughness value i.e., Ra 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 = L, 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 of the surface to be tested is compared with that of a specimen of known roughness 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 60° 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.

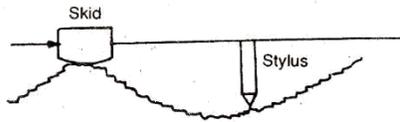
(viii) Reflected Light Intensity: In this method a beam of light of known quantity is projected upon the surface. This light is reflected in several directions as beams of lesser intensity and the change in light intensity in different directions is measured by a photocell. The measured intensity changes 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.

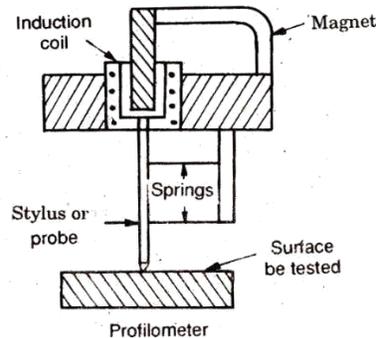
Disadvantages:

- (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:

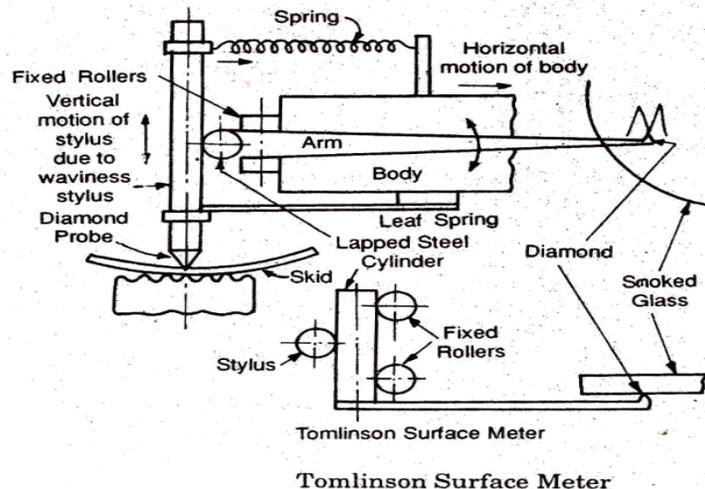


Profilometer is an indicating and recording instrument used to measure roughness in microns. The principle of the instrument is similar to gramophone pick up. It consists of two principal units: a tracer and an amplifier. Tracer is a finely pointed stylus. It is mounted in the pick up unit which consists 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:

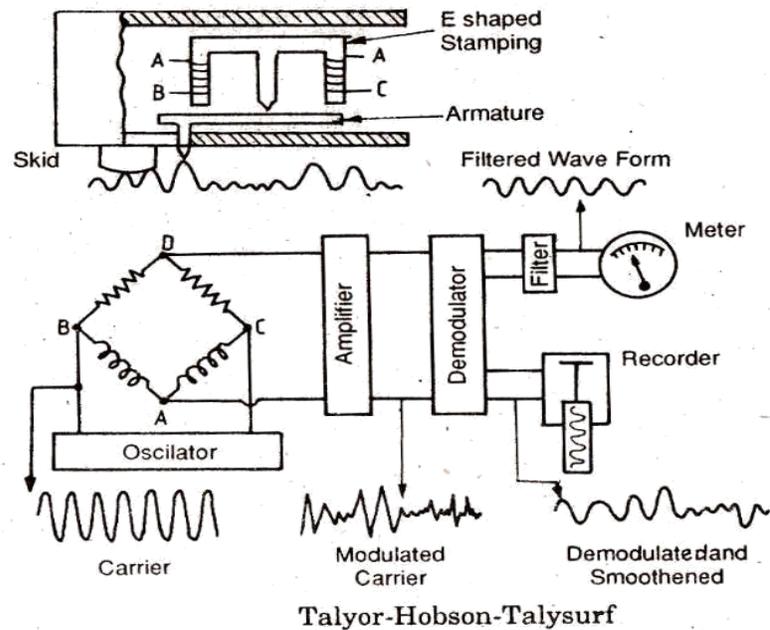
The Tomlinson surface meter is a comparatively cheap and reliable instrument. It was originally designed by Dr. Tomlinson.



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 scribe 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 scribe on smoked glass is obtained by the movement of the arm. This vertical movement of the scribe 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:

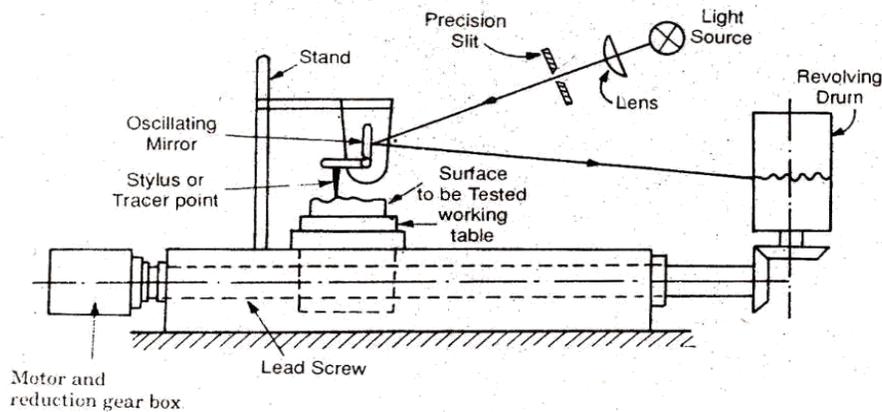


Taylor-Hobson Talysurf is a stylus and skid type of instrument working on carrier modulating principle. Its response is more rapid and accurate as compared to Temlinson Surface Meter. The measuring head of this instrument consists of a sharply pointed diamond stylus of about 0.002 mm tip radius and skid 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 ($A_1 + A_3 + A_5$) enclosed below it. The R_a value is given by, $R_a(CLA) = \frac{\sum A}{L}$.

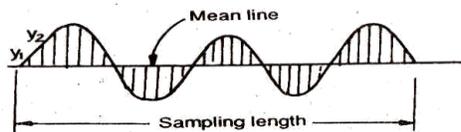


Fig. 7.21

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,

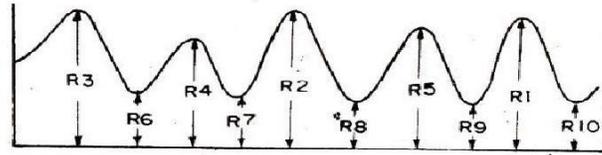


Fig. 7.22.

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

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.

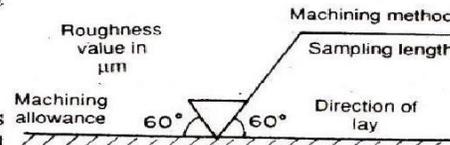


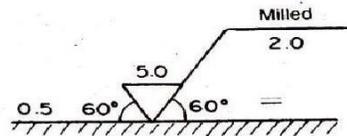
Fig. 7.23.

(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 $5 \mu\text{m } R_a$ 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.

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

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

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,

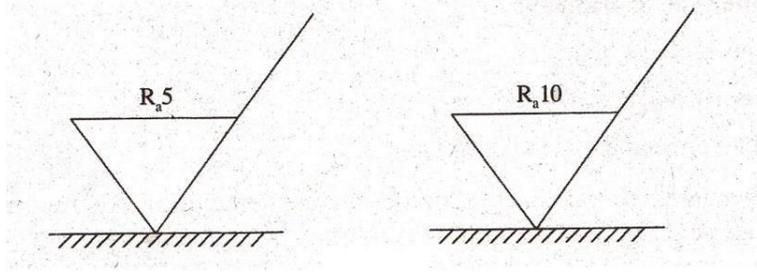
$$R_a 8.0(2.5)$$

Here surface sampling length is 2.5 mm p

(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	N12	~
25	N11	▽
12.5	N10	
6.3	N9	
3.2	N8	▽▽
1.6	N7	
0.8	N6	
0.4	N5	▽▽▽
0.2	N4	
0.1	N3	
0.05	N2	▽▽▽▽
0.025	N1	