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.
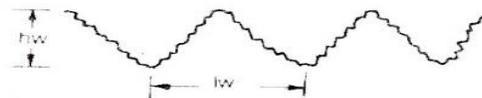
Irregularities on the surface of the part:-

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.
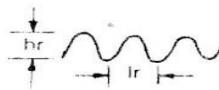
micro geometrical error   macro geometrical error

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 son 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 lr / hr denoting the micro-errors is less than 50, where lr = length along the surface and hr = 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 lw / hw denoting the macro-errors is more than 50. Where, lw = length along the surface and kw = 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.
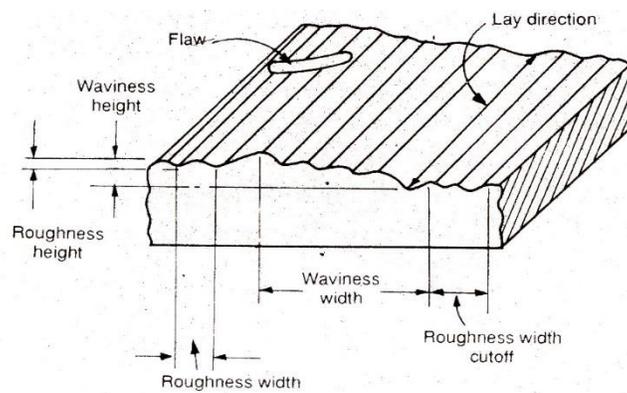
Elements of surface texture

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 canter of a surface obtained by using instrument

Laws: Flaws are surface irregularities or imperfections which occur art 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.

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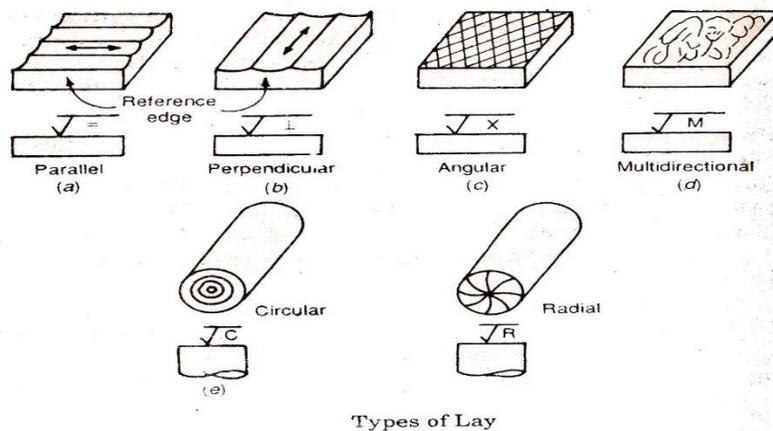
Lay: It is the direction of predominant surface pattern produced by tool marks or scratches. It is determined by the method of production used. Symbols used to indicate the direction of lay are given below:

| | = 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 parallelogram 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.

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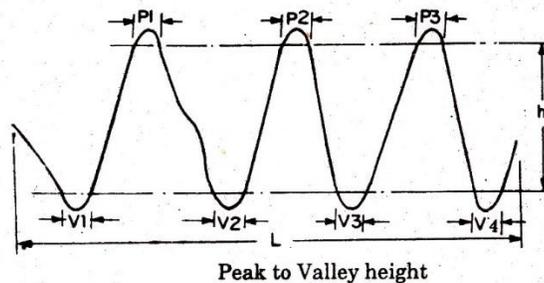
To, overcomes this PV (Peak to Valley) height is defined as the distance between a pair of lines running parallel `to the general 'lay' of the trace positioned so that the length lying within the peaks at, the top is 5% of the trace length, and that within the valleys at the bottom is 10% of the trace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

(2) The average roughness: For assessment off 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.
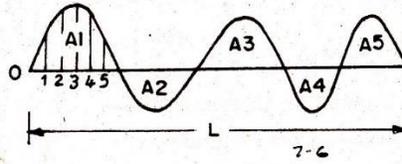
Centre Line Average or Arithmetic Average is defined as the average values of the ordinates from the mean line, regardless of the arithmetic signs of the ordinates

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

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

$$= \frac{\Sigma A}{L} \qquad \ldots(ii)$$

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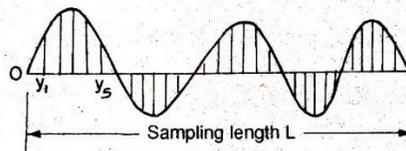
R.M.S value is defined as the squre root of the arithmetic mean of the values of the squares of the ordinates of the surface measured from a mean line. It is obtained by setting many equidistant ordinates on the mean line ($y_1, y_2, y_3 \ldots.$)and then taking the root of the mean of the squared ordinates.

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

$$\text{Then,}$$

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

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

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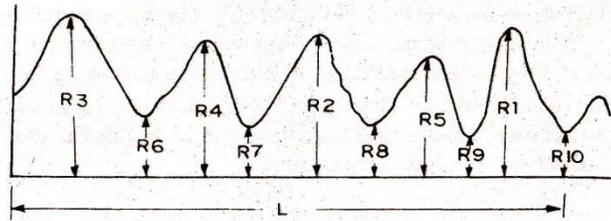
(3) Form factor and Bearing Curves: There are certain characteristic which may be used to evaluate surface texture.

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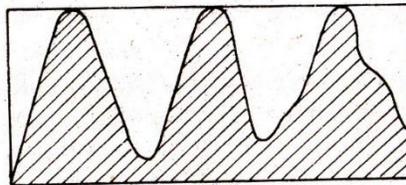
$$\text{Degree of fullness } (K) = \frac{\text{Area of metal}}{\text{Area of enveloping rectangle}}$$

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

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.
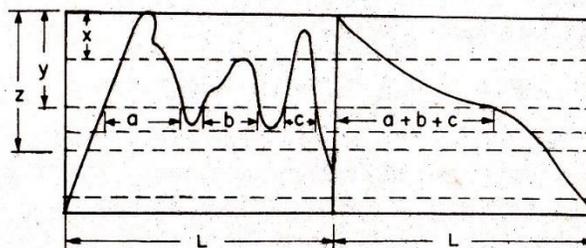
Conventional Method for Designing Surface finigh:

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

(a) Roughness value i.e., Ra value in mm

(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 = ⊥, X, M, C, R
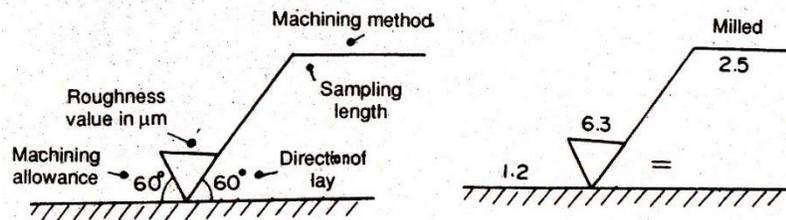
Measurement of surface finish surfaces texture:

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, e of the surface W 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) Microscopicc Inspection

(v) Surface photographs

(vi) Micro-Interferometer

(vii) Wallace surface Dynomometer

(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, babbit, 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.

<u>Principle, constructive and operation of stylus Probe type surface texture measuring instruments:</u>

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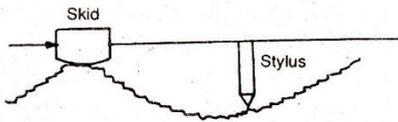
Stylus which is a fine point made of diamond or any such hard material is drawn over the surface to be tested. The movements of the stylus are used to modulate a high frequency carrier current or to generate a voltage signal. The output is then amplified by suitable means and used to operate a recording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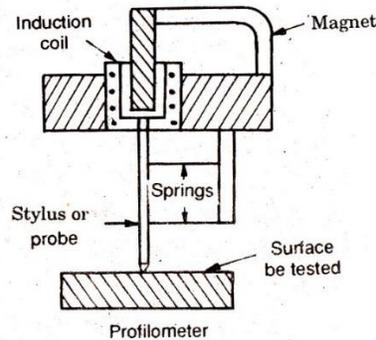
Profilometer

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.
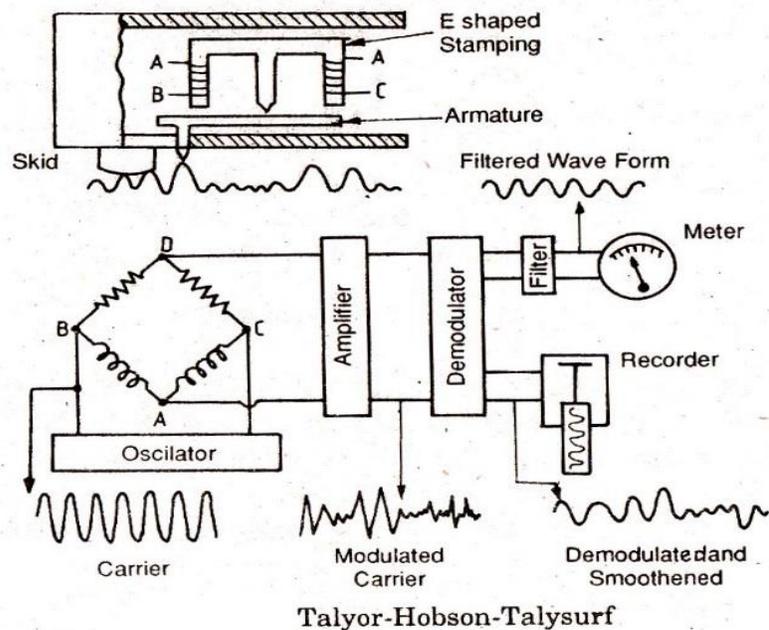
(b) The Tomlinson surface meter:

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

Tomlinson Surface Meter
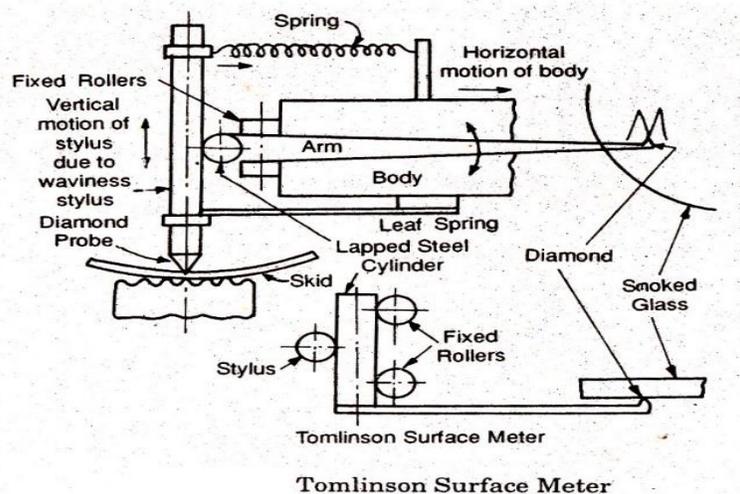
It consists of a diamond probe (stylus) held by spring pressure against the surface of a lapped steel cylinder and is attached to the body of the instrument by a leaf spring. The lapped cylinder is supported on one side by the probe and on the either side by fixed rollers. Alight spring steel arm is 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:


Talyor-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 comparred 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) Proyilograph : 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.
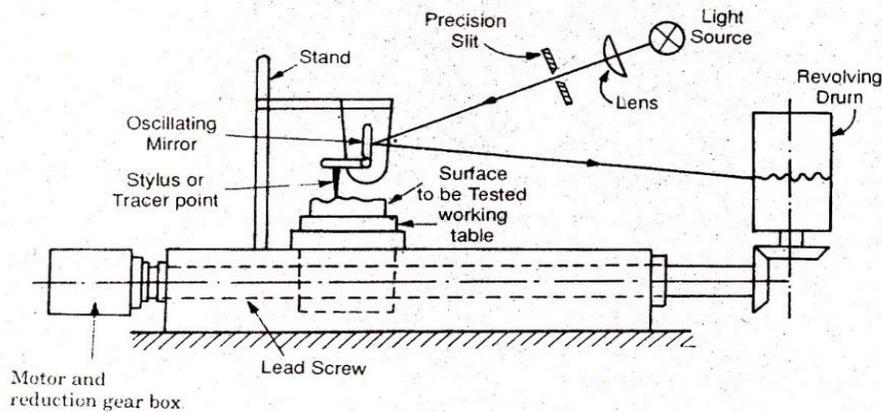
The stylus which is pivoted to a mirror moves over the tested surface. Oscillations of the tracer point are transmitted to the mirror. A light source sends a beam of light through lens and a precision slit to the oscillating mirror. The reflected beam is directed to a revolving drum, upon which a sensitised 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 Ra and Rz 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 Ra 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 Ra 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 Ra value is given by, $Ra(CLA) = \dfrac{\Sigma A}{L}$.
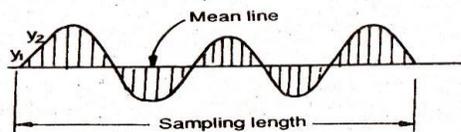

Fig. 7.21

R$_2$ 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,
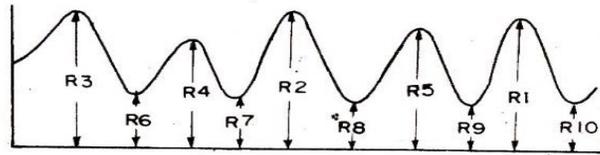

Fig. 7.22.

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

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

and $R_6, R_7 \ldots R_{10}$ 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 $\bigtriangledown$.

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

(2) Machining allowance in mm.

(3) Sampling length in mm.

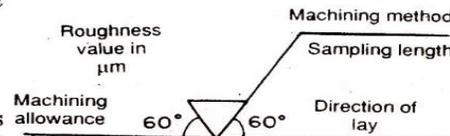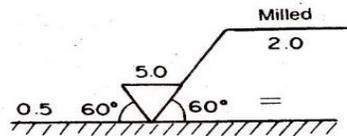(4) Method of machining such as milled, ground turned, tapped, shaped etc.

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 μm Ra 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 Ra value $= \dfrac{y_1 + y_2 + y_3 + \ldots + y_n}{n}$

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

$$= 25.5 \text{ microns}$$

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

$$= \sqrt{\frac{33^2 + 25^2 + 30^2 + 19^2 + 22^2 + 18^2 + 27^2 + 28^2 + 20^2}{10}}$$

$$= 26.03 \text{ microns}$$

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.

Sol. C.L.A. $= \dfrac{\Sigma A}{L} \times \dfrac{1}{\text{vertical scale}} \times \dfrac{1}{\text{horizontal scale}}$

$= \dfrac{(160 \times 95 + 90 + 65 + 180 + 170 + 50 + 150)}{0.8} \times 15000 \times 100$

$= 0.8 \ \mu m.$

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.

$$\text{C.L.A.value} = \dfrac{\begin{array}{c}45 + 25 + 40 + 25 + 35 + 16 + 40 + 22 + 25 + 34 + 25 \\ + 40 + 20 + 36 + 28 + 18 + 20 + 30 + 38\end{array}}{20}$$

$= 29.35$

$$\text{RMS Value} = \sqrt{\dfrac{\begin{array}{c}45^2 + 25^2 + 40^2 + 25^2 + 35^2 + 16^2 + 40^2 + 22^2 + 25^2 + 34^2 + 25^2 \\ + 40^2 + 20^2 + 36^2 + 28^2 + 18^2 + 20^2 + 25^2 + 30^2 + 38^2\end{array}}{20}}$$

$= 930.96$

ISI Symbols for Indication of surface Finish

The surface roughness is represented in figure. If the matching 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,

$R_{a_{16.0}}^{8.0}$ or $R_a^{8.0-16.0}$

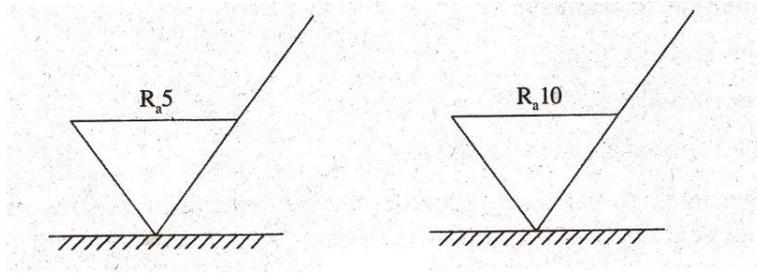(ii) The surface roughness and sampling length can be represented as,

$R_a 8.0 (2.5)$

Here surface sampling length is 2.5 mm p

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

$R_a 1.6$ 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.

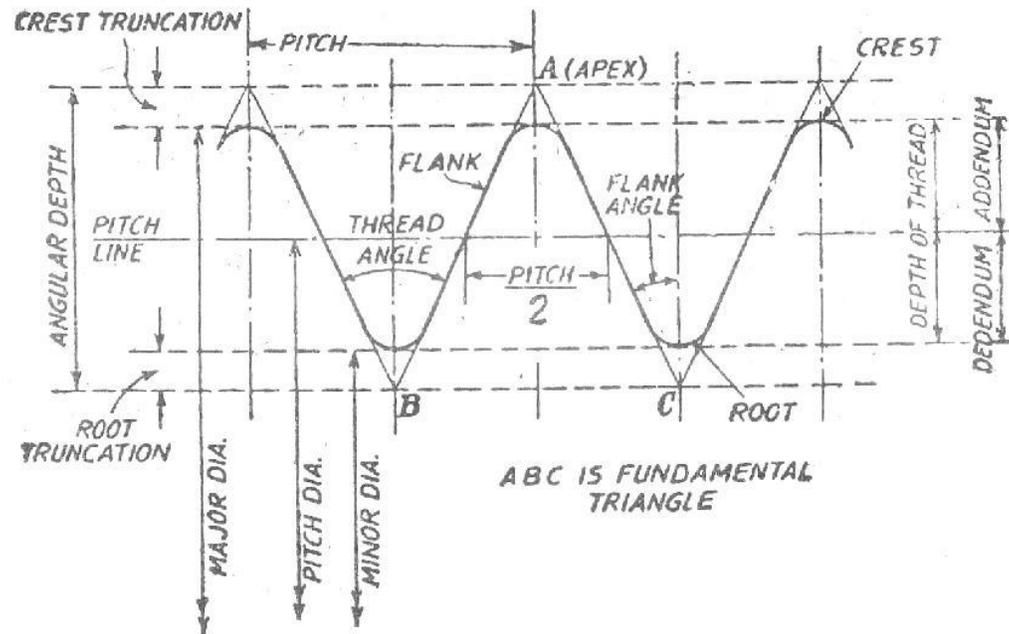| Roughness Values (R_a) (μm)	Roughness Grade Number	IS Roughness Symbol
50	N 12	~
25	N 11	∇
12.5	N 10	
6.3	N 9	
3.2	N 8	∇∇
1.6	N 7	
0.8	N 6	
0.4	N 5	∇∇∇
0.2	N 4	
0.1	N 3	
0.05	N 2	∇∇∇∇
0.025	N 1	

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

CHAPTER 5

SCREW THREADS

5.1   Terminology of Screw Threads:

1. **Screw thread.** A screw thread is the helical ridge produced by forming a continuous helical groove of uniform section on the external or internal surface of a cylinder or cone. A screw thread formed on a cylinder is known as straight or parallel screw thread, while the one formed on a cone or frustum of a cone is known as tapered screw thread.

2. **External thread**. A thread formed on the outside of a workpiece is called external thread e.g., on bolts or studs etc.

3. **Internal thread**. A thread formed on the inside of a workpiece is called internal thread e.g. on a nut or female screw gauge.

4. **Multiple-start screw thread**. This is produced by forming two or more helical grooves, equally spaced and similarly formed in an axial section on a cylinder. This gives a 'quick traverse' without sacrificing core strength.

5. **Axis of a thread.** This is imaginary line running longitudinally through the centre of the screw.

6. **Hand (Right or left hand threads).** Suppose a screw is held such that the observer is looking along the axis. If a point moves along the thread in clockwise direction and thus moves away

from the observer, the thread is right hand ; and if it moves towards the observer, the thread is left hand.

7. **Form, of thread.** This is the shape of the contour of one- complete thread as seen in axial section.

8. **Crest of thread**. This is defined as the prominent part of thread, whether it is external or internal.

9. **Root of thread**. This is defined as the bottom of the groove between the two flanks of the thread, whether it be external or internal.

10. **Flanks of thread.** These are straight edges which connect the crest with the root.

11. **Angle of thread {Included angle).** This is the angle between the flanks or slope of the thread measured in an axial plane.

12. **Flank angle.** The flank angles are the angles between individual flanks and the perpendicular to the axis of the thread which passes through the vertex of the fundamental triangle. The flank angle of a symmetrical thread is commonly termed as the half- angle of thread.

13. **Pitch.** The pitch of a thread is the distance, measured parallel to the axis of the thread, between corresponding points on adjacent thread forms in the same axial plane and on the same side of axis. The basic pitch is equal to the lead divided by the number of thread starts. On drawings of thread sections, the pitch is shown as the distance from the centre of one thread crest to the centre of the next, and this representation is correct for single start as well as multi-start threads.

14. **Lead.** Lead is the axial distance moved by the threaded part, when it is given one complete revolution about its axis with respect to a fixed mating thread. It is necessary to distinguish between measurements of lead from measurement of pitch, as uniformity of pitch measurement does not assure uniformity of lead. Variations in either lead or pitch cause the functional or virtual diameter of thread to differ from the pitch diameter.

15. **Thread per inch.** This is the reciprocal of the pitch in inches.

16. **Lead angle**. On a straight thread, lead angle is the angle made by the helix of the thread at the pitch line with plane perpendicular to the axis. The angle is measured in an axial plane.

17. **Helix angle.** On straight thread, the helix angle is the angle made by the helix of the thread at the pitch line with the axis. The angle is measured in an axial plane.

18. **Depth of thread**. This is the distance from the crest or tip of the thread to the root of the thread measured perpendicular to the longitudinal axis or this could be defined as the distance measured radially between the major and minor cylinders.

19. **Axial thickness.** This is the distance between the opposite faces of the same thread measured on the pitch cylinder in a direction parallel to the axis of thread.

20. **Fundamental triangle**. This is found by extending the flanks and joining the points B and C. Thus in Fig. 13.2, triangle ABC is referred to as fundamental triangle. Here BC=pitch and the vertical height of the triangle is called the angular or theoretical depth. The point A is the apex of the triangle ABC.

21. **Truncation.** A thread is sometimes truncated at the crest or at the root or at both crest and root. The truncation at the crest is the radial distance from the crest to the nearest apex of the fundamental triangle. Similarly the truncation at the root is the radial distance from the root to the nearest apex.

22. **Addendum.** For an external thread, this is defined as the radial distance between the major and pitch cylinders. For an internal thread this is the radial distance between the minor and pitch cylinders.

23. **Dedendum.** This is the radial distance between the pitch and minor cylinder for external thread, and for internal thread, this is the radial distance between the major and pitch cylinders.

24. **Major diameter.** In case of a straight thread, this is the diameter of the major cylinder (imaginary cylinder, co-axial with the screw, which just touches the crests of an external thread or the root of an internal thread). It is often referred to as the outside diameter, crest diameter or full diameter of external threads.

25. **Minor diameter.** In case of straight thread, this is the diameter of the minor cylinder (an imaginary cylinder, co-axial with the screw Which just touches the roots of an external thread or the crest of an internal thread). It is often referred to as the root diameter or cone diameter of external threads.

26. **Effective diameter or pitch diameter.** In case of straight thread, this is the diameter of the pitch cylinder (the imaginary' cylinder which is co-axial with the axis of the screw, and intersects the flank of the threads in such a way as to make the width of threads and width of the spaces between the threads equal). If the pitch cylinder be imagined as generated by a straight line parallel to the axis of screw that straight line is then referred to as the pitch line. Along the

pitch line, the widths of the threads and the widths of the spaces are equal on a perfect thread. This is the most important dimension at it decides the quality of the fit between the screw and the nut.

27. **Functional (virtual) diameter.** For an external or internal thread, this is the pitch diameter of the enveloping thread of perfect pitch, lead and flank angles having full depth of engagement but clear at crests and roots. This is defined over a specified length of thread. This may be greater than the simple effective diameter by an amount due to errors in pitch and angle of thread. The virtual diameter being the modified effective diameter by pitch and angle errors, is the most important single dimension of a screw thread gauge.

5.2. ERRORS IN THREADS

- In the case of plain shafts and holes, there is only one dimension(i.e. diameter), which has to be considered

- While in the case of screw threads there are at least five important elements, Major Diameter, Minor Diameter, Effective Diameter, Pitch And Angle Of The Thread Form

- Errors on the major and minor diameters will cause interference with the mating thread. Similarly pitch and angle errors are also not desirable as they cause a progressive tightening and interference on assembly.

PITCH ERRORS IN SCREW THREADS:

Generally the threads are generated by a point cutting tool.

The ratio of the linear velocity of tool and angular velocity of the work must be correct and constant, otherwise pitch errors will occur.

If there is some error in pitch, then the total length of thread engaged will be either too great or too small, the total pitch error in overall length of the thread being called the cumulative pitch error.

Various pitch errors can be classified as:

Progressive

Periodic

Irregular

Eratic.

(i) **PROGRESSIVE PITCH ERROR.**

This error occurs when the tool work velocity ratio is incorrect.

May caused due to pitch errors in the lead screw of the lathe or other generating machine.

The other possibility is by using an incorrect gear or an approximate gear train between work and lead screw e.g.,


Fig. 13·4. Progressive Error.
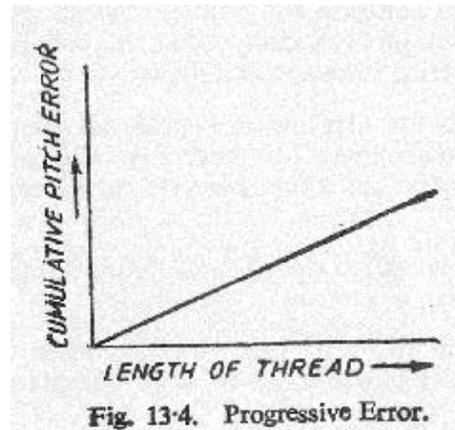
II. **PERIODIC PITCH ERROR**

This repeats itself at regular intervals.

Successive portions of the thread are either longer or shorter than the mean.

Error occurs when the tool work velocity ratio is not constant.

Results when a thread is cut from a leadscrew which lacks squareness causing leadscrew to move backward and forward once in each revolution.

Errors are cyclic and pitch increases to a maximum, and then reduces through normal value to a minimum and so on. The graph between the cumulative pitch error and length of threads for this error will, therefore, be of sinusoidal form.

Fig. 13·5. Periodic Error.
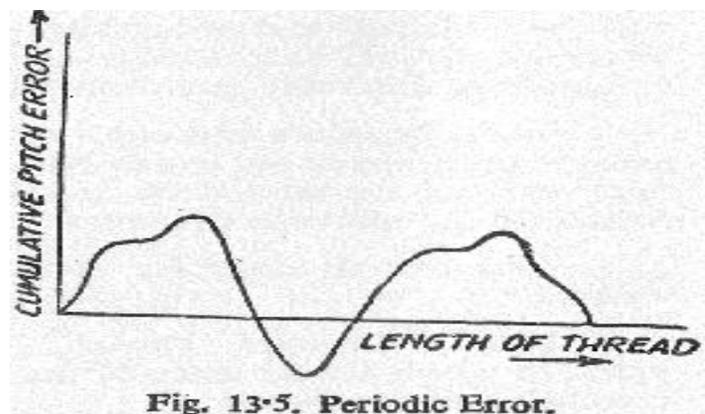
iii) Irregular Errors. These arise from disturbances in the machining set-up, variations in the cutting properties of material etc. Thus they have no specific causes and correspondingly no specific characteristics also.

Erratic Pitch. This is the irregular error in pitch and varies irregularly in magnitude over different lengths of thread.

iv) Drunken error:

– Error occurs when thread is not cut to the true helix angle.

–

6.3   Measurement of various elements in screw threads:

Most important six elements

a) Major Diameter

b) Minor Diameter

c) Effective Diameter

d) Pitch

e) Thread Angle

f) Thread Form.

a) Major Diameter:

Major Diameter is usually measured by

❑ MICROMETER

❑ BENCH MICROMETER

A good quality hand micrometer is quite suitable. In taking readings, a light pressure must be used as the anvils make contact with the gauge at points only and otherwise the errors due to compression can be introduced. It is, however, also desirable to check the micrometer reading on a cylindrical standard of approximately the same size, so that the zero error etc., might not come into picture.
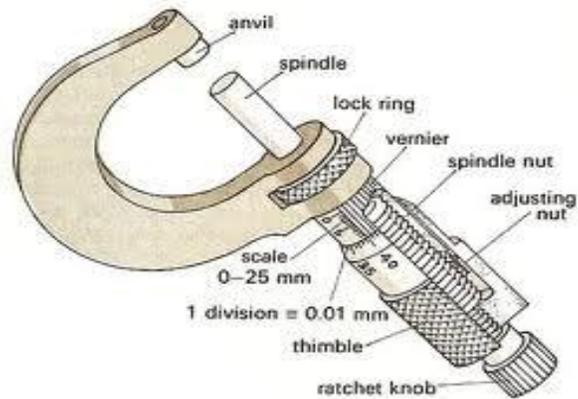
For greater accuracy and convenience, the major diameter is measured by bench micrometer. This instrument was designed by N.P.L. to estimate some deficiencies inherent in the normal hand micrometer. It uses constant measuring pressure and with this machine the error due to pitch error in the micrometer thread is avoided. In order that all measurements are made at the same pressure, a fiducial indicator is used in place of the fixed anvil. In this machine there is no provision for mounting the workpiece between the centres and it is to be held in hand. This is so, because, generally the centres of the workpiece are not true with its diameter. This machine is used as a comparator in order to avoid any pitch errors of micrometers, zero error setting etc. A calibrated setting cylinder is used as the setting standard.
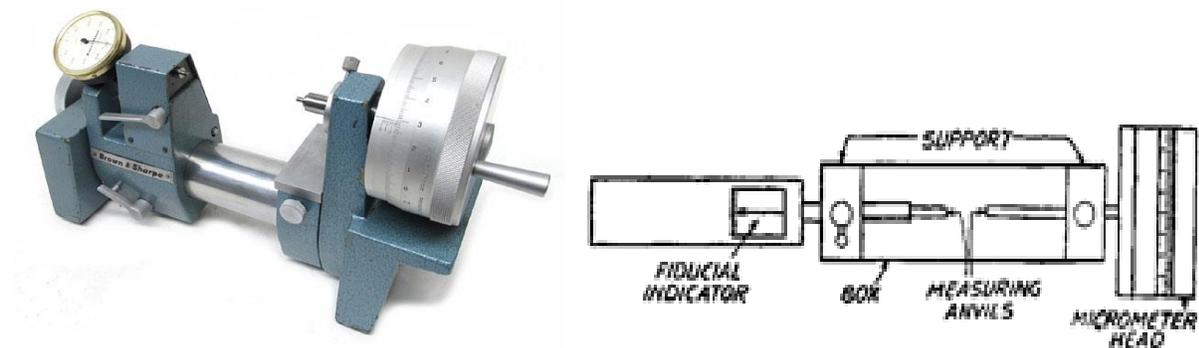

Measurement of Major Dia for Internal Screw Thread:

Stylus probe instrument is used for MEASURING Major diameter of internal screw thread as shown
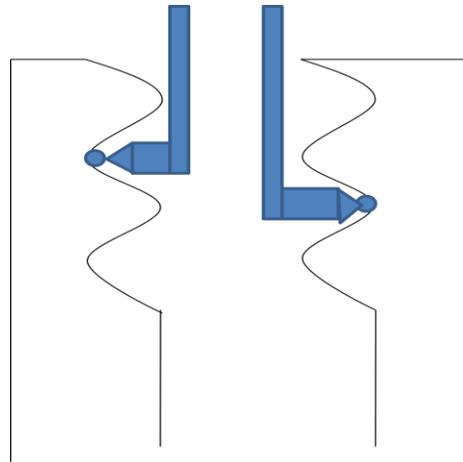
b) **Measurement of Minor Diameter:**

This is also measured by a comparative process using small Vee-pieces which make contact with a root of the thread. The Vee-pieces are available in several sizes having suitable radii at the edges. The included angle of Vee-pieces is less than the angle of the thread to be checked so that it can easily probe to the root of the thread. To measure the minor diameter by Vee-pieces is suitable for only Whitworth and B.A. threads which have a definite radius at the root of the thread. For other threads, the minor diameter is measured by the projector or microscope.
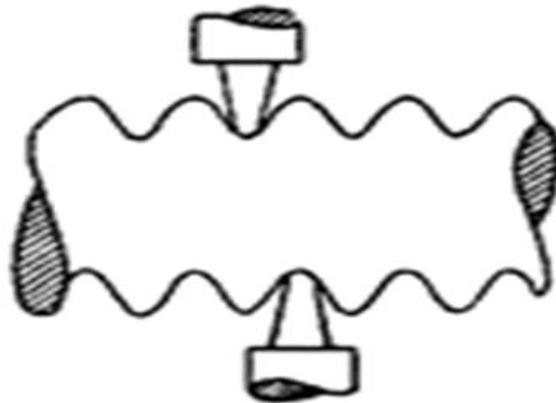
The measurement is carried out on a floating carriage diameter measuring machine in which the threaded work-piece is mounted between centres and a bench micrometer is constrained to move at right angles to the axis of the centre by a Vee-ball slide. The method of the application of Vee-pieces in the machine is shown diagrammatically in Fig.. The dimensions of Vee-pieces play no important function as they are interposed between the micrometer faces and the cylindrical standard when standard reading is taken. It is important while taking

readings, to ensure that the micrometer be located at right angles to the axis of the screw being measured. The selected Vees are placed on each side of the screw with their bases against the micrometer faces. The micrometer head is then advanced until the pointer of the indicator is opposite the zero mark, and note being made of the reading. The screw is then replaced by standard reference disc or a plain cylindrical standard plug gauge of approximately the core diameter of the screw to be measured and second reading of the micrometer is taken.

c) **Effective Diameter Measurements**.

The effective diameter or the pitch diameter can be measured by . any one of the following methods :

(i) The micrometer method

ii) The one wire, two wire, or three wire or rod method.

Two Wire Method.

The effective diameter of a screw thread may be ascertained by placing two wires or rods of identical diameter between the flanks of the thread, as shown in Fig. 13.15, and measuring the distance over the outside of these wires. The effective diameter E I s then calculated as
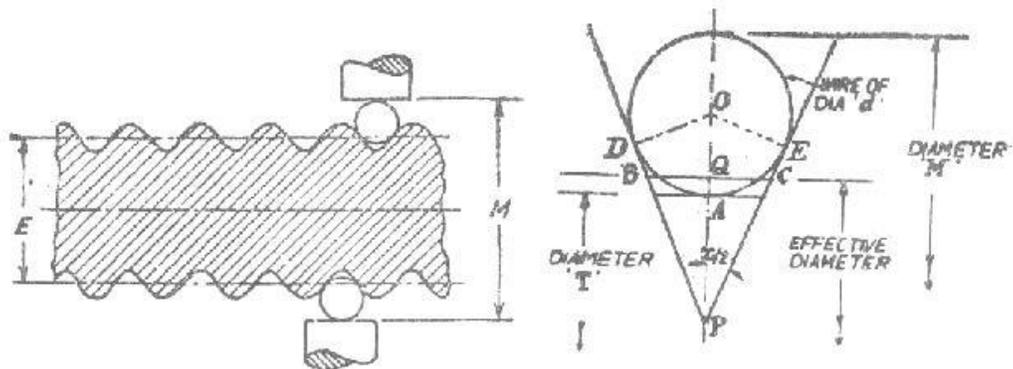
$$E = T + P$$

Where T= Dimension under the wires =M—2d

M=dimension over the wires, d= diameter of each wire

$$E = T + P$$
$$\text{Where} \quad T = \text{Dimension under the wires}$$
$$= M - 2d$$

M=dimension over the wires, d=diameter of each wire

The wires used are made of hardened steel to sustain the wear and tear in use. These are given a high degree of accuracy and finish by lapping to suit different pitches. Dimension T can also be determined by placing wires over a standard cylinder of diameter greater than the diameter under the wires and noting the reading R1 and then taking reading with over the gauge, say R2.

Then T=S—(R1—R2).

P=It is a value which depends upon the dia of wire and pitch of the thread.

If P= pitch of the thread, then

P= 0.9605p−1.1657d (for Whitworth thread).

P= 0.866p—d (for metric thread).

Actually P is a constant Value which has to be added to the diameter under the wires to give the effective diameter. The expression for the value of P in terms of p (pitch), d (diameter of wire) and x (thread angle) can be derived as follows :

In Fig (b), since BC lies on the effective diameter line

BC= ½ pitch=½ p

OP=d cosec x∕2∕2

PA=d (cosecx∕2−1)∕2

PQ=QC cot x∕2=p∕4 cot x∕2

AQ=PQ−AP=p cot x∕2∕4 – d(cosec x∕2 −1)∕2

AQ is half the value of P

∴ P value=2AQ

=p∕2 cot x∕2 −d (cosecx∕2−1)

Two wire method can be carried out only on the diameter measuring machine described for measuring the minor diameter, because alignment is not possible by 2 wires and can be provided only by the floating carriage machine. In the case of three wire method, 2 wire, on one side help in aligning the micrometer square to the thread while the third placed on the other side permits taking of readings.

Three Wire Method.

This method of measuring the effective diameter is an accurate method. In this three wires or rods of known diameter are used ; one on one side and two on the other side {Fig. (a) and (b)]. This method ensures the alignment of micrometer anvil faces parallel to the thread axis. The
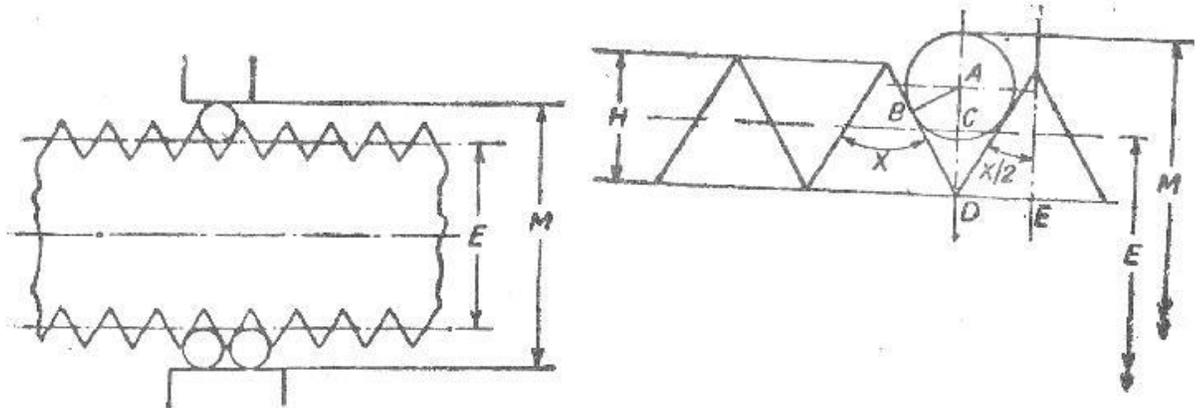
wires may be either held in hand or hung from a stand so as to ensure freedom to the wires to adjust them under micrometer pressure.

M=distance over wires E=effective diameter

r=radius of the wires d=diameter of wires

h =height of the centre or the wire or rod from the effective

x=angle of thread.

From fig.(b),

AD = AB cosec x∕2 = r cosec x∕2

H = DE cot x∕2 = p∕2 cot x∕2

CD = ½H = p∕4 cot x∕2

H = AD−CD

r = cosec x∕2− p∕4 cot x∕2

Distance over wires=M = E+2h+2r

= E+2(r cosec x∕2 – p∕4 cot x∕2)+2r

= E+2r (l+cosec x∕2)− p∕2 cot x∕2

or M = E+d (1+cosec x∕2) − p∕2 cot x∕2

(since 2r = 0)

(i) In case of Whitworth thread:

X = 55°, depth of thread = 0.64 p, so that

E= D—0.64 p and cosec x∕2 = 2.1657

Cot x∕2 = 1.921

M = E+d(1l+cosec x∕2) — p∕2 cot x∕2

= D−0.64p+d(1+2.1657)−p∕2(1.921)

$= D+3.1657d−1.6005p$

$M = D+3.1657d—1.6p$

where D=outside dia.

(ii) In case of metric threads:

Depth of thread=0.6495p

so, $E = D-0.6495p$.

$x = 60°$, cosec $x/2 = 2$; cot $x/2 = 1.732$

$M = D−0.6495 p+d(l+2)—p/2 (1.732)$

$= D+3d−(0.6495+0.866)p$

$= D+3d—1.5155p$.

We can measure the value of M practically and then compare with the theoretical values with the help of formulae derived above. After finding the correct value of M and knowing d, E can be found out.If the theoretical and practical values of M (i.e. measured over wires) differ, then this error is due to one or more of the quantities appearing in the formula.

Effect of lead angle on measurement by 3- wire method. If the lead angle is large (as with worms; quick traversing lead screw,etc .) then error in measurement is about 0'0125 mm when lead angle is 41° for 60° single thread series. For lead angles above 4£°, the compensation for rake and compression must also be taken into account. There is no recommendation for **B.S.W.** threads.

Rake Correction in U.S. Standard :

$E = M + cot \ x/2/2n—- − x(1 +cosec \ x/2+s2/2 \ cos \ x/2 \ cot \ x/2)$

where

$x/2$ =half the included angle of threads.

E = effective diameter

M = actually measured diameter over wires:

n = number of threads/inch.

d = diameter of wire.

S = tangent of the helix angle in thread.

Best size wire Method.

This wire is of such diameter that it makes contact with the flanks of the thread on the effective diameter or pitch line. The effective diameter can be measured with any diameter wire which

makes contact on the true flank of the thread, but the values so obtained will differ from those obtained with 'best size' wires if there is any error in angle or form of thread. t is recommended that for measuring the effective diameter, always the best size wire should be used and for this condition the wire touches the flank at mean diameter line within ±1/5 of flank length
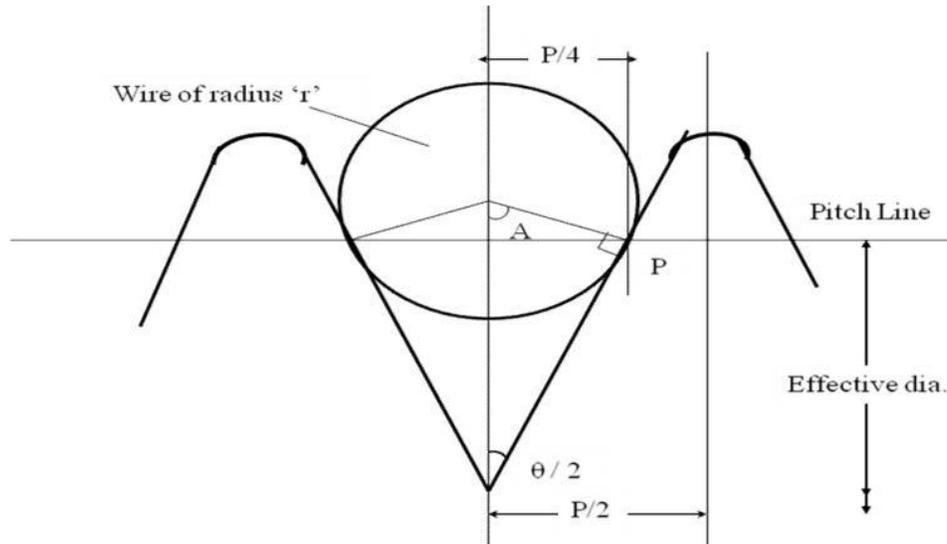
Let the thread angle be θ/2

Then in ∆le OAP, $\sin POA = \dfrac{AP}{OP}$

Or $\sin \left(90^0 - \dfrac{\theta}{2}\right) = \dfrac{AP}{OP}$

$OP = \dfrac{AP}{\sin\left(90^0 - \dfrac{\theta}{2}\right)} = \dfrac{AP}{\cos\dfrac{\theta}{2}} = AP \sec\dfrac{\theta}{2}$

Since, $OP = r = AP \sec\dfrac{\theta}{2}$

And wire diameter $= D_b = 2r = 2AP \sec\dfrac{\theta}{2}$

Since AP lies on the pitch line

$AP = \dfrac{P}{4}$ where, p is the pitch of the thread

Therefore, $D_b = \dfrac{2P}{4} \sec\dfrac{\theta}{2}$

Therefore, $\boxed{D_b = \dfrac{P}{2} \sec\dfrac{\theta}{2}}$

Gear Measurement

Gears are a mechanical drive which transmits power through toothed wheel. In this gear drive, the driving wheel is in direct contact with driven wheel. The accuracy of gearing is the very

important factor when gears are manufactured. The transmission efficiency is almost 99 in gears. So it is very important to test and measure the gears precisely. For proper inspection of gear, it is very important to concentrate on the raw materials, which are used to manufacture the gears, also very important to check the machining the blanks, heat treatment and the finishing of teeth. The gear blank should be tested for dimensional accuracy (face width, bore, hub, length, and outside diameter), and eccentricity. As outside diameter forms the datum from where the tooth thickness is measured, it forms an important item to be controlled. Concentricity of the blanks is also essential and the side faces should be true to the bore. On very precise gears details like tip radius, shape of root provided and surface finish are also measured.

The most commonly used forms of gear teeth are

        1. Involute

        2. Cycloidal

        ☐ The involute gears also called as straight tooth or spur gears.

        ☐ The cycloidal gears are used in heavy and impact loads.

        ☐ The involute rack has straight teeth.

        ☐ The involute pressure angle is either 20° or 14.5°

Types of gears

1. Spur gear:-

        Cylindrical gear whose tooth traces is straight line.

        These are used for transmitting power between parallel shafts.

2. Spiral gear :-

        The tooth of the gear traces curved lines.

3. Helical gears:-

        These gears used to transmit the power between parallel shafts as well as non-parallel and non-intersecting shafts.

        It is a cylindrical gear whose tooth traces is straight line.

4. Bevel gears:-

        The tooth traces are straight-line generators of cone.

        The teeth are cut on the conical surface. It is used to connect the shafts at right angles.
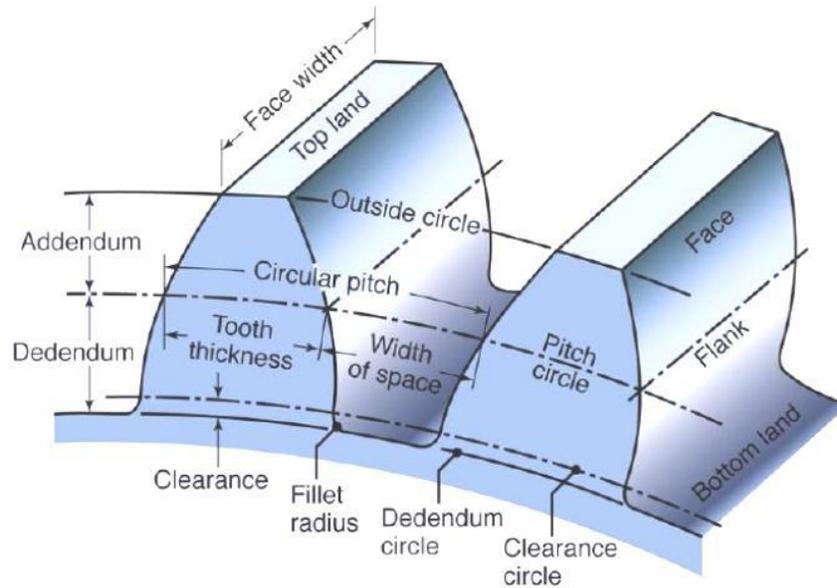
5. Worm and Worm wheel :

        It is used to connect the shafts whose axes are non-parallel and non-intersecting.

6. Rack and Pinion:-

      Rack gears are straight spur gears with infinite radius.

Terminology of gears:

1. Tooth profile:

      ☐ It is the shape of any side of gear tooth in its cross section.

2. Base circle:

      ☐ It is the circle of gear from which the involute profile is derived.

      ☐ Base circle diameter Pitch circle diameter x Cosine of pressure angle of gear

3. Pitch circle diameter (PCD):

      ☐ The diameter of a circle which will produce the same motion as the toothed gear wheel

4. Pitch circle

      ☐ It is the imaginary circle of gear that rolls without slipping over the circle of its mating gear.

5. Addendum circle:

      ☐ The circle coincides with the crests (or) tops of teeth.

6. Dedendum circle (or) Root circle:

      ☐ This circle coincides with the roots (or) bottom on teeth.

7. Pressure angle (a):

☐ It is the angle making by the line of action with the common tangent to the pitch circles of mating gears.

8. Module(m):

☐ It is the ratio of pitch circle diameter to the total number of teeth.

9. Circular pitch

☐ It is the distance along the pitch circle between corresponding points of adjacent teeth

10. Addendum:

☐ Radial distance between tip circle and pitch circle. Addendum value = 1 module.

11. Dedendum:

☐ Radial distance between itch circle and root circle, Dedendum value = 1 .25 module.

12. Clearance (C):

☐ A mount of distance made by the tip of one gear with the root of mating gear.

Clearance = Difference between Dedendum and addendum values

13. Blank diameter:

☐ The diameter of the blank from which gear is out. Blank diameter = PCD + 2m

14. Face:

☐ Part of the tooth in the axial plane lying between tip circle and pitch circle.

15. Flank:

☐ Part of the tooth lying between pitch circle and root circle.

16. Top land:

☐ Top surface of a tooth

17. Lead angle:

☐ The angle between the tangent to the helix and plane perpendicular to the axis of cylinder.

18. Backlash:

☐ The difference between the tooth thickness and the space into which it meshes.

Gear Tooth Caliper

In gear tooth vernier method the thickness is measured at the pitch line. Gear tooth thickness varies from the tip of the base circle of the tooth, and the instrument is capable of measuring the thickness at a specified position on the tooth. The tooth vernier caliper consists of vernier scale and two perpendicular arms. In the two perpendicular arms one arm is used to

measure the thickness and other arm is used to measure the depth. Horizontal vernier scale reading gives chordal thickness (W) and vertical vernier scale gives the chordal addendum. Finally the two values e compared. The theoretical values of 'W' and 'd' can be found out by considering one tooth in the gear and it can be verified.

pitch circle
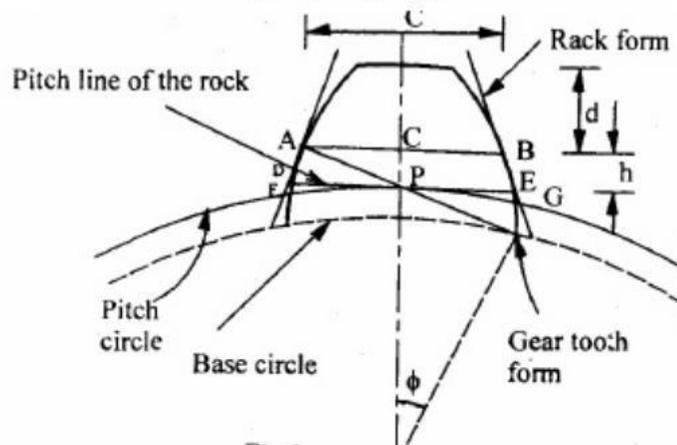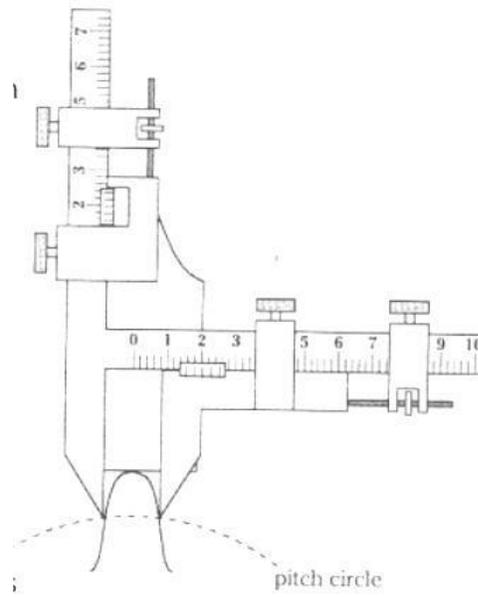
In fig note that w is a chord ADB and tooth thickness is specified by AEB. The distance d is noted and adjusted on instrument and it is slightly greater than addendum CE Therefore, 'W' is chordal thickness and 'd' is named as chordal addendum.

So, W = AB = 2AD

And angle, $AOD = \theta = \dfrac{360}{4n}$

Where, n = number of teeth

W = 2AD = 2 x AO sinθ

= 2R sin 360 / 4n

Where, R = Pitch circle radius

Module, $m = \dfrac{\text{Pitch Circle Diameter}}{\text{No.of teeth}} = \dfrac{2R}{n}$

Therefore, $R = \dfrac{nm}{2}$

And $OD = R \cos\theta = \dfrac{nm}{2} \cos\left(\dfrac{90}{n}\right)$

$OD = \dfrac{nm}{2} \cos\left(\dfrac{90}{n}\right)$

Also from the figure,
d = OC – OD

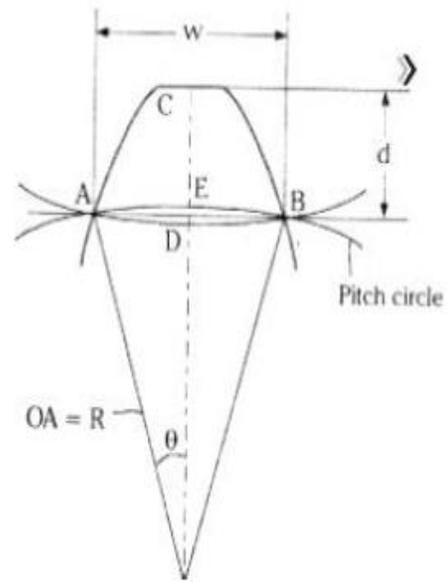Addendum is the radial distance from the pitch circle to the tip of the tooth. Its value is equal to one module

But   OC = OE + Addendum = R + m

$= \dfrac{nm}{2} \mid m$

And $\qquad OD = R\cos\theta$

$$= \frac{nm}{2}\cos\left(\frac{90}{N}\right)$$

Therefore, $\qquad d = \frac{Nm}{2} + m - \frac{Nm}{2}\cos\left(\frac{90}{N}\right)$

$$\boxed{d = \frac{Nm}{2}\left[1 + \frac{2}{N} - \cos\left(\frac{90}{N}\right)\right]}$$

Pitch circle

$OA = R$

Vernier method like the chordal thickness and chordal addendum are depends upon the number of teeth. Due to this for measuring large number of gears different calculations are to be made for each gear. So these difficulties are avoided by this constant chord method.
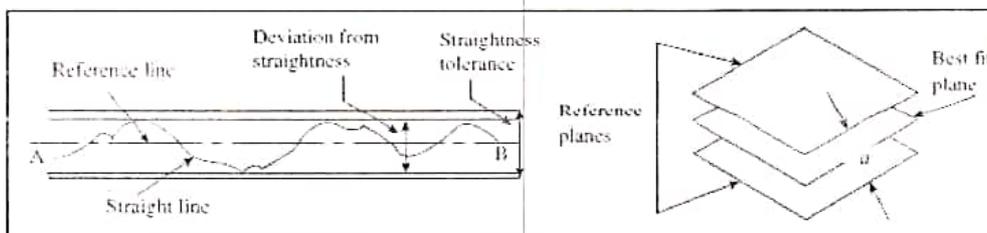
FLATNESS MEASUREMENT

Measurement of flatness of surface:

Machine tool tables, which hold work pieces during machining, should have a high degree of flatness. Many metrological devices like the sine bar invariably need a perfectly flat surface plate. Flatness error may be defined as the minimum separation of a pair of parallel planes that will just contain all the points on the surface. Figure 10.7 illustrates the measure of flatness error a. It is possible, by using simple geometrical approaches, to fit a best-fit plane for the macro surface topography.

Flatness is the deviation of the surface from the best-fit plane. According to IS: 2063-1962, a surface is deemed to be flat within a range of measurement when the variation of the perpendicular distance of its points from a geometrical plane (this plane should be exterior to the surface to be tested) parallel to the general trajectory of the plane to be tested remains below a given value.


Straightness of a line   measurement of flatness error

The geometrical plane may be represented either by means of a surface plane or by a family of straight lines obtained by the displacement of a straight edge, a spirit level, or a light beam. While there are quite a few methods for measuring flatness, such as the beam comparator method, interferometry technique, and laser beam measurement, the following paragraphs explain the simplest and most popular method of measuring flatness using a spirit level or a clinometer.

Measurement of flatness error

Assuming that a clinometer is used for measuring angular deviations, a grid of straight lines, as shown in Figure is formulated. Care is taken to ensure that the maximum area of the flat table or surface plate being tested is covered by the grid. Lines AB, DC, AD, and BC are

drawn parallel to the edges of the flat surface; the two diagonal lines DB and AC intersect at the centre point O. Markings are made on each line at distances corresponding to the base length of the clinometer.
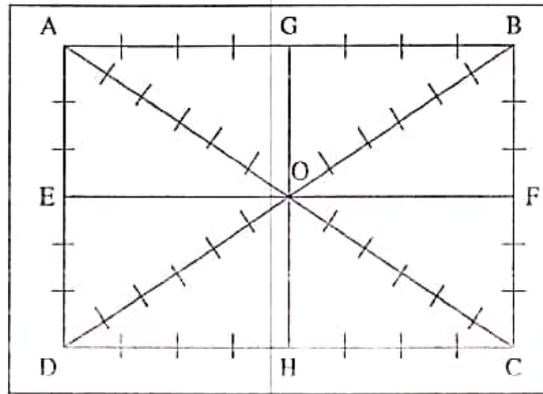

Grid lines for flatness test

The following is a step-by-step procedure to measure flatness error:

1. Carry out the straightness test on all the lines and tabulate the readings up to the cumulative error column. Figure gives an example of line AB.

2. We know that a plane is defined as a 2D entity passing through a minimum of three points not lying on the same straight line. Accordingly, a plane passing through the points A, B, and D is assumed to be an arbitrary plane, relative to which the heights of all other points are determined. Therefore, the ends of lines AB, AD, and BD are corrected to zero and the heights of points A, B, and D are forced to zero.

3. The height of the centre 'O' is determined relative to the arbitrary plane ABD. Since O is also the mid-point of line AC, all the points on AC can be fixed relative to the arbitrary plane ABD. Assume A = 0 and reassign the value of O on AC to the value of O on BD. This will readjust all the values on AC in relation to the arbitrary plane ABD.

4. Next, point C is fixed relative to the plane ABD; points B and D are set to zero. All intermediate points on BC and DC are also adjusted accordingly.
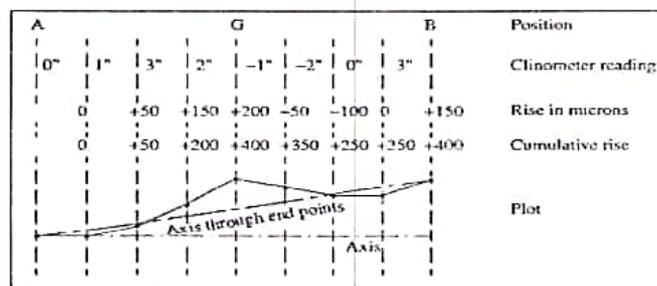
Straightness plot for line AB

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5. The same procedure applies to lines EF and GH. The midpoints of these lines should also coincide with the known midpoint value of O.

6. Now, the heights of all the points, above and below the reference plane ABD, are plotted as shown in Figure. Two lines are drawn parallel to and on either side of the datum plane, such that they enclose the

7. Outer most points. The distance between these two outer lines is the flatness error.
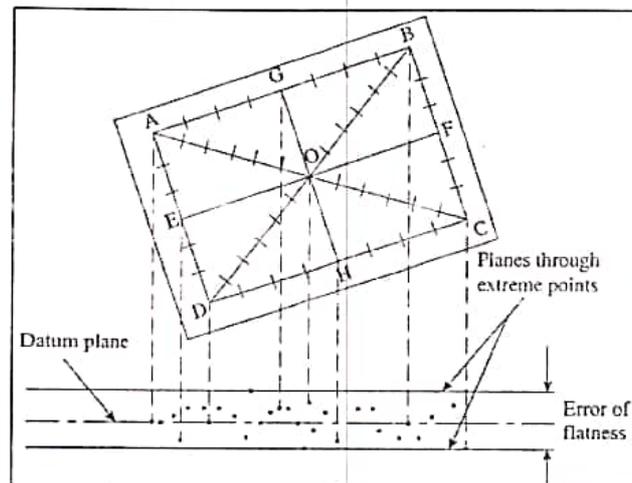
Plot of heights of all points with reference to the datum plane ABD

Some authors argue that the reference plane ABD that is chosen in this case may not be the best datum plane. They recommend further correction to determine the minimum separation between a pair of parallels that just contains all the points on the surface. However, for all practical purposes, this method provides a reliable value of flatness error, up to an accuracy of $10 \ \mu m$.

Instruments used for flatness measurement:

       1. Straight edge

   2. Surface plate

       3. Auto collimator...Etc.

1. Straight edge:

A **straightedge** is a tool with an edge free from curves, or straight, used for transcribing straight lines, or checking the straightness of lines. If it has equally spaced markings along its length, it is usually called a ruler.

Straightedges are used in the automotive service and machining industry to check the flatness of machined mating surfaces.

True straightness can in some cases be checked by using a laser line level as an optical straightedge: it can illuminate an accurately straight line on a flat surface such as the edge of a plank or shelf.

A pair of straightedges called winding sticks are used in woodworking to amplify twist (wind) in pieces of wood.
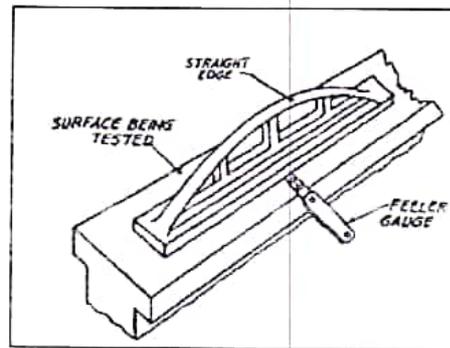
Straight edge

An idealized straightedge is used in compass-and-straightedge constructions in plane geometry. It may be used:

- Given two points, to draw the line connecting them.
- Given a point and a circle, to draw either tangent.
- Given two circles, to draw any of their common tangents.

It may not be marked or used together with the compass so as to transfer the length of one segment to another.

It is possible to do all compass and straightedge constructions without the straightedge. That is, it is possible, using only a compass, to find the intersection of two lines given two points on each, and to find the tangent points to circles. It is not, however, possible to do all constructions using only a straightedge. It *is* possible to do them with straightedge alone given one circle and its center.

2. Surface plate:

A **surface plate** is a solid, flat plate used as the main horizontal reference plane for precision inspection, marking out (layout), and tooling setup. The surface plate is often used as the baseline for all measurements to the work piece, therefore one primary surface is finished extremely flat with accuracy up to 0.00001 in or 250 nm for a grade AA or AAA plate. Surface plates are a very common tool in the manufacturing industry and are often permanently

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attached to robotic type inspection devices such as a coordinate-measuring machine. Plates are typically square or rectangular. One current British Standard includes specifications for plates from 160 mm x 100 mm to 2500 mm x 1600 mm.
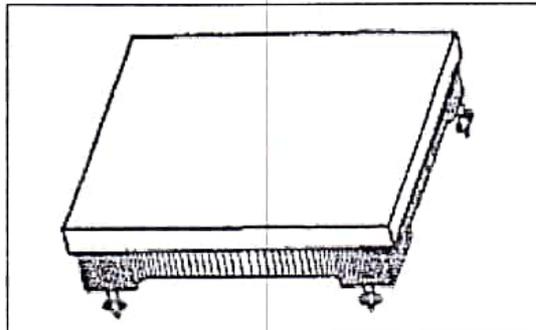
Surface plate

3. Autocollimator

It is a special form of telescope that is used to measure small angles with a high degree of resolution. It is used for various applications such as precision alignment, verification of angle standards, and detection of angular movement, among others. It projects a beam of collimated light onto a reflector, which is deflected by a small angle about the vertical plane. The light reflected is magnified and focused on to an eyepiece or a photo detector. The deflection between the beam and the reflected beam is a measure of the angular tilt of the reflector. Figure illustrates the working principle of an autocollimator.

The reticle is an illuminated target with a cross-hair pattern, which is positioned in the focal plane of an objective lens. A plane mirror perpendicular to the optical axis serves the purpose of reflecting an image of the pattern back on to the observation point. A viewing system is required to observe the relative position of the image of the cross-wires. This is done in most of the autocollimators by means of a simple eyepiece. If rotation of the plane reflector by an angle q results in the displacement of the image by an amount d, then, $d = 2fq$, where f is the focal length of the objective lens.

It is clear from this relationship that the sensitivity of an autocollimator depends on the focal length of the objective lens. The longer the focal length, the larger the linear displacement for a given tilt of the plane reflector. However, the maximum reflector tilt that can be accommodated is consequently reduced. Therefore, there is a trade-off between sensitivity and measuring range. The instrument is so sensitive that air currents between the optical path and the target mirror can cause fluctuations in the readings obtained. This effect is more severe when the distance between the two increases. Therefore, an autocollimator is housed inside a

sheet-metal or a PVC plastic casing to ensure that air currents do not hamper measurement accuracy.

Autocollimators may be classified into three types:

1. Visual or conventional autocollimator
2. Digital autocollimator
3. Laser autocollimator
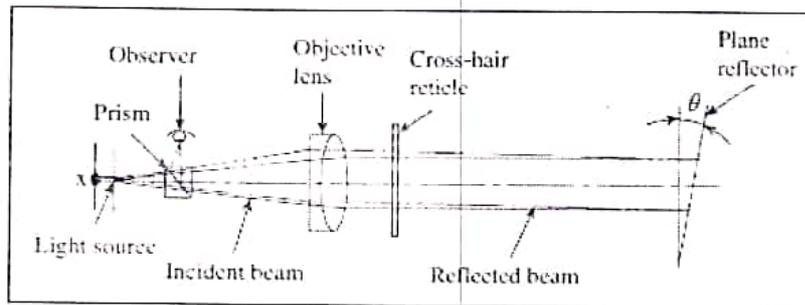
Principle of autocollimator

Visual Autocollimator

In this type of autocollimator, the displacement of the reflected image is determined visually. A pinhole light source is used, whose reflected image is observed by the operator through an eyepiece. Visual collimators are typically focused at infinity, making them useful for both short and long-distance measurements. The plane reflector is one of the vital parts of an autocollimator, because a mirror that is not flat will defocus the return image, resulting in poor definition of the image. High-quality mirrors with a flatness tolerance of 1 μm per 100 mm are used. Most visual collimators have a resolution of 3–5" over a distance of 1.5 m.

The following are some of the typical applications of visual autocollimators:

1. Determination of angular measurements up to 3"
2. Determination of straightness of machine guide ways
3. Determination of parallelism of slide movements with respect to guide ways
4. Flatness estimation of machine tables, surface plates, etc.
5. Verification of right angle prisms for angular errors
6. Angle comparisons of reflecting surfaces

Digital Autocollimator

A digital autocollimator uses an electronic photo detector to detect the reflected light beam. A major advantage of this type of collimator is that it uses digital signal processing technology to detect and process the reflected beam. This enables the filtering out of stray scattered light,

which sharpens the quality of the image. The illuminated target reticle slit is imaged back in its own plane through the objective lens and reflecting mirror. It is then re-imaged onto a vibrating slit by means of a relay lens. A photocell positioned behind the vibrating slit generates an output, which captures both the magnitude and the direction of rotation of the mirror from a central null position. These instruments have a resolution of up to 0.01 arc-second and a linearity of 0.1%. Since the output is digital in nature, it can be transferred to a data acquisition system, thereby facilitating storage and further processing of data. Another major advantage is that it can also measure angles of dynamic systems to a high degree of resolution, thanks to high sampling rates of digital electronic systems.

The following are some of the applications of a digital autocollimator:

1. Angular measurement of static as well as dynamic systems
2. Alignment and monitoring of robotic axes
3. Verification of angular errors of rotary tables, indexing heads, and platforms of machine parts
4. Remote monitoring of alignment of large mechanical systems

Laser Autocollimator

Laser autocollimators represent the future of precision angle measurement in the industry. Superior intensity of the laser beam makes it ideal for the measurement of angles of very small Objects (1 mm in diameter) as well as for long measuring ranges that extend to 15 m or more. Another marked advantage is that a laser autocollimator can be used for the measurement of Non-mirror-quality surfaces. In addition, the high intensity of the laser beam creates ultra-low noise measurements, thereby increasing the accuracy of measurement. TL40 and TL160 lasers are popular in autocollimators.

MACHINE TOOL ALIGNMENT TESTS

The basic objective of conducting acceptance tests is to ensure that all relative movements of the machine tool conform well within the accepted limits of deviations from designed values. This is important since the dimensions of the work part depend, to a large extent, on the accuracy of the mating parts of the machine tool. The phrase *acceptance test* is coined to signify the fact that the machine buyer will inspect the alignment of various parts of the machine tool in detail and will 'accept' the machine tool from the vendor's factory only after it conforms to accepted norms.

We can broadly classify the various tests under the following groups:

1. Tests for ensuring levelling of the machine tool in both horizontal and vertical planes
2. Tests for flatness of machine bed and straightness as well as parallelism of bed ways and bearing surfaces
3. Tests for Perpendicularity of guide ways with respect to other guide ways or bearing surfaces
4. Tests for true running of the machine spindle and its axial movements
5. Tests for assessing parallelism of spindle axis to guide ways or bearing surfaces
6. Tests for line of movements for slides, cross-slides, and carriages
7. Practical tests for assessing dimensional and geometric accuracy in machining

The following are the important tests carried out on a lathe:

Levelling of machine First and foremost. the machine should be checked for accuracy of levelling. The machine should be installed such that the lathe bed is truly horizontal. A sensitive spirit level or a clinometer can be used to verify the levelling of the machine. The spirit level is moved over the designated distance specified in the test chart, and the deviation is noted down. The test is carried out in both longitudinal and transverse directions.
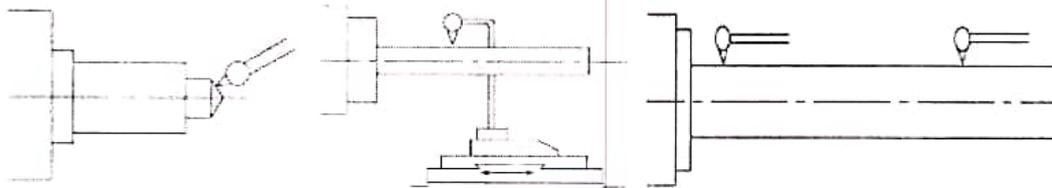
True running of main spindle The main spindle. while running. should not have any play or radial deviations from its axis. This is tested using a test mandrel of acceptable quality. The mandrel is fitted to the spindle bore and the dial indicator feeler is made to contact the mandrel surface as shown in Figure. The spindle is gently rotated by hand. and the deviations of the dial indicator are noted down. The dial indicator base is mounted on the carriage. The deviation should be within acceptable limits.

Axial slip of main spindle The spindle should have true running in a direction parallel to its axis. This is easily checked by placing the dial indicator feeler against the spindle face and giving slight rotation to the spindle. The deviations should be within acceptable limits. The test is repeated at a diametrically opposite location to ensure that the spindle does not have an axial slip.

Levelling of the machine   true running of main spindle   axial slip of main spindle
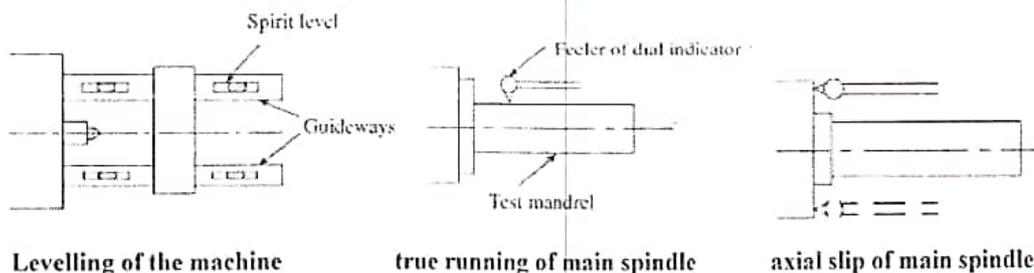
True running of headstock centre The headstock centre is the live centre of the machine; if it is not true, accuracy of the work piece will suffer. The work piece will develop eccentricity if the error is too much. The feeler of the dial indicator is pressed perpendicular to the taper surface of the centre, and the spindle is rotated. The deviation indicates the trueness of the headstock centre. The test procedure is illustrated in Figure.

Parallelism of main spindle Parallelism of the spindle is crucial for generating accurate dimensions. Any error in parallelism will result in a tapered surface after machining. In order to test parallelism, a test mandrel is made use of. It is fitted into the spindle bore and dial gauge readings are taken over a specified length, as shown in Figure. Two readings are taken, one in a horizontal plane and the other in a vertical plane, on one of the sides of the mandrel. It is important to see that excess overhang of the mandrel does not result in a sag due to its own weight.

True running of head stock center   parallelism of main spindle   true running of spindle taper bore

True running of taper bore of main spindle The lathe spindle bore has a standard taper. Unless this taper is concentric with the spindle axis, work pieces will have undesired taper or eccentricity. A test mandrel is fitted to the tapered bore of the spindle, and dial gauge readings are taken at the two extreme ends of the mandrel. This value should be well within the allowable limits.
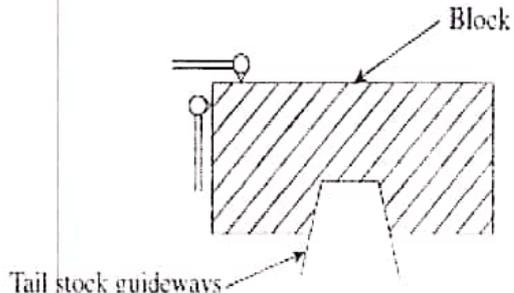
Parallelism of tailstock sleeve to carriage movement A tailstock is generally used to hold long work pieces. The dead centre of the tailstock is mounted on the end of the sleeve, which moves in an axial direction. The sleeve surface should be perfectly parallel to the movement of the carriage. A mandrel is put in the sleeve socket and dialling is done by mounting the dial gauge base on the tool post, as shown in Figure. The test should be carried out in both the horizontal and vertical planes.

Parallelism of tailstock guide ways to carriage movement The tailstock guide ways should be parallel to the movement of the carriage. Whenever long jobs are being turned, it becomes necessary to shift the tailstock along its guide ways. While doing so, the job axis should

perfectly coincide with the tailstock centre. If this condition is not satisfied, the work piece will develop an undesirable taper. A test block, specially designed for the purpose, is placed on the guide ways, as shown in Figure. The dial indicator base is mounted on the carriage and the feeler is made to contact the work piece. The carriage is moved for the specified distance and the deviation is noted down. The test is carried out in both the horizontal and vertical planes.
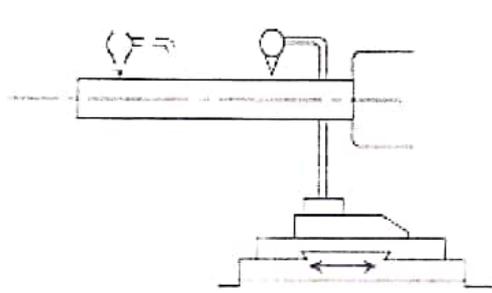
Parallelism of a tail stock sleeve   Parallelism of a tail stock guide ways

Practical tests Actual machining is carried out in order to ascertain not only the accuracy of alignment but also the rigidity of the machine tool. At least three turning operations are mandatory, namely chucking (using the chuck only), turning between centres, and facing. The operations are performed with prescribed values of cutting speed, feed rate, and depth of cut. Table illustrates the recommended ways of conducting practical tests on lathes.

| Operation	Workpiece diameter (mm)	Permissible error (mm)
Chucking	50–100	0.01
Turning between centres	100–200	0.02
Facing	100–200	0.02

Recommended practical tests

Acceptance Tests for Milling Machines

It is presumed that the student is aware of the various types of milling machines. However, we will deal with some of the important tests conducted on a horizontal milling machine in order to provide the student with a fair knowledge of the methodology.

Axial slip of spindle A spindle may have an axial slip, which is the axial movement of the spindle during its rotation. Axial slip may occur due to the following reasons: errors due to worn-out spindle bearings, face of the locating shoulder of the spindle not being in a plane perpendicular to the axis of the spindle, and irregularities in the front face of the spindle. Figure 10.25 illustrates the test for measuring the axial slip of the spindle. The feeler of the dial gauge is held against the front face of the spindle and the base is mounted on the table. The position

of the dial gauge (in order to measure axial slip) is denoted by A in the figure. The spindle is gently rotated by hand and the dial gauge reading is noted down. The test is repeated at a diametrically opposite spot. The maximum deflection should be well within the prescribed limits.
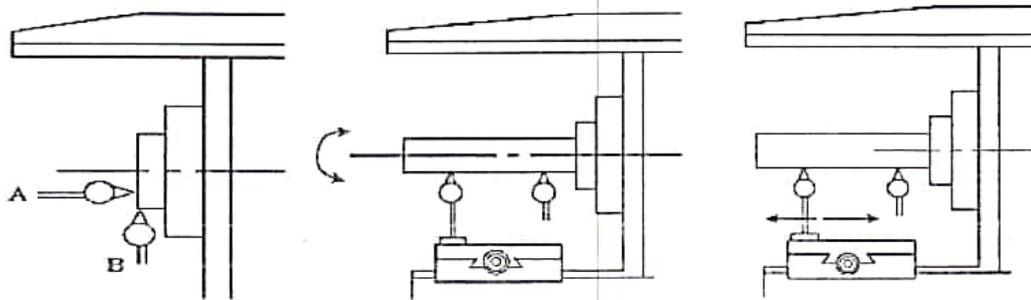

Measuring axial slip of spindle   true running of spindle taper   paralellism of work table to spindle axis

Eccentricity of external diameter of spindle Position B of the dial gauge shown in Figure is used to determine the eccentricity of the external diameter of the spindle. The feeler is made to contact the spindle face radially, and the dial gauge base is mounted on the machine table. The spindle is gently rotated by hand and the dial gauge deviation is noted down. The maximum deviation gives the eccentricity of the external diameter of the spindle, and it should be well within specified limits.
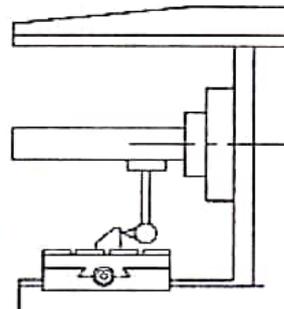
True running of inner taper of spindle The spindle of a milling machine is provided with a standard taper, which matches with the tooling used on the machine. The axis of the taper should be perfectly coincident with the axis of the spindle. Otherwise, the work pieces will develop undesired taper or eccentricity after machining. This condition is checked by using a test mandrel that fits into the spindle taper. The dial gauge is mounted on the machine table, and the feeler is made to contact the mandrel at one end of the mandrel, as shown in Figure. The maximum deviation of the dial gauge is noted by gently rotating the spindle by hand. The test is repeated at the other end of the mandrel.

Parallelism of work table surface to spindle axis Work pieces are clamped on the top surface of the work table of the machine. We should ensure that the work table surface is parallel to the spindle axis; otherwise, milled surfaces will not meet quality requirements. A test mandrel is fitted to the spindle. If the machine has an arbour, the arbour surface is checked for parallelism. The feeler of the dial gauge is made to contact the mandrel or arbour, as the case may be, and the base of the dial gauge is kept on the table surface. Now the dial gauge base is moved on the table surface in a direction parallel to the spindle axis till the extreme end, as

shown in Figure. The dial gauge deflection is noted down, which should be well within the permissible limits.
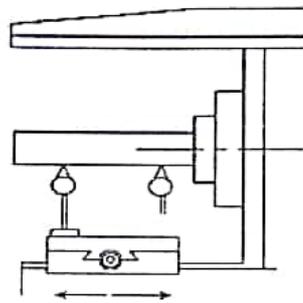

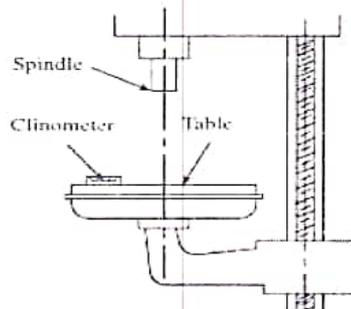Parallelism of table movement with spindle axis   parallelism of T-slots with table movement

Parallelism of transverse movement of table to spindle axis The machine table is set in its mean position and the dial gauge base is mounted on the table. The feeler is made to contact the mandrel and the table is given motion in the transverse direction. The test is carried out both in the horizontal and vertical planes of the mandrel. The deviation on the dial indicator should be within permissible limits.
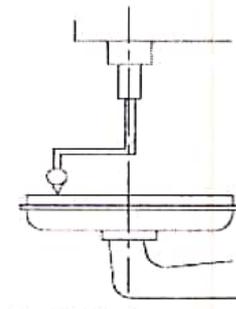
Parallelism of T-slots to table movement A number of T-slots are provided on the machine table to enable accurate clamping of work holding devices, which in turn hold the work pieces. The vertical surfaces of the T-slots should be perfectly parallel to the longitudinal axis of the machine in the horizontal plane. Generally, the test is carried out for the central T-slot, and an accessory, namely a Tenon, is used. A Tenon is a 150 mm long simple bracket, which fits into the T-slot. While sitting in a T-slot, a butting surface projects out, which is parallel to the vertical surface of a T-slot. The dial gauge base is mounted on the spindle and the feeler is made to contact the Tenon, as shown in Figure. Now, the machine table is moved longitudinally while the tennon block is held stationary. Deviations from parallelism are noted from the dial gauge.
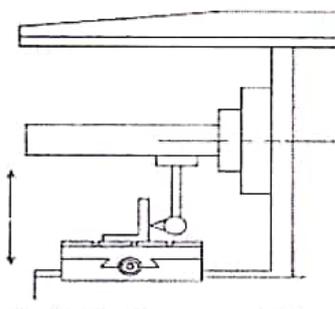
Squareness of T-slots with the spindle   **flatness o table**   **Squareness of table with the Spindle axis**

Scanned with CamScanner

Squareness of T-slots with machine spindle Unless the T-slots are parallel to the spindle axis, slots or key ways cut on the work piece will not be aligned in the required direction. As in the previous case, this test is also generally carried out for the central T-slot. The table is approximately set in a mid-position, and a Tenon block is inserted in the T-slot. The dial gauge base is fixed to the mandrel and the feeler is brought in contact with the vertical surface of the Tenon. Now, the Tenon is moved towards one of the ends and the dial gauge swung to establish contact with the Tenon. The reading on the dial gauge is noted. The Tenon block is moved towards the other end and the dial gauge swung the other way in order to establish contact again. The difference in reading, which is a measure of the squareness error, is noted down. The preceding paragraphs provided some insight into the important acceptance tests carried out on a horizontal milling machine. It is recommended that 25–30 different tests be carried out on a milling machine before it can be accepted for production work. Only a few tests are highlighted here. The student is advised to visit the metrology laboratory in the institute and go through the detailed acceptance charts provided by the machine suppliers. Subsequent to the aforementioned tests, it is recommended to carry out practical tests by milling test pieces. One has to check for accuracy in surface milling, end milling, and slot milling before certifying the machine to be fit for use on a production shop floor.

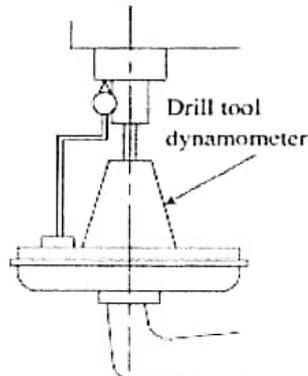*Acceptance Tests for Drilling Machines*

There are various types of drilling machines such as sensitive drilling machine, pillar-type drilling machine, and radial drilling machine. This section deals with the acceptance tests recommended for a pillar-type drilling machine.

Flatness of clamping surface of table This test is performed for the table of the milling machine. The table surface provides support to either clamp the work piece directly or to clamp a fixture that holds the work piece. The test is performed using a sensitive spirit level or a clinometer with good resolution. **Squareness of clamping surface of table with spindle axis** It is important to ensure that the clamping surface of the machine table is perfectly square with the axis of the spindle. Unless this condition is satisfied, the drilled hole will not be parallel to the spindle axis. The arrangement for the test is shown in Figure. The dial gauge base is mounted on the spindle, and the feeler is made to touch the machine table and set to zero. Now, the table is rotated slowly by 180°, without disturbing the dial gauge base, which is in the spindle. The change in reading is noted down; it is then checked to see if it is within the permissible limits.
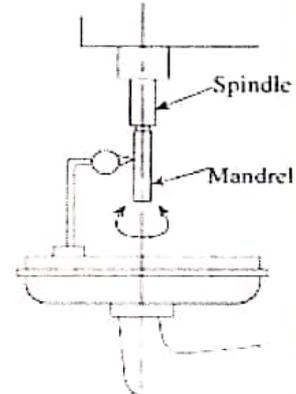
13

Squareness of spindle axis with table This is the corollary to the aforementioned test. Even though the mounting arrangement for the dial gauge is the same, the spindle rather than the table is moved by 180°, in order to determine the error in squareness
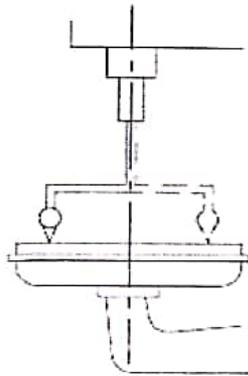
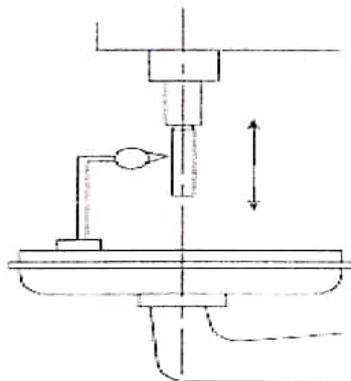
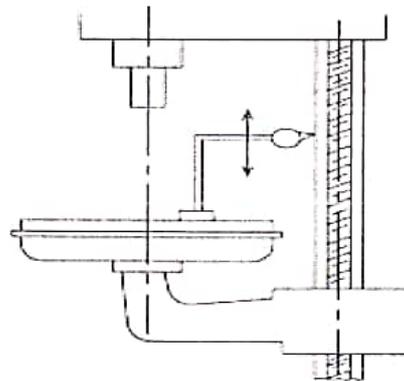Squareness of the spindle axis with the table   deflection of a spindle   true running of a spindle taper

Total deflection of spindle During the drilling operation, the spindle experiences high axial force. The spindle should not deflect excessively due to this force. Otherwise, the drilled hole will have error of straightness and eccentricity. In order to evaluate deflection of the spindle, a drill tool dynamometer (DTD) is used. The DTD provides a means of applying a known amount of load on the spindle. The drill spindle is loaded by moving the drill head downwards and recording the value of force on the DTD display screen. The base of the dial indicator is placed on the machine table. The feeler is held against the spindle face. The recommended pressure is applied on the spindle and the dial gauge deflection is noted down.

Parallelism of a spindle axis with its vertical movement   Squareness of guide ways with table

True running of spindle taper The true running of a spindle taper is tested using a test mandrel. The test mandrel is loaded in the spindle and the dial gauge base is fixed on the machine table. The feeler is made to contact the mandrel surface and the spindle is gently rotated by hand. The dial indicator reading is noted down and it is ascertained if the reading is within permissible limits. The test is repeated at three different locations to ensure its validity.

Parallelism of spindle axis to its vertical movement While drilling holes, the spindle is given feed in the vertical direction, and therefore, it is necessary to ensure that the vertical movement of the spindle is parallel to its axis. The test setup is illustrated in Fig. 10.36. The mandrel is fixed in the spindle, and the dial gauge is mounted with the feeler making contact with the mandrel at the bottom. The spindle is moved vertically by hand feed and the dial gauge reading is noted down. The test is repeated in another plane by rotating the spindle through 90°. The total deflection shown by the dial gauge should be well within the allowable limits.

Squareness of drill head guide ways with table The drill head in a pillar-type machine moves up and down in order to accommodate various work piece sizes. This up and down movement is facilitated by guide ways. Therefore, it is important to ensure that this motion of the drill head is perfectly square with the clamping surface of the work table. If this condition is not met, the drilled holes will be skewed from the vertical axis and the work piece will fail to pass inspection.