UNIT-5

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.

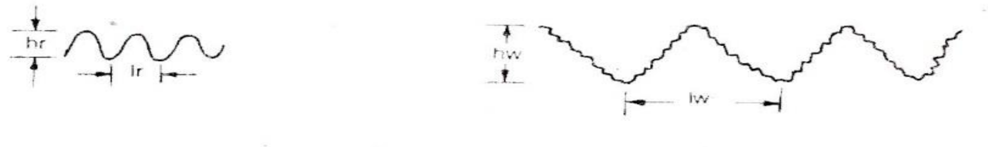
Second Order: The irregularities caused due to vibrations of any kind are called second order irregularities.

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 Ir = length along the surface and hr = deviation of surface from the ideal one.

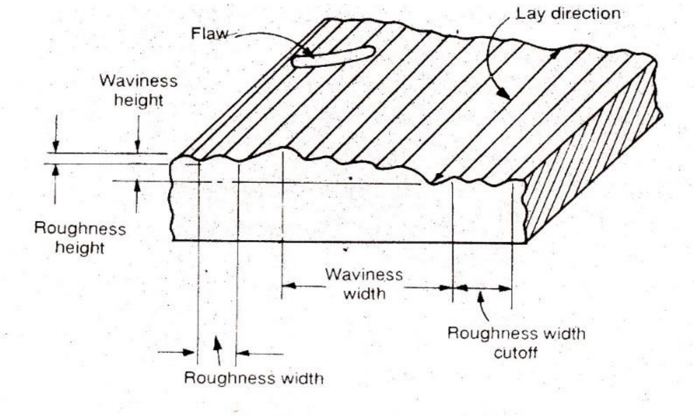
(ii) Secondary texture (Waviness):

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 Iw / hw denoting the macro-errors is more than 50. Where, Iw = 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.

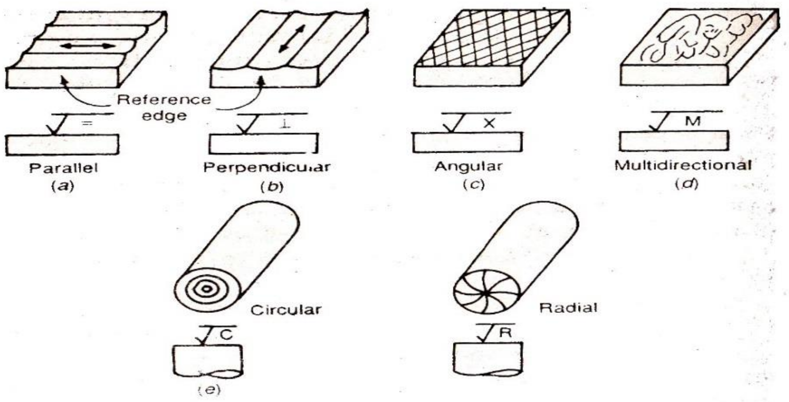
Roughness Width cutoff: This is the maximum width of surface irregularities that is included in the measurement of roughness height. This is always greater than roughness width and is rated in centimetres.

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

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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:

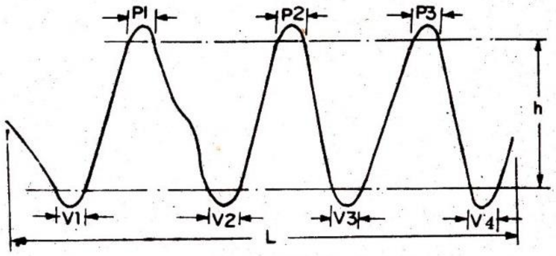
(1) Peak to valley height method

(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.

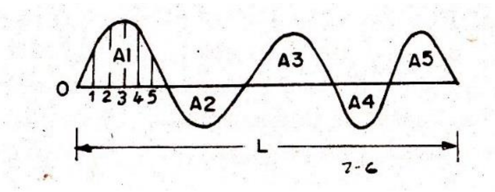


Peak to Valley height

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

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

Also

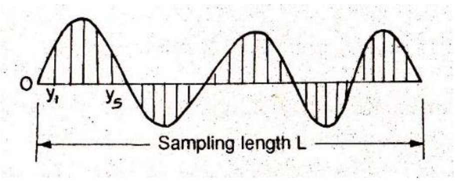
$$\text{C.L.A.} = \frac{A_1 + A_2 + A_3 + \ldots\ldots A_n}{L}$$

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

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.

<u>(b) R.M.S. Method:</u> 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.

Then,

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

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

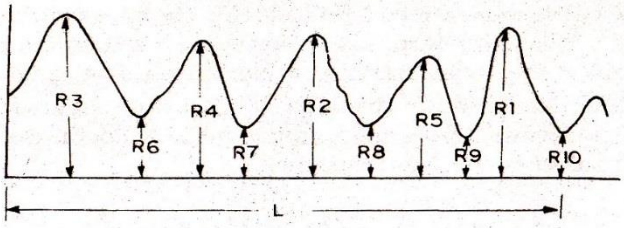
<u>(c) Ten Point Height Method:</u> In this method, the average difference between the five highest peaks and five lowest valleys of surface texture within the sampling length, measured from a line parallel to the mean line and not crossing the profile is used to denote the amount of surface roughness.

Mathematically,

$$R_2 = \text{ten point height of irregularities}$$

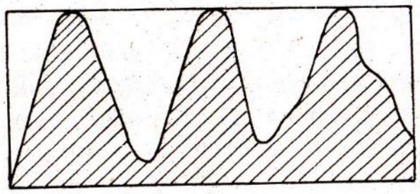
$$= \frac{1}{5}\left[(R_1 + R_2 + R_3 + R_4 + R_5) - (R_6 + R_7 + R_8 + R_9 + R_{10})\right]$$

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.

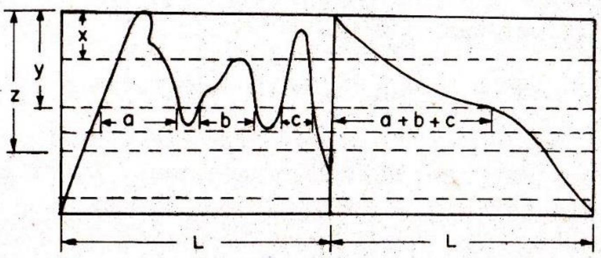
Form Factor: The load carrying area of every surface is often much less than might be thought. This is shown by reference to form factor. The form factor is obtained by measuring the area of material above the arbitrarily chosen base line in the section and the area of the enveloping rectangle. Then,



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

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

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

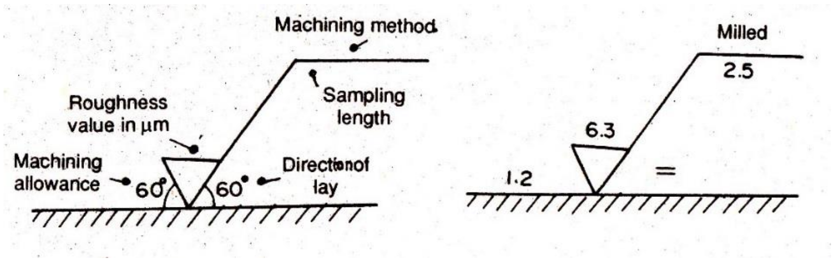
(a) Roughness value i.e., Ra value in mm

(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.

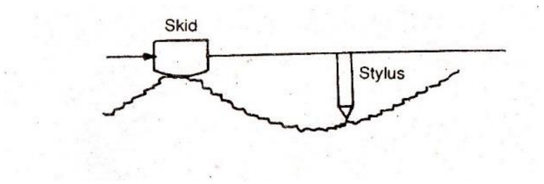
(viii)Reflected Light Intensity: In this method a beam of light of known quantity is projected upon the surface. This light is reflected in several directions as beams of lesser intensity and the change in light intensity in different directions is measured by a photocell. The measured intensity changes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

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

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



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

Stylus type instruments generally consist of the following units:

(i) Skid or shoe

(ii) Finely pointed stylus or probe

(iii) An amplifying device for magnifying the stylus movement and indicator

(iv) Recording device to produce a trace and ~

(v) Means for analyzing the trace.

Advantages:

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

Disadvantages:

(i) These instruments are bulky and complex.

(ii) They are relatively fragile.

(iii) Initial cost is high.

(iv) Measurements are limited to a section of a surface.

(v) Needs skilled operators for measurements.

(vi) Distance between stylus and skid and the shape of the skid introduce errors in measurement for wavy surfaces.

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

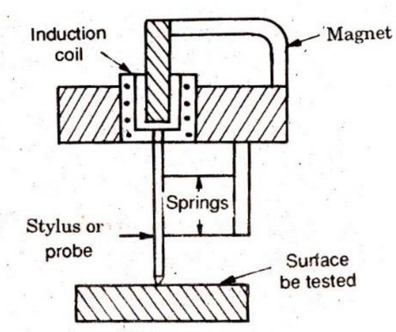
(a) Profilometer

(b) The Tomlinson surface meter.

(c) The Taylor Hobson Talysurf

(d) Profilograph.

(a) Profilometer:



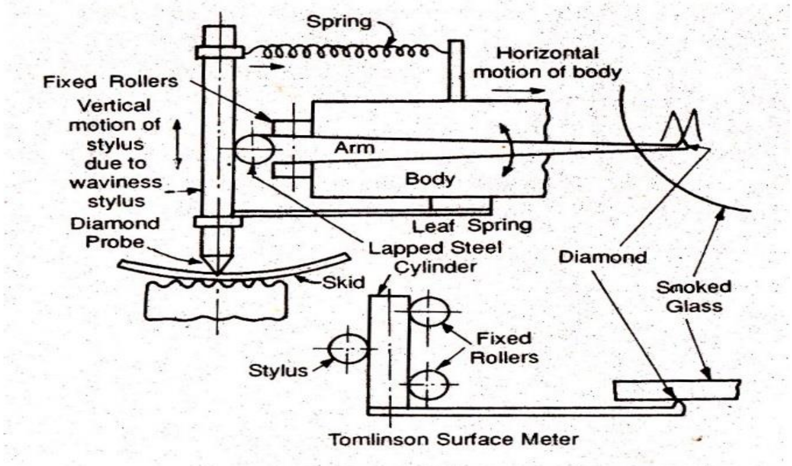
Profilometer

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.

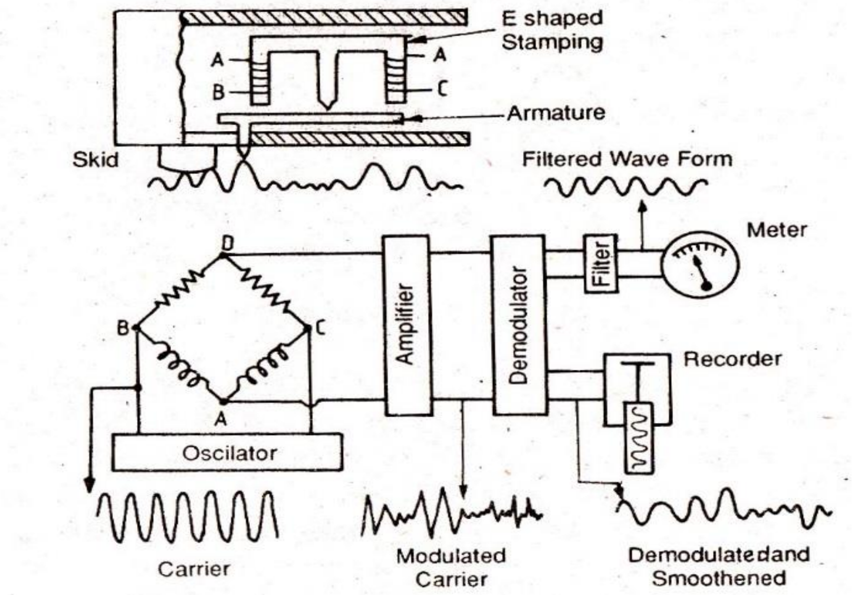


Tomlinson Surface Meter

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:



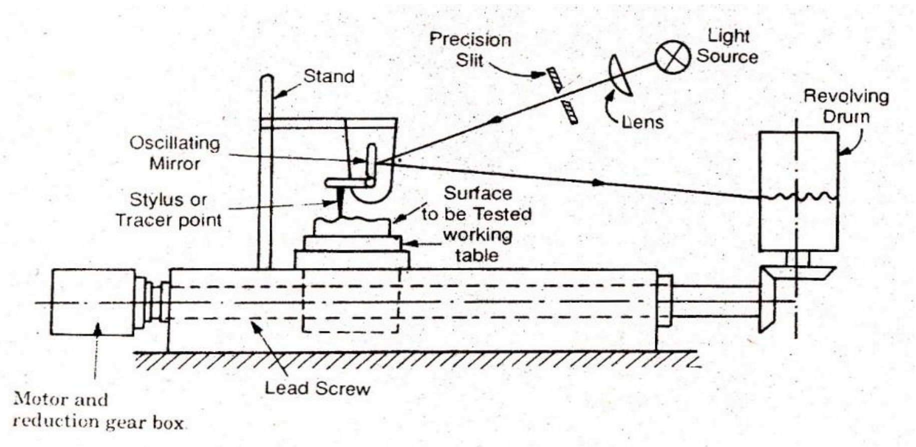
Talyor-Hobson-Talysurf

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.

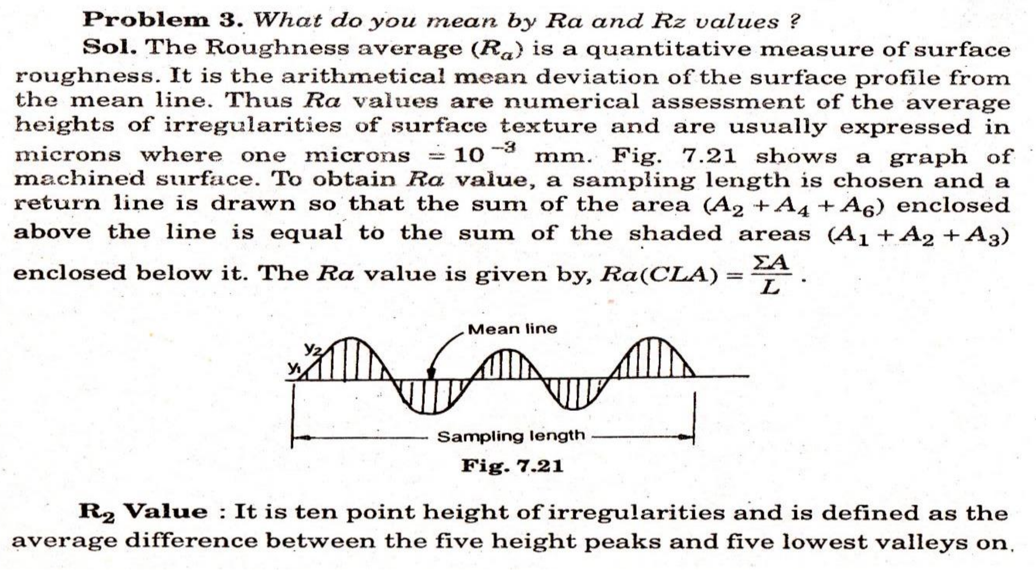
(d) Profilograph:

(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, $Ra(CLA) = \frac{\Sigma A}{L}$.

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,

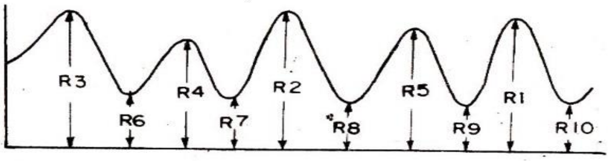


Fig. 7.22.

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

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 ∇.

(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.

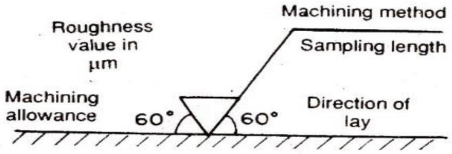


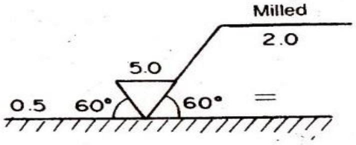
Fig. 7.23.

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

=, ⊥ ,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 $= \dfrac{y_1 + y_2 + y_3 + \ldots + y_n}{n}$

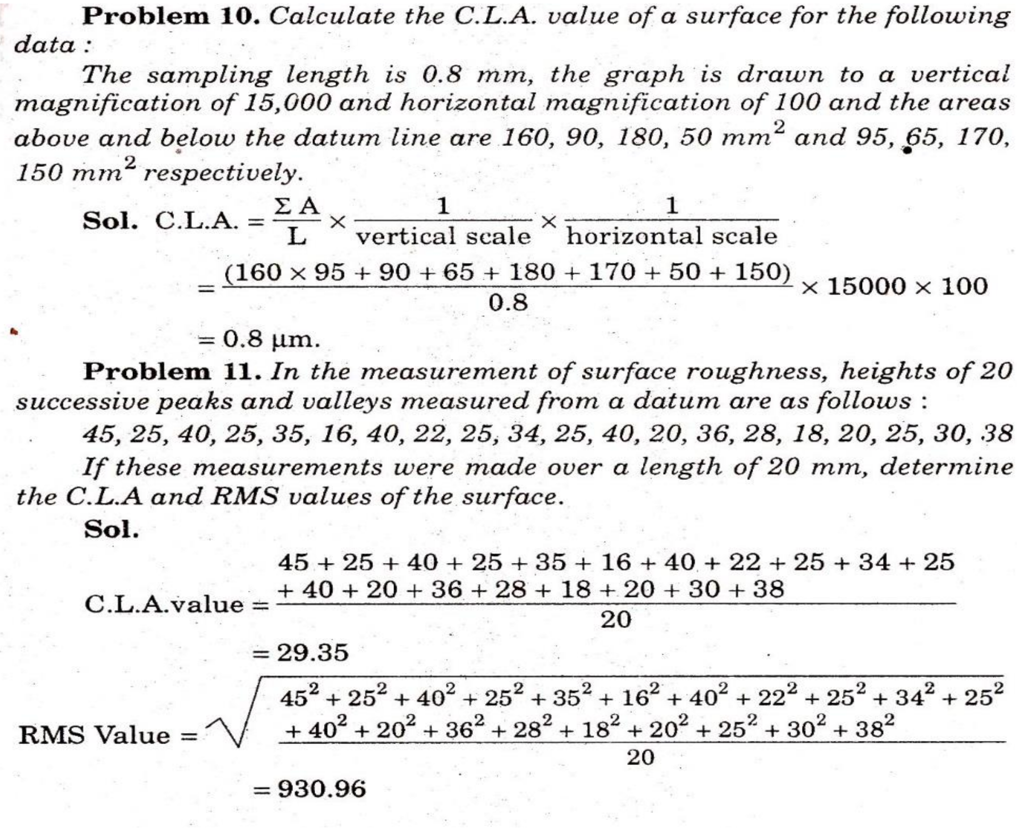
$$= \frac{33 + 25 + 30 + 19 + 22 + 18 + 27 + 29 + 20}{10}$$

= 25.5 microns

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

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

= 26.03 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 mm^2 and 95, 65, 170, 150 mm^2 respectively.

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

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.

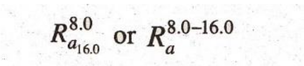
Sol.
$$\text{C.L.A.value} = \frac{45 + 25 + 40 + 25 + 35 + 16 + 40 + 22 + 25 + 34 + 25 + 40 + 20 + 36 + 28 + 18 + 20 + 30 + 38}{20}$$
$$= 29.35$$
$$\text{RMS Value} = \sqrt{\frac{45^2 + 25^2 + 40^2 + 25^2 + 35^2 + 16^2 + 40^2 + 22^2 + 25^2 + 34^2 + 25^2 + 40^2 + 20^2 + 36^2 + 28^2 + 18^2 + 20^2 + 25^2 + 30^2 + 38^2}{20}}$$
$$= 930.96$$

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,

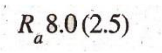
Representation of Surface Roughness:

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



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

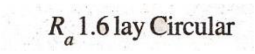
(ii) The surface roughness and sampling length can be represented as,



$R_a 8.0\,(2.5)$

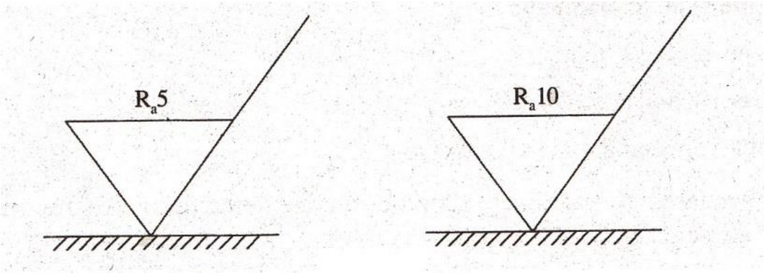
Here surface sampling length is 2.5 mm p

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



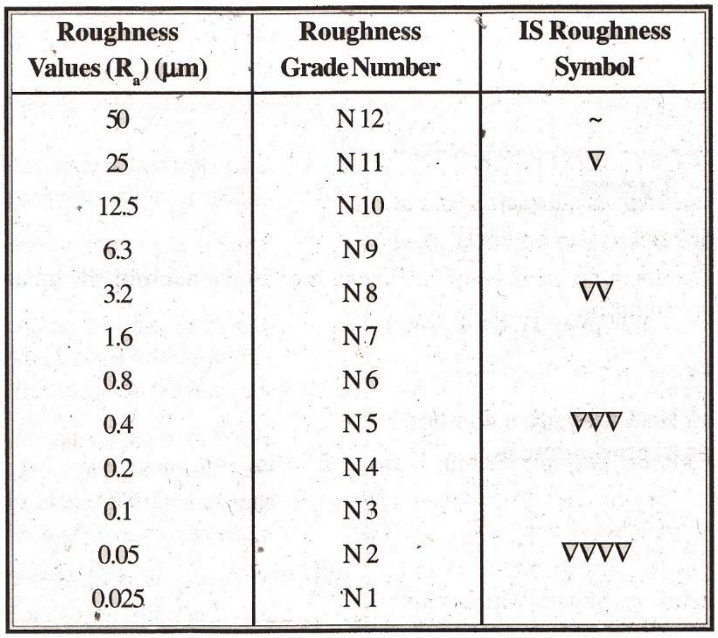
R_a 1.6 lay Circular

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*/////////////////////////////

OPTICAL MEASURING INSTRUMENTS

FLAT SURFACE MEASUREMENT

INTRODUCTION

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

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

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

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

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

3.1 **Tool Maker's Microscope**

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

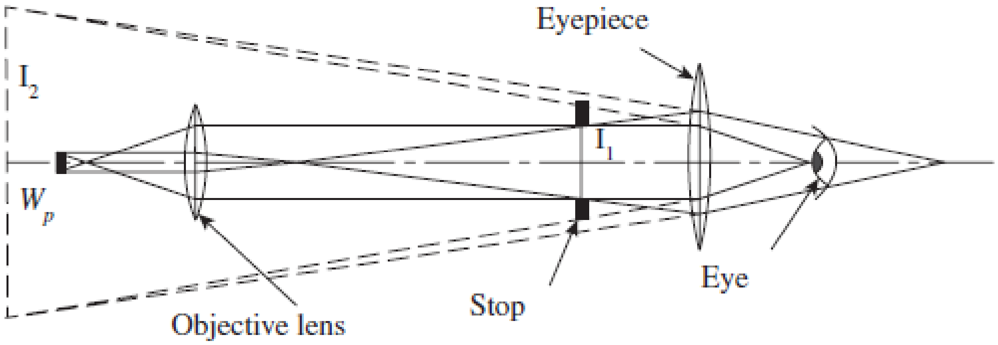


Fig. 3.1 Principle of microscopy

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

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

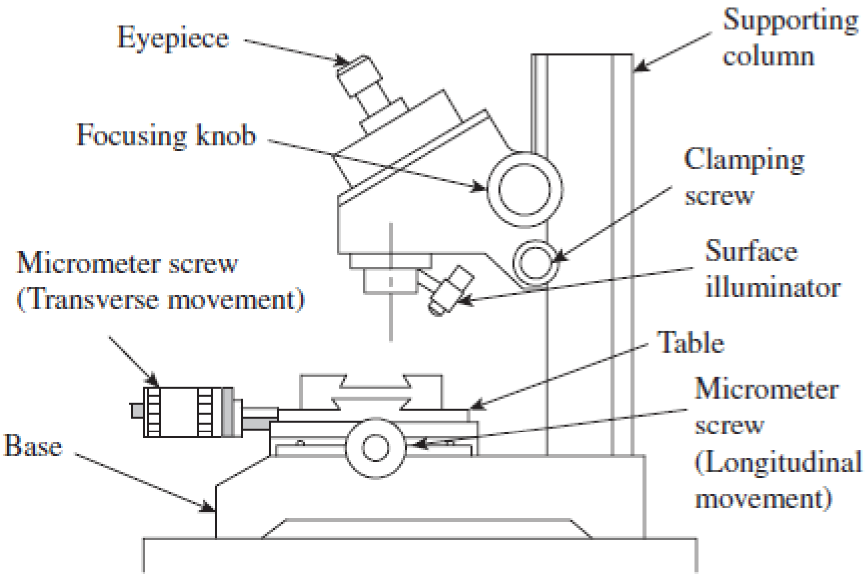


Fig. 3.2 Tool maker's microscope

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

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

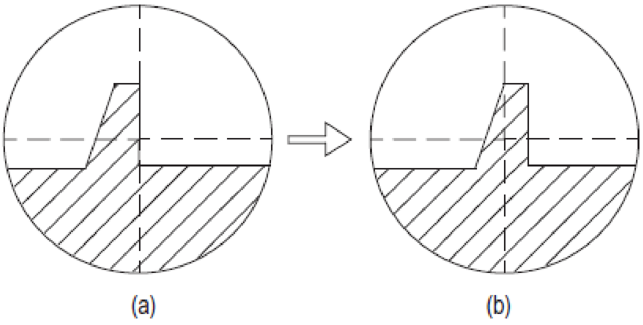


Fig. 3.3 Alignment of cross-wires with the measuring point (a) Reading R1 (b) Reading R2

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

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

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

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

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

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

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

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

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

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

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

Applications of Tool Maker's Microscope

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

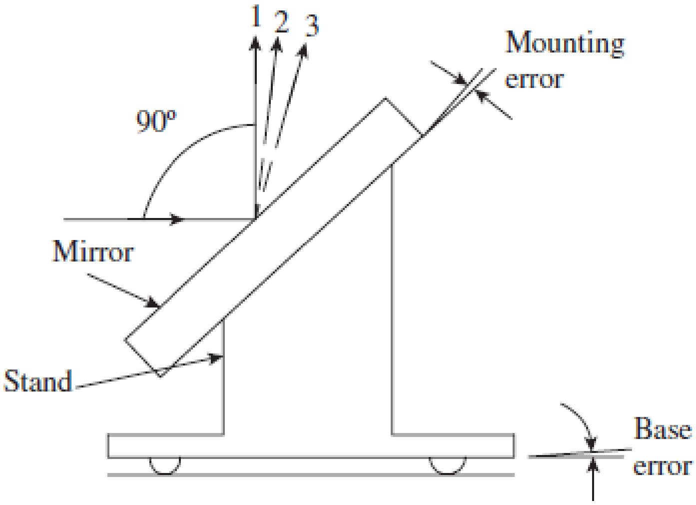
3. It helps determine the dimensions of small holes, which cannot be measured with micrometers and callipers.
4. It facilitates template matching inspection. Small screw threads and involute gear teeth can be inspected using the optional template reticles.
5. It enables inspection of tapers on small components up to an accuracy of 61.

3.2 Profile Projector:

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

3.2.1 Optical Squares

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



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

Fig. 3.4 Mirror reflecting light by 90°

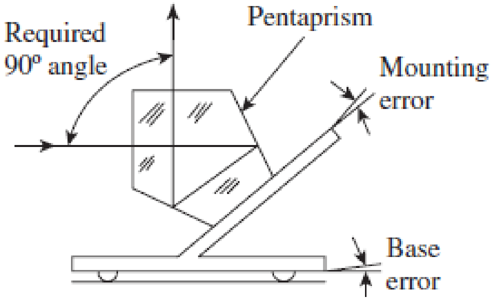


Fig. 3.5 Optical square

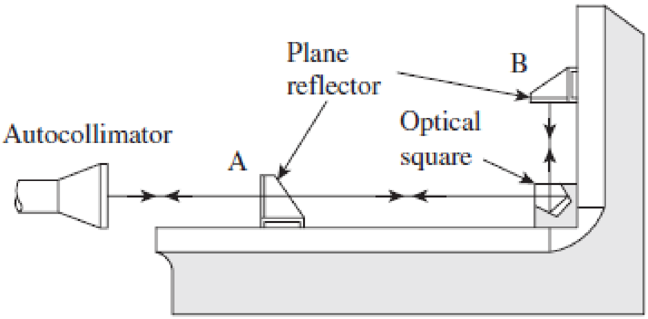


Fig. 3.6 Use of an optical square to test squareness

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

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

7.3 OPTICAL INTERFERENCE

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

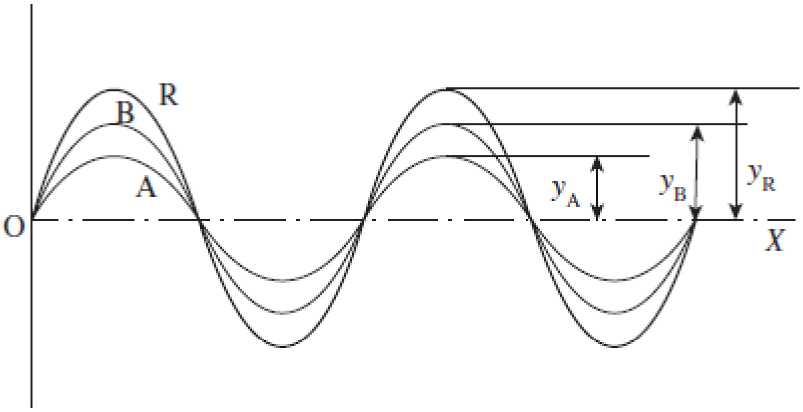


Fig. 3.7 Two waves of different amplitudes that are in phase

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

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

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

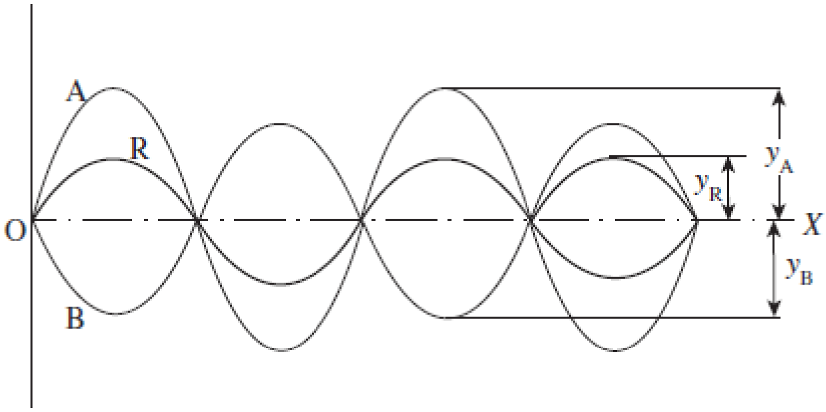


Fig. 3.8 *Two waves of different amplitudes, out of phase by 180°*

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

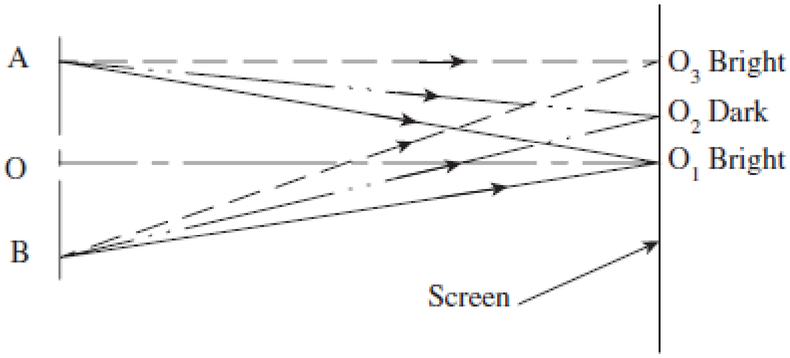


Fig. 3.9 Formation of fringes

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

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

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

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

3.4 INTERFEROMETRY

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

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

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

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

3.4.1 Optical Flats

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

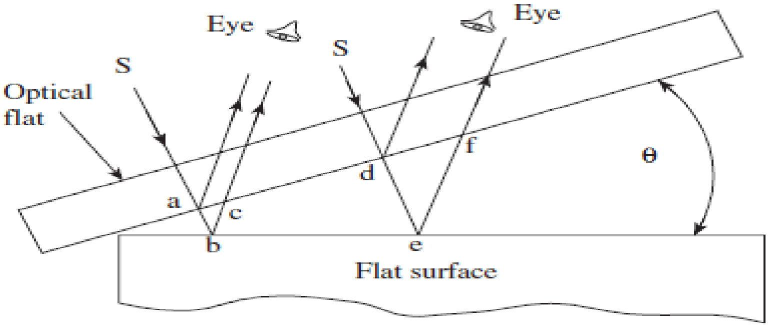


Fig. 3.10 Fringe formation in an optical flat

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

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

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

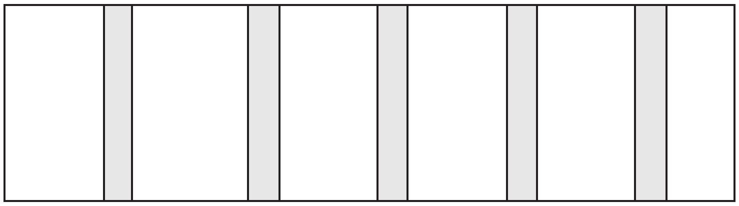


Fig. 3.11 Interference fringes

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

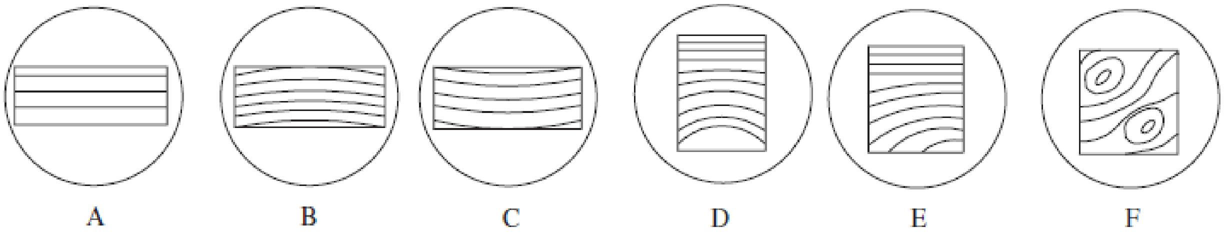


Fig. 7.12 Fringe patterns reveal surface conditions

Comparative Measurement with Optical Flats

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

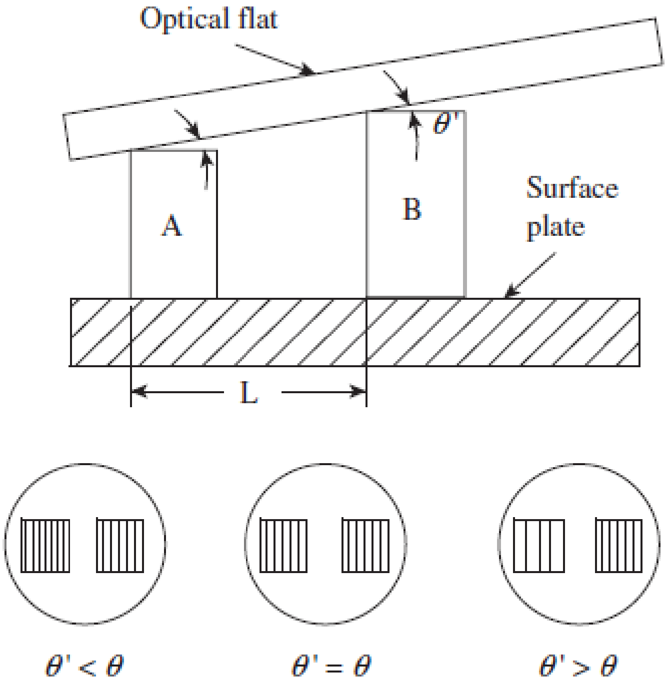


Fig. 3.13 Height measurement using an optical flat

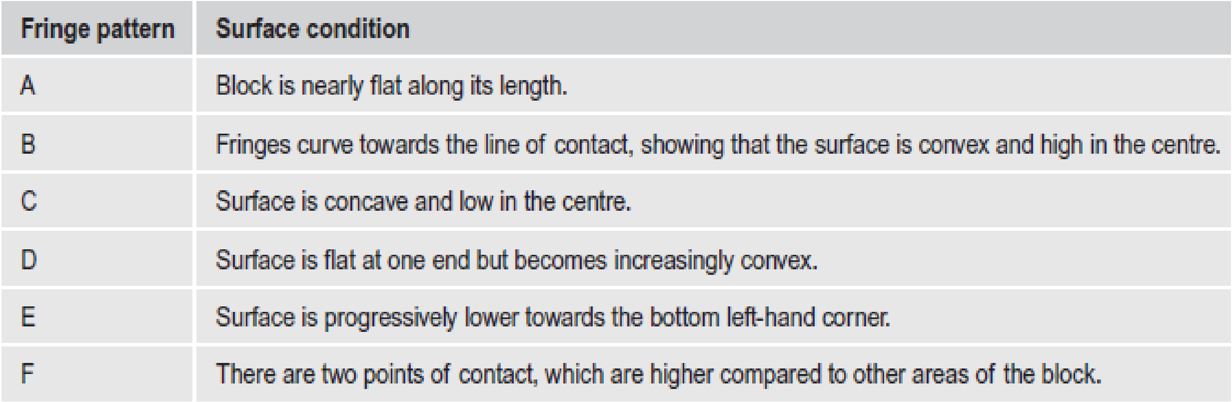
A monochromatic light source is used and the fringe patterns are observed with the help of a magnifying glass. It can be seen from the figure that the optical flat makes inclinations of q and q ' with the top surfaces of the two slip gauges. Ideally, the two angles should be the same. However, in most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

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

$h = \mathrm{l}LN\ 2l$

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

Table 3.2 Fringe patterns and the resulting surface conditions



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

3.5 INTERFEROMETERS

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

3.5.1 NPL Flatness Interferometer

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

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

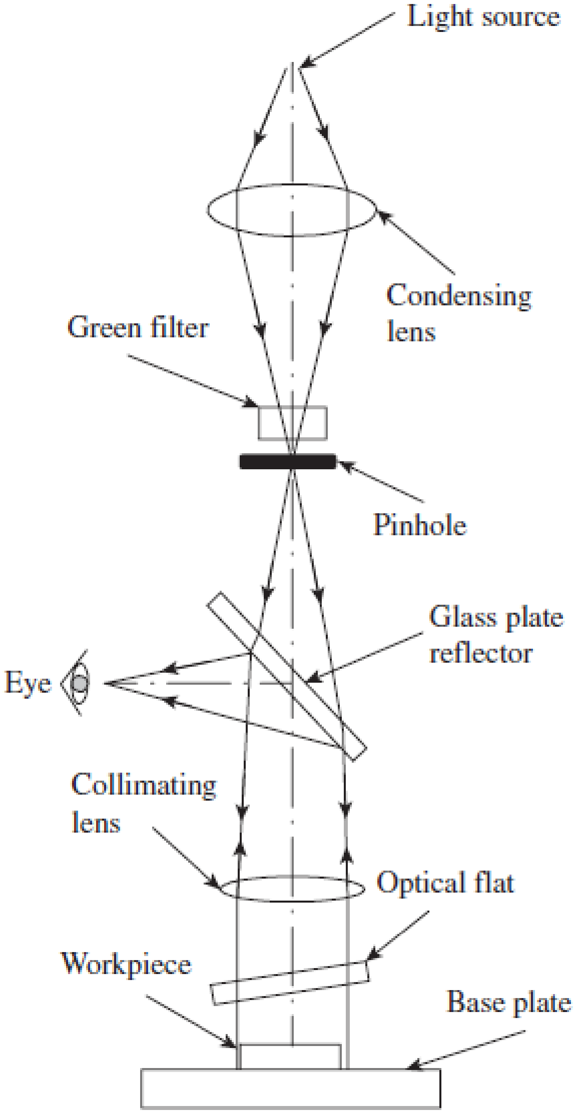


Fig. 3.14 Optical system of an NPL flatness interferometer

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

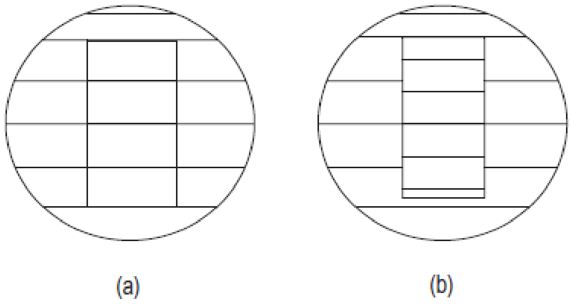


Fig. 3.15 Example of fringe patterns

(a) Equal fringes on parallel surfaces

(b) Unequal fringes due to flatness error

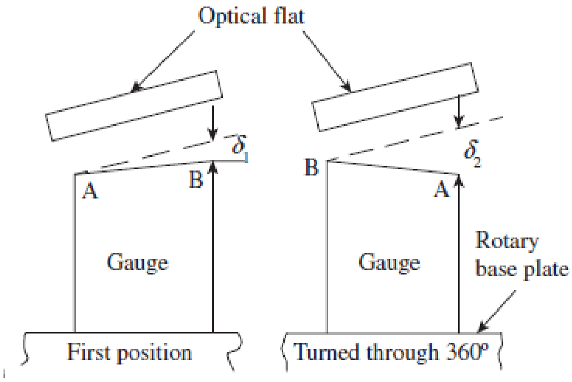


Fig. 3.16 testing parallelism in gauges

Measuring Error in Parallelism

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

Let us consider a gauge that shows *n*1 fringes along its length in the first position and *n*2 in the second position. As seen in Fig. 3.16, the distance between the gauge and the optical flat in the first position has increased by a distance *d*1, over the length of the gauge, and in the second position by a distance *d*2. It is clear that the distance between the gauge and the optical flat changes by λ/2, between adjacent fringes.

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

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

3.5.2 Pitter–NPL Gauge Interferometer

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

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

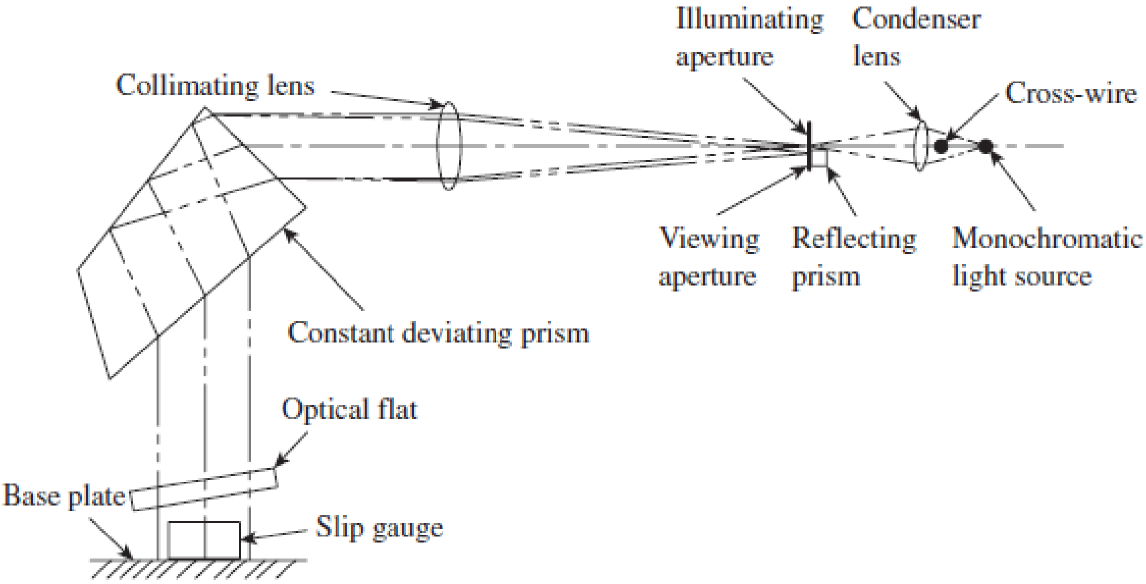


Fig. 3.17 Optical system of the Pitter–NPL gauge interferometer

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

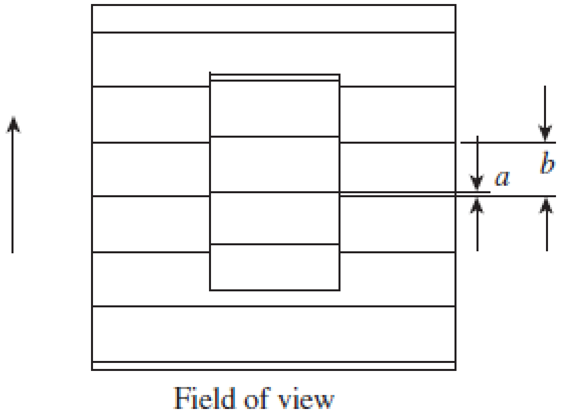


Fig. 7.18 Field of view of fringe pattern

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

$f = a/b$

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

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

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