UNIT IV FORM MEASUREMENT

Principles and Methods of straightness – Flatness measurement – Thread measurement, gear measurement, surface finish measurement, Roundness measurement – Applications.

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4.1 Principles and Methods of straightness

"A line is said to be straight over a given length, if variation in distance of all points lying on line from two planes perpendicular to each other and parallel to general direction of line, remains within the specified tolerance limits".

The reference planes are so chosen that, their intersection is parallel to the straight line joining two points, which are located on the line to be tested and close to ends of the length under measurement. Tolerance on straightness of a line is defined as, "the maximum deviation in relation to the reference straight line going to the two extremities or ends of line under examination".

4.1.1 Test for Straightness by Using Spirit Level and Auto-collimator

• Tests for straightness can be carried out by using spirit level or autocollimator.

•The above instruments determine the straightness of any surface by measuring the relative angular position of various adjacent sections of surface to be tested.

• For this purpose, initially a straight line is drawn on the surface under test. Then this drawn line is divided into number of equidistant sections.

• If spirit level is used, then length of each section should be equal to length of base of spirit level.

• If auto-collimator is used, then length of each section should be equal to length of base of plane reflector.

• Generally, the bases of spirit level block or reflector are fitted with two legs (or feets), such that,

(i) Feets or legs have line contact with the surface under test, and

(ii) Entire surface of base does not touch the surface under test.

This ensures that, angular deviation obtained is between the two specified points.

(i) Spirit Level:

• The block of spirit level is moved linearly on the surface to be tested, in number of steps. Every step chosen is equal to the pitch distance between centre lines of two feets.

• When block of spirit level is kept on a perfectly flat surface, we observe that, vapour bubble is resting at the middle and topmost position of glass tube indicating zero reading on the scale engraved on glass tube.

• But, when the block of spirit level is moved over surface test, then this vapour bubble moves away from the middle position due to irregularities in straightness of surface. This variation in the spirit level is measured, which gives the angular variation in the direction of block.

• Angular variation can be correlated in terms of the difference of height between two points by knowing the least count of level and length of the base.

• Limitation of spirit level: It can be used to find out variation in straightness of horizontal surface only.

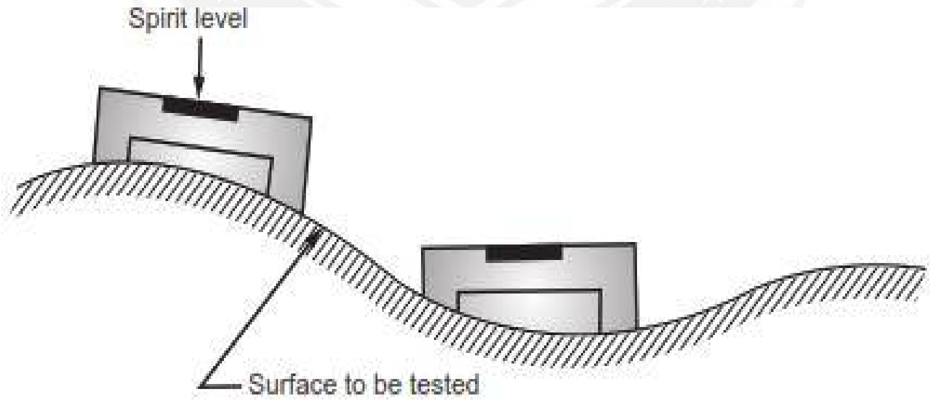


Fig. 4.1 Test for Straightness by Using Spirit Level

[source: Metrology and Quality Control, Vinod Thombre Patil, Pg. No 212]

(ii) Auto-collimator:

• Auto-collimator can be used to measure the straightness of surface in any plane.

• Auto-collimator is placed at a distance of 0.5 to 0.75 metre from the surface to be tested. It is held in desired position on any rigid support, which is independent of the surface to be tested.

• A parallel beam from auto-collimator is projected along the length of surface to be tested.

• A block resting on two legs or feets is placed on the surface under test.

• Block carries a plane vertical reflector mounted on its extreme left side in such a way that, face of reflector is facing auto-collimator.

• Plane reflector and auto-collimator are arranged in such a way that,

(i) image of cross wires of the collimator appears very near to the centre of eyepiece, and

(ii) linear movement of reflector over the entire length of surface under test is completed.

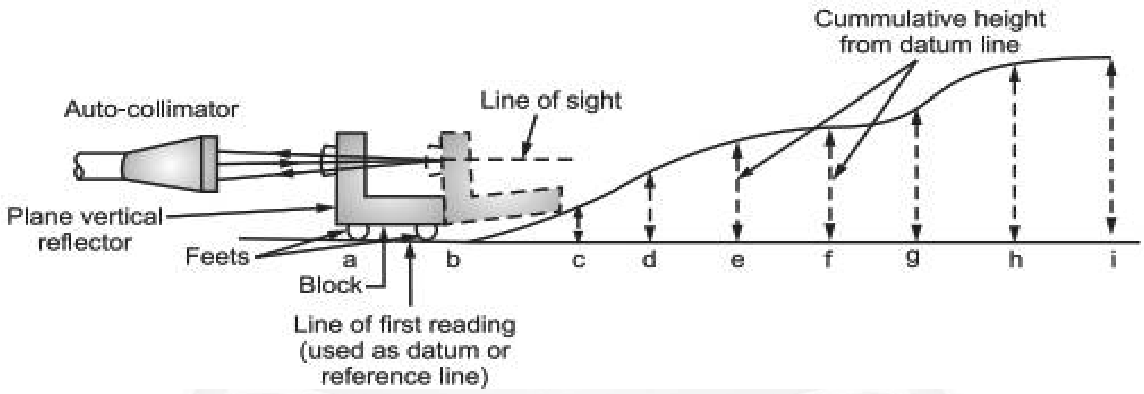


Fig. 4.2 Auto-collimator checking straightness

[source: Metrology and Quality Control, Vinod Thombre Patil, Pg. No 212]

• Now, the reflector is moved towards the other end of surface in steps equal to the centre distance between the two legs or feets. During this movement, the tilting of reflector is noted down in seconds from the eyepiece.

1 second of arc = 0.000006 mm/mm

• Now, the reflector is set at first position a-b (perfectly flat and straight) and first micrometer reading is noted down. This line is labelled as 'a-b' is treated as datum line or reference line. Successive readings at positions b-c, c-d, d-e …… and so on, are taken, till the plane reflector completes its linear movement over the entire length of surface under test.

4.2 Flatness measurement

Machine tool tables, which hold workpieces 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. 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.

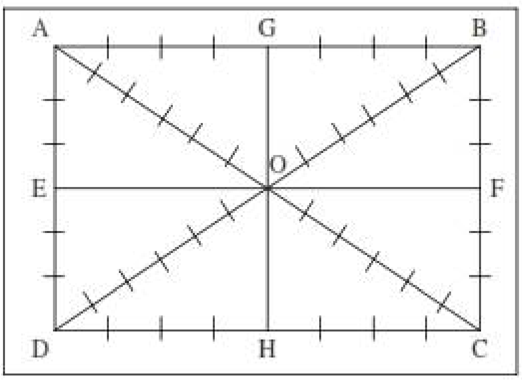


Fig. 4.3 Grid lines for flatness Test

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 255]

4.2.1 Measurement of flatness error

Assuming that a clinometer is used for measuring angular deviations, a grid of straight lines, as shown in Fig. 4.3., 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.

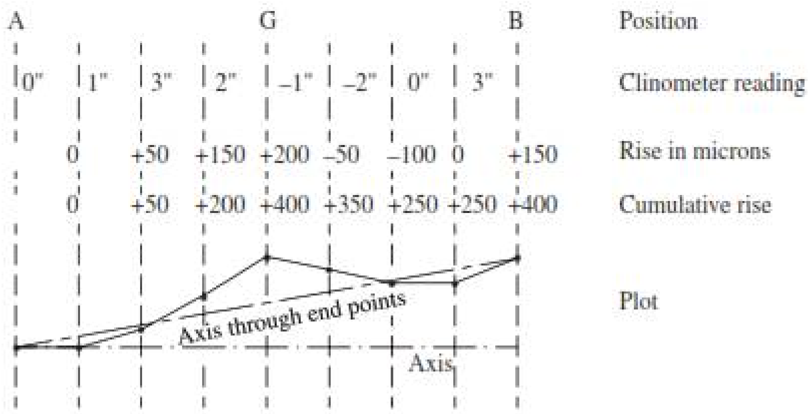


Fig. 4.4 Straightness plot for line AB

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 255]

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

1. Carry out the straightness test, as per the procedure described in Chapter 5, on all the lines and tabulate the readings up to the cumulative error column. Figure 10.9 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.

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 Fig. 4.5. Two lines are drawn parallel to and on either side of the datum plane, such that they enclose the outermost points. The distance between these two outer lines is the flatness error.

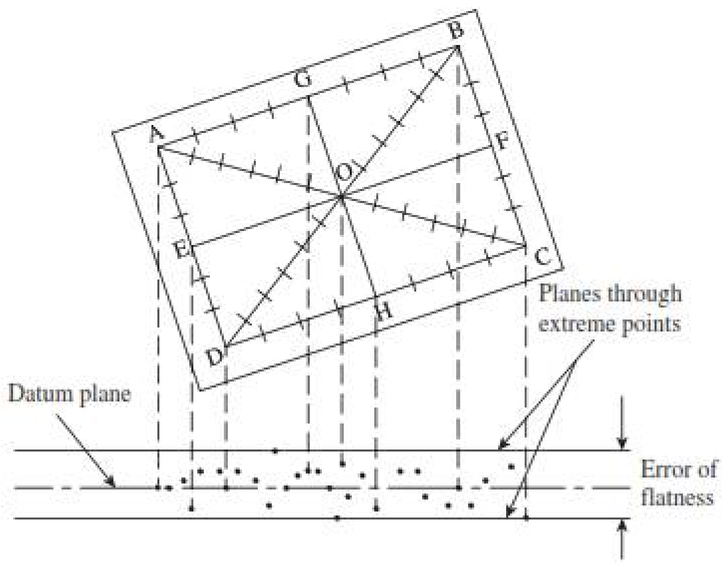


Fig. 4.5 Plot of heights of all points with reference to the datum plane ABD

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 256]

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 μm.

4.3 SCREW THREAD MEASUREMENT

- Screw threads are used to transmit the power and motion, and also used to fasten two components with the help of nuts, bolts and. studs.
- There is a large variety of screw threads varying in their form, by included angle, head angle, helix angle etc.
- The screw threads are mainly classified into

  1) External thread

  2) Internal thread.

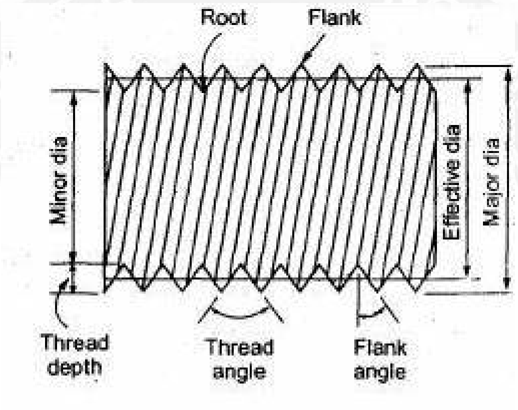


Fig. 4.6 External thread

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.12]

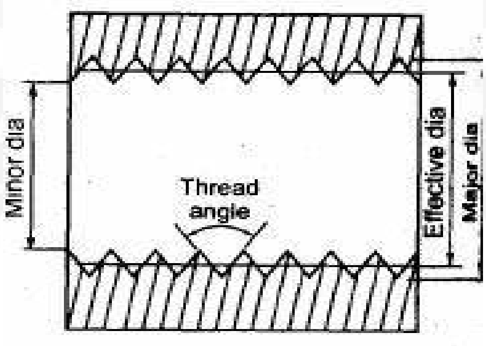


Fig. 4.7 Internal thread

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.13]

4.3.1 SCREW THREAD TERMINOLOGY

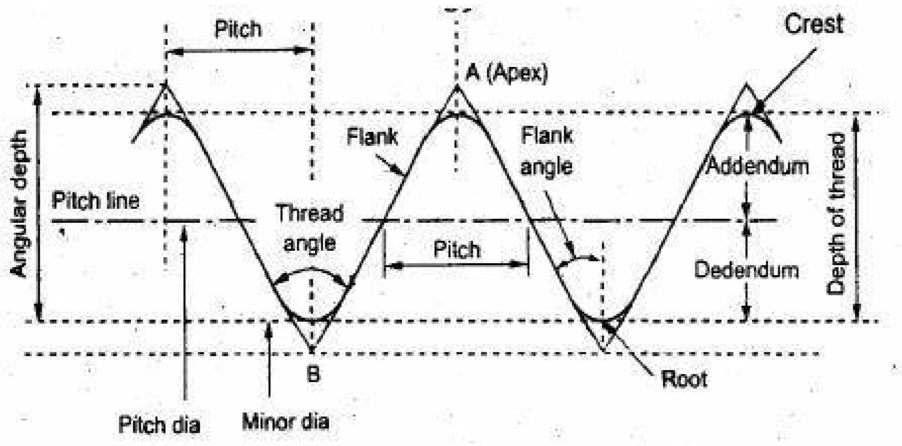


Fig. 4.8 Screw Thread Terminology

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.14]

1) Screw thread:

It is a continuous helical groove of specified cross-section produced on the external or internal surface.

2) Crest:

It is top surface joining the two sides of thread.

3) Flank:

Surface between crest and root.

4) Root:

The bottom of the groove between the two flanks of the thread

5 Lead:

Lead = number starts x pitch

6) Pitch:

The distance measured parallel to the axis from a point on a thread to the corresponding next point.

7) Helix angle:

The helix is the angle made by the helix of the thread at the pitch line with the axis.

8) Flank angle:

Angle made by the flank of a thread with the perpendicular to the thread axis.

9) Depth of thread:

The distance between the crest and root of the thread.

10) Included angle:

Angle included between the flanks of a thread measured in an axial plane.

11) Major diameter:

Diameter of an imaginary co-axial cylinder which would touch the crests of external or internal thread.

12) Minor diameter (Root diameter or Core diameter):

Diameter of an imaginary co-axial cylinder which would touch the roots of an external thread.

13) Addendum

- Radial distance between the major and pitch cylinders for external thread.
- Radial distance between the minor and pitch cylinder for internal thread.

14) Dedendum:

- Radial distance between the pitch and minor cylinder = For external thread.
- Radial distance between the major and pitch cylinders = For internal thread.

4.3.2 ERROR IN THREAD

The errors in screw thread may arise during the manufacturing or storage of threads. The errors either may cause in following six main elements in the thread.

1) Major diameter error

2) Minor diameter error

3) Effective diameter error

4) Pitch error

5) Flank angles error

6) Crest and root error

1) Major diameter error:

It may cause reduction in the flank contact and interference with the matching threads.

2) Minor diameter error:

It may cause interference, reduction of flank contact.

3) Effective diameter error:

If the effective diameter is small the threads will be thin on the external screw and thick on an internal screw.

4) Pitch errors:

If error in pitch, the total length of thread engaged will be either too high or too small.

The various pitch errors may classify into

1. Progressive error.

2. Periodic error.

3. Drunken error.

4. Irregular error.

1) Progressive error:

The pitch of the thread is uniform but is longer or shorter its nominal value and this is called progressive.

Causes of progressive error:

1. In correct linear and angular velocity ratio.

2. In correct gear train and lead screw.

3. Saddle fault.

4. Variation in length due to hardening.

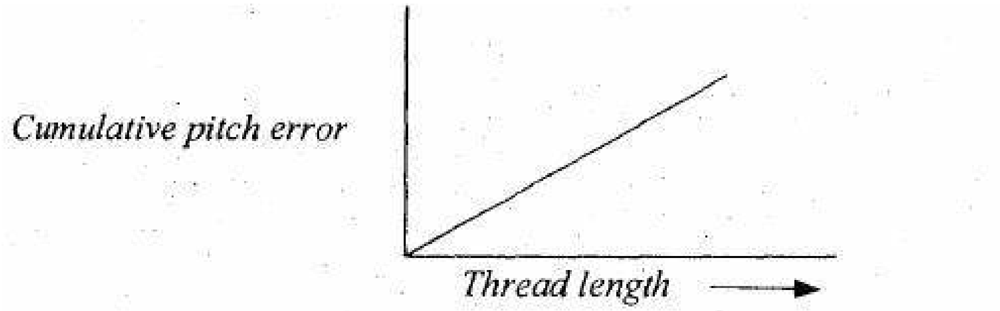


Fig. 4.9 Progressive Error

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.16]

2. Periodic error

These are repeats itself at regular intervals along the thread

Causes of periodic error:

1. Un uniform tool work velocity ratio.

2. Teeth error in gears.

3. Lead screw error.

4. Eccentric mounting of the gears.

3) Drunken error

- Drunken errors are repeated once per turn of the thread in a Drunken thread.
- In Drunken thread the pitch measured parallel to the thread axis. If the thread is not cut to the true helix the drunken thread error will form

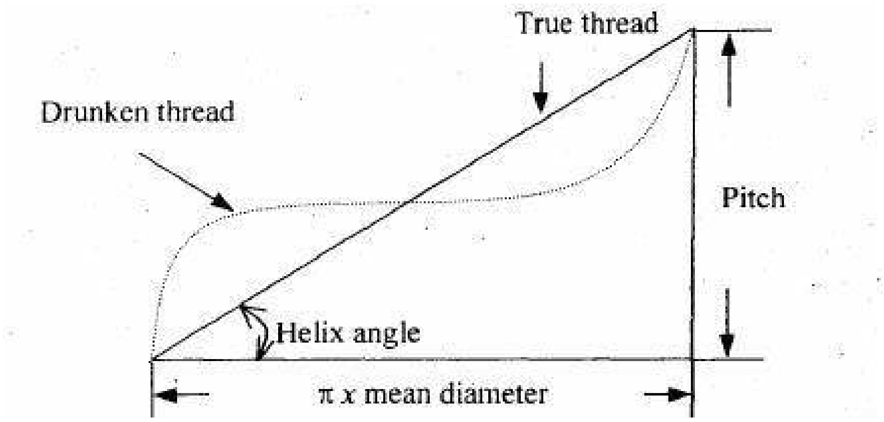


Fig. 4.10 Drunken error

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.17]

4) Irregular errors:

It is varying irregular manner along the length of the thread.

Irregular error causes:

1. Machine fault.

2. Non-uniformity in the material.

3. Cutting action is not correct.

4. Machining disturbances.

Effect of pitch errors:

- Increase the effective diameter of the bolt and decreases the diameter of nut.
- The functional diameter of the nut will be less.
- Reduce the clearance.
- Increase the interference between mating threads.

4.3.3 MEASUREMENT OF VARIOUS ELEMENTS OF THREAD

To find out the accuracy of a screw thread it will be necessary to measure the following:

1) Major diameter.

2) Minor diameter.

3) Effective or Pitch diameter.

4) Pitch

5) Thread angle and form

1. Measurement of major diameter:

The instruments which are used to find the major diameter are by

- Ordinary micrometer
- Bench micrometer.

a) Ordinary micrometer:

- The ordinary micrometer is quite suitable for measuring the external major diameter.
- It is first adjusted for appropriate cylindrical size (S) having the same diameter (approximately). This process is known as 'gauge setting'.
- After taking this reading ' R the micrometer is set on the major diameter of the thread, and the new reading is ' R2

Then the major diameter, $D = S \pm (R_1 - R_2)$

S = Size of setting gauge

R_1 = Micrometer reading over setting gauge.

R_2 = Micrometer reading over thread.

b) Bench micrometer:

- For getting the greater accuracy the bench micrometer is used for measuring the major diameter.
- In this process the variation in measuring Pressure, pitch errors are being neglected.
- The fiducial indicator is used to ensure all the measurements are made at same pressure.
- The instrument has a micrometer head with a vernier scale to read the accuracy of 0.002mm. Calibrated setting cylinder having the same diameter as the major diameter of the thread to be measured is used as setting standard.

- ❖ After setting the standard, the setting cylinder is held between the anvils and the reading is taken.
- ❖ Then the cylinder is replaced by the threaded work piece and the new reading is taken.

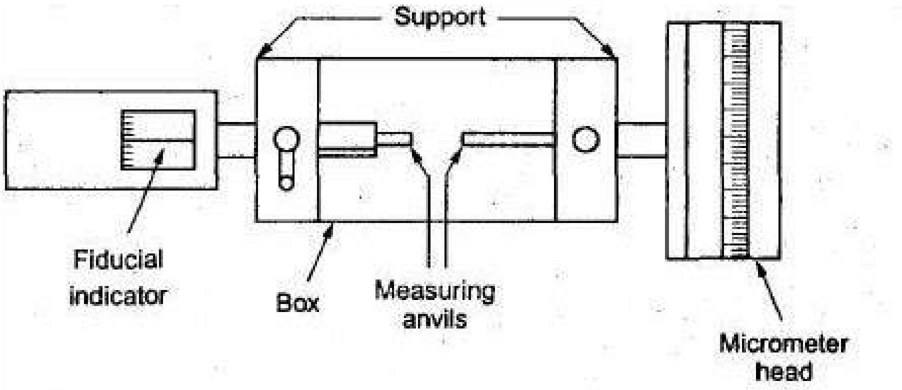


Fig. 4.11 Bench micrometer

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.20]

∴ The major diameter of screw thread

$$= S \pm (D_2 - D_1)$$

Where, S = Diameter of the setting cylinder.

R_2 = Micrometer Reading on screw thread

R_1 = Micrometer reading on setting cylinder.

Measurement of the major diameter of an Internal thread:

- ➢ The Inter thread major diameter is usually measured by thread comparator fitted with ball-ended styli.
- ➢ First the Instrument is setted for a cylindrical reference having the same diameter of major diameter of internal thread and the reading is taken.
- ➢ Then the floating head is retracted to engage the tips of the styli at the root of spring under pressure.
- ➢ For that the new reading is taken,

major diameter of internal thread is $= D \pm (R_2 - R_1)$

D = Cylindrical standard diameter

R_2 = Thread reading

R_1 = Dial Indicator reading on the standard.

2) Measurement of Minor diameter:

- The minor diameter is measured by a comparative method by using floating carriage diameter measuring machine and small 'V pieces which make contact with the root of the thread.
- These V pieces are made in several sizes, having suitable radii at the edges.
- V pieces are made of hardened steel.
- The floating carriage diameter-measuring machine is a bench micrometer mounted on a carriage.

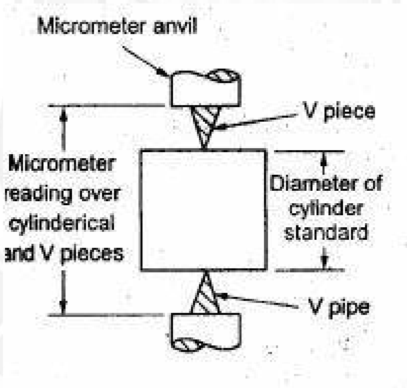


Fig. 4.12 Anvils being set

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.23]

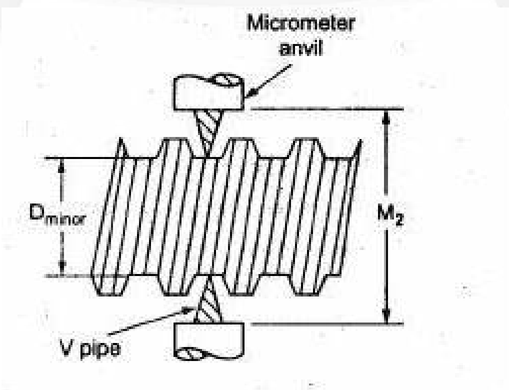


Fig. 4.13 Thread being measured

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.23]

Measurement process:

- The threaded work piece is mounted between the centers of the instrument and the V pieces are placed on each side of the work piece and then the reading is noted.
- After taking this reading the work piece is then replaced by a standard reference

cylindrical setting gauge.

The minor diameter of the thread = $D \pm (R_2 - R_1)$

Where, D = Diameter of cylindrical gauge

R_2 = Micrometer reading on threaded work piece.

R_1 = Micrometer reading on cylindrical gauge.

Measurement of Minor diameter of Internal threads:

The Minor diameter of Internal threads are measured by

1. Using taper parallels

2. Using Rollers.

1. Using taper parallels:

- For diameters less than 200mm the use of Taper parallels and micrometer is very common.
- The taper parallels are pairs of wedges having reduced and parallel outer edges.
- The diameter across their outer edges can be changed by sliding them over each other.

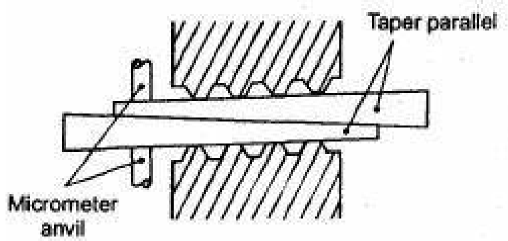


Fig. 4.14 Measurement of minor diameter of internal thread using taper parallels

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.24]

2. Using rollers:

- **Fo**r more than 20mm diameter this method is used. Precision rollers are inserted inside the thread and proper slip gauge is inserted between the rollers.
- The minor diameter is then the length of slip gauges plus twice the diameter of roller.

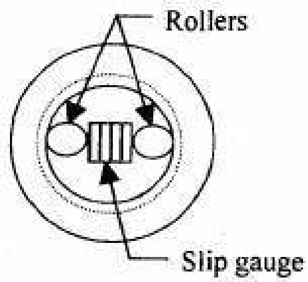


Fig. 4.15 Measurement of minor diameter of thread using rollers

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.24]

3. Measurement of effective diameter

Effective diameter measurement is carried out by following methods.

1. One wire,

2. two wires, or

3. three wires method.

4. Micrometer method.

1. (a) One wire method:

- **Th**e only one wire is used in this method.
- The wire is placed between two threads at one side and on the other side the anvil of the measuring micrometer contacts the crests.
- First the micrometer reading dl is noted on a standard gauge whose dimension is approximately same to be obtained by this method.
- Now the setting gauge is replaced by thread and the new reading is taken as 'd_2'.

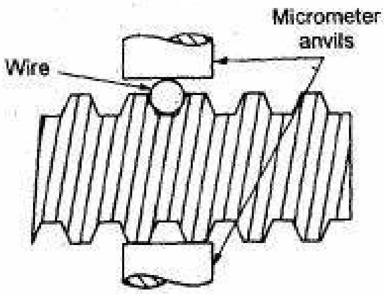


Fig. 4.16 One wire method

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.25]

i.e. 'd_2' then effective diameter = $D \pm (d_1 - d_2)$

When D = Size of setting gauge

b) Two wire method:

Two-wire method of measuring the effective diameter of a screw thread is given below.

- In this method wires of suitable size are placed between the standard and the micrometer anvils.
- First the micrometer reading is taken and let it be R
- Then the standard is replaced by' the screw thread to be measured and the new reading is taken.
- The new reading is R

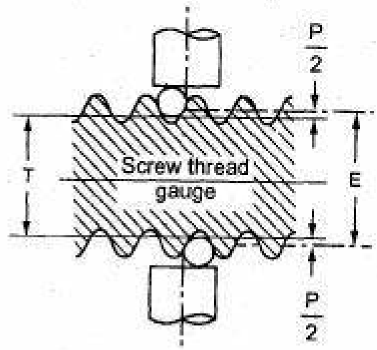


Fig. 4.17 Two wire method

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.26]

From the above reading

The effective diameter E is calculated by $E = T + P$

Where, T = Dimension under the wires = $M - 2d$

M = Dimension over the wires

d = diameter of each wire

If P' = Pitch of thread then

$$P = 0.9605\,P' - 1.1657d \Rightarrow \text{Whitworth thread.}$$

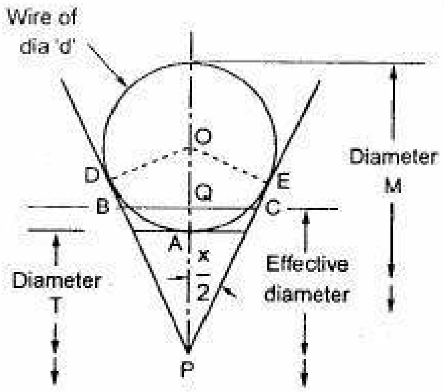
$$P = 0.866\,P' - d \Rightarrow \text{For metric thread.}$$

Here, P =The difference between the effective diamet and the diameter under the wires.

The diameter under the wires 'T' also can be determined by

$$T = S - (R_1 - R_2)$$

Where, S = The diameter of the standard.



The P value can be derived in terms of P (Pitch), d (Diameter of wire) and x thread angle is as follows

BC lies on the effective diameter.

$$\therefore \text{BC} = \frac{1}{2}\,Pitch = \frac{1}{2}\,P$$

$$\text{Next OP} = \frac{d\,Cosec\,(x/2)}{2}$$

And AQ = PQ – AP

Where,

PQ = QC Cot (x/2) = P/4 Cot (x/2)

$$\text{PQ} = \frac{P}{4}\,Cot\,(x/2)$$

$$\therefore \text{AQ} = \frac{P}{4}\,Cot\,(x/2) - \text{AP}$$

Here, $$\text{AP} = \frac{d\,(Cosec\,x/2 - 1)}{2}$$

$$\therefore \text{AQ} = \frac{P\,Cot\,(x/2)}{4} - \frac{d\,(Cosec\,x/2 - 1)}{2}$$

and

AQ is half the value of P

$\therefore P$ value = 2AQ

$$P = \frac{P}{2} Cot\frac{x}{2} - d\left[Co\sec\frac{x}{2} - 1\right]$$

c. Three Wire method:

The three-wire method is the accurate method.

- In this method three wires of equal and precise diameter are placed in the groves at opposite sides of the screw.
- In this one wire on one side and two on the other side are used. The wires either may held in hand or hung from a stand.
- This method ensures the alignment of micrometer anvil faces parallel to the thread axis.

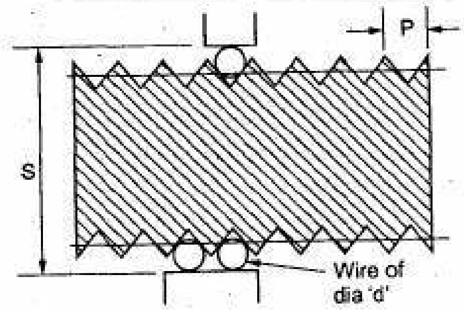


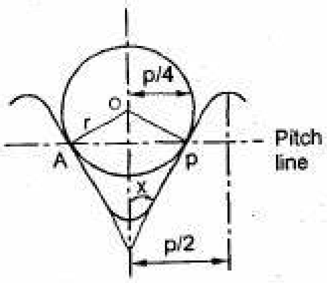
Fig. 4.18 Three wire method

[source: Metrology and Measurements, Dr.G. K Vijayaraghavan, Pg. No 4.28]

4.3.4 BEST WIRE SIZE-DEVIATION:

- Best wire diameter is that may contact with the flanks of the thread on the pitch line.
- The figure shows the wire makes contact with the flanks of the thread on the pitch.

Hence best wire diameter,



$$db = 2Ap\ secx$$

Where, db = Wire diameter

x = Included angle

$$AP = p/4$$

$$\therefore\ db = 2\ p/4\ sec\ x$$

$$\boxed{db = p_2\ secx}$$

4.4 GEAR MEASUREMENT

4.4.1 GEAR TERMINOLOGY

Each gear has a unique form or geometry. The gear form is defined by various elements. An illustration of the gear highlighting the important elements is referred to as ‘gear terminology’. This section explains the types of gears and their terminology.

4.4.1.1 Introduction

- Gears is 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 blanks should be tested for dimensional accuracy and tooth thickness for the forms of gears.
- 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°.

4.4.2 Types of Gears

The common types of gears used in engineering practices are described in this section. The information provided here is very brief, and the reader is advised to read a good book on ‘theory of machines’ to understand the concepts better.

4.4.2.1 Spur gears These gears are the simplest of all gears. The gear teeth are cut on the periphery and are parallel to the axis of the gear. They are used to transmit power and motion between parallel shafts.

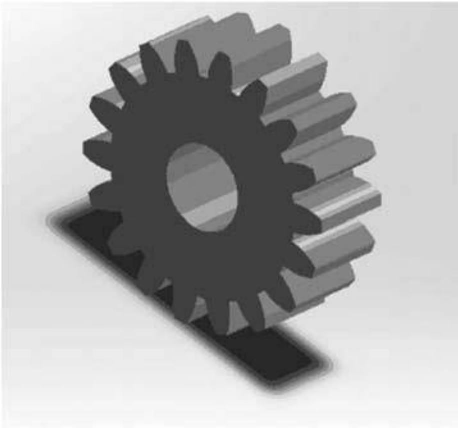


Fig. 4.19 Spur gears

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 189]

4.4.2.2 Helical gears The gear teeth are cut along the periphery, but at an angle to the axis of the gear. Each tooth has a helical or spiral form. These gears can deliver higher torque since there are more number of teeth in a mesh at any given point of time. They can transmit motion between parallel or non-parallel shafts.

Fig. 4.20 Helical gears

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 189]

4.4.2.3 Herringbone gears These gears have two sets of helical teeth, one right-hand and the other left-hand, machined side by side.

Fig. 4.21 Herringbone gears

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 189]

4.4.2.4 Worm and worm gears A worm is similar to a screw having single or multiple start threads, which form the teeth of the worm. The worm drives the worm gear or worm wheel to enable transmission of motion. The axes of worm and worm gear are at right angles to each other.

Fig. 4.22 Worm and worm gears

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 190]

4.4.2.5 Bevel gears These gears are used to connect shafts at any desired angle to each other. The shafts may lie in the same plane or in different planes.

Fig. 4.23 Bevel gears

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 190]

4.4.2.6 Hypoid gears These gears are similar to bevel gears, but the axes of the two connecting shafts do not intersect. They carry curved teeth, are stronger than the common types of bevel gears, and are quiet-running. These gears are mainly used in automobile rear axle drives.

4.4.3 Gear terminology

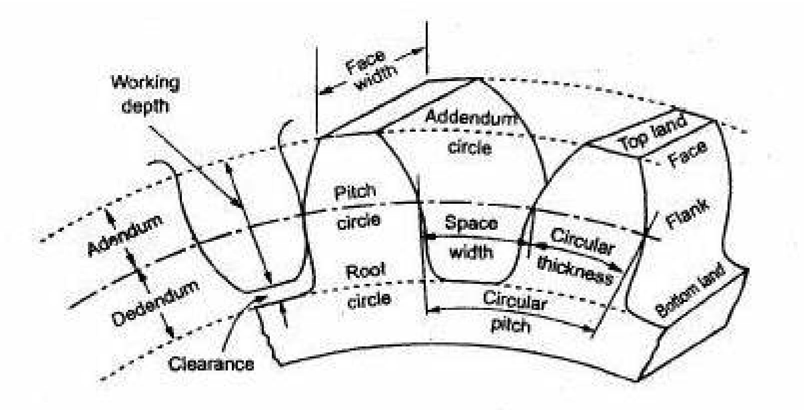


Fig. 4.24 Spur gear terminology

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 190]

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.

$$\alpha = 14\ 1/2^\circ \text{ or } 20^\circ.$$

8.Module(m):

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

$$m = \frac{d}{n}$$

Where, d = Pitch circle diameter.

n = Number of teeth.

9. Circular pitch:

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

$$P_C = \frac{\pi d}{n} = \pi m$$

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 .25module.

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.

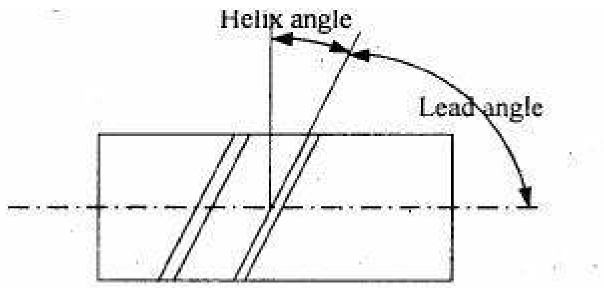
15. Flank:

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

16. Top land:

Top surface of a tooth.

17. Helix angle:



The angle between the tangents to helix angle.

18. Lead angle:

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

19. Backlash:

- The difference between the tooth thickness and the space into which it meshes.
- If we assume the tooth thickness as t and width ‘t then

$$\text{Back lash} = t_2 - t_1$$

4.4.4 ERRORS IN SPUR GEARS

A basic understanding of the errors in spur gears during manufacturing is important before we consider the possible ways of measuring the different elements of gears. A spur gear is a rotating member that constantly meshes with its mating gear. It should have the perfect geometry to maximize transmission of power and speed without any loss. From a metrological point of view, the major types of errors are as follows:

1. Gear blank runout errors
2. Gear tooth profile errors
3. Gear tooth errors
4. Pitch errors
5. Runout errors
6. Lead errors
7. Assembly errors

4.4.4.1 Gear blank runout errors Gear machining is done on the gear blank, which may be a cast or a forged part. The blank would have undergone preliminary machining on its outside diameter (OD) and the two faces. The blank may have radial runout on its OD surface due to errors in the preliminary machining. In addition, it may have excessive face runout. Unless these two runouts are within prescribed limits, it is not possible to meet the tolerance requirements at later stages of gear manufacture.

4.4.4.2 Gear tooth profile errors These errors are caused by the deviation of the actual tooth profile from the ideal tooth profile. Excessive profile error will result in either friction between the mating teeth or backlash, depending on whether it is on the positive or negative side.

4.4.4.3 Gear tooth errors This type of error can take the form of either tooth thickness error or tooth alignment error. The tooth thickness measured along the pitch circle may have a large amount of error. On the other hand, the locus of a point on the machined gear teeth may not follow an ideal trace or path. This results in a loss in alignment of the gear.

4.4.4.4 Pitch errors Errors in pitch cannot be tolerated, especially when the gear transmission system is expected to provide a high degree of positional accuracy for a machine slide or axis. Pitch error can be either single pitch error or accumulated pitch error. Single pitch error is the error in actual measured pitch value between adjacent teeth. Accumulated pitch error is the difference between theoretical summation over any number of teeth intervals and summation of actual pitch measurement over the same interval.

4.4.4.5 Runout errors This type of error refers to the runout of the pitch circle. Runout causes vibrations and noise, and reduces the life of the gears and bearings. This error creeps in due to inaccuracies in the cutting arbour and tooling system.

4.4.4.6 Lead errors This type of error is caused by the deviation of the actual advance of the gear tooth profile from the ideal value or position. This error results in poor contact between the mating teeth, resulting in loss of power.

4.4.4.7 Assembly errors Errors in assembly may be due to either the centre distance error or the axes alignment error. An error in centre distance between the two engaging gears results in either backlash error or jamming of gears if the distance is too little. In addition, the axes of the two gears must be parallel to each other, failing which misalignment will be a major problem.

4.4.5 MEASUREMENT OF GEAR ELEMENTS

A number of standard gear inspection methods are used in the industry. The choice of the inspection procedure and methods not only depends on the magnitude of tolerance and size of the gears, but also on lot sizes, equipment available, and inspection costs. While a number of analytical methods are recommended for inspection of gears, statistical quality control is normally resorted to when large quantities of gears are manufactured. The following elements of gears are important for analytical inspection:

1. Runout
2. Pitch
3. Profile
4. Lead
5. Backlash
6. Tooth thickness

4.4.5.1 Measurement of Runout

Runout is caused when there is some deviation in the trajectories of the points on a section of a circular surface in relation to the axis of rotation. In case of a gear, runout is the resultant of the radial throw of the axis of a gear due to the out of roundness of the gear profile. Runout tolerance is the total allowable runout. In case of gear teeth, runout is measured by a specified probe such as a cylinder, ball, cone, rack, or gear teeth. The measurement is made perpendicular to the surface of revolution. On bevel and hypoid gears, both axial and radial runouts are included in one measurement.

A common method of runout inspection, called a single-probe check uses an indicator with a single probe whose diameter makes contact with the flanks of adjacent teeth in the area of the pitch circle. On the other hand, in a two-probe check one fixed and one free-moving probe, are positioned on diametrically opposite sides of the gear and make contact with identically located elements of the tooth profile. The range of indications obtained with the two-probe check during a complete revolution of the gear is twice the amount resulting from the single-probe check.

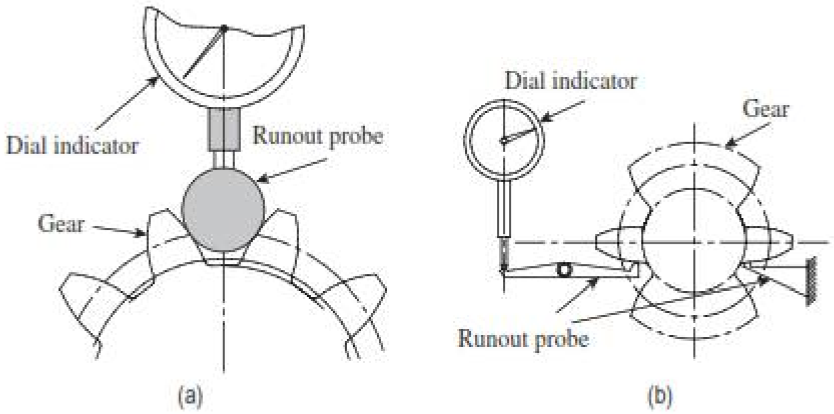


Fig. 4.25 Measurement of radial runout

(a) Single-probe check (b) Two-probe check

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 194]

4.4.5.2 Measurement of Pitch

Pitch is the distance between corresponding points on equally spaced and adjacent teeth. Pitch error is the difference in distance between equally spaced adjacent teeth and the measured distance between any two adjacent teeth. The two types of instruments that are usually employed for checking pitch are discussed in this section.

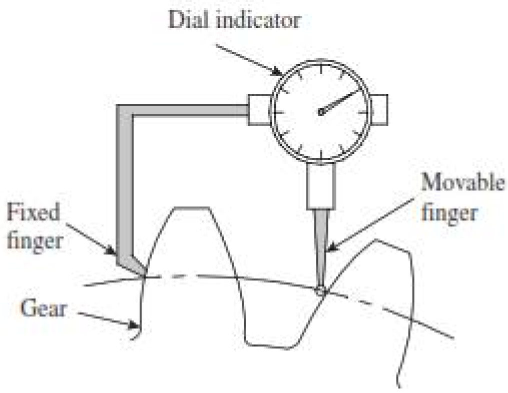


Fig. 4.26 Pitch-measuring instrument

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 194]

Pitch-measuring Instruments

These instruments enable the measurement of chordal pitch between successive pairs of teeth. The instrument comprises a fixed finger and a movable finger, which can be set to two identical points on adjacent teeth along the pitch circle. The pitch variation is displayed on a dial indicator attached to the instrument. In some cases, the pitch variation is recorded on a chart recorder, which can be used for further measurements. A major limitation of this method is that readings are influenced by profile variations as well as runout of the gear.

Pitch-checking Instrument

A pitch-checking instrument is essentially a dividing head that can be used to measure pitch variations. The instrument can be used for checking small as well as large gears due to its portability. It has two probes one fixed, called the anvil, and the other movable, called the measuring feeler. The latter is connected to a dial indicator through levers.

The instrument is located by two adjacent supports resting on the crests of the teeth. A tooth flank is butted against the fixed anvil and locating supports. The measuring feeler senses the corresponding next flank. The instrument is used as a comparator from which we can calculate the adjacent pitch error, actual pitch, and accumulated pitch error.

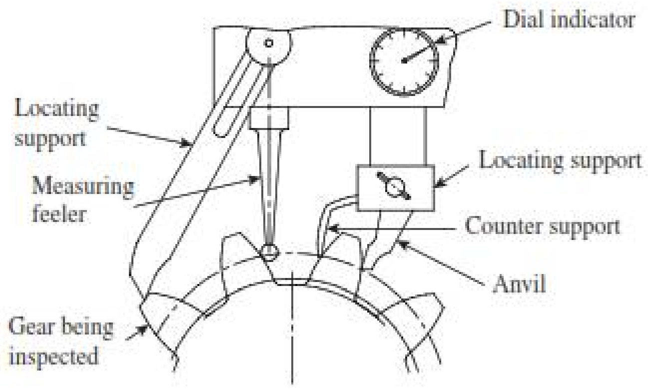


Fig. 4.27 Pitch-checking instrument

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 195]

4.4.5.3 Measurement of Profile

The profile is the portion of the tooth flank between the specified form circle and the outside circle or start of tip chamfer. Profile tolerance is the allowable deviation of the actual tooth form from the theoretical profile in the designated reference plane of rotation. As the most commonly used profile for spur and helical gears is the involute profile, our discussions are limited to the measurement of involute profile and errors in this profile. We will now discuss two of the preferred methods of measuring a tooth profile.

Profile Measurement Using Special Profile-measuring Instruments

The gear to be inspected is mounted on an arbour on the gear-measuring machine. The probe is brought into contact with the tooth profile. To obtain the most accurate readings, it is essential that the feeler (probe) is sharp, positioned accurately, and centered correctly on the origin of the involute at 0° of the roll. The machine is provided with multiple axes movement to enable measurement of the various types of gears. The measuring head comprising the feeler, electronic unit, and chart recorder can be moved up and down by operating a handwheel.

The arbour assembly holding the gear can be moved in two perpendicular directions in the horizontal plane by the movement of a carriage and a cross-slide. Additionally, the base circle disk on which the gear is mounted can be rotated by 360°, thereby providing the necessary rotary motion for the gear being inspected. The feeler is kept in such a way that it is in a spring-loaded contact with the tooth flank of the gear under inspection. As the feeler is mounted exactly above the straight edge, there is no movement of the feeler if the involute is a true involute. If there is an error, it is sensed due to the deflection of the feeler, and is amplified by the electronic unit and recorded by the chart recorder. The movement of the feeler can be amplified 250, 500, or 1000 times, the amplification ratio being selected by a selector switch. When there is no error in the involute profile, the trace on the recording chart will be a straight line. Gleason gear inspection machine, a product of Gleason Metrology Systems Corporation, USA, follows the fundamental design aspect of any testing machine with the capability to handle up to 350 mm dia gears. It also integrates certain object-oriented tools to achieve faster cycle times and a better human–machine interaction.

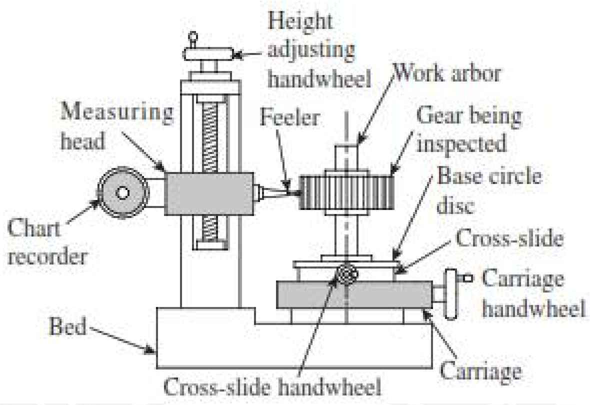


Fig. 4.28 Gear-measuring machine

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 197]

4.4.5.4 Measurement of Lead

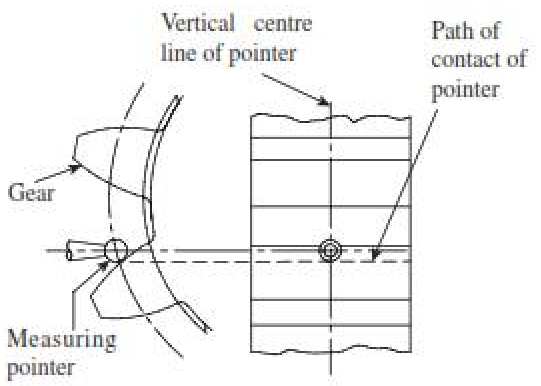


Fig. 4.29 Measurement of lead

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 197]

Lead is the axial advance of a helix for one complete rotation about its axis. In case of spur gears, lead tolerance is defined as the allowable deviation across the face width of a tooth surface. Control of lead is necessary in order to ensure adequate contact across the face width when gear and pinion are in mesh.

A measuring pointer traces the tooth surface at the pitch circle and parallel to the axis of the gear. The measuring pointer is mounted on a slide, which travels parallel to the centre on which the gear is held. The measuring pointer is connected to a dial gauge or any other suitable comparator, which continuously indicates the deviation. The total deviation shown by the dial indicator over the distance measured indicates the amount of displacement of the gear tooth in the face width traversed.

Measurement of lead is more important in helical and worm gears. Interested readers are advised to refer to a gear handbook to learn more about the same.

4.4.5.5 Measurement of Backlash

If the two mating gears are produced such that tooth spaces are equal to tooth thicknesses at the reference diameter, then there will not be any clearance in between the teeth that are getting engaged with each other. This is not a practical proposition because the gears will get jammed even from the slightest mounting error or eccentricity of bore to the pitch circle diameter. Therefore, the tooth profile is kept uniformly thinned. This results in a small play between the mating tooth surfaces, which is called a backlash.

We can define backlash as the amount by which a tooth space exceeds the thickness of an engaging tooth. Backlash should be measured at the tightest point of mesh on the pitch circle, in a direction normal to the tooth surface when the gears are mounted at their specified position. Backlash value can be described as the shortest or normal distance between the trailing flanks when the driving flank and the driven flank are in contact. A dial gauge is usually employed to measure the backlash. Holding the driver gear firmly, the driven gear can be rocked back and forth. This movement is registered by a dial indicator having its pointer positioned along the tangent to the pitch circle of the driven gear.

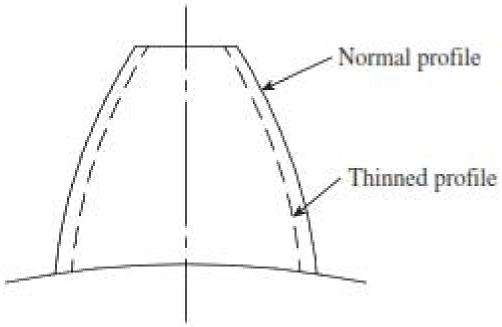


Fig. 4.30 Tooth thinning

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 198]

4.4.5.6 Measurement of Tooth Thickness

Various methods are recommended for the measurement of gear tooth thickness. There is a choice of instruments such as the gear tooth calliper, and span gauging or tooth span micrometer. Constant chord measurement and measurement over rolls or balls are additional options. Two such methods, namely measurement with gear tooth calliper and tooth span micrometer are discussed in detail here.

Measurement with Gear Tooth Callipers

This is one of the most commonly used methods and perhaps the most accurate one. It has two vernier scales, one horizontal and the other vertical. The vertical vernier gives the position of a blade, which can slide up and down. When the surface of the blade is flush with the tips of the measuring anvils, the vertical scale will read zero. The blade position can be set to any required value by referring to the vernier scale.

It is clear that tooth thickness should be measured at the pitch circle (chord thickness C_1C_2 in the figure). Now, the blade position is set to a value equal to the addendum of the gear tooth and locked into position with a locking screw. The calliper is set on the gear in such a manner that the blade surface snugly fits with the top surface of a gear tooth. The two anvils are brought into close contact with the gear, and the chordal thickness is noted down on the horizontal vernier scale.

Let d = Pitch circle diameter

g_c = Chordal thickness of gear tooth along the pitch circle

h_c = Chordal height

z = Number of teeth on the gear

Chordal thickness g_c = Chord C_1C_2

= 2(pitch circle radius) × sin ç

= $2 \times \frac{d}{2} \times$ sin ç

= d sin ç

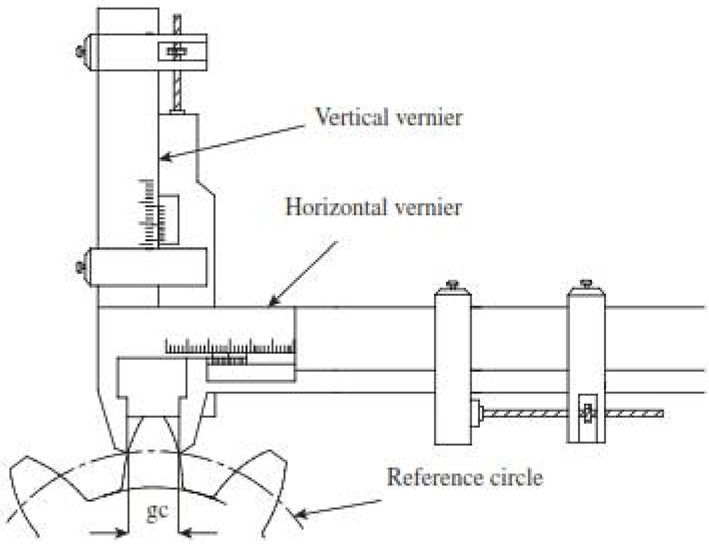


Fig. 4.31 Gear tooth calliper

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 199]

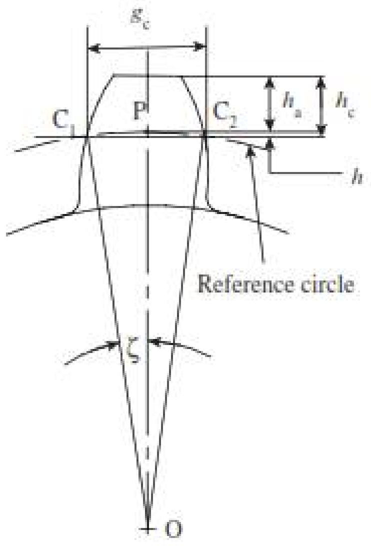


Fig. 4.32 Chordal thickness and chordal height

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 199]

Arc $C_1PC_2 = \frac{d}{2} \times 2ç$ (value of ç in radians)

$= d \times ç = \frac{\pi d}{2z}$

Therefore, $ç = \frac{\pi}{2z}$

$g_c = d\sin(\pi/2z)$ (where $\pi/2z$ is in radians)

$g_c = d\sin(90/2z)$ (argument of sin is in degrees)

Chordal height $h_c = h_a + \Delta h = m + \Delta h$

However, $\Delta h(d - \Delta h) = \frac{gc}{2} \times \frac{gc}{2}$

and $4(\Delta h)^2 - 4\Delta h \times d + g_c^2 = 0$

$\Delta h = [d \pm \sqrt{d^2 - g_c^2}]/2$

$= [d - \sqrt{d^2 - g_c^2}]/2$; the other value is neglected because $\Delta h > d$ is not possible.

Neglecting $(\Delta h)^2$, we get $\Delta h \times d = g_c^2/4$

$\Delta h = g_c^2/4d$

Thus, $h_c = h_a + g_c^2/4d = m + g_c^2/4d$

Therefore, $g_c = d \sin (90°/z)$

and $h_c = m + g_c^2/4d$

4.4.6 COMPOSITE METHOD OF GEAR INSPECTION

Composite action refers to the variation in centre distance when a gear is rolled in tight mesh with a standard gear. It is standard practice to specify composite tolerance, which reflects gear runout, tooth-to-tooth spacing, and profile variations. Composite tolerance is defined as the allowable centre distance variation of the given gear, in tight mesh with a standard gear, for one complete revolution. The Parkinson gear testing machine is generally used to carry out composite gear inspection.

4.4.6.1 Parkinson Gear Tester

It is a popular gear testing machine used in metrology laboratories and tool rooms. The gear being inspected will be made to mesh with a standard gear, and a dial indicator is used to capture radial errors. The standard gear is mounted on a fixed frame, while the gear being inspected is fixed to a sliding carriage. The two gears are mounted on mandrels, which facilitate accurate mounting of gears in machines, so that a dial indicator will primarily measure irregularities in the gear under inspection. A dial indicator of high resolution is used to measure the composite error, which reflects errors due to runout, tooth-to-tooth spacing, and profile variations.

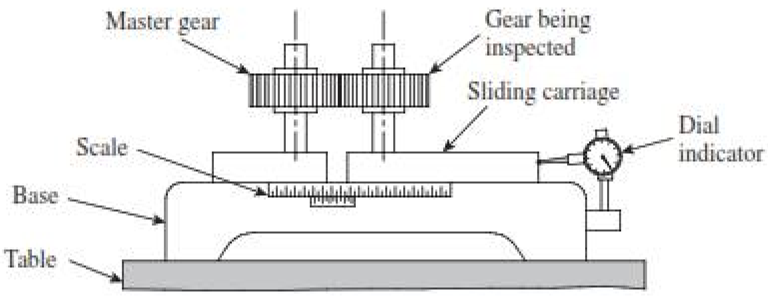


Fig. 4.33 Parkinson gear tester

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 202]

To start with, the two gears are mounted on respective mandrels and the slide comprising the standard gear is fixed at a convenient position. The sliding carriage is moved along the table, the two gears are brought into mesh, and the sliding carriage base is also locked in its position. Positions of the two mandrels are adjusted in such a way that their axial distance is equal to the gear centre distance as per drawings. However, the sliding carriage is free to slide for a small distance on steel rollers under a light spring force. A vernier scale attached to the machine enables measurement of the centre distance up to 25 μm. The dial indicator is set to zero and the gear under inspection is rotated. Radial variations of the gear being inspected are indicated by the dial indicator. This variation is plotted on a chart or graph sheet, which indicates the radial variations in the gear for one complete rotation.

A waxed paper recorder can be fitted to the machine so that a trace of the variations of a needle in contact with the sliding carriage is made simultaneously. The mechanism can be designed to provide a high degree of magnification.

4.5 SURFACE FINISH MEASUREMENT

4.5.1 Introduction:

- When we are producing components by various methods of manufacturing process it is not possible to produce perfectly smooth surface and some irregularities are formed.
- These irregularities are causes some serious difficulties in using the components. So, it is very important to correct the surfaces before use.
- The factors which are affecting surface roughness are

1. Work piece material
2. Vibrations
3. Machining type
4. Tool, and fixtures

The geometrical irregularities can be classified as

1. First order

2.Second order

3 Third order

4.Fourth order

1. First order irregularities:

These are caused by lack of straightness of guide ways on which tool must move.

2. Second order irregularities:

These are caused by vibrations

3. Third order irregularities:

These are caused by machining.

4. Fourth order irregularities:

These are caused by improper handling machines and equipments.

4.5.2 SURFACE METROLOGY CONCEPTS

If one takes a look at the topology of a surface, one can notice that surface irregularities are superimposed on a widely spaced component of surface texture called waviness. Surface irregularities generally have a pattern and are oriented in a particular direction depending on the factors that cause these irregularities in the first place.

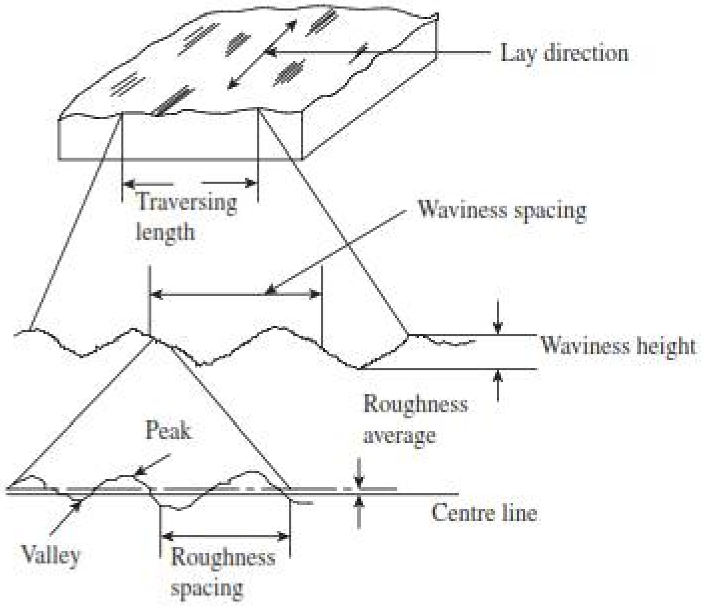


Fig. 4.34 Waviness and roughness

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 218]

Surface irregularities primarily arise due to the following factors:

1. Feed marks of cutting tools

2. Chatter marks on the workpiece due to vibrations caused during the manufacturing operation

3. Irregularities on the surface due to rupture of workpiece material during the metal cutting Operation

4. Surface variations caused by the deformation of workpiece under the action of cutting forces

5. Irregularities in the machine tool itself like lack of straightness of guideways

4.5.3 TERMINOLOGY

Roughness The American Society of Tool and Manufacturing Engineers (ASTME) defines roughness as the finer irregularities in the surface texture, including those irregularities that result from an inherent action of the production process. Roughness spacing is the distance between successive peaks or ridges that constitute the predominant pattern of roughness. Roughness height is the arithmetic average deviation expressed in micrometres and measured perpendicular to the centre line.

Waviness It is the more widely spaced component of surface texture. Roughness may be considered to be superimposed on a wavy surface. Waviness is an error in form due to incorrect geometry of the tool producing the surface. On the other hand, roughness may be caused by problems such as tool chatter or traverse feed marks in a supposedly geometrically perfect machine. The spacing of waviness is the width between successive wave peaks or valleys. Waviness height is the distance from a peak to a valley.

Lay It is the direction of the predominant surface pattern, ordinarily determined by the production process used for manufacturing the component. Symbols are used to represent lays of surface pattern

Flaws These are the irregularities that occur in isolation or infrequently because of specific causes such as scratches, cracks, and blemishes.

Surface texture It is generally understood as the repetitive or random deviations from the nominal surface that form the pattern of the surface. Surface texture encompasses roughness, waviness, lay, and flaws.

Errors of form These are the widely spaced repetitive irregularities occurring over the full length of the work surface. Common types of errors of form include bow, snaking, and lobbing.

4.5.4 ANALYSIS OF SURFACE TRACES

It is required to assign a numerical value to surface roughness in order to measure its degree. This will enable the analyst to assess whether the surface quality meets the functional requirements of a component. Various methodologies are employed to arrive at a representative parameter of surface roughness. Some of these are 10-point height average (Rz), root mean square (RMS) value, and the centre line average height (Ra), which are explained in the following paragraphs.

4.5.4.1 Ten-point Height Average Value

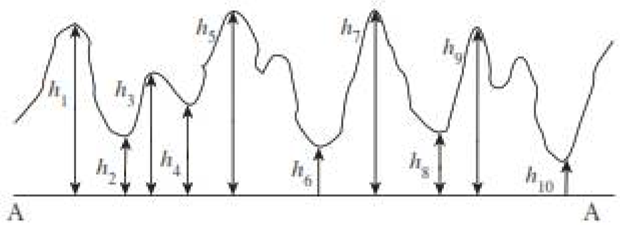


Fig. 4.35 Measurement to calculate the 10-point height average

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 220]

It is also referred to as the peak-to-valley height. In this case, we basically consider the average height encompassing a number of successive peaks and valleys of the asperities. As can be seen in Fig., a line AA parallel to the general lay of the trace is drawn. The heights of five consecutive peaks and valleys from the line AA are noted down.

The average peak-to-valley height Rz is given by the following expression:

$$Rz = \frac{(h_1 + h_3 + h_5 + h_7 + h_9) - (h_2 + h_4 + h_6 + h_8 + h_{10})}{5} \times \frac{1000}{\text{Vertical magnification}} \ \mu\text{m}$$

4.5.4.2 Root Mean Square Value

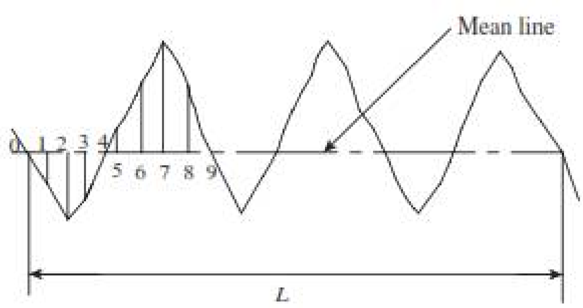


Fig. 4.36 Representation of an RMS value

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 220]

Until recently, RMS value was a popular choice for quantifying surface roughness; however, this has been superseded by the centre line average value. The RMS value is defined as the square root of the mean of squares of the ordinates of the surface measured from a mean line.

Figure illustrates the graphical procedure for arriving at an RMS value. With reference to this figure, if h_1, h_2, ..., h_n are equally spaced ordinates at points 1, 2, ..., n, then

$$h_{RMS} = \frac{\sqrt{(h_1^2 + h_2^2 + \ldots + h_n^2)}}{n}$$

4.5.4.3 Centre Line Average Value

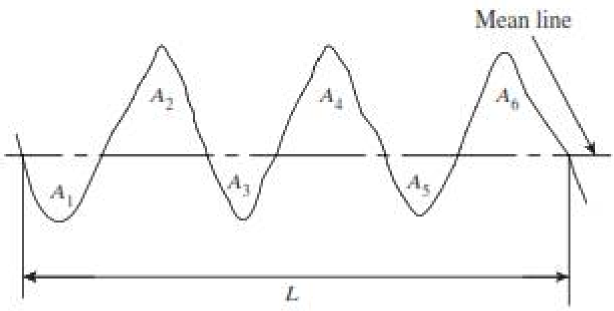


Fig. 4.37 Representation of Ra value

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 221]

The Ra value is the prevalent standard for measuring surface roughness. It is defined as the average height from a mean line of all ordinates of the surface, regardless of sign. With reference to Fig., it can be shown that

$$\text{Ra} = \frac{A_1 + A_2 + \ldots + A_N}{L}$$
$$= \Sigma A / L$$

4.5.5 Methods of measuring surface finish

The methods used for measuring the surface finish is classified into

1. Inspection by comparison

2. Direct Instrument Measurements

4.5.5.1. Inspection by comparison methods:

- In these methods the surface texture is assessed by observation of the surface.
- The surface to be tested is compared with known value of roughness specimen and finished by similar machining process.
- The various methods which are used for comparison are

  1. Touch Inspection.
  2. Visual Inspection.
  3. Microscopic Inspection.
  4. Scratch Inspection.
  5. Micro Interferometer.
  6. Surface photographs.
  7. Reflected Light Intensity.
  8. Wallace surface Dynamometer.

4.5.5.1.1. Touch Inspection

It is used when surface roughness is very high and in this method the fingertip is moved along the surface at a speed of 25mm/second and the irregularities as up to 0.0 125mm can be detected.

4.5.5.1.2. Visual Inspection:

In this method the surface is inspected by naked eye and this measurement is limited to rough surfaces.

4.5.5.1.3. Microscopic Inspection:

In this method finished surface is placed under the microscopic and compared with the surface under inspection. The light beam also used to check the finished surface by projecting the light about 60° to the work.

4.5.5.1.4. Scratch Inspection:

The materials like lead, plastics rubbed on surface is inspected by this method. The impression of this scratches on the surface produced is then visualized.

4.5.5.1.5. Micro-Interferometer:

Optical flat is placed on the surface to be inspected and illuminated by a monochromatic source of light.

4.5.5.1.6. Surface Photographs:

Magnified photographs of the surface are taken with different types of illumination. The defects like irregularities are appear as dark spots and flat portion of the surface appears as bright.

4.5.5.1.7. Reflected light Intensity:

A beam of light is projected on the surface to be inspected and the light intensity variation on the surface is measured by a photocell and this measured value is calibrated

4.5.5.1.8. Wallace surface Dynamometer:

It consists of a pendulum in which the testing shoes are clamped to a bearing surface and a pre-determined spring pressure can be applied and then, the pendulum is lifted to its initial starting position and allowed to swing over the surface to be tested.

4.5.6 DIRECT INSTRUMENT MEASUREMENTS

- Direct methods enable to determine a numerical value of the surface finish of any surface.
- These methods are quantitative analysis methods and the output is used to operate recording or indicating instrument.
- Direct Instruments are operated by electrical principles. These instruments are classified into two types according to the operating principle.
- In this is operated by carrier-modulating principle and the other is operated by voltage-generating principle, and in the both types the output is amplified.
- Some of the direct measurement instruments are

1. Stylus probe instruments.
2. Tomlinson surface meter.
3. Profilometer.
4. Taylor-Hobson Talysurf

4.5.6.1 Stylus probe instruments.

There are two types of stylus instruments: true datum and surface datum, which are also known as skidless and skid type, respectively. In the skidless instrument, the stylus is drawn across the surface by a mechanical movement that results in a precise path. The path is the datum from which the assessment is made. In the skid-type instrument, the stylus pickup unit is supported by a member that rests on the surface and slides along with it. This additional member is the skid or the shoe.

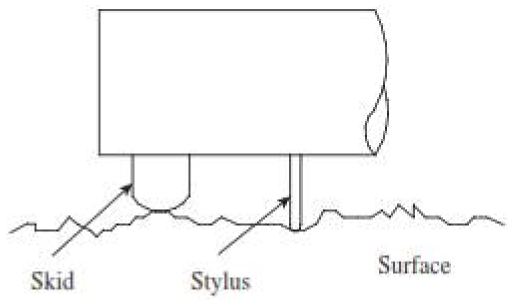


Fig. 4.38 Skid and stylus type

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 224]

Skids are rounded at the bottom and fixed to the pickup unit. They may be located in front of or behind the stylus. Some instruments use a shoe as a supporting slide instead of a skid. Shoes are flat pads with swivel mountings in the head. The datum created by a skid or a shoe is the locus of its centre of curvature as it slides along the surface.

The stylus is typically a diamond having a cone angle of 90° and a spherical tip radius of 1–5 µm or even less. The stylus tip radius should be small enough to follow the details of the surface irregularities, but should also have the strength to resist wear and shocks. Stylus load should also be controlled so that it does not leave additional scratch marks on the component being inspected.

In order to capture the complete picture of surface irregularities, it is necessary to investigate waviness (secondary texture) in addition to roughness (primary texture). Waviness may occur with the same lay as the primary texture. While a pointed stylus is used to measure roughness, a blunt stylus is required to plot the waviness.

Advantage:

Any desired roughness parameter can be recorded.

Disadvantages:

1. Fragile material cannot be measured.

2. High Initial cost.

3. Skilled operators are needed to operate.

4.5.6.2 Tomlinson Surface Meter.

The sensing element is the stylus, which moves up and down depending on the irregularities of the workpiece surface. The stylus is constrained to move only in the vertical direction because of a leaf spring and a coil spring. The tension in the coil spring P causes a similar tension in the leaf spring. These two combined forces hold a cross-roller in position between the stylus and a pair of parallel fixed rollers. A shoe is attached to the body of the instrument to provide the required datum for the measurement of surface roughness.

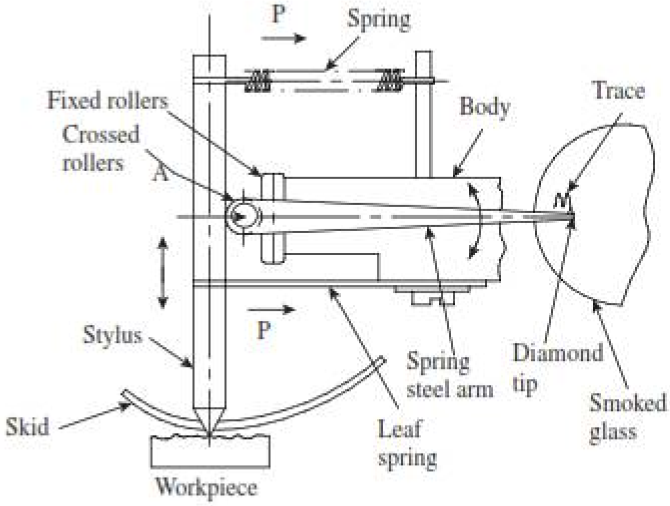


Fig. 4.39 Tomlinson surface meter

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 224]

A light spring steel arm is P Spring attached to the cross-roller and carries a diamond tip. The translatory motion of the stylus causes rotation of the cross roller about the point A, which in turn is converted to a magnified motion of the diamond point. The diamond tip traces the profile of the workpiece on a smoked glass sheet. The glass sheet is transferred to an optical projector and magnified further. Typically, a magnification of the order of 50–100 is easily achieved in this instrument.

In order to get a trace of the surface irregularities, a relative motion needs to be generated between the stylus and the workpiece surface. Usually, this requirement is met by moving the body of the instrument slowly with a screw driven by an electric motor at a very slow speed. Anti-friction guide-ways are used to provide friction-free movement in a straight path.

4.5.6.3. Taylor–Hobson Talysurf.

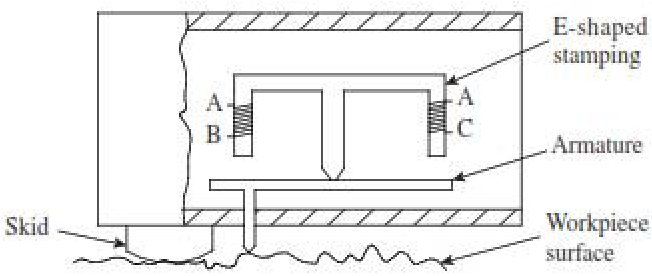


Fig. 4.40 Taylor–Hobson Talysurf

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 225]

The Taylor–Hobson talysurf works on the same principle as that of the Tomlinson surface meter. However, unlike the surface meter, which is purely a mechanical instrument, the talysurf is an electronic instrument. This factor makes the talysurf a more versatile instrument and can be used in any condition, be it a metrology laboratory or the factory shop floor.

The stylus is attached to an armature, which pivots about the centre of piece of an E-shaped stamping. The outer legs of the E-shaped stamping are wound with electrical coils. A predetermined value of alternating current (excitation current) is supplied to the coils. The coils form part of a bridge circuit. A skid or shoe provides the datum to plot surface roughness. The measuring head can be traversed in a linear path by an electric motor. The motor, which may be of a variable speed type or provided with a gear box, provides the required speed for the movement of the measuring head.

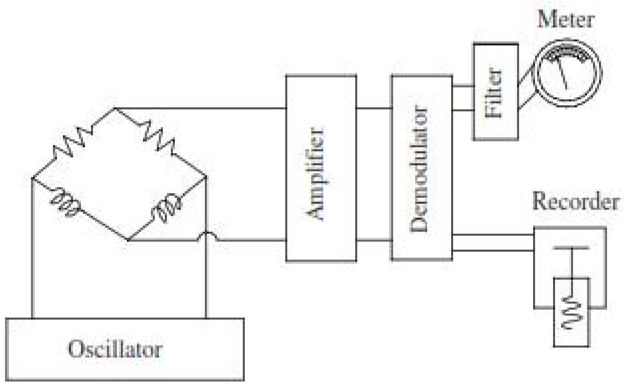


Fig. 4.41 Bridge circuit and electronics

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 225]

As the stylus moves up and down due to surface irregularities, the armature is also displaced. This causes variation in the air gap, leading to an imbalance in the bridge circuit. The resulting bridge circuit output consists of only modulation. This is fed to an amplifier and a pen recorder is used to make a permanent record. The instrument has the capability to calculate and display the roughness value according to a standard formula.

4.5.6.4. Profilometer.

A profilometer is a compact device that can be used for the direct measurement of surface texture. A finely pointed stylus will be in contact with the workpiece surface. An electrical pickup attached to the stylus amplifies the signal and feeds it to either an indicating unit or a recording unit. The stylus may be moved either by hand or by a motorized mechanism.

The profilometer is capable of measuring roughness together with waviness and any other surface flaws. It provides a quick-fix means of conducting an initial investigation before attempting a major investigation of surface quality.

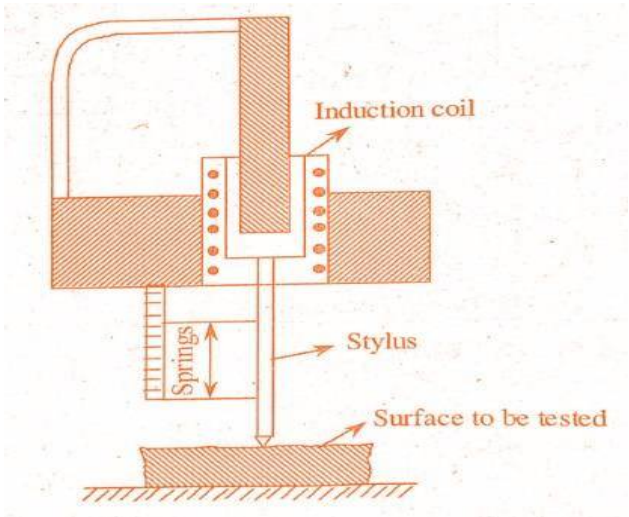


Fig. 4.42 Profilometer

[source: http://www.mechanicaleducation.com/2018/10/what-is-profilometer-and-uses-of-profilometer.html]

4.5.7 Other methods for measuring surface roughness

4.5.7.1 Profilograph

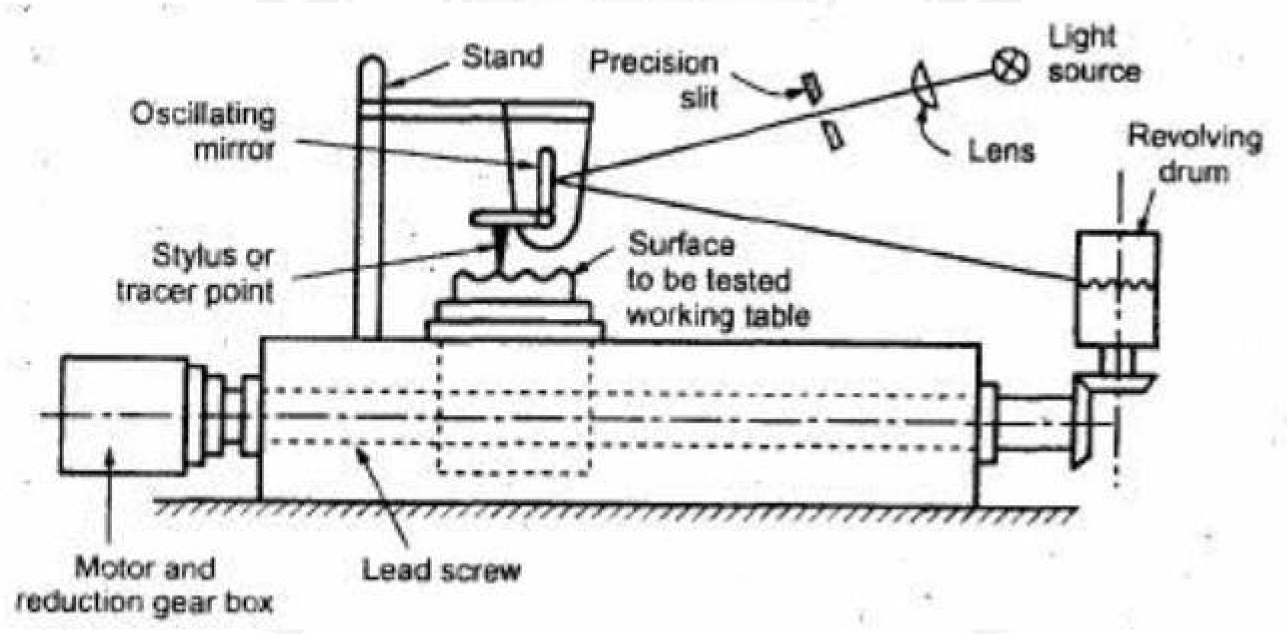


Fig. 4.43 Profilograph

[source: https://www.slideshare.net/navroznavodia/surface-finish-measurement-mechanical-measurement-and-metrology]

- ❖ The surface finish to be checked work piece is placed on the table.
- ❖ The table can move either side by lead screw and the stylus is pivoted over the tested surface, so the oscillation in the stylus due to surface irregularities are transmitted to the mirror.
- ❖ A light source sends a beam of light through lens and a precision slit to the mirror, and the reflected beam is directed to revolving drum.

- Upon the revolving drum a sensitive film is attached. The revolving drum can be rotated by two bevel gears and the gears are attached to the same lead screw.
- Finally, the profilogram will be obtained from the sensitive film and it is analysed.

4.5.7.2 Double microscope

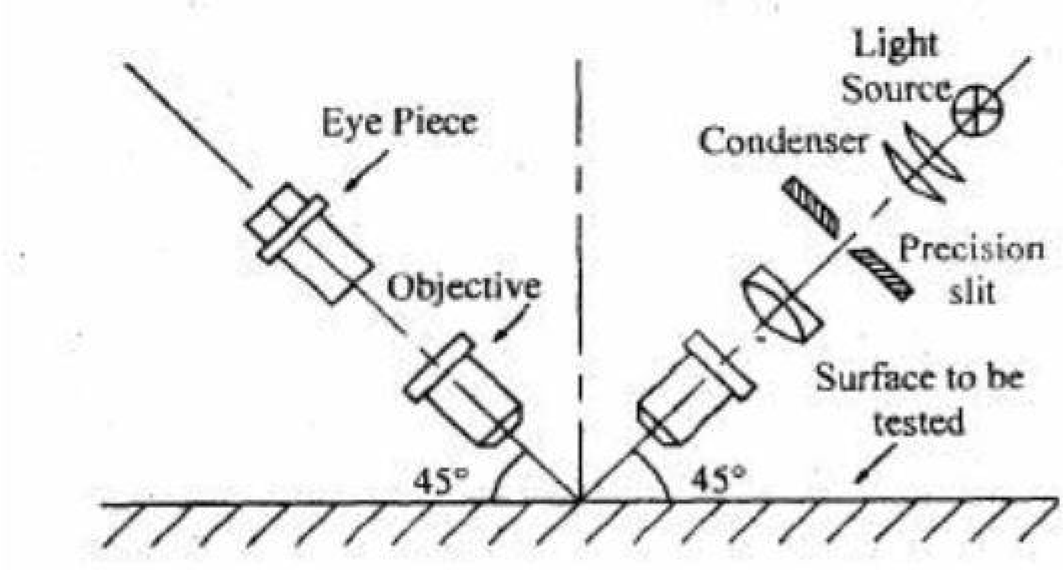


Fig. 4.44 Profilograph

[source: https://www.slideshare.net/navroznavodia/surface-finish-measurement-mechanical-measurement-and-metrology]

- It is an optical method for measuring the surface roughness, working principle is a thin film of light strikes the surface to be tested by an angle of 45° through the condenser and precision slit and the observing microscope is also inclined at an angle. of 45° to the tested surface.
- The surface is illuminated by a projection tube and it is observed by an eyepiece through the microscope.
- The eyepiece contains an eyepiece micrometer and it is used to measure the irregularities.

4.6 Roundness measurement

Roundness is defined as a condition of a surface of revolution. Where all points of the surface intersected by any plane perpendicular to a common axis in case of cylinder and cone.

Roundness is a geometric aspect of surface metrology and is of great importance because the number of rotational bearings in use is much more than that of linear bearings. Many machine parts, such as a machine spindle or the hub of a gear, have circular cross sections; these parts should have roundness with a very high degree of accuracy.

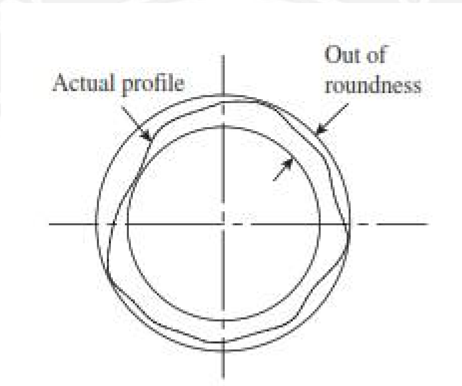


Fig. 4.45 Out of roundness

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 243]

Roundness is defined as a condition of surface of revolution where all points of the surface intersected by any plane perpendicular to a common axis are equidistant from the axis. It is obvious that any manufactured part cannot have perfect roundness because of limitations in the manufacturing process or tools; we need to determine how much deviation from perfect roundness can be tolerated so that the functional aspects of the machine part are not impaired. This leads to the definition of out of roundness as a measure of roundness error of a part. It is the radial distance between the minimum circumscribing circle and the maximum inscribing circle, which contain the profile of the surface at a section perpendicular to the axis of rotation.

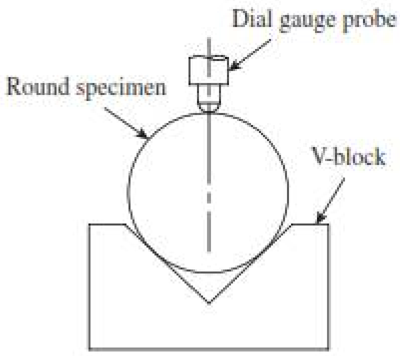


Fig. 4.46 Use of a V-block for measuring out of roundness

[source: Engineering Metrology and Measurements, N.V. Raghavendra, Pg. No 243]

Roundness error can be measured in various ways. Accessories required for the measurement comprise a surface plate, a V-block, and a dial gauge with a stand. The V-block is kept on the surface plate, and the cylindrical work part is positioned on the V-block. Care should be taken to ensure that the axis of the work part is parallel to the edges of the 'V' of the V-block. The dial gauge is mounted on its stand and the plunger is made to contact the surface of the work part. A light contact pressure is applied on the plunger so that it can register deviations on both the plus and minus sides. The dial gauge reading is set to zero. Now the work part is slowly rotated and the deviations of the dial indicator needle on both the plus and minus sides are noted down. The difference in reading for one complete rotation of the work part gives the value of out of roundness.

4.6.1 Devices used for measurement of roundness

1) Diametral gauge.

2) Circumferential conferring gauge => a shaft is confined in a ring gauge and rotated against a set indicator probe.

3) Rotating on center

4) V-Block

5) Three-point probe.

6) Accurate spindle.

4.6.1.1. Diametral method:

- The measuring plungers are located 180° a part and the diameter is measured at several places.
- This method is suitable only when the specimen is elliptical or has an even number of lobes.
- Diametral check does not necessarily disclose effective size or roundness.
- This method is unreliable in determining roundness.

4.6.1.2. Circumferential confining gauge:

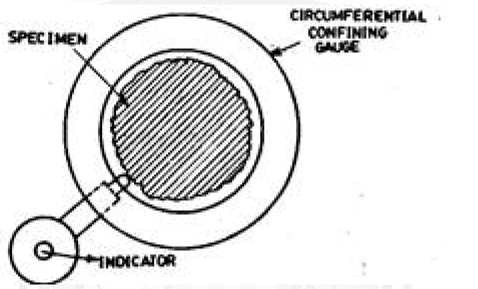


Fig. 4.47 Circumferential confining gauge

[source: http://what-when-how.com/metrology/measurement-of-circularity-metrology/]

- It is useful for inspection of roundness in production.
- This method requires highly accurate master for each size part to be measured. The clearance between part and gauge is critical to reliability.
- This technique does not allow for the measurement of other related geometric characteristics, such as concentricity, flatness of shoulders etc.

4.6.1.3. Rotating on centers:

- The shaft is inspected for roundness while mounted on center.
- In this case, reliability is dependent on many factors like angle of centers, alignment of centres, roundness and surface condition of the centres and centre holes and run out of piece.
- Out of straightness of the part will cause a doubling run out effect and appear to be roundness error,

4.6.1.4. V-Block:

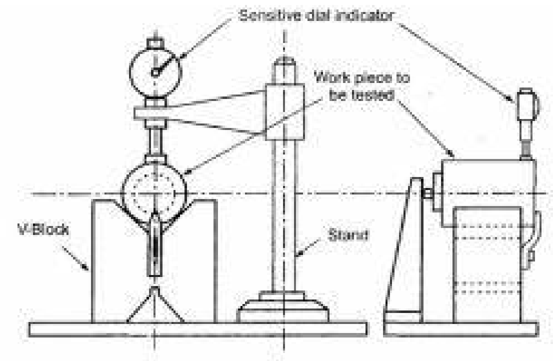


Fig. 4.48 V-Block

[source: https://www.brainkart.com/article/Roundness-Measurement_5856/]

- The V block is placed on surface plate and the work to be checked is placed upon it.
- A diameter indicator is fixed in a stand and its feeler made to rest against the surface of the work. The work is rotated to measure the rise on fall of the work piece.
- For determining the number of lobes on the work piece, the work piece is first tested in a 60° V-Block and then in a 90° V-Block.
- The number of lobes is then equal to the number of times the indicator pointer deflects through 360° rotation of the work piece.

Limitations:

a) The circularity error is greatly by affected by the following factors.

(i) If the circularity error is i\e, then it is possible that the indicator shows no variation.

(ii) Position of the instrument i.e. whether measured from top or bottom.

(iii) Number of lobes on the rotating part.

b) The instrument position should be in the same vertical plane as the point of contact of the part with the V-block.

c) A leaf spring should always be kept below the indicator plunger and the surface of the part.

4.6.1.5. Three-point probe

- The fig. shows three probes with 120° spacing is very, useful for determining effective size they perform like a 60° V-block.
- 60° V-block will show no error for 5 a 7 lobes magnify the error for 3-lobed parts show partial error for randomly spaced lobes.

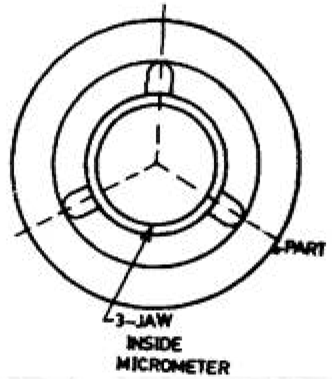


Fig. 4.49 Three point probe

[source: https://www.brainkart.com/article/Roundness-Measurement_5856/]

4.6.1.6 Roundness measuring spindle

There are following two types of spindles used.

4.6.1.6.1. Overhead spindle:

- Part is fixed in a staging plat form and the overhead spindle carrying the comparator rotates separately from the part.
- It can determine roundness as well as camming (Circular flatness). Height of the work piece is limited by the location of overhead spindle.
- The concentricity can be checked by extending the indicator from the spindle and thus, the range of this check is limited.

4.6.1.6.2. Rotating table:

Spindle is integral with the table and rotates along with it. The part is placed over the spindle and rotates past a fixed comparator

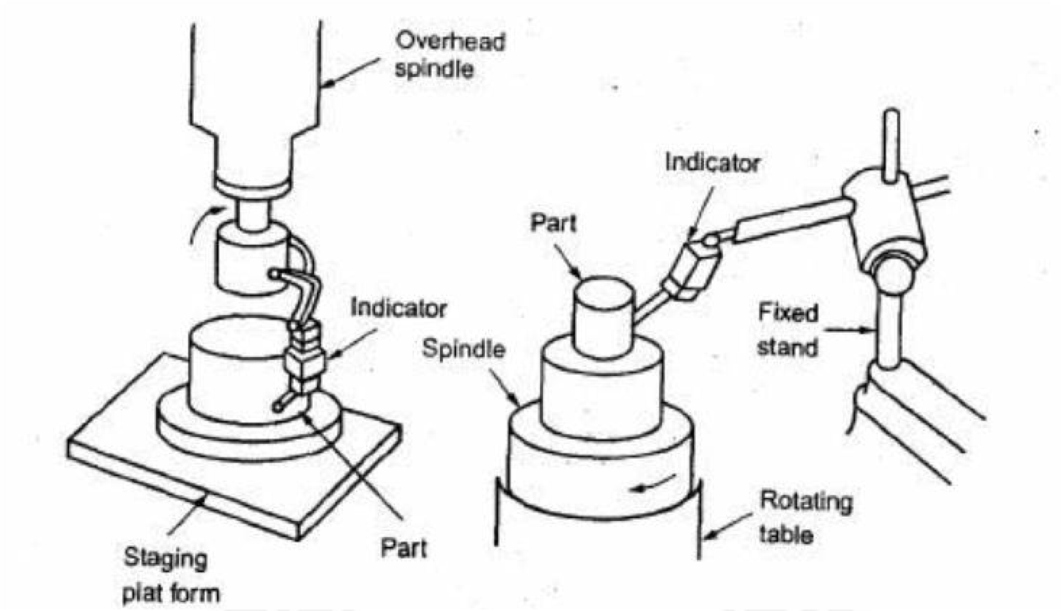


Fig. 4.50 Roundness measuring spindle Rotating table

[source: https://www.brainkart.com/article/Roundness-Measurement_5856/]

4.6.2 Modern Roundness Measuring Instruments

- This is based on use of microprocessor to provide measurements of roundness quickly and in a simple way; there is no need of assessing out of roundness. Machine can do centering automatically and calculate roundness and concentricity, straightness and provide visual and digital displays.
- A computer is used to speed up calculations and provide the stand reference circle.

(i) Least square circle:

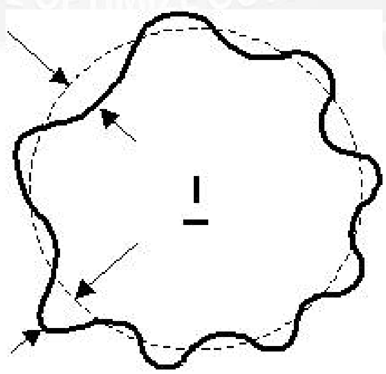


Fig. 4.51 Least square circle

[source: https://www.taylor-hobson.com/resource-center/faq/what-reference-circles-are-there]

- The sum of the squares of a sufficient no. of equally spaced radial ordinates measured from the circle to the profile has minimum value.
- The center of such circle is referred to as the least square center. Out of roundness is defined as the radial distance of the maximum peak from the circle (P) plus the distance of the maximum valley from this circle

(ii) Minimum zone or Minimum radial separation circle:

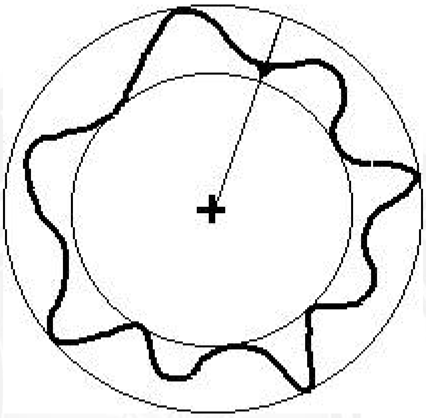


Fig. 4.52 Minimum zone circle

[source: https://www.taylor-hobson.com/resource-center/faq/what-reference-circles-are-there]

- These are two concentric circles. The value of the out of roundness is the radial distance between the two circles.
- The center of such a circle is termed as the minimum zone center. These circles can be found by using a template.

(iii) Maximum inscribed circle:

- This is the largest circle. Its center and radius can be found by trial and error by compare or by template or computer. Since V = 0 there is no valleys inside the circle.

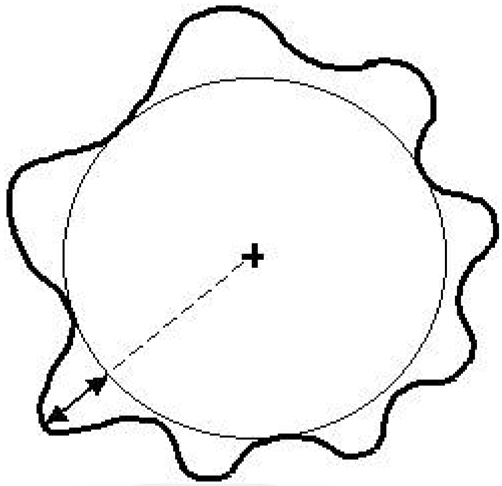


Fig. 4.53 Maximum inscribed circle

[source: https://www.taylor-hobson.com/resource-center/faq/what-reference-circles-are-there]

(iv) Minimum circumscribed circles:

- This is the smallest circle. Its center and radius can be found by the previous method since P = 0 there is no peak outside the circle.
- The radial distance between the minimum circumscribing circle and the maximum inscribing circle is the measure of the error circularity. The fig shows the trace produced by a recording instrument.

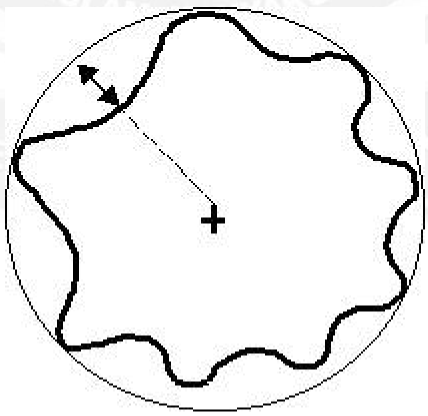


Fig. 4.54 Minimum circumscribed circles

[source: https://www.taylor-hobson.com/resource-center/faq/what-reference-circles-are-there]

- This trace to draw concentric circles on the polar graph which pass through the maximum and minimum points in such way that the radial distance be minimum circumscribing circle containing the trace or the n inscribing circle which can fitted into the trace is minimum.
- The radial distance between the outer and inner circle is minimum is considered for determining the circularity error.
- Assessment of roundness can be done by templates.
- The out off roundness is defined as the radial distance of the maximum peak (P) from the least square circle plus the distance of the maximum valley (V) from the least square circle.
- All roundness analysis can be performed by harmonic and slope analysis.