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.

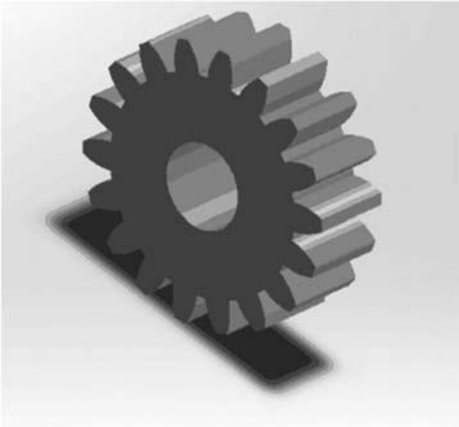


Fig. 4.19 Spur gears

[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.

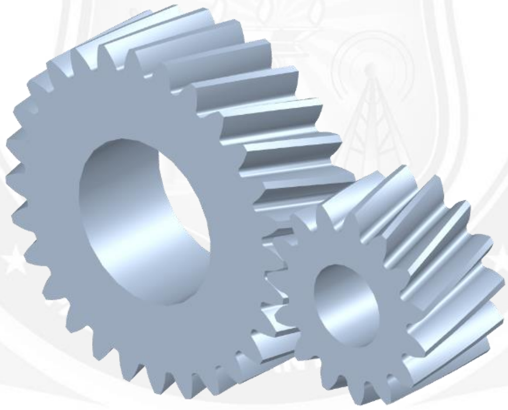


Fig. 4.20 Helical gears

[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

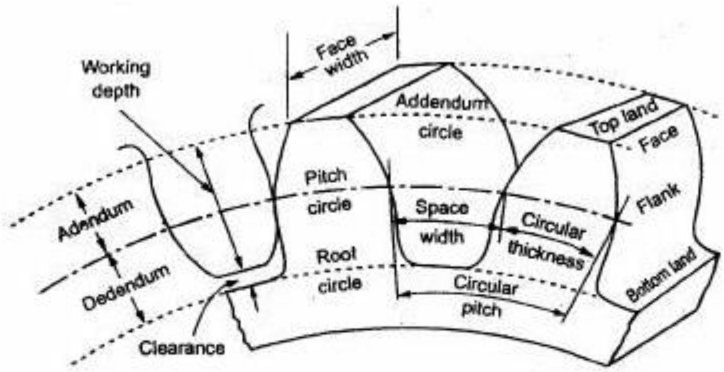


Fig. 4.24 Spur gear terminology

[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.

$\alpha = 14\ 1/2^\circ$ or 20°.

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.

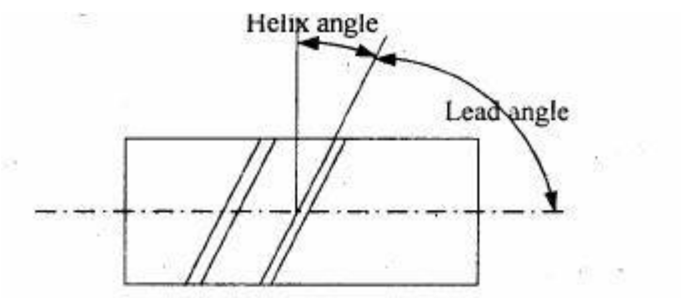
15. Flank:

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.

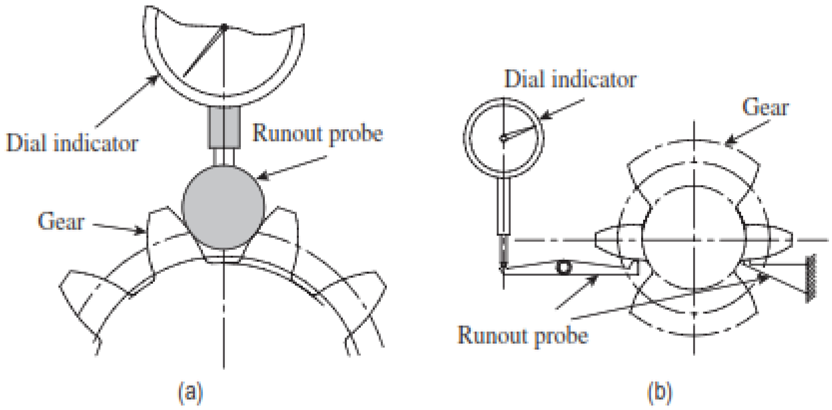


Fig. 4.25 Measurement of radial runout

(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.

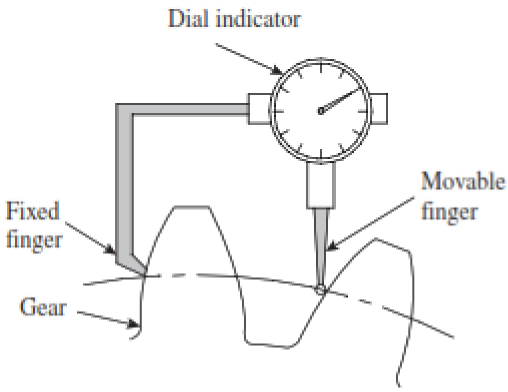


Fig. 4.26 Pitch-measuring instrument

[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.

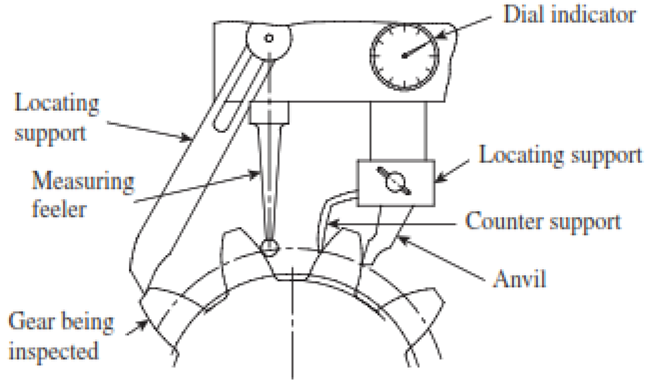


Fig. 4.27 Pitch-checking instrument

[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.

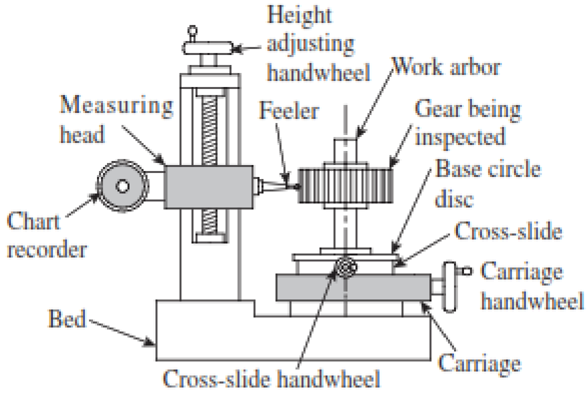


Fig. 4.28 Gear-measuring machine

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

4.4.5.4 Measurement of Lead

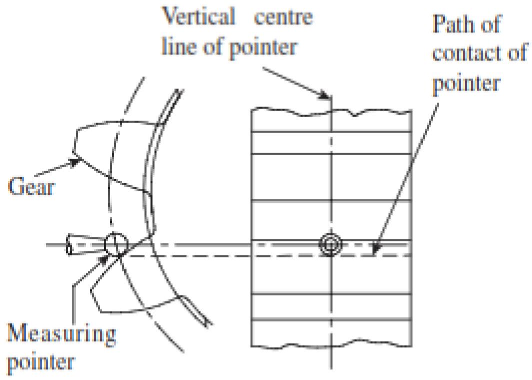


Fig. 4.29 Measurement of lead

[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.

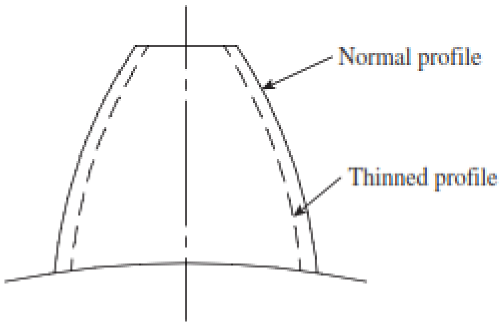


Fig. 4.30 Tooth thinning

[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

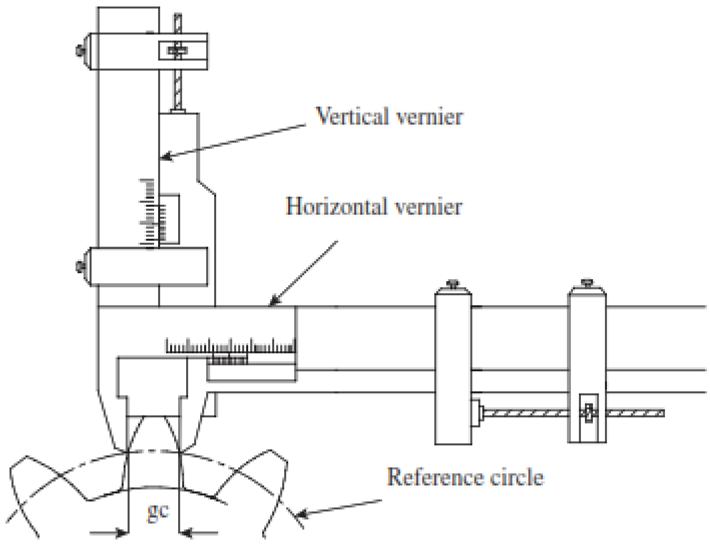


Fig. 4.31 Gear tooth calliper

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

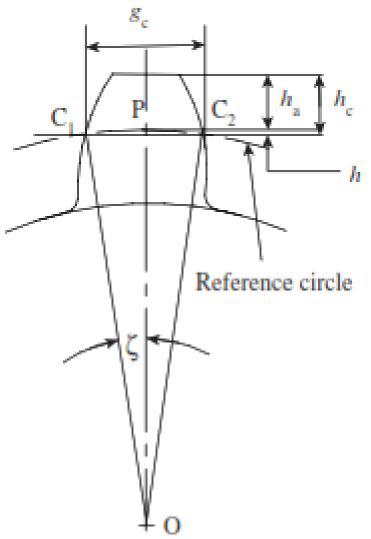


Fig. 4.32 Chordal thickness and chordal height

[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.

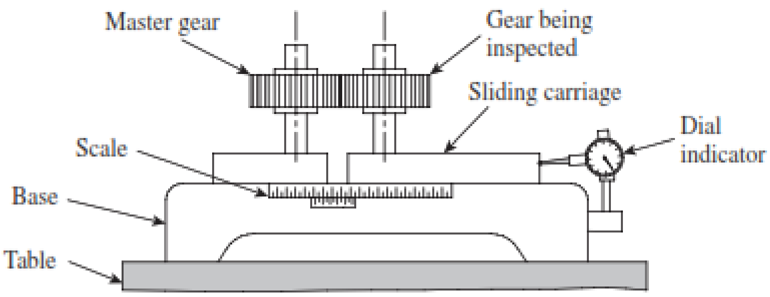


Fig. 4.33 Parkinson gear tester

[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.