UNIT 6 GEAR GENERATION AND FINISHING OPERATIONS

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6.1 INTRODUCTION

Gear is one of the important machine tool elements which is an integral and inevitable part of power transmission system. A gear is a round blank having teeth along its periphery. Gears are used to transfer power or torque from prime mover to the place where it is to be used. Along with the transmission of power gears also transfer the accurate velocity ratio between two shafts.

Velocity ratio is defined as the ratio of rpm (revolution per minute) of driven shaft to the rpm of driver shaft. Power is normally transferred with the help of pair of gears in mesh together, each of these two are mount on driven shaft and driver shaft.

$$\text{Velocity Ratio} = \frac{\text{RPM of driven shaft or driven gear}}{\text{RPM of gear driver shaft or driver}}$$

The gear mounted on the driver shaft is called driver gear and an other gear mounted on the driven shaft is called driven gear. Driver gear and driven gear both constitute a pair of mating gears, these gears are identical with reference to all parameters except their diameters and number of teeth. Two gears mating and transferring power and exact velocity ratio are shown in Figure 6.1. For any pair of malting gears the mandatory condition is their peripheral speed should be exactly same.

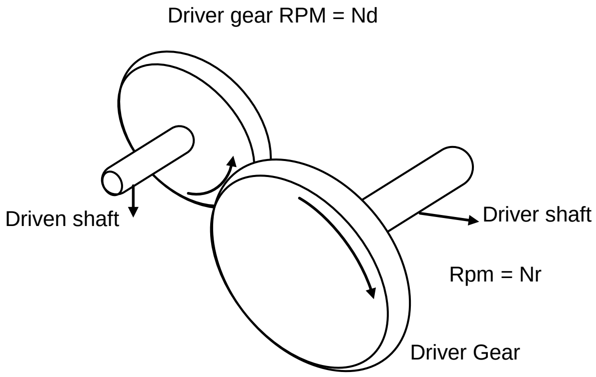

Figure 6.1 : Power Transfer between Driver and Driven Gears

If diameters of driven gear and driver gear are respectively 'D_d' and 'D_r' and these are revolving at N_d and N_r rpm respectively. Then peripheral speed of driver gear = peripheral speed of driven gear.

or $$\pi D_r \; N_r = \pi D_d \; N_d$$

or $$\frac{N_d}{N_r} = \frac{D_r}{D_d} = \text{velocity ratio}$$

Gears are vastly used to form mechanism for transferring power from place of its generation to other parts in the machine this is to effect change in speed, torque or both. speeds of two different parts in a machine can also be maintained relatively and precisely. Different types of gears are used for this purpose. Selection of a particular type of gear depends on so many factors such as relative position of two shafts, power and velocity ratio (*VR*) to be transferred, space limitation, percentage reduction of velocity, running conditions, accuracy of transmission. To understand the gear manufacturing or gear cutting process it is necessary to understand gear terminology first, which is discussed later.

Objectives

After studying this unit, you should be able to understand

- introduction of gears and their applications,
- gear related terminology,
- classification of gear manufacturing methods,
- process of gear shaping,
- gear cutting by gear shaper, its controlling parameters,
- advantages of gear shaping process,
- gear shaping by different types of cutters,
- gear hobbing process, its different types,
- controlling parameters of gear hobbing process,
- advantages and limitations of gear hobbing process,
- describe the gear milling, gear finishing, gear shaving, gear burnishing, roll finishing of gears process,
- explain the gear lapping and honing process, and
- understand the grinding of a gear.

6.2 GEAR TERMINOLOGY

The gear terminology is explained below with reference to a spur gear which is a particular type of a gear. The detail of gear terminology is also indicated in Figure 6.2.

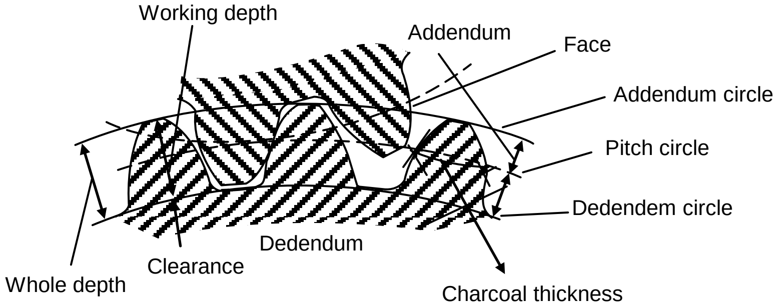

Figure 6.2 : Gear Tooth Terminology

Gear Blank

The metallic workpiece accurately sized and shaped which is used as workpiece for gear cutting is called gear blank. The diameter of gear blank is called gear blank diameter.

Addendum Circle

It is an imaginary circle which passes through top of all gear teeth and represents maximum diameter of a gear. This maximum diameter is equal to gear blank diameter.

Addendum

Addendum of a gear is the radial distance between addendum circle and pitch circle of the gear.

Pitch Circle

This is an imaginary circle along which thickness of a gear tooth becomes equal to spacing between them.

Deddndum

It is the radial distance between pitch circle and root circle of a gear.

Root Circle

Root circle is an imaginary circle which is supposes to pass through root of all gear teeth.

Tooth Clearance

This is the distance between the top of a tooth of one gear and the bottom of the corresponding tooth of other mating gear is known as clearance or tooth clearance.

Pressure Angle

The angle made by the line of action with the common tangent to the pitch circle is called pressure angle.

Face

It is the portion of the tooth lying between top of the tooth and pitch circle.

Flank

This is portion of the gear tooth between its pitch circle and root circle.

Thickness of a Gear Tooth

It is also called chorodal thickness of gear tooth. It is width of two gear tooth measured along the pitch circle. At the pitch circle width of gear tooth becomes equal to the width of spacing between two consecutive gear teeth.

Backlash

It is difference between actual tooth thickness and the width of space at which it meshes with other gear.

Circular Pitch

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

Diametral Pitch

It is number of teeth of a gear per unit of pitch circle diameter.

$$\text{Diametal pitch } (p) = \frac{N}{d}$$

where 'N' is the number of teeth 'd' is the pitch circle diameter.

Module

It is reciprocal of diameteral pitch. It is linear distance in mm that each tooth of the gear would occupy if the gear teeth were spaced along the pitch diameter.

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

with usual notations; *m* is module of gear.

6.3 METHOD OF GEAR MANUFACTURING

In broader sense the gears can be manufactured by the following three methods.

(a) **Casting**

For casting of gears sand moulds or permanent moulds are prepared, then molten metal is poured into the mold cavity to get the required gear. Cast iron gears are made by this method comfortably. These gears (casted gears) cannot be very fine, these are rough, low strength, and with some inaccuracies in operation. There cost of production is very low. This method is recommended for manufacturing of large sized gears where cost and power transmission are important than operating accuracy and noise level.

(b) **Plastic Moulding**

Plastic mould is also one of the way of gear manufacturing. In plastic moulding gears of plastic material can be manufactured by using injection moulding or compression moulding. These are the very light duties gears used for transmission of very low amount of power but maintains velocity ratio accurately.

Plastic moulding is also used for making gears of metal. In this process the metallic workpiece is heated first to bring it to a plastic state and then it is moulded to the required shape with the help of mechanical tools, die, and application of pressure. This process is used to make light duty smaller gears with accuracy. Non-ferrous metals can also be used as raw material for gear making by plastic moulding methods.

(c) **Machining**

This is most widely used gear manufacturing method. Gear blank of accurate size and shape is first prepared by cutting it from metal stock. The gear blank can also be the metal casting. This method lies under the category of chip forming process. Gear is prepared by cutting one by one tooth in the gear blank of desired shape and size along it periphery. Different gear cutting methods are used in this category. These methods are described in details.

6.3.1 Gears Shaping

Gear shaping is one of the gear generating methods. In this process gear tooth are accurately sized and shaped by cutting them by a multipoint cutting tool. Various gear shaping processes are listed and then described below :

(a) Gear cutting by gear shaper.

(b) Rack planning process.

(c) Hobbing process.

Gear Cutting by Gear Shaper

This process uses a pinion shaped cutter carrying clearance on the tooth face and sides and a hole at its centre for mounting it on a stub arbor or spindle of the machine. The cutter is mounted by keeping its axis in vertical position. It is also made reciprocating along the vertical axis up and down with adjustable and predecide amplitude. The cutter and the gear blank both are set to rotate at very low rpm about their respective axis. The relative rpm of both (cutter and blank) can be fixed to any of the available value with the help of a gear train. This way all the cutting teeth of cutter come is action one-by-one giving sufficient time for their cooling and incorporating a longer tool life. The specific advantages of the process over other processes, its product cycle time is very low and negligible dimensional variability from one unit to other in case of mass production. The principle of gear cutting by this process as explained above is depicted in the Figure 6.3. The main parameters to be controlled in the process are described below.

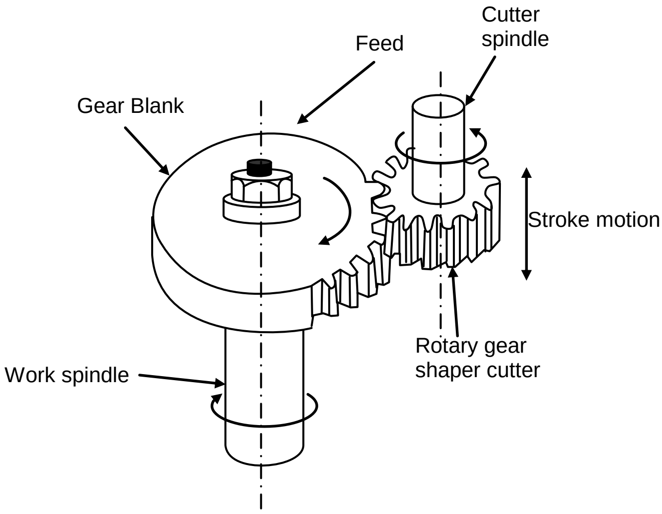

Figure 6.3 : Process of Gear Cutting by Shaper Cutter

Cutting Speed

Shaper cutter can move vertically upward and downward during the operation. The downward during the operation. The downward movement of the cutter is the cutting stroke and its speed (linear) with which it comes down is the cutting speed. After the completion of cutting stroke, cutter comes back to its top position which is called return stroke. There is no cutting in the return stroke. Length of cutting stroke can be adjusted to any value out of available values on the machine.

Indexing Motion

Indexing motion is equivalent to feed motion in the gear shaping operation. Slow rotations of the gear cutter and workpiece provide the circular feed to the operation. These two rpms are adjusted with the help of a change gear mechanism. The rpm are relatively adjusted such that each rotation of the cutter the gear blank revolves through $\frac{n}{N}$ revolution.

where $n \rightarrow$ Number of teeth of cutter, and

N = Number of teeth to be cut on the blank.

Depth of Cut

Indexing movement or circular feed and reciprocating motions continue until the required numbers of teeth to the required depth are made all along the periphery of the gear blank. The required depth is maintained gradually by cutting the teeth into two or three pass. In each successive pass, the depth of cut is increased as compared to its previous path. This gradual increase in depth of cut takes place by increasing the value of linear feed in return stroke.

The whole of this process is carried out an a gear shaping machine which is of the shape of a column and knee type milling machine. All the motions given to gear blank and gear cutter are set controlled very precisely. A setup of gear shaping machine is shown in Figure 6.4.

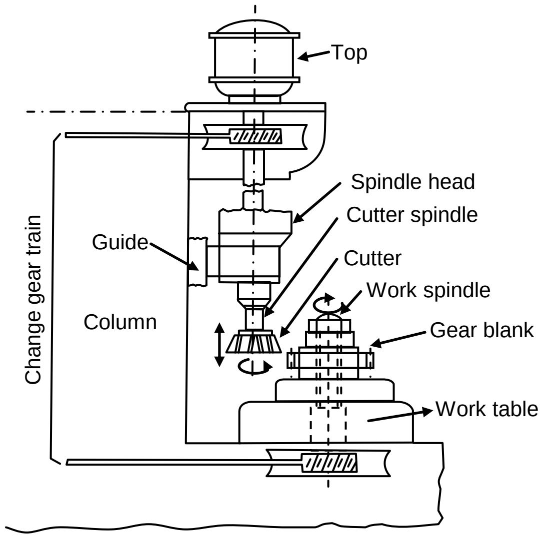

Figure 6.4 : Setup for Gear Shaping Machine

Advantages of Gear Shaping Process

Main advantages of gear shaping process are described below :

(a) Shorter product cycle time and suitable for making medium and large sized gears in mass production.

(b) Different types of gears can be made except worm and worm wheels.

(c) Close tolerance in gear cutting can be maintained.

(d) Accuracy and repeatability of gear tooth profile can be maintained comfortably.

(e) For same value of gear tooth module a single type of cutter can be used irrespective of number of teeth in the gear.

Limitations

Main limitations of gear shaping process are described below :

(a) It cannot be used to make worm and work wheel which is a particular type of gear.

(b) There is no cutting in the return stroke of the gear cutter, so there is a need to make return stroke faster than the cutting stroke.

(c) In case of cutting of helical gears, a specially designed guide containing a particular helix and helix angle, corresponding to the teeth to be made, is always needed on urgent basis.

Gear Shaping by Rack Shaped Cutter

In this method, gear cutting is done by a rack shaped cutter called rack type cutter. The principle is illustrated in Figure 6.5. The working is similar to shaping process done by gear type cutter.

The process involves rotation (low rpm) of the gear blank as the rack type cutter reciprocates along a vertical line. Cutting is done only in the downward stroke, the upward stroke is only a return movement. The main difference of this method with the previous one is that once the full length of the rack is utilized the gear cutting of operation is stopped to bring the gear blank to its starting position so that another pass of gear cutting can be started. So this operation is intermittent for cutting larger gears having large number of teeth over their periphery.

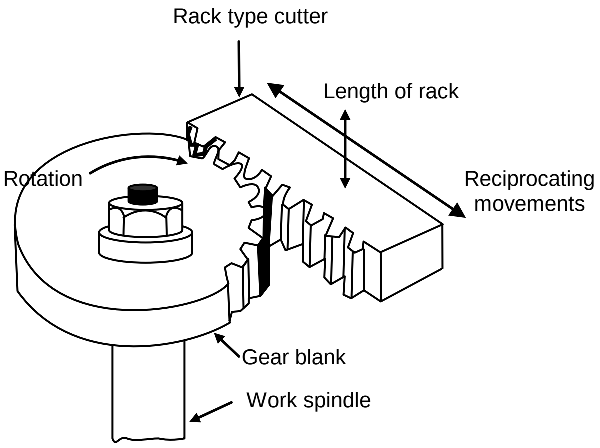

Figure 6.5 : Gear Cutting by Rack Shaped Cutter

Another popular method of gear chopping is Rack Planning Process which is described below.

Rack Planning Process

This process is used for shaping of spur and helical gear teeth with the help of a rack type cutter. In this process the gear blank is mounted on a horizontal aims and rotated impertinently. At the same time the gear blank is kept in mesh with a reciprocating rack type cutter. The process is shown in Figure 6.6. The teeth cutter gradually removes material to cut the teeth and to make the required profile. The whole operation includes some important operations. These are feeding cutter into the blank, rolling the blank intermittently and keeping cutter in mesh with the rolling gear blank. After each mesh the gear blank is rolled by an amount equal to one pitch of gear tooth. After each cutting, the rack is withdrawn and re-meshed after the rotation of gear blank.

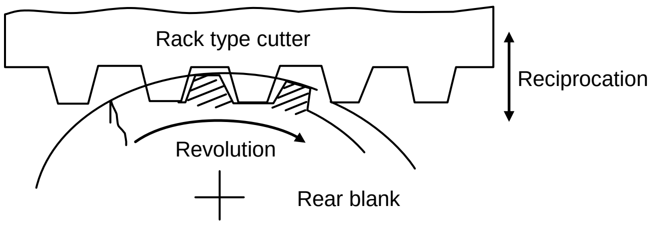

Figure 6.6 : Gear Shaping by Rack Type Cutter

A few of the initial teeth of rack type cutter perform the cutting action and remaining teeth to very small removal of workpiece material, these are used to maintain dimensional accuracy of the already cut teeth and to provide them a good finishing.

The basic principle of gear shaping is same but by slight altering the process some more different methods of gear shaping are discussed below.

Sunderland Process

This process is named after the name of its inventor. In this process the cutter reciprocates in a direction towards and away from the gear blank. The process is illustrated in Figure 6.7. Cutter is gradually fed into the gear blank to the required depth. As soon as cutting is completed upto the desired depth, the blank rotates through one pitch distance. The cutter also moves along with the blank and then suddenly withdraws, stepped back by an amount equal to one pitch distance and again made to reciprocate in the normal way. The gear blank does not move till the completion of whole cutting upto the required depth. The whole motion and movement control is basically maintained with the help of synchronous motor and gear train.

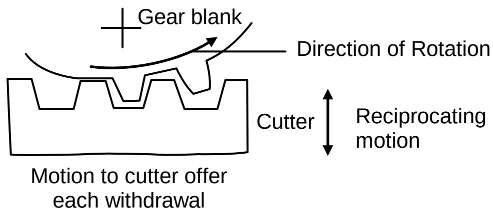

Figure 6.7 : Process of Sunderland Gear Shaping Process

Mang Process

In this process gear blank is mounted on the machine table, keeping its axis in a vertical position. The cutter head, carrying rack type cutter, slides vertically in the sides provided at the front of the machine. The cutter can be set at any angle in a vertical plane. The cutter can also be made reciprocating in any direction. The rest of the process re-samples with other gear shaping processes.

Gear Hobbing Process

In addition to the gear shaping process another process used for gear generation is gear hobbing. In this process, the gear blank is rolled with a rotating cutter called hob. Gear hobbing is done by using a multipoint cutting tool called gear hob. It looks like a worm gear having a number of straight flutes all around its periphery parallel to its axis. These flutes are so shaped by giving proper angles to them so that these work as cutting edges. In gear hobbing operation, the hob is rotated at a suitable rpm and simultaneously fed to the gear blank. The gear blank is alos kept as revolving. Rpm of both, gear blank and gear hob are so synchronized that for each revolution of gear bob the gear blank rotates by a distance equal to one pitch distance of the gear to be cut. Motion of both gear blank and hob are maintained continuously and steady. A gear hob is shown in Figure 6.8 and the process of gear hobbing is illustrated in Figure 6.9. The hob teeth behave like screw threads, having a definite helix angle. During operation the hob is tilted to helix angle so that its cutting edges remain square with the gear blank. Gear hobbing is used for making a wide variety of gears like spur gear, helical, hearing-bone, splines and gear sprockets, etc.

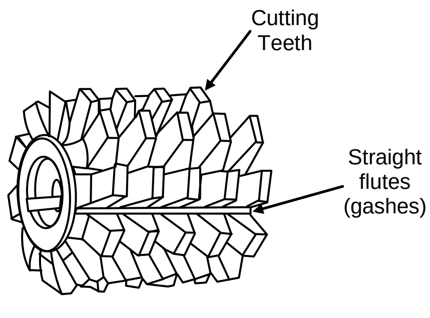

Figure 6.8 : Gear Hob

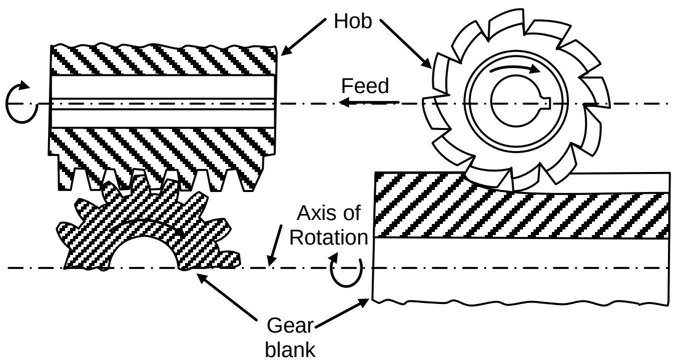

Figure 6.9 : Process of Gear Hobbing

Three important parameters are to be controlled in the process of gear hobbing indexing movement, feed rate and angle between the axis of gear blank and gear hobbing tool (gear hob). A schematic diagram of the setup of a gear hobbing machine is illustrated in Figure 6.10. The aims of hob are set at an inclination equal to the helix angle of the hob with the vertical axis of the blank. If a helical gear is to be cut, the hob axis is set at an inclination equal to the sum of the helix angle of the hob and the helix angle of the helical gear. Proper gear arrangement is used to maintain rpm ratio of gear blank and hob.

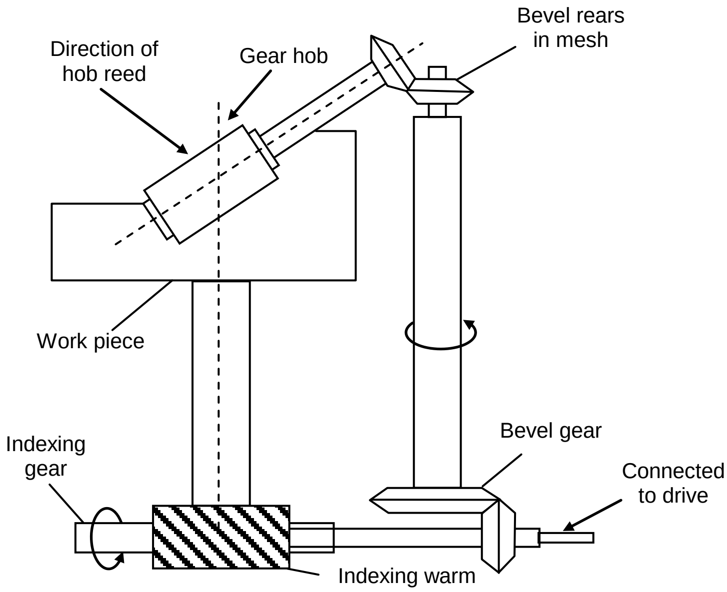

Figure 6.10 : Setup for Gear Hobbing Machine

The operation of gear hobbing involves feeding the revolving hob till it reaches to the required depth of the gear tooth. Simultaneously it is fed in a direction parallel to the axis of rotation. The process of gear hobbing is classified into different types according to the directions of feeding the hob for gear cutting. The classification is described as given below.

Hobbing with Axial Feed

In this process the gear hob is fed against the gear blank along the face of the blank and parallel to its axis. This is used to make spur and helical gears.

Hobbing with Radial Feed

In this method the hob and gear blanks are set with their axis normal to each other. The rotating hob is fed against the gear blank in radial direction or perpendicular to the axis of gear blank. This method is used to make the worm wheels.

Hobbing with Tangential Feed

This is also used for cutting teeth on worm wheel. In this case, the hob is held with its axis horizontal but at right angle to the axis of the blank. The hob is set at full depth of the tooth and then fed forward axially. The hob is fed tangential to the face of gear blank.

Advantages and Limitations of Gear Hobbing Process

Advantages of gear hobbing process are described below :

(a) Gear hobbing is a fast and continuous process so it is realized as economical process as compared to other gear generation processes.

(b) Lower production cycle time, i.e. faster production rate.

(c) The process has a larger variability's in the following of sense as compared to other gear machining processes.

  (i) Capable to make wide variety of gears like spur gear, helical gears, worms, splines, sprockets, etc.

  (ii) Process of required indexing (named so) is quite simplified and capable to make any number of teeth with consistent accuracy of module.

  (iii) A special type of gear named harringbon gear cam be generated by gear hobbing exclusively.

  (iv) Wide variety of batch size (small to large volume) can be accommodated by this process.

(d) Several gear blanks, mounted on the same arbor, can be processed simultaneously.

(e) Hob is multipoint cutting tool having multi cutting teeth or edges at a time few number of cutting edges work so lots of time is available to dissipate the generated heat. There is no over heating and cutting tool.

In addition to above mentioned large number of advantages there is one glaring limitation of the process of gear hobbing. That is manufacturing of internal gears is not possible.

6.5 GEAR MILLING

The gear milling operation is used for gear cutting. All types of gears can be made by using gear milling. Milling cutter is selected specifically for a particular type of gear and module. The periphery of the gear blank is divided into required number of equi-spaced parts. The required number of parts should be equal to the number teeth to be made on the gear blank. The method of dividing the periphery is called indexing which is an integral part of the operation of gear milling. The details of the operation of gear milling and indexing are explained in Unit 1 of this course.

Gear milling is a slower process of gear generation as compared to other gear generation process. In this process gear is generated by cutting one-by-one tooth. Gears are to be made, it is not suitable for larger batch size. The other methods required very high capital cost and setup cost as compared to gear milling so these are not economical for smaller batch size, only gear cutting by milling operation is recommended for smaller batch size.

6.6 GEAR FINISHING OPERATIONS

Surface of gear teeth produced by any of the generating process is not accurate and of good quality (smooth). Dimensional inaccuracies and rough surface generated so become the source of lot of noise, excessive wear, play and backlash between the pair of gears in mesh. These all result in loss of power to be transmitted and incorrect velocity ratios. This can be summarized as inefficient power transmission. In order to over come these problems some finishing operations are recommended for the produced gears. Sometimes poor quality of finish and dimensional inaccuracies occur due to hardening of a produced gear. The prepared (generated) gear is subjected to various hardening processes leading to various problems creating inaccuracies. So finishing operations are to be done at last. Commonly used gear finishing operations are described below.

6.7 GEAR SHAVING

Gear shaving is a process of finishing of gear tooth by running it at very high rpm in mesh with a gear shaving tool. A gear shaving tool is of a type of rack or pinion having hardened teeth provided with serrations. These serrations serve as cutting edges which do a scrapping operation on the mating faces of gear to be finished. Both are gears in mesh are pressed to make proper mating contact. A shaving tool with serrated teeth is explained by illustration in Figure 6.11.

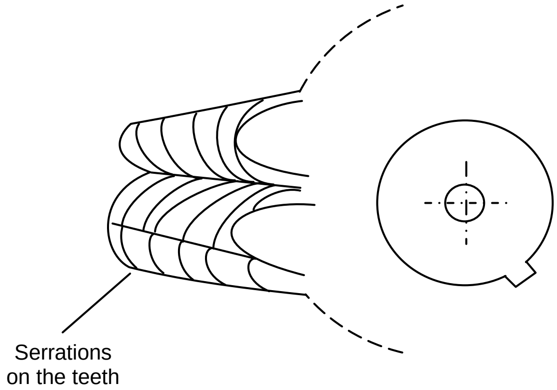

Figure 6.11 : Gear Shaving Tool

6.8 ROLL FINISHING OF GEAR TOOTH

This process involves use of two hardened rolling dies containing very accurate tooth profile of the gear to be finished. The gear to be finished is et in between the two dies as shown in Figure 6.12 and all three are revalued about their axis. Pressure is exerted by both the rolling dies over the gear to be finished. The material of the die is very hard as compare to the material of gear so there is a plastic deformation of high points and burrs on the profile of gear tooth resulting to smooth surface.

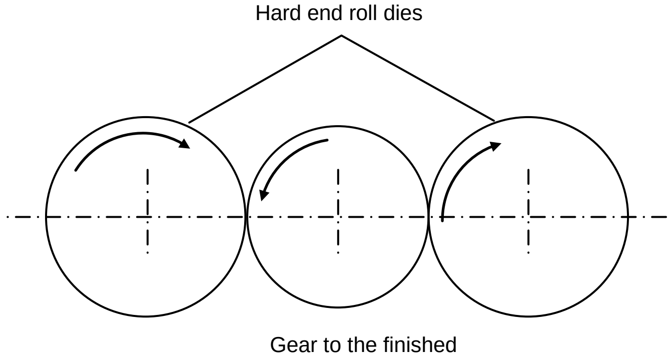

Figure 6.12 : Roll Finishing

6.9 GEAR BURNISHING

The gear to be finished is mounted on a vertical reciprocating shaft and it is kept in mesh with three hardened burnishing compatible gears. The burnishing gears are fed into the cut gear and revalued few revaluations in both the directions. Plastic deformation of irregularities in cold state takes place to give smooth surface of the gear.

Gear Grinding

In this operation abrasive grinding wheel of a particular shape and geometry are used for finishing of gear teeth. Gear to be finished is mounted and reciprocated under the grinding wheel. Each of the gear teeth is subjected to grinding operations this way. The operation is illustrated in the Figure 6.13.

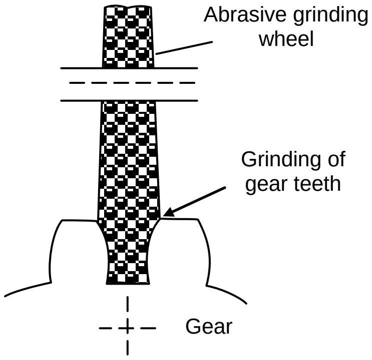

Figure 6.13 : Gear Grinding

Lapping of a Gear

The process of lapping is used to improve surface finish of already made teeth. In this process the gear to be lapped is run under load in mesh with cast iron toothed laps. Abrasive paste is introduced between the teeth. It is mixed with oil and made to flow through the teeth. One of the mating members (either gear or lapping tool) is reciprocated axially along with the revaluations.

6.10 GEAR HONNING

It is used for super finishing of the generated gear teeth. Honing machines are generally used for this operation. The hones are rubbed against the profile generated on the gear tooth. Gear lapping and gear honing are the lost finishing operations of a gear generation process.

In the above gear finishing operations some operations are based on metal cutting by removing very small size of chips like gear shaving, gear grinding, lapping and honing and some other operations like gear burnishing, roll finishing and based on finishing by plastic deformation of metal.

6.11 SUMMARY

Gear and gear trains are one of the important part of machine tool system used to transfer power and accurate velocity ratio from its place of generation to the placed of utilization. A gear is normally evaluated on the basis of some of its important parameters covered as gear terminology. Gear manufacturing is possible by using different methods like gear milling, gear shaping, gear hobbng, etc. Gear milling is recommended for very small batch size of gears as it is comparatively slower process and its associated capital cost and setup costs are comparatively lower. Gear shaping is also a type of gear cutting process, where gear is cut using a special purpose machine named as gear shaper and specific gear cutting tool. A particular tool and setup is used to make large number of gears (large batch size) keeping its initial cost low. Gear shaping is done by different processes like gear shaping by gear shaper, gear shaping by rack shaped cutter, gear shaping by rack planning process, sunderland process and mang process. All these process differ slightly. Their description and relative comparison is described in the unit.

Gear hobbing is another gear generation process with the help of hobbing tool. Gear hobbing is classified on the basis of type of feed, its direction given to hobbing tool. The feed directions are avail feed, tangential feed and radial feed. Advantages limitations of process of gear hobbing are also discussed in the unit. All the generating processes are followed by gear finishing operations. Main gear finishing operations are gear shaving, roll finishing, gear burnishing and gear grinding. Their related machine setup and process details are described in the unit. Gear lapping and gear honing are two more gear finishing operations which are carried out at last. These are considered as ultra finishing operations. Their process details are also described in the unit.

6.12 ANSWERS TO SAQs

Refer the preceding text for all the Answers to SAQs.