Program : **B.Tech**

Subject Name: **Manufacturing Technology**

Subject Code: **ME-405**

Semester: **4th**

Unit-2

GEAR MACHINING

Gears are important machine elements and widely used in various mechanisms and devices to transmit power and motion positively (without slip) between parallel, intersecting (axis) and non-intersecting non parallel shafts:

- Without change in the direction of rotation
- With change in the direction of rotation
- Without change of speed (of rotation)
- With change in speed at any desired ratio

Often some gearing system (rack – and – pinion) is also used to transform rotary motion into linear motion and vice-versa. There are large varieties of gears used in industrial equipments as well as a variety of other applications.

Special attention is paid to gear manufacturing because of the specific requirements to the gears. The gear tooth flanks have a complex and precise shape with high requirements to the surface finish. Gears can be manufactured by most of manufacturing processes. (casting, forging, extrusion, powder metallurgy, blanking, etc.)

But machining is applied to achieve the final dimensions, shape and surface finish in the gear. The initial operations that produce a semi finishing part ready for gear machining as referred to as blanking operations; the starting product in gear machining is called a gear blank.

Two principal methods of gear manufacturing include:

- **Gear forming** - where the profile of the teeth are obtained as the replica of the form of the cutting tool (edge); e.g., milling, broaching etc.
- **Gear generation** - where the complicated tooth profile are provided by much simpler form cutting tool (edges) through rolling type, tool – work motions, e.g., hobbing, gear shaping etc.

Each method includes a number of machining processes, the major of them discussed in this section.

Manufacture of gears needs several processing operations in sequential stages depending upon the material and type of the gears and quality desired. *Those stages generally are:*

- Preforming the blank without or with teeth.
- Annealing of the blank, if required, as in case of forged or cast steels.
- Preparation of the gear blank to the required dimensions by machining.
- Producing teeth or finishing the preformed teeth by machining.
- Full or surface hardening of the machined gear (teeth), if required.
- Finishing teeth, if required, by shaving, grinding etc.
- Inspection of the finished gears.

TYPES OF GEARS

Spur Gear

Gears having cylindrical pitch surfaces are called cylindrical gears. Spur gears belong to the parallel shaft gear group and are cylindrical gears with a tooth line which is straight and parallel to the shaft. Spur gears are the most widely used gears that can achieve high accuracy with relatively easy production processes. They have the characteristic of having no load in the axial direction (thrust load). The larger of the meshing pair is called the gear and smaller is called the pinion.

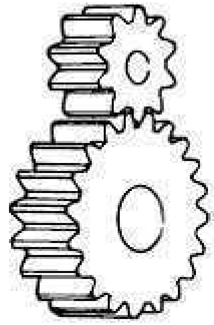

Fig.-2.1 Spur Gear

Helical Gear

Helical gears are used with parallel shafts similar to spur gears and are cylindrical gears with winding tooth lines. They have better teeth meshing than spur gears and have superior quietness and can transmit higher loads, making them suitable for high speed applications. When using helical gears, they create thrust force in the axial direction, necessitating the use of thrust bearings. Helical gears come with right hand and left hand twist requiring opposite hand gears for a meshing pair.

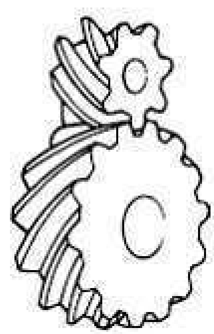

Fig.-2.2 Helical Gear

Gear Rack

Same sized and shaped teeth cut at equal distances along a flat surface or a straight rod is called a gear rack. A gear rack is a cylindrical gear with the radius of the pitch cylinder being infinite. By meshing with a cylindrical gear pinion, it converts rotational motion into linear motion. Gear racks can be broadly divided into straight tooth racks and helical tooth racks, but both have straight tooth lines. By machining the ends of gear racks, it is possible to connect gear racks end to end.

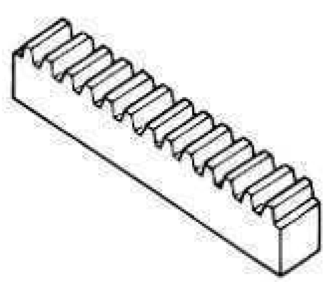

Fig.-2.3 Gear Rack

Bevel Gear

Bevel gears have a cone shaped appearance and are used to transmit force between two shafts which intersect at one point (intersecting shafts). A bevel gear has a cone as its pitch surface and its teeth are cut along the cone. Kinds of bevel gears include straight bevel gears, helical bevel gears, spiral bevel gears, miter gears, angular bevel gears, crown gears, zerol bevel gears and hypoid gears.

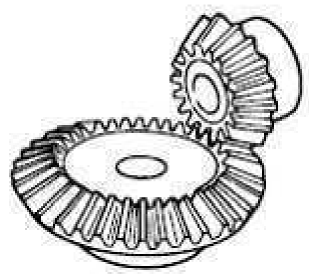

Fig.-2.4 Bevel Gear

Spiral Bevel Gear

Spiral bevel gears are bevel gears with curved tooth lines. Due to higher tooth contact ratio, they are superior to straight bevel gears in efficiency, strength, vibration and noise. On the other hand, they are more difficult to produce. Also, because the teeth are curved, they cause thrust forces in the axial direction. Within the spiral bevel gears, the one with the zero twisting angle is called zerol bevel gear.

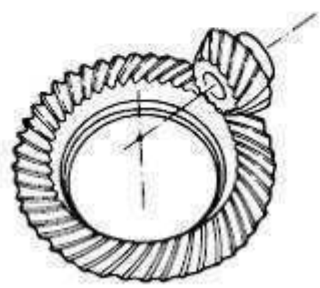

Fig.-2.5 Spiral Bevel Gear

Screw Gear

Screw gears are a pair of same hand helical gears with the twist angle of 45° on non-parallel, non-intersecting shafts. Because the tooth contact is a point, their load carrying capacity is low and they are not suitable for large power transmission. Since power is transmitted by the sliding of the tooth surfaces, it is necessary to pay attention to lubrication when using screw gears. There are no restrictions as far as the combinations of number of teeth.

Fig.-2.6 Screw Gear

Miter Gear

Miter gears are bevel gears with a speed ratio of 1. They are used to change the direction of power transmission without changing speed. There are straight miter and spiral miter gears. When using the spiral miter gears it becomes necessary to consider using thrust bearings since they produce thrust force in the axial direction. Besides the usual miter gears with 90° shaft angles, miter gears with any other shaft angles are called angular miter gears.

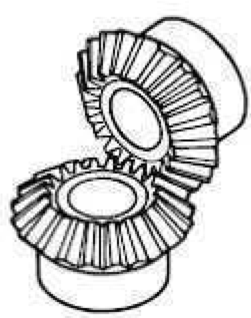

Fig.-2.7 Miter Gear

Worm Gear

A screw shape cut on a shaft is the worm, the mating gear is the worm wheel, and together on non-intersecting shafts is called a worm gear. Worms and worm wheels are not limited to cylindrical shapes. There is the hour-glass type which can increase the contact ratio, but production becomes more difficult. Due to the sliding contact of the gear surfaces, it is necessary to reduce friction. For this reason, generally a hard material is used for the worm, and a soft material is used for worm wheel. Even though the efficiency is low due to the sliding contact, the rotation is smooth and quiet. When the lead angle of the worm is small, it creates a self-locking feature.

Fig.-2.8 Worm Gear

Internal gear

Internal gears have teeth cut on the inside of cylinders or cones and are paired with external gears. The main use of internal gears are for planetary gear drives and gear type shaft couplings. There are limitations in the number of teeth differences between internal and external gears due to involute interference, trochoid interference and trimming problems. The rotational directions of the internal and external gears in mesh are the same while they are opposite when two external gears are in mesh.

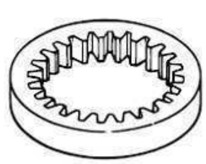

Fig.-2.9 Internal Gear

GEAR FORMING

Production of gears by gear forming method uses a single point cutting tool or a milling cutter having the same form of cutting edge as the space between the gear teeth being cut. This method uses simple and cheap tools in conventional machines and the setup required is also simple. *The principle of gear forming is shown in Fig. 2.10.*

Shaping, planning and slotting

Fig. 2.11 schematically shows how teeth of straight toothed spur gear can be produced in shaping machine. Both productivity and product quality are very low in this process. So this process is used only for making one or few teeth on one or two pieces of gears as and when required for repair and maintenance purpose. The planning and slotting machines work on the same principle. Planning machine is used for making teeth of large gears whereas slotting, generally, for internal gears.

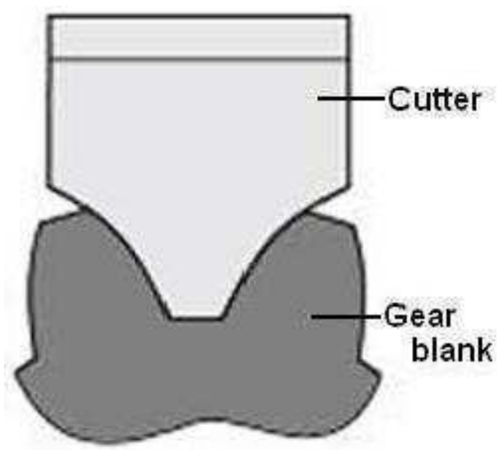

Fig. 2.10 Principle of gear forming

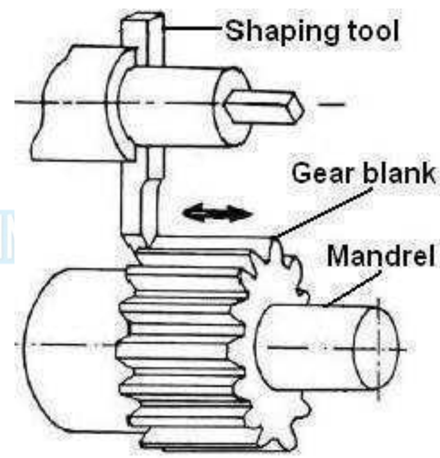

Fig. 2.11 Gear teeth cutting in ordinary shaping machine

Milling

Gear teeth can be produced by both disc type and end mill type form milling cutters in a milling machine. Fig. 2.12 illustrates the production of external spur gear teeth by using disc type and end mill type cutters. Fig. 2.13 shows the form cutters used for finishing cuts and for rough cuts. Fig. 2.14 illustrates the production of external helical gear teeth by using form milling cutter. Fig. 2.15 shows the dividing head and foot stock used to index the gear blank in form milling.

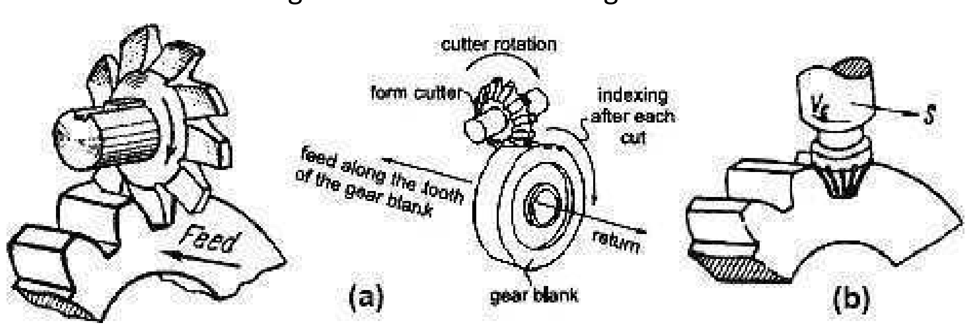

Fig. 2.12 Producing external teeth by form milling cutters

Fig. 2.13 Form milling cutters

(a) disc type and (b) end mill type

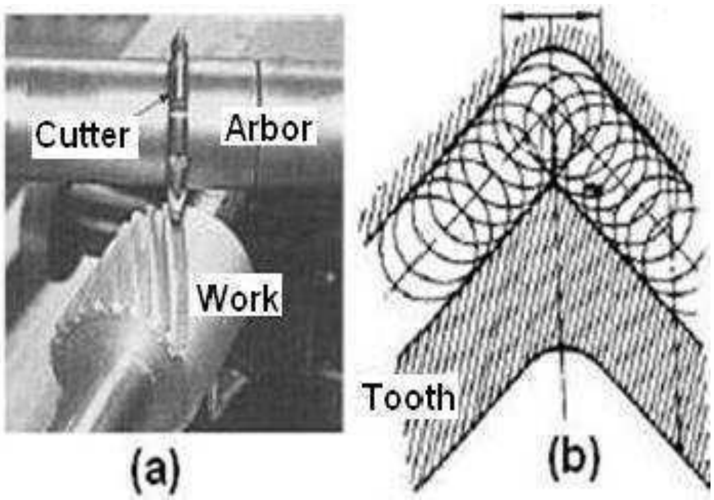

Fig. 2.14 Producing external teeth by form milling used cutters (a) single helical and (b) double helical teeth milling

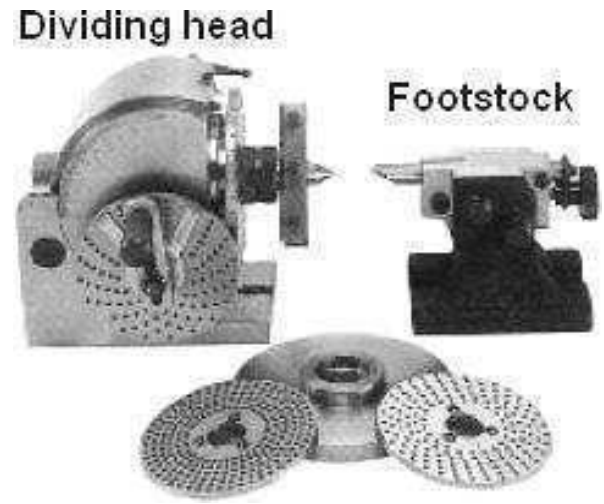

Fig. 2.15 Dividing head and footstock to index the gear blank in form

The form milling cutter called DP (Diametral Pitch, used in inch systems which is equivalent to the inverse of a module) cutter have the shape of the teeth similar to the tooth space with the involute form of the corresponding size gear. These can be used on either horizontal axis or vertical axis milling machines, through horizontal axis is more common.

The cutting tool is fed radially into the work piece till the full depth is reached. Then the work piece is fed past the cutter to complete the machining of one tooth space. Milling of gears is relatively common process in machine shops; it is suitable for small volume production.

The work piece is actually mounted in the dividing head. In form milling, indexing of the gear blank is required to cut all the teeth. Indexing is the process of evenly dividing the circumference of a gear blank into equally spaced divisions. The index head of the indexing fixture is used for this purpose.

The index fixture consists of an index head (also dividing head, gear cutting attachment) and footstock, which is similar to the tailstock of a lathe. The index head and footstock attach to the worktable of the milling machine. An index plate containing graduations is used to control the rotation of the index head spindle. Gear blanks are held between centers by the index head spindle and footstock. Workpieces may also be held in a chuck mounted to the index head spindle or may be fitted directly into the taper spindle recess of some indexing fixtures.

Production of gear teeth by form milling are characterized by:

- Use of HSS form milling cutters.
- Use of ordinary milling cutters.
- Low production rate:
  - Need of indexing after machining each tooth gap.
  - Slow speed and feed.
- Low accuracy and surface finish.
- Inventory problem – due to need of a set of eight cutters for each module – pressure

angle combination.

- End mill type cutters are used for teeth of large gears and / or module.

Fast production of teeth of spur gears by parallel multiple teeth shaping

In principle, it is similar to ordinary shaping but all the tooth gaps are made simultaneously, without requiring indexing, by a set of radially in feeding single point form tools as indicated in Fig. 2.16. This old process was highly productive but became almost obsolete for very high initial and running costs.

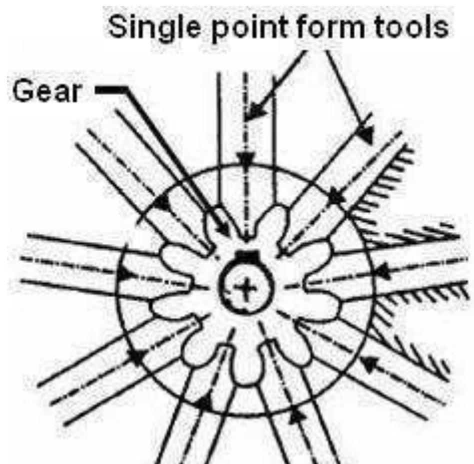

Fig. 2.16 High production of straight teeth of external spur gears by parallel shaping

Fast production of teeth of spur gears by Broaching

Teeth of small internal and external spur gears; straight or single helical, of relatively softer materials are produced in large quantity by this process. Fig. 2.17 (a and b) schematically shows how external teeth are produced by a broaching in one pass. The process is rapid and produces fine surface finish with high dimensional accuracy. However, because broaches are expensive and a separate broach is required for each size of gear, this method is suitable mainly for high-quantity production.

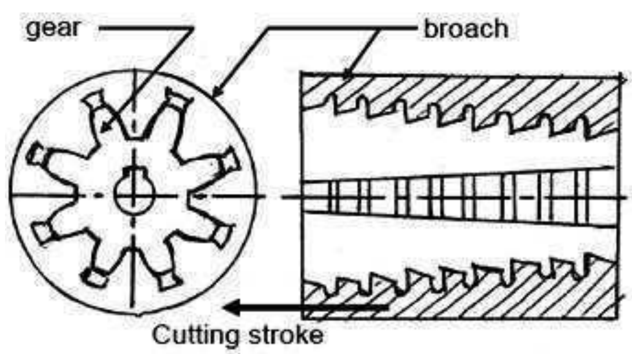

Fig. 2.17 (a) High production of straight teeth segment of external spur gears by broaching

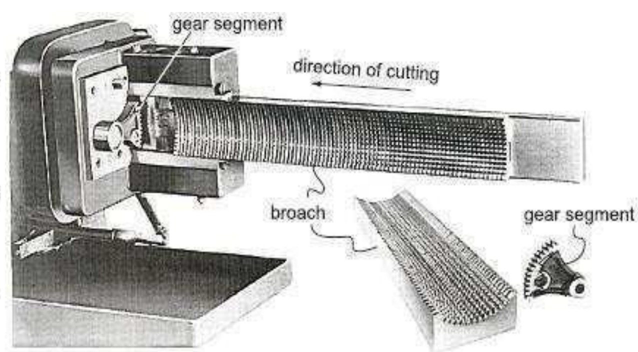

Fig. 2.17 (b) Broaching the teeth of a gear by horizontal external broaching in one pass

GEAR GENERATION

To obtain more accurate gears, the gear is generally generated using a cutter, which is similar to the gear with which it meshes by following the general gear theory. The gears produced by generation are more accurate and the manufacturing process is also fast.

Generation method is characterized by automatic indexing and ability of a single cutter to cover the entire range of number of teeth for a given combination of module and pressure angle and hence provides high productivity and economy. These are used for large volume production.

In gear generating, the tooth flanks are obtained (generated) as an outline of the subsequent positions of the cutter, which resembles in shape the mating gear in the gear pair. In gear generating, two machining processes are employed, shaping and milling. There are several modifications of these processes for different cutting tool used:

- Milling with a hob (gear hobbing).
- Gear shaping with a pinion-shaped cutter.
- Gear shaping with a rack-shaped cutter.

Cutters and blanks rotate in a timed relationship: a proportional feed rate between them is maintained. Gear generating is used for high production runs and for finishing cuts.

Sunderland method using rack type cutter

Fig. 2.18 schematically shows the principle of this generation process where the rack type HSS cutter (having rake and clearance angles) reciprocates to accomplish the machining (cutting) action while rolling type interaction with the gear blank like a pair of rack and pinion.

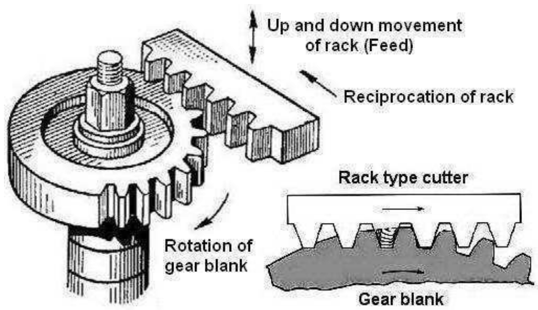

Fig. 2.18 External gear teeth generation by rack type cutter

The favorable and essential applications of this method (and machine) include:

- Moderate size straight and helical toothed external spur gears with high accuracy and finish.
- Cutting the teeth of double helical or herringbone gears with a central recess (groove).
- Cutting teeth of straight or helical fluted cluster gears.

However this method needs, though automatic, few indexing operations. Advantages of this method involve a very high dimensional accuracy and cheap cutting tool (the rack type cutter's teeth blanks are straight, which makes sharpening of the tool easy). The process can be used for low-quantity as well as high-quantity production of spur and helical external gears.

Gear shaping

In principle, gear shaping is similar to the rack type cutting process, except that, the linear type rack cutter is replaced by a circular cutter as indicated in Fig. 2.19, where both the cutter and the blank rotate as a pair of spur gears in addition to the reciprocation of the cutter. Fig. 2.20 schematically shows the generating action of a gear-shaper cutter.

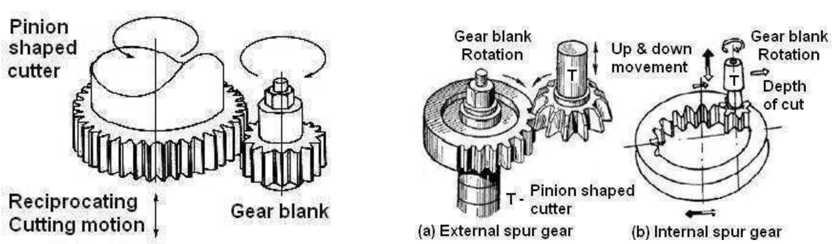

Fig. 2.19 Setup of gear teeth generation by gear shaping operation with a pinion-shaped cutter

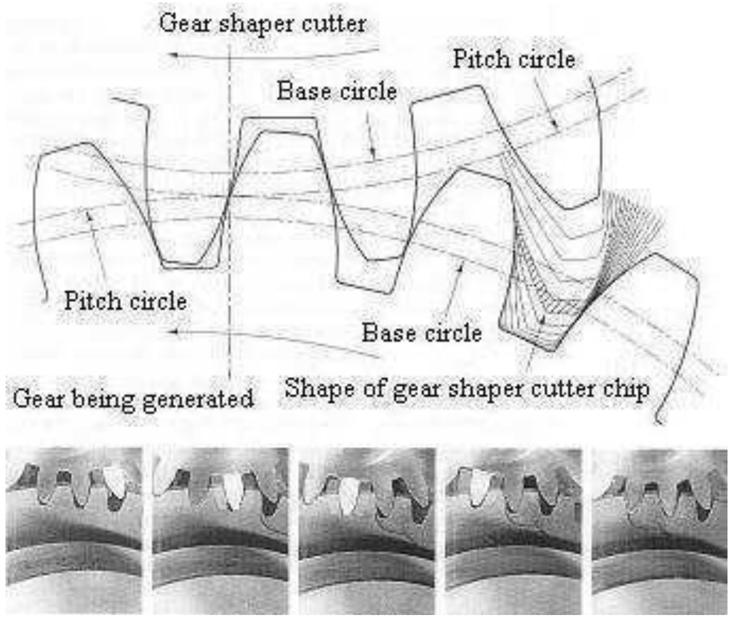

Fig. 2.20 Generating action of a gear-shaper cutter; (Bottom) series of photographs showing various stages in generating one tooth in a gear by means of a gear-shaper cutter, action taking place from right to left. One tooth of the cutter was painted white.

The gear shaper cutter is mounted on a vertical ram and is rotated about its axis as it performs the reciprocating action. The work piece is also mounted on a vertical spindle and rotates in mesh with the shaping cutter during the cutting operation. The relative rotary motions of the shaping cutter and the gear blank are calculated as per the requirement and incorporated with the change gears.

The cutter slowly moves into the gear blank surface with incremental depths of cut, till it reaches the full depth. The cutter and gear blank are separated during the return (up) stroke and come to the correct position during the cutting (down) stroke. Gear shaping can cut internal gears, splines and continuous herringbone gears that cannot be cut by other processes. The gear type cutter is made of HSS and possesses proper rake and clearance angles.

The additional advantages of gear shaping over rack type cutting are:

- Separate indexing is not required at all.
- Straight or helical teeth of both external and internal spur gears can be produced with high accuracy and finish.
- Productivity is also higher.

Gear hobbing

Gear hobbing is a machining process in which gear teeth are progressively generated by a series of cuts with a helical cutting tool (hob). The gear hob is a formed tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges. All motions in hobbing are rotary, and the hob and gear blank rotate continuously as in two gears meshing until all teeth are cut. This process eliminates the unproductive return motion of the gear shaping operation. The work piece is mounted on a vertical axis and rotates about its axis.

The hob is mounted on an inclined axis whose inclination is equal to the helix angle of the hob. The hob is rotated in synchronization with the rotation of the blank and is slowly moved into the gear blank till the required tooth depth is reached in a plane above the gear blank.

The tool-work configuration and motions in hobbing are shown in Fig. 2.21, where the HSS or carbide cutter having teeth like gear milling cutter and the gear blank apparently interact like a pair of worm and worm wheel. The hob (cutter) looks and behaves like a single or multiple start worms. Having lesser number (only three) of tool – work motions, hobbing machines are much more rigid, strong and productive than gear shaping machine. But hobbing provides lesser accuracy and finish and is used only for cutting straight or helical teeth (single) of external spur gears and worm wheels.

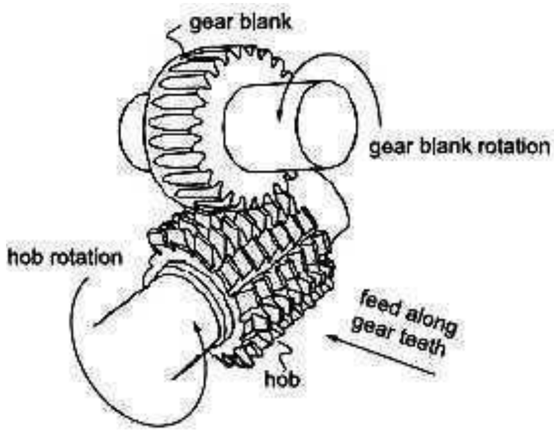

Fig. 2.21 Setup of gear hobbing operation

Fig. 2.22 shows the generation of different types of gears by gear hobbing.

When bobbing a spur gear, the angle between the hob and gear blank axes is 90° minus the lead angle at the hob threads. For helical gears, the hob is set so that the helix angle of the hob is parallel with the tooth direction of the gear being cut. Additional movement along the tooth length is necessary in order to cut the whole tooth length. Machines for cutting precise gears are generally CNC type and often are housed in temperature controlled rooms to avoid dimensional deformations.

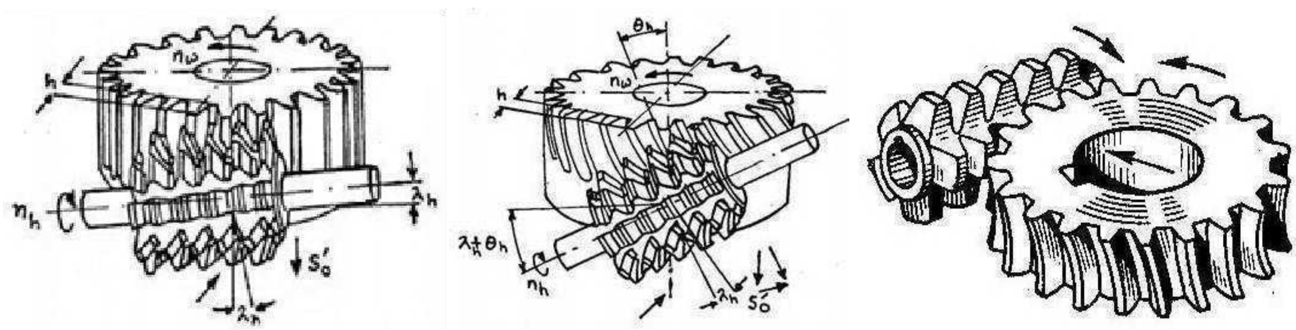

Fig. 2.22 Generation of external gear teeth by hobbing (a) spur gear (b) helical gear and (c) worm wheel

