

# Module 7

## Screw threads and gear manufacturing methods

# Lesson 32 Manufacturing of Gears.

## Instructional objectives

At the end of this lesson, the students will be able to

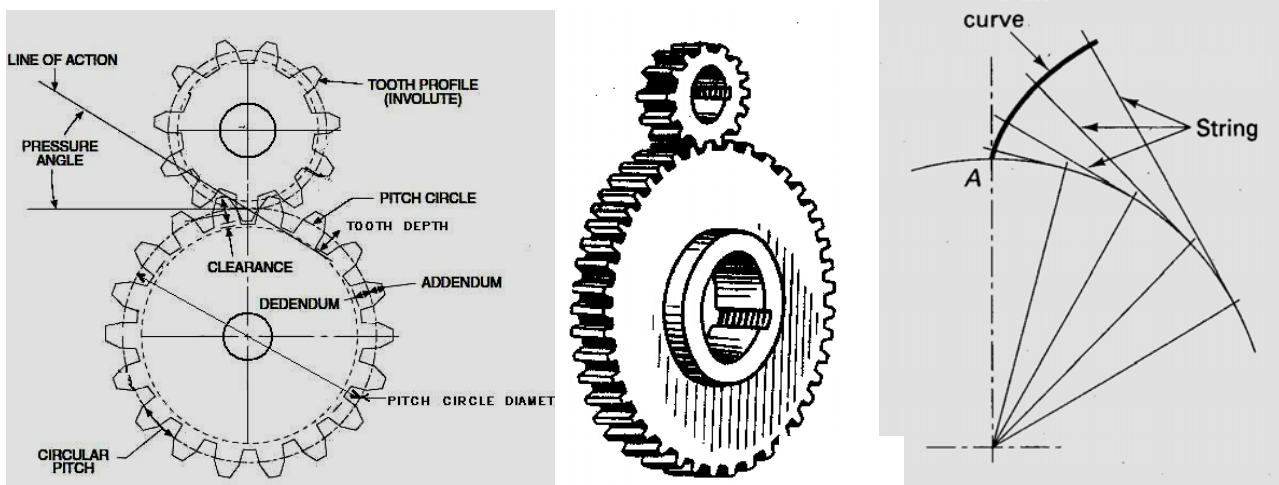
- (i) State the basic purposes of use of gears
- (ii) Cite the general applications of gears
- (iii) Classify the types of gears of common use
- (iv) Specify gears
- (v) Describe the different methods of manufacturing various types of gears
  - (a) Preforming
  - (b) Producing gear teeth by machining
  - (c) Finishing gear teeth

### (i) Basic Purpose Of Use Of Gears

Gears are widely used in various mechanisms and devices to transmit power and motion positively (without slip) between parallel, intersecting (axis) or 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.



**Fig. 7.2.1** Features of spur gears and involute tooth profile

Gears are basically wheels having, on its periphery, equispaced teeth which are so designed that those wheels transmit, without slip, rotary motion smoothly and uniformly with minimum friction and wear at the mating tooth – profiles. To achieve those favourable conditions, most of the gears have their tooth form based on involute curve, which can simply be defined as Locus of a point on a straight line which is rolled on the periphery of a circle or Locus of the end point of a stretched string while its unwinding over a cylinder as indicated in Fig. 7.2.1

## (ii) General Applications Of Gears

Gears of various type, size and material are widely used in several machines and systems requiring positive and stepped drive. The major applications are :

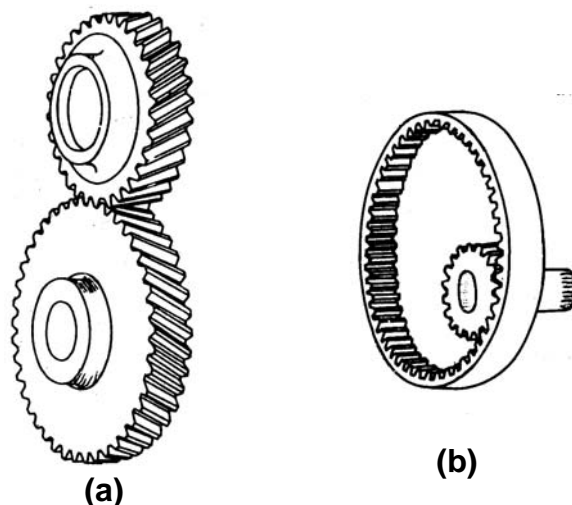
- Speed gear box, feed gear box and some other kinematic units of machine tools
- Speed drives in textile, jute and similar machineries
- Gear boxes of automobiles
- Speed and / or feed drives of several metal forming machines
- Machineries for mining, tea processing etc.
- Large and heavy duty gear boxes used in cement industries, sugar industries, cranes, conveyors etc.
- Precision equipments, clocks and watches
- Industrial robots and toys.

## (iii) Types Of Gears And Their Characteristics

Gears are broadly classified

### (a) According to configuration (Fig. 7.2.2)

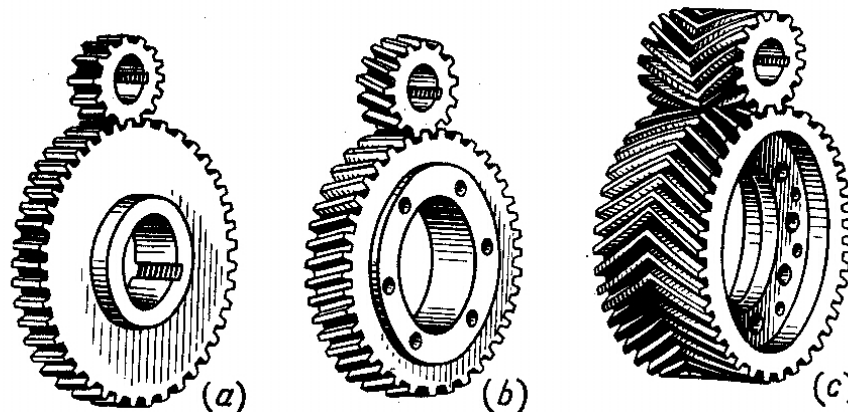
- External gear
- Internal gear



**Fig. 7.2.2** Configuration of (a) external and (b) internal gears

**(b) According to axes of transmission**

- **Spur gears** – transmitting rotation between parallel shafts as shown in Fig. 7.2.3
  - Straight toothed
  - Helical toothed
    - Single helical
    - double helical (herringbone)



**Fig. 7.2.3** (a) Straight toothed (b) Helical and (c) Double helical gears

Compared to straight toothed gears, helical toothed gears run more smoothly and can transmit larger torque. Double helical gears are of large size and used for heavy torque transmission.

- **Bevel gears** – transmitting motion between intersecting shafts (axes) (Fig. 7.2.4)
  - Straight toothed
  - Helical toothed
    - Spiral bevel gear
    - Hypoid gear

Helical toothed bevel gears are used for smoother and larger torque transmission.

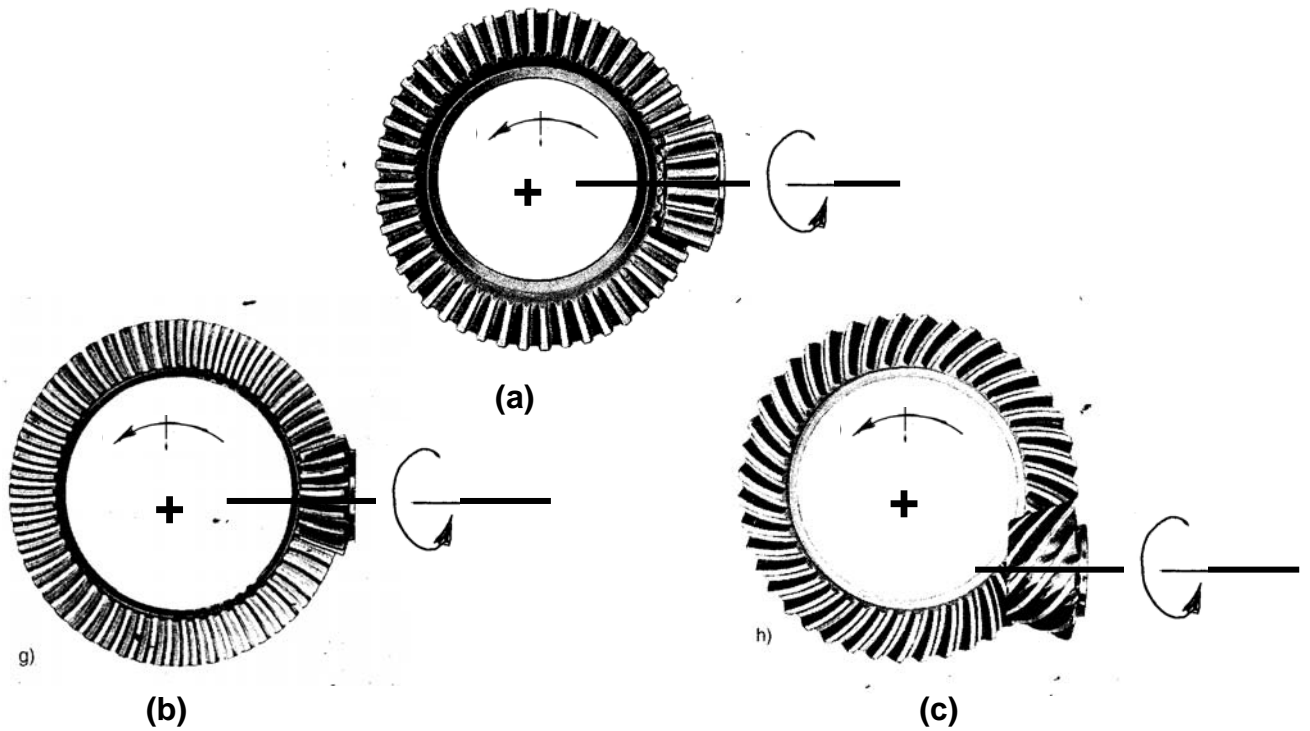
- **Gears transmitting motion and power between non-parallel non-intersecting shafts** (Fig. 7.2.5)
  - Worm and worm wheel
  - Spiral gears
  - Skewed or hypoid bevel gears

Worm and worm wheel are generally used for speed reduction but are irreversible i.e., rotation can be transmitted only from the worm to the worm wheel unless the helix angle is too large.

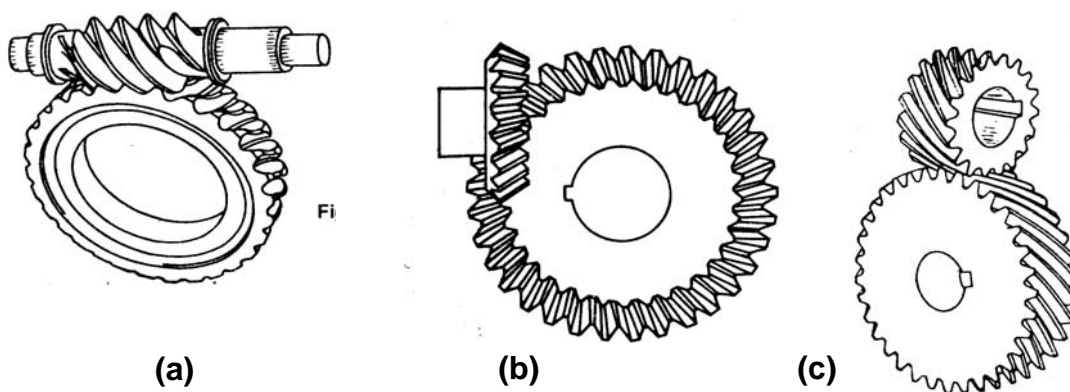
Spiral gears are used when torque or power to be transmitted is insignificant.

**(c) According to pattern of motion**

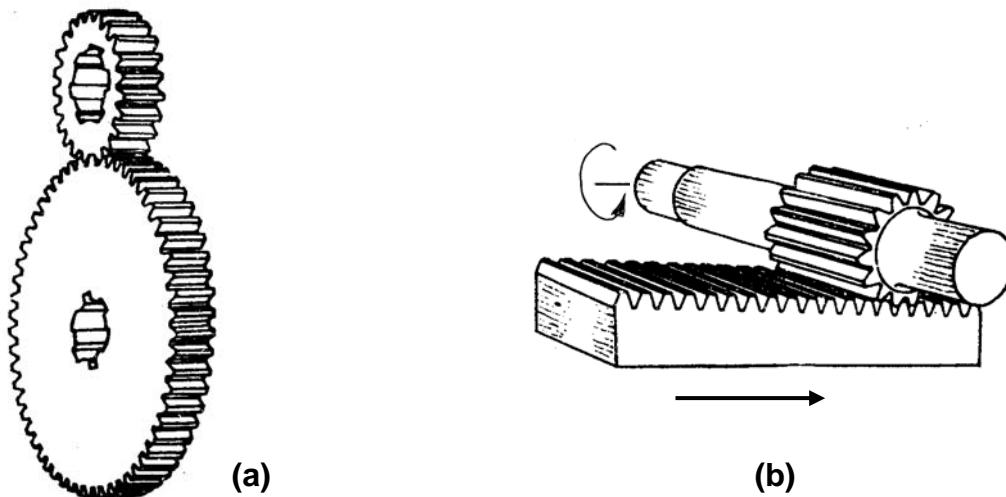
- Rotation to rotation : - (Fig. 7.2.6) wheel type gears
- Rotation to translation or vice versa – e.g. rack and pinion
  - Straight toothed
  - Helical toothed



**Fig. 7.2.4** Bevel gears; (a) straight toothed, (b) spiral and hypoid gears



**Fig. 7.2.5** Gears transmitting power between non-parallel non intersecting shafts. (a) worm and worm wheel, (b) hypoid gear and (c) spiral gears.



**Fig. 7.2.6** Gearing systems transforming (a) rotation to rotation and (b) rotation to translation

#### (iv) Specification Of Gears

Gears are generally specified by their

- Type; e.g. spur, bevel, spiral etc.
  - Material
  - Size or dimensions
  - Geometry
  - Special features, if any
- **Type of gears** – has already been discussed in the previous section (iii)
  - **Gear materials**

The materials of most of the gears used for transmitting reasonable torque and speed mainly need to be mechanically strong in shear and bending, sufficiently tough and resistant to wear, fatigue and chemical degradation.

However, the material for any gear is selected based on,

- The working condition ie, power, speed and torque to be transmitted
- Working environment, i.e., temperature, vibration, chemical etc.
- Ease of manufacture
- Overall cost of material and manufacture

The materials generally used for making gears are :

- Δ Ferrous metals – for high loads
  - Grey cast iron – preferred for reasonable strength and wear resistance, ease of casting and machining and low cost
  - Forged or rolled high carbon steels and alloy steels (Ni-Cr, Mo etc.) which are either fully hardened or surface hardened for use under high stresses and speed.

- Δ Non ferrous metals – for light load
  - Aluminium, bronze and brass are used for making gears having fine teeth and working at very light load – e.g., in equipments, toys etc. or against hard steel mating gears
  - Aluminium alloys like aluminium bronze, Zinc – Al. alloy etc.
- Δ Non-metals – widely used for light load, non-precision and noiseless operation. Polymers (plastics) : both thermoplastic and thermosetting type and various composites (metals, graphite, wood dust or ceramic powders dispersed in thermosetting plastics)

- **Size or major dimensions**

The dimensional features that are used to express or specify the gears are ;

- Δ For spur gears and worm wheels
  - number of teeth,  $z$
  - module,  $m$
  - helix angle, if any ( $\theta$ )
  - width ( $b$ )

For example, pitch circle diameter (PCD) =  $mZ/\cos\theta$

- Δ For worm (single or double toothed gears)
  - number of start
  - module helix angle length

- **Gear geometry**

Some geometrical features also need to be mentioned while specifying gears, such as,

- Δ Pressure angle
- Δ Addendum and dedendum

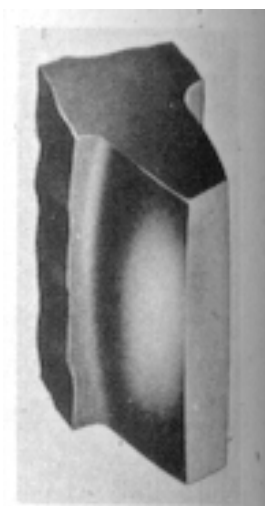
- **Special features**

If there be any special feature, that also has to be included with gear specification, such as

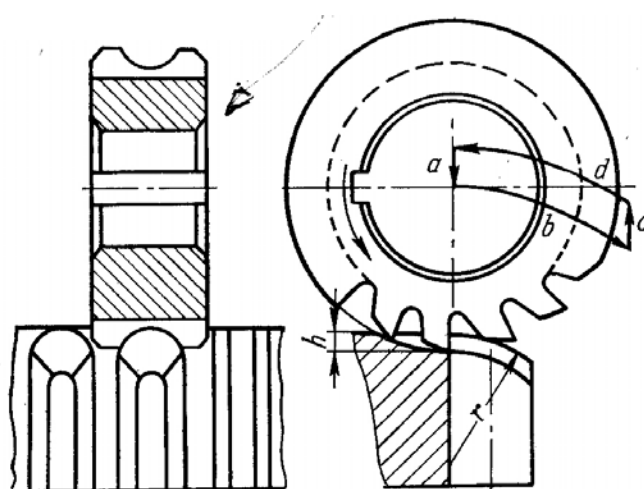
- Tooth bevelling for safe handling
- Tooth crowning for uniform wear and long service life
- Tooth rounding for easy engagement

as indicated in Fig. 7.2.7





(a)



(b)

**Fig. 7.2.7** Modification of spur gear tooth; (a) crowning and (b) tooth rounding

## (V) Manufacture Of Gears

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.

In this section, performing, producing teeth by machining and gear teeth finishing have been discussed in detail.

### Preforming Gear Blanks

- **Casting**

Gear blanks and even gears along with teeth requiring substantial to little machining or finishing are produced by various casting processes.

- o **Sand casting**

The blanks of large cast iron gears, if required to be made one or few pieces, are produced by sand casting. Then the blank is prepared to appropriate dimensions and the teeth are produced by machining that cast preform. Complete gears with teeth can also be directly produced by such casting and used at low speed in machineries like farm

machinery and hand operated devices where gear accuracy and finish are not that much required.

- o **Metal mould casting**

Medium size steel gears with limited accuracy and finish are often made in single or few pieces by metal mould casting. Such unfinished gears are used in several agro-industries. For general and precision use the cast preforms are properly machined.

- o **Die casting**

Large lot or mass production of small gears of low melting point alloys of Al, Zn, Cu, Mg etc. are done mainly by die casting. Such reasonably accurate gears are directly or after little further finishing are used under light load and moderate speeds, for example in instruments, camera, toys.

- o **Investment casting**

This near-net-shape method is used for producing small to medium size gears of exotic materials with high accuracy and surface finish hardly requiring further finishing. These relatively costly gears are generally used under heavy loads and stresses.

- o **Shell mould casting**

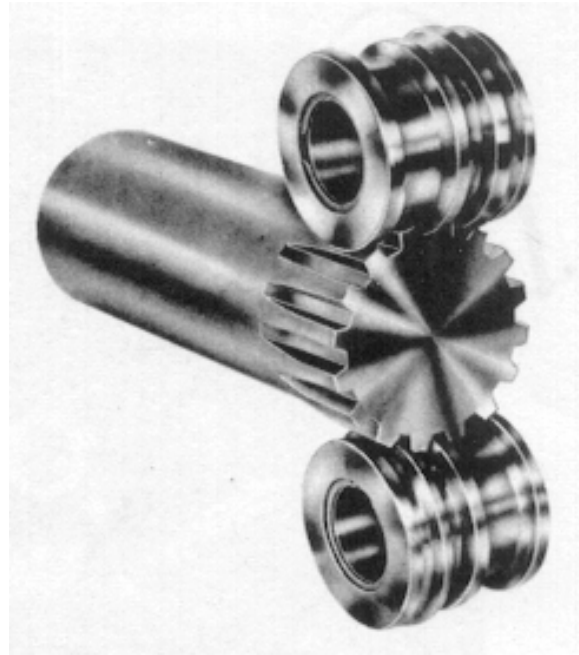
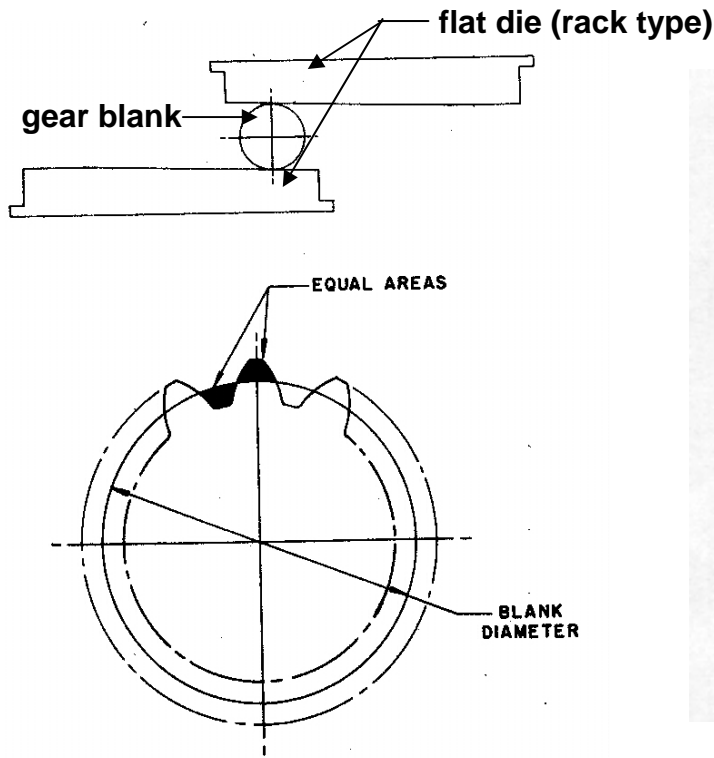
Small gears in batches are also often produced by this process. The quality provided by this process lies in between that of sand casting and investment casting.

- o **Centrifugal casting**

The solid blanks or the outer rims (without teeth) of worm wheels made of cast iron, phosphor bronze or even steel are preferably preformed by centrifugal casting. The preforms are machined to form the gear blank of proper size. Then the teeth are developed by machining.

- **Manufacture of gears by rolling**

The straight and helical teeth of disc or rod type external steel gears of small to medium diameter and module are generated by cold rolling by either flat dies or circular dies as shown in Fig. 7.2.8. Such rolling imparts high accuracy and surface integrity of the teeth which are formed by material flow unlike cutting. Gear rolling is reasonably employed for high productivity and high quality though initial machinery costs are relatively high. Larger size gears are formed by hot rolling and then finished by machining



**Fig. 7.2.8** Production of teeth of spur gears by rolling.

- **Powder metallurgy**

Small size high quality external or internal spur, bevel or spiral gears are also produced by powder metallurgy process. Large size gears are rolled after briquetting and sintering for more strength and life. Powder metallurgically produced gears hardly require any further finishing work.

- **Blanking in Press tool**

Mass production of small and thin metallic gears requiring less accuracy and finish are often done by blanking from sheets by suitably designed die and punch. Such gears are used for clocks, watches, meters, toys etc. However, quality gears can also be produced by slight finishing (shaving) after blanking.

- **Plastic moulding**

Small to medium size plastic gears with or without metal core are manufactured in large quantity by injection moulding. Such moderately accurate and less noisy gears, both external and internal types, are used under light loads such as equipments, toys, meters etc.

- **Extrusion process**

High quality small metallic or non metallic external gears are often produced in large quantity by extrusion. Number of gears of desired width are obtained by parting from the extruded rod of gear – section.

- **Wire EDM**

Geometrically accurate but moderately finished straight toothed metallic spur gears, both external and internal type, can be produced by wire type Electro-discharge Machining (EDM) as shown in Fig. 7.2.9



**Fig. 7.2.9** *Production of teeth of external and internal spur gears by Wire-Electrodischarge machining (EDM)*

## **Production of Gear Teeth by Machining**

It appears from the previous section that gears are manufactured in several routes ;

- Δ The preformed blanks of approximate shape and irregular surface are machined to desired dimensions and finish and then the teeth are produced generally by machining and occasionally by rolling.
- Δ Full gears with teeth are made by different processes and then finished by further machining and / or grinding
- Δ Accurate gears in finished form are directly produced by near – net – shape process like rolling, plastic moulding, powder metallurgy etc. requiring slight or no further finishing.

The most commonly practiced method is preforming the blank by casting, forging etc. followed by pre-machining to prepare the gear blank to desired dimensions and then production of the teeth by machining and further finishing by grinding if necessary.

Gear teeth are produced by machining based on

- **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.
- **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.

- **Methods of production of gear teeth by machining on Forming principle**

- **Shaping, planing and slotting**

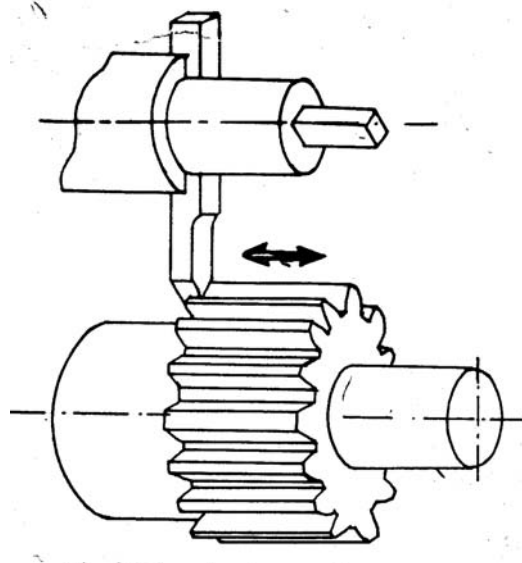
Fig. 7.2.10 schematically shows how teeth of straight toothed spur gear can be produced in shaping machine, if necessary. Both productivity and product quality are very low in this process which therefore, is used, if at all, for making one or few teeth on one or two pieces of gears as and when required for repair and maintenance purpose. In principle planing and slotting machines work on the same principle. Planing machine is used, if required at all, for making teeth of large gears whereas slotting, generally, for internal gears.

- **Milling**

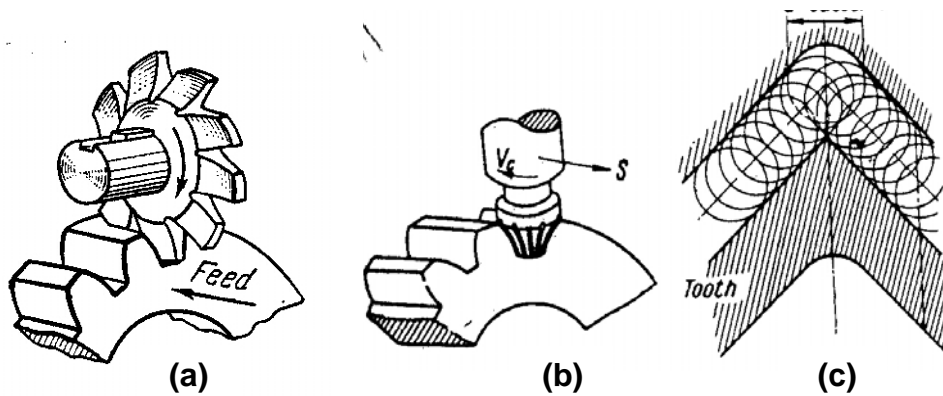
Gear teeth can be produced by both disc and end mill type form milling cutter as shown in Fig. 7.2.11

Production of gear teeth by form milling are characterised by :

- use of HSS form milling cutters
- use of ordinary milling machines
- low production rate for
  - 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.



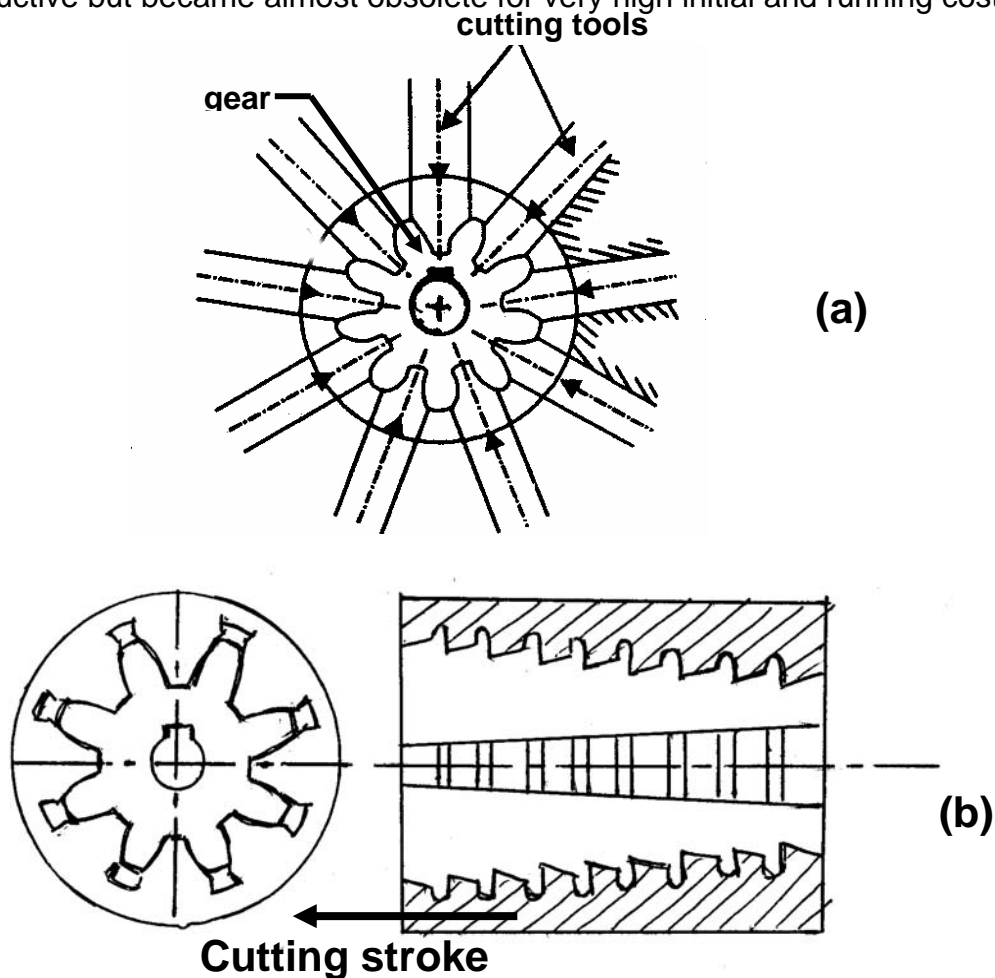
**Fig. 7.2.10** Gear teeth cutting in ordinary shaping machine.



**Fig. 7.2.11** Producing external teeth by form milling cutters (a) disc type and end mill type for (b) single helical and (c) double helical teeth

- o **Fast production of teeth of spur gears**
  - **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 infeeding single point form tools as indicated in Fig. 7.2.12(a). This old process was highly productive but became almost obsolete for very high initial and running costs.



**Fig. 7.2.12** High production of straight teeth of external spur gears by (a) parallel shaping (forming) and (b) broaching

- **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. 7.2.12 (b) schematically shows how external teeth are produced by a broaching in one pass. This method leads to very high productivity and quality but cost of machine and broach are very high.

- **Production of gear teeth by machining on Generation principle**

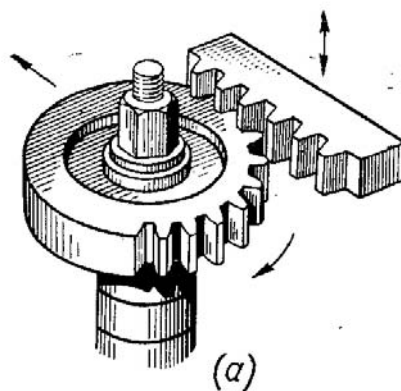
Generation method is characterised by automatic indexing and ability of a single cutter to cover the entire range of number of teeth for a given combination of module and pressure angle and hence provides high productivity and economy.

- **Sunderland method using rack type cutter**

Fig. 7.2.13 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. The favourable 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.



**Fig. 7.2.13** External gear teeth generation by rack type cutter  
(Sunderland method)

- **Gear shaping**

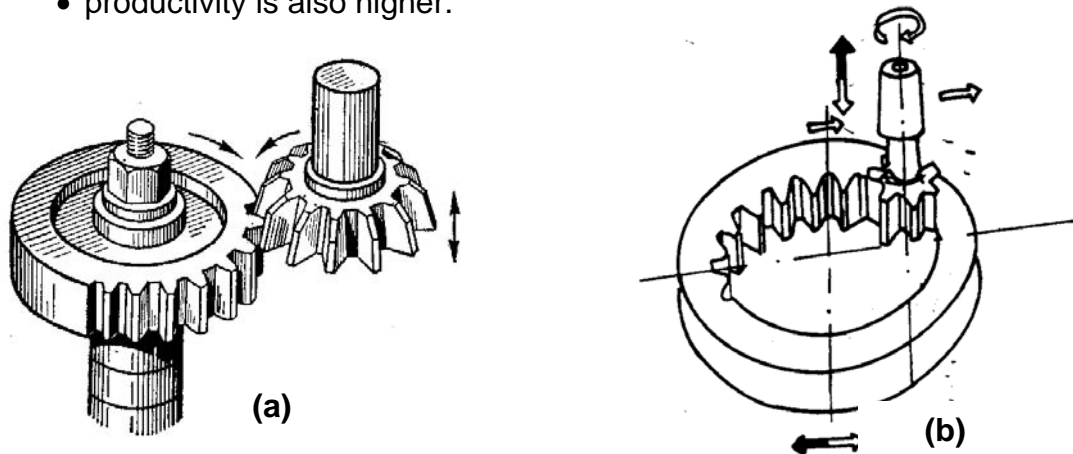
In principle, gear shaping is similar to the rack type cutting process, excepting that, the linear type rack cutter is replaced by a circular cutter as indicated in Fig. 7.2.14, where both the cutter and the blank rotate as a pair of spur gears in addition to the reciprocation of the cutter.

Generation method is characterised 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.

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 :

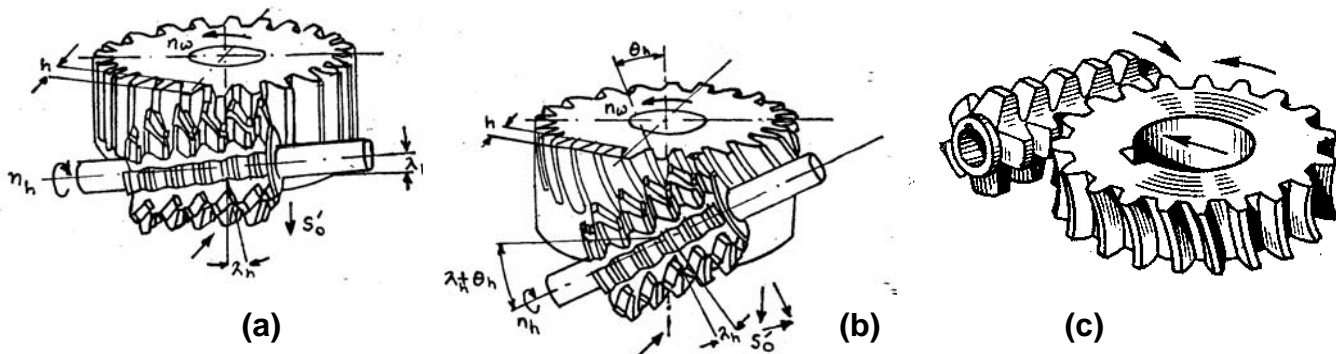
- separate indexing is not required at all
- straight or helical teeth of both external and internal spur gears can be produced with high accuracy and finish
- productivity is also higher.



**Fig. 7.2.14** Gear teeth generation by gear shaping (a) external and (b) internal spur gear

#### o Hobbing

The tool-work configuration and motions in hobbing are shown in Fig. 7.2.15, 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 worm. 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. 7.2.15** Generation of external gear teeth by Hobbing : (a) straight tooth (b) helical tooth and (c) worm wheel



### \* Manufacture of worm

The screw like single or multi-start worms (gears) made of steel are generally made by machining like long thread milling or by cold rolling like thread rolling followed by heat treatment for surface hardening and finishing by grinding.

### \* Manufacture of bevel gears

In manufacture of bevel gears, first the blanks are preformed by casting or forging followed by machining to desired dimensions in lathes or special purpose machine.

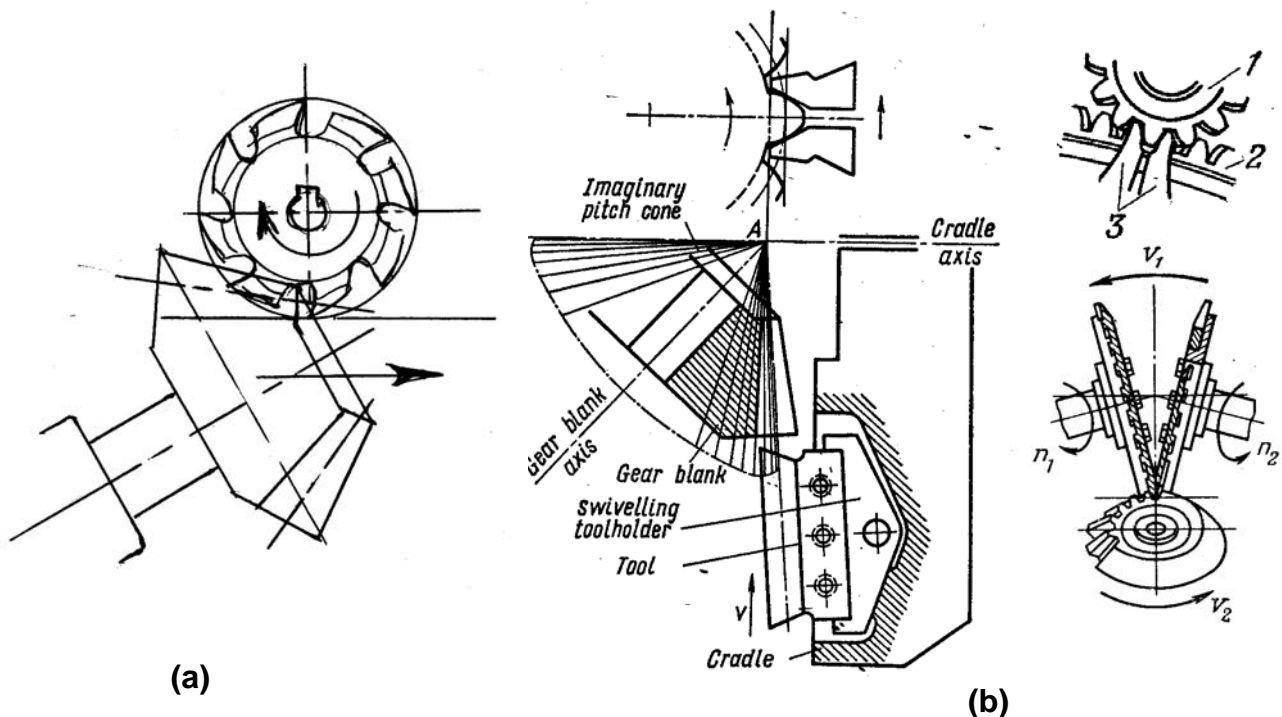
Then the teeth are produced in the blank by machining. The way of machining and machine tool are chosen based on the form of teeth and volume of production as follows :

#### Δ Straight toothed bevel gear

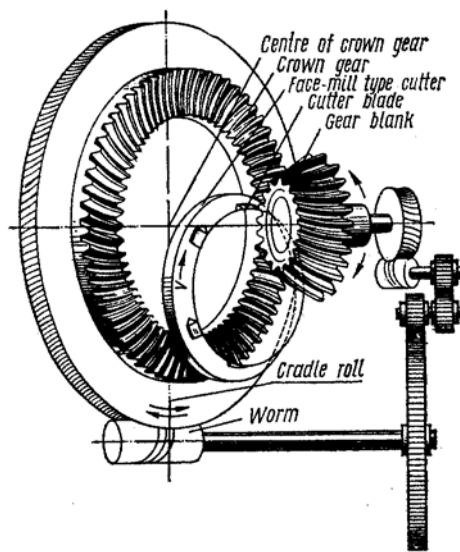
- Forming by milling cutter – low productivity and quality hence employed for production requiring less volume and precision
- Generation – high accuracy and finish, hence applied for batch to mass production.

Fig. 7.2.16 schematically shows the principle of forming and generation of teeth of straight toothed bevel gear. In generation process, the inner flanks of two adjacent teeth are developed with involute profile by the straight teeth of the cutters under rolling action.

- #### Δ Teeth of spiral and hypoid bevel gears are produced by almost the same generation principle but the cutter resembles face milling cutter as shown in Fig. 7.2.17.



**Fig. 7.2.16** Production of teeth of straight toothed spur gear by (a) forming and (b) generation



**Fig. 7.2.17** Generation of teeth of spiral and hypoid bevel gear.

## Finishing of Gear Teeth

For smooth running, good performance and long service life, the gears need

- to be accurate in dimensions and forms
- to have high surface finish and
- to be hard and wear resistive at their tooth flanks

which are achieved by some gear teeth finishing work after near accurate preforming and machining. Small gears made by cold rolling generally do not require further finishing. If a rolled gear needs further surface hardening only then little finishing by grinding and / or lapping is done after hardening.

Gears produced to near-net-shape by die casting, powder metallurgy, extrusion, blanking etc. need little finishing.

But machined and hardened gear teeth are essentially finished for accuracy and surface finish.

Common methods of gear teeth finishing

Gear teeth, after preforming and machining, are finished generally by;

- o for soft and unhardened gears
  - gear shaving
  - gear rolling or burnishing
- o for hard and hardened gears
  - grinding
  - lapping
- o for soft but precision gears
  - shaving followed by surface hardening and then lapping

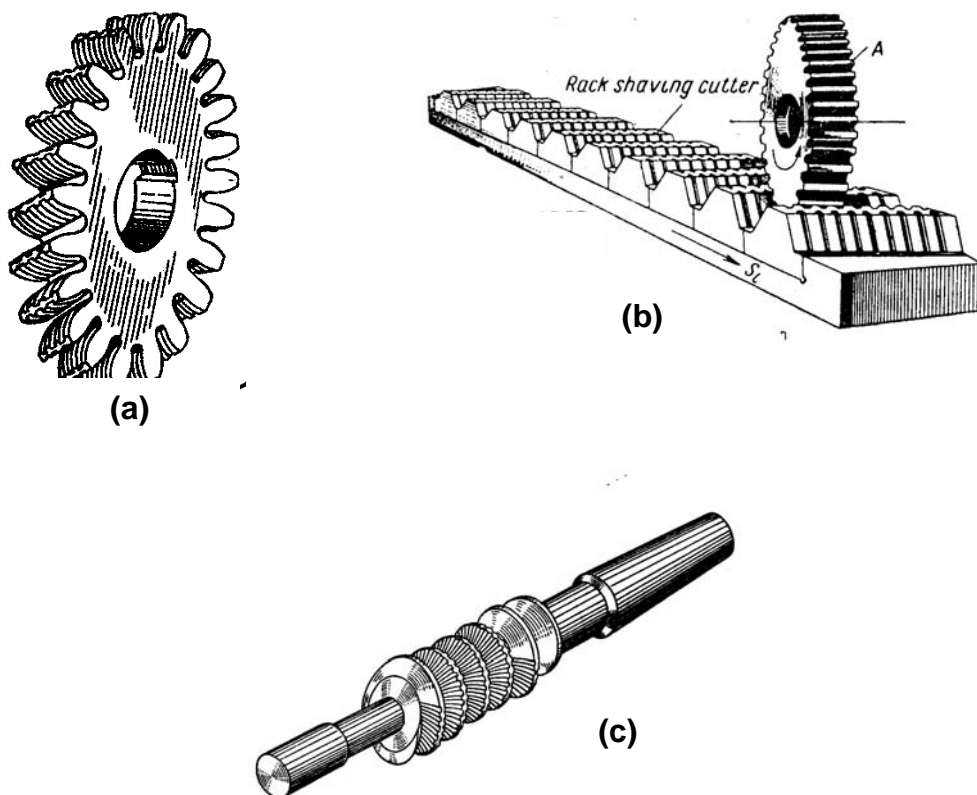
### o Gear shaving

The teeth of straight or helical toothed external spur gears and worm wheels of moderate size and made of soft materials like aluminium alloy, brass, bronze, cast iron etc. and unhardened steels are mostly finished by shaving process. Fig. 7.2.18 shows the different types of shaving cutters which while their finishing action work apparently as a spur gear, rack or worm in mesh with the conjugate gears to be finished. All those gear, rack or worm type shaving cutters are of hard steel or HSS and their teeth are uniformly serrated as shown in Fig. 7.2.19(a) to generate sharp cutting edges.

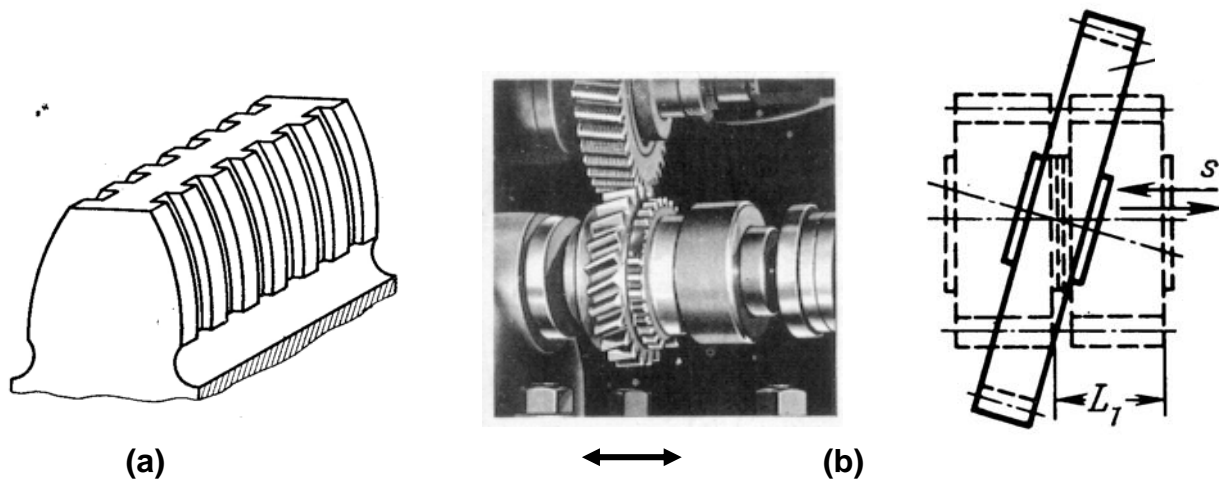
While interacting with the gears, the cutting teeth of the shaving cutter keep on smoothening the mating gear flanks by fine machining to high accuracy and surface finish. For such minute cutting action, the shaving teeth need an actual or apparent movement relative to the mating teeth along their length as indicated in Fig. 7.2.19 (b).

### o Gear rolling or burnishing

In this method the machined gear is rolled under pressure with three hardened master gears of high accuracy and finish. The minute irregularities of the machined gear teeth are smeared off by cold plastic flow, which also helps in improving the surface integrity of the desired teeth.



**Fig. 7.2.18** Gear shaving cutters of (a) spur gear type (b) rack and (c) worm type



**Fig. 7.2.19** Cutting teeth of gear shaving (a) cutter and its (b) action

### o Gear teeth grinding

Grinding is a very accurate method and is, though relatively expensive, more widely used for finishing teeth of different type and size of gears of hard material or hardened surfaces. The properly formed and dressed wheel finishes the gear teeth flanks by fine machining or abrading action of the fine abrasives.

Like gear milling, gear grinding is also done on two principles

- Δ Forming
- Δ Generation, which is more productive and accurate

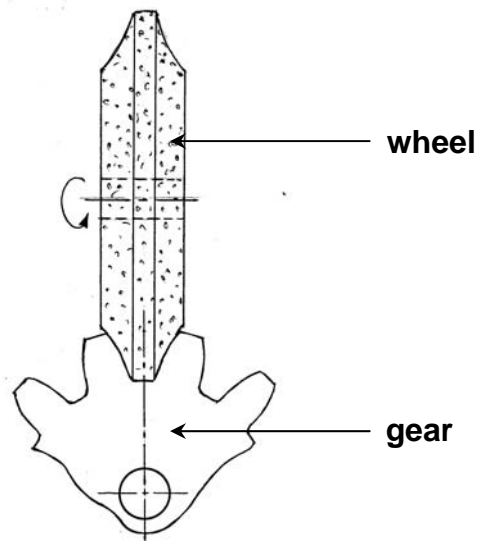
#### Δ Gear teeth grinding on forming principle

This is very similar to machining gear teeth by a single disc type form milling cutter as indicated in Fig. 7.2.20 where the grinding wheel is dressed to the form that is exactly required on the gear. Need of indexing makes the process slow and less accurate. The wheel or dressing has to be changed with change in module, pressure angle and even number of teeth. Form grinding may be used for finishing straight or single helical spur gears, straight toothed bevel gears as well as worm and worm wheels.

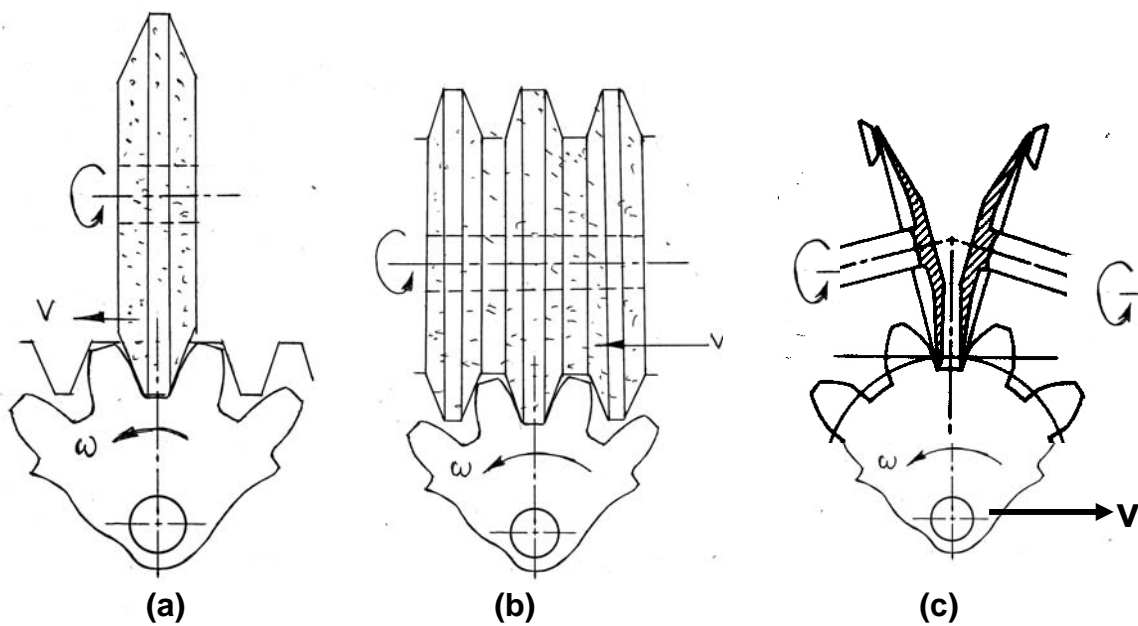
#### Δ Gear teeth grinding on generation principle

Fig. 7.2.21 schematically shows the methods of finishing spur gear teeth by grinding on generation principle.

The simplest and most widely used method is very similar to spur gear teeth generation by one or multi-toothed rack cutter. The single or multi-ribbed rotating grinding wheel is reciprocated along the gear teeth as shown. Other tool – work motions remain same as in gear teeth generation by rack type cutter as indicated in Fig. 7.2.13. For finishing large gear teeth a pair of thin dish type grinding wheels are used as shown in Fig. 7.2.21 (c). Whatsoever, the contacting surfaces of the wheels are made to behave as the two flanks of the virtual rack tooth.



**Fig. 7.2.20** Gear teeth finishing by form grinding



**Fig. 7.2.21** Gear teeth grinding on generation principle.

### Δ Gear teeth finishing by lapping

The lapping process only corrects minute deviations from the desired gear tooth profiles. The gear to be finished after machining and heat treatment and even after grinding is run in mesh with a gear shaped lapping tool or another mating gear of cast iron. An abrasive lapping compound is used in between them. The gear tooth contact substantially improves by such lapping.