

GATE Study Material

Principle Of Machine Tools

(Production And Industrial Engineering)



MACHINE TOOL DRIVES

Learning Objectives:

- Introduction to machine tool drives & mechanisms
- Working and auxiliary motions in machine tool
- Parameters defining working motions of machine tool
- Mechanical transmission and its elements
- Broadly Classification of transmission of rotary motion
- Stepped Speed Drives in Machine Tools
 - Belting
 - Pick-Off Gears
 - Gear boxes
- AP & GP for stepping speeds of gears
- Structural formula & structural diagrams
- Feed gear boxes
- Stepped Speed Drives in Machine Tools.
- Hydraulic transmission and its elements

Introduction

The machine tool is a machine that imparts the required shape to workpiece with the desired accuracy by removing metal from the workpiece in the form of chips. In view of the extremely vast range of shapes that are in practice imparted to various industrial components, there exists a very large nomenclature of machine tools. Machine tools can be classified by different criteria as given below:

1. By the degree of automation into
 - a. Machine tool with manual control
 - b. Semi-automatic machine tools and
 - c. Automatic machine tool.
2. By weight into
 - a. Light duty machine tools weighing up to 1 tonne.
 - b. Medium duty machine tools weighing up to 10 tonne and
 - c. Heavy duty machine tools weighing greater than 10 tonne.
3. By the degree of specialisation into
 - a. General purpose machine tools – which can perform various operations on workpiece of different shapes and sizes.
 - b. Single purpose machine tools – which can perform single operation on work pieces of a particular shape and different sizes and

- c. Special machine tools – which can perform a single operation on workpiece of particular shape and size.

Working and Auxiliary Motions in Machine tools

For obtaining the required shape on the workpiece, it is necessary that the cutting edge of the cutting tool should move in a particular manner with respect to the workpiece. The relative movement between the workpiece and cutting edge can be obtained either by the motion of the workpiece, the cutting tool, or by a combination of the motions of the workpiece and cutting tool. These motions which are essential to impart the required shape to the workpiece are known as working motions. Working motions can further be classified as:

1. Drive motion or primary cutting motion
2. Feed motion

Working motions in machine tools are generally of two types: rotary & translatory. Working motions of some important groups of machine tools are shown in figure:

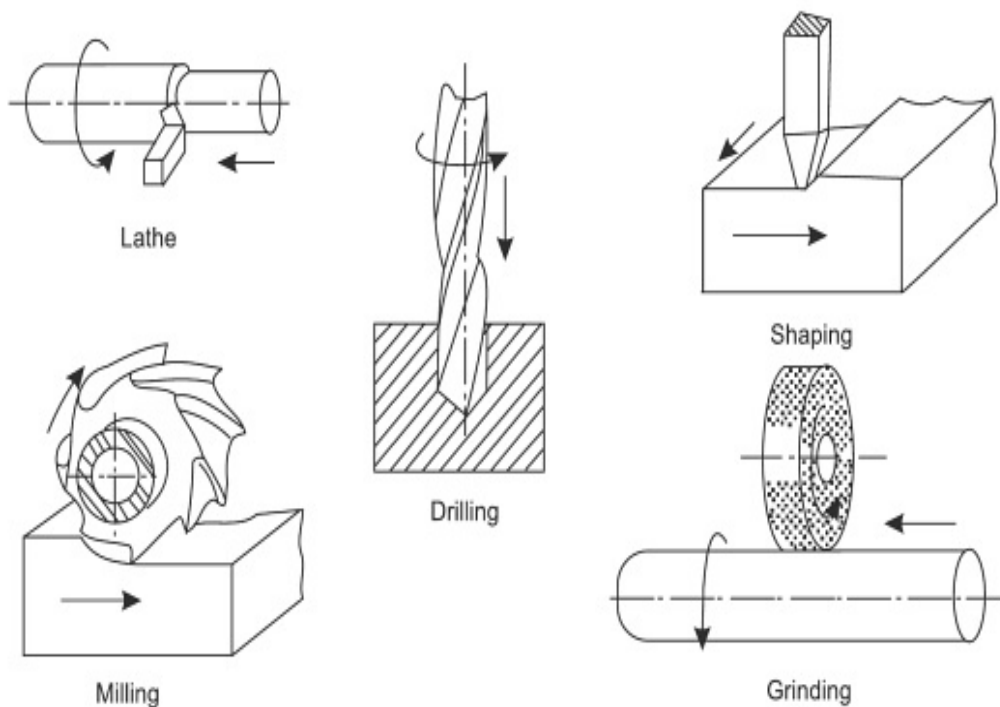


Fig. 1.1 Working motions for some machine tools

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1. *For lathes and boring machines*
 - drive motion—rotary motion of workpiece
 - feed motion—translatory motion of cutting tool in the axial or radial direction
2. *For drilling machines*
 - drive motion—rotary motion of drill
 - feed motion—translatory motion of drill
3. *For milling machines*
 - drive motion—rotary motion of the cutter
 - feed motion—translatory motion of the workpiece
4. *For shaping, planing, and slotting machines*
 - drive motion—reciprocating motion of cutting tool
 - feed motion—intermittent translatory motion of workpiece
5. *For grinding machines*
 - drive motion—rotary motion of the grinding wheel
 - feed motion—rotary as well as translatory motion of the workpiece.

Besides the working motions, a machine tool also has provision for auxiliary motions. The auxiliary motions do not participate in the process of formation of the required surface but are nonetheless necessary to make the working motions fulfil their assigned function. Examples of auxiliary motions in machine tools are clamping and unclamping of the workpiece, idle travel of the cutting tool to the position from where cutting is to proceed, changing the speed of drive and feed motions, engaging and disengaging of working motions, etc.

In machine tools, the working motions are powered by an external source of energy (electrical or hydraulic motor). The auxiliary motions may be carried out manually or may also be power-operated depending upon the degree of automation of the machine tool. In general-purpose machine tools, most of the auxiliary motions are executed manually. On the other hand, in automatic machines, all auxiliary motions are automated and performed by the machine tool itself. In between these two extremes, there are machine tools in which the auxiliary motions are automated to various degrees, i.e., some auxiliary motions are automated while others are performed manually.

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Machine Tools produce desired geometrical surfaces on solid bodies (preformed blanks) and for that they are basically comprised of;

- Devices for firmly holding the tool and work
- Drives for providing power and motions to the tool and work
- Kinematic system to transmit motion and power from the sources to the tool-work
- Automation and control systems
- Structural body to support and accommodate those systems with sufficient strength and rigidity.

For material removal by machining, the work and the tool need relative movements and those motions and required power are derived from the power source(s) and transmitted through the kinematic system(s) comprised of a number and type of mechanisms.

(i) Concept of Generatrix and Directrix

- Generation of flat surface

The principle is shown in Fig. 2.1 where on a flat plain a straight line called Generatrix (G) is traversed in a perpendicular direction called Directrix (D) resulting a flat surface.

- Generation of cylindrical surfaces

The principles of production of various cylindrical surfaces (of revolution) are shown in Fig. 2.2, where,

- A long straight cylindrical surface is obtained by a circle (G) being traversed in the direction (D) parallel to the axis as shown in Fig. 2.2(a)
- A cylindrical surface of short length is obtained by traversing a straight line (G) along a circular path (D) as indicated in Fig. 2.2(b)
- Form cylindrical surfaces by rotating a curved line (G) in a circular path (D) as indicated in Fig. 2.2 (c and d).

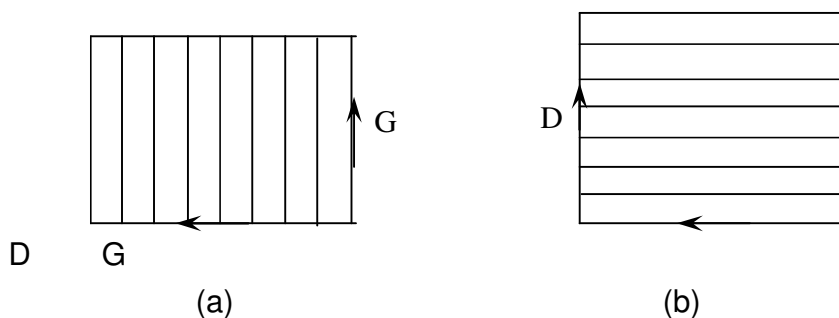


Fig. 2.1 Generation of flat surfaces by Generatrix and Directrix.

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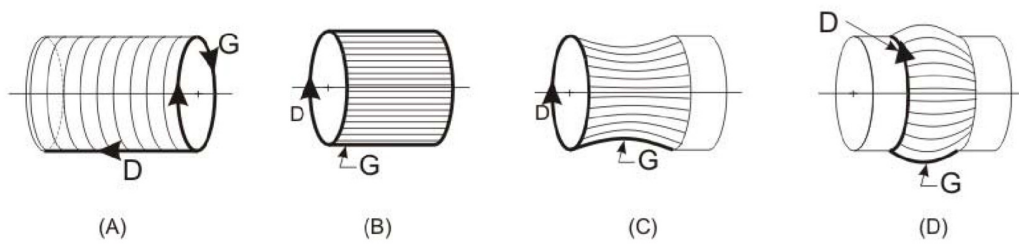


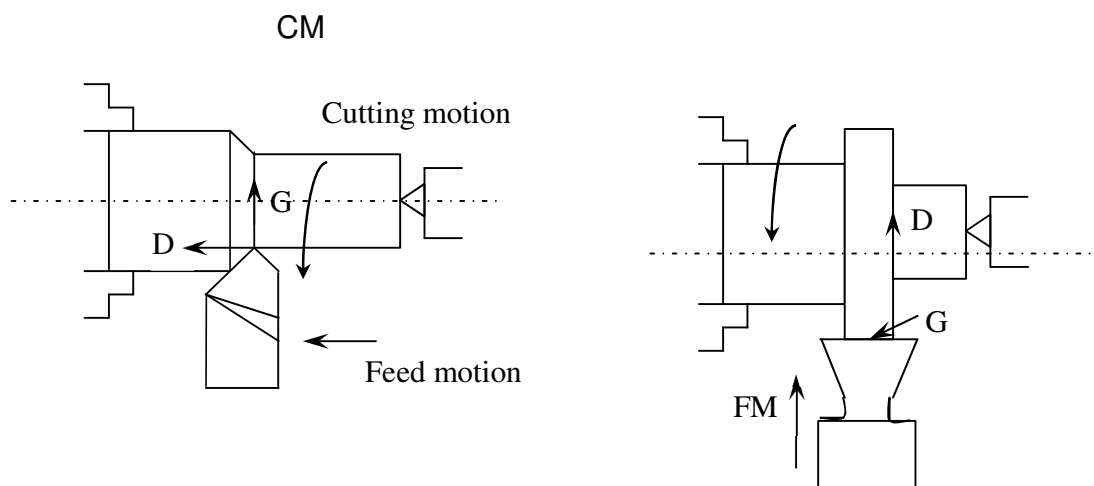
Fig. 2.2 Generation of cylindrical surfaces (of revolution)

(ii) Tool – work motions

The lines representing the Generatrix and Directrix are usually produced by the locus of a point moving in two different directions and are actually obtained by the motions of the tool-tip (point) relative to the work surface. Hence, for machining flat or curved surfaces the machine tools need relative tool work motions, which are categorized in following two groups:

- Formative motions
namely
 - Cutting motion (CM)
 - Feed motion (FM)
- Auxiliary motions
such as – Indexing motion
 - Additional feed motion
 - Relieving motion

The Generatrix and Directrix, tool and the work and their motions generally remain interconnected and in different way for different machining work. Such interconnections are typically shown in Fig. 2.3 for straight turning and in Fig. 2.4 for shaping.



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(a) longitudinal turning

(b) transverse turning

Fig. 2.3 Principle of turning (cylindrical surface)

The connections in case of straight longitudinal turning shown in Fig. 2.3 (a) are:

Generatrix (G) – Cutting motion (CM) – Work (W)

Directrix (D) – Feed motion (FM) – Tool (T)

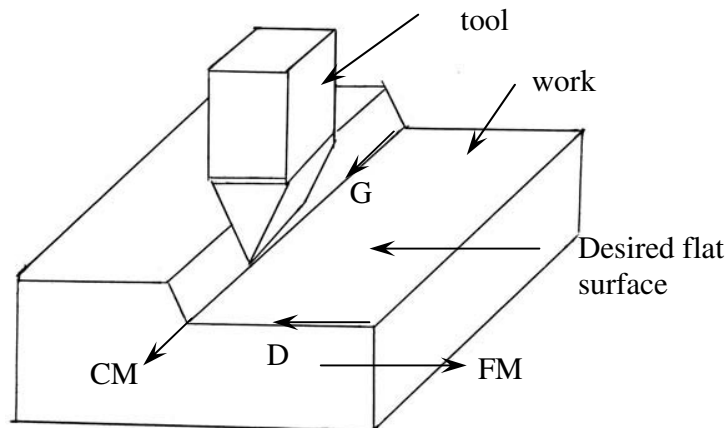


Fig. 2.4 Principle of producing flat surface in shaping machine

In case of making flat surface in a shaping machine as shown in Fig. 2.4 the connections are:

G – CM – T

D – FM – W

which indicates that in shaping flat surfaces the Generatrix is provided by the cutting motion imparted to the cutting tool and the Directrix is provided by the feed motion of the work.

Flat surfaces are also produced by planing machines, mainly for large jobs, where the cutting motion is imparted to the work and feed motion to the tool and the connections will be:

G – CM – Work

D – FM – Tool

The Genratrix and Directrix can be obtained in four ways:

- Tracing (Tr) – where the continuous line is attained as a trace of path of a moving point as shown in Fig. 2.3 and Fig. 2.4.

Module 1

- Forming (F) – where the Generatrix is simply the profile of the cutting edge as indicated in Fig. 2.2 (c and d)
- Tangent Tracing (TTr) – where the Directrix is taken as the tangent to the series of paths traced by the cutting edges as indicated in Fig. 2.5.
- Generation (G): Here the G or D is obtained as an envelope being tangent to the instantaneous positions of a line or surface which is rolling on another surface. Gear teeth generation by hobbing or gear shaping is the example as can be seen in Fig. 2.6.

Fig. 2.5 typically shows the tool-work motions and the corresponding Generatrix (G) and Directrix (D) while producing flat surface by a plain or slab milling cutter in a conventional horizontal arbour type milling machine. The G and D are connected here with the tool work motions as

G – x – T – F
 D – FM – W – T.Tr
 CM – T

Here G and D are independent of the cutting motion and the G is the line of contact between the milling cutter and the flat work surface. The present cutter being of roller shape, G has been a straight line and the surface produced has also been flat. Form milling cutters will produce similar formed surfaces as shown in Fig. 2.7 where the 'G' is the tool-form.

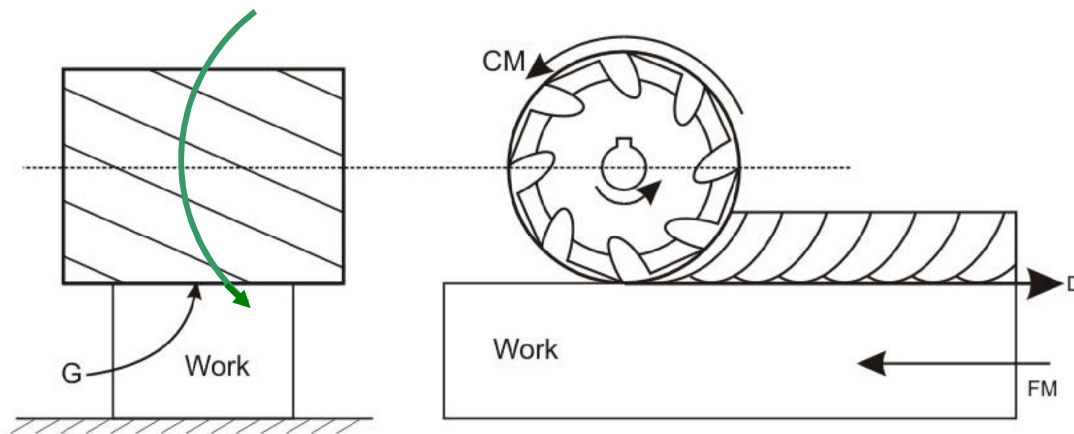


Fig. 2.5 Directrix formed by tangent tracing in plain milling

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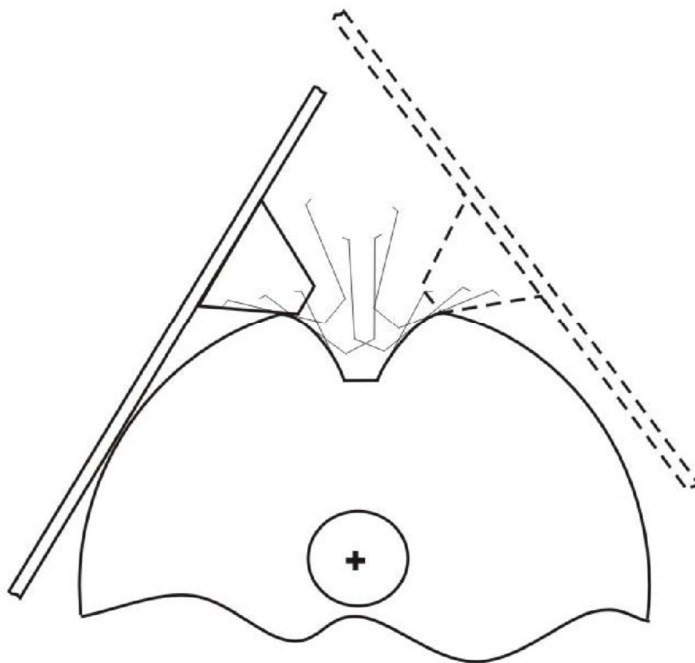
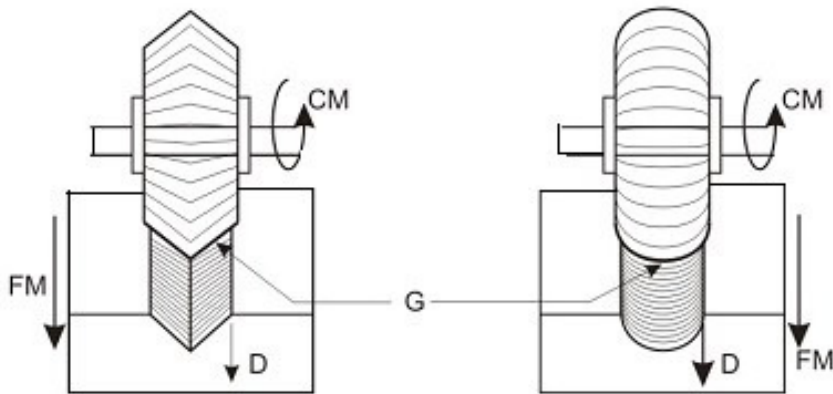


Fig. 2.6 Generatrix (or Directrix) in gear teeth cutting by generation.

Fig. 2.7 Tool-work motions and G & D in form milling

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For making holes in drilling machines both the cutting motion and the feed motion are imparted to the cutting tool i.e., the drill bit whereas the workpiece remains stationary. This is shown in Fig. 2.8. The G and D are linked with the tool-work in the way:

G – CM – T – Tr
D – FM – W – Tr

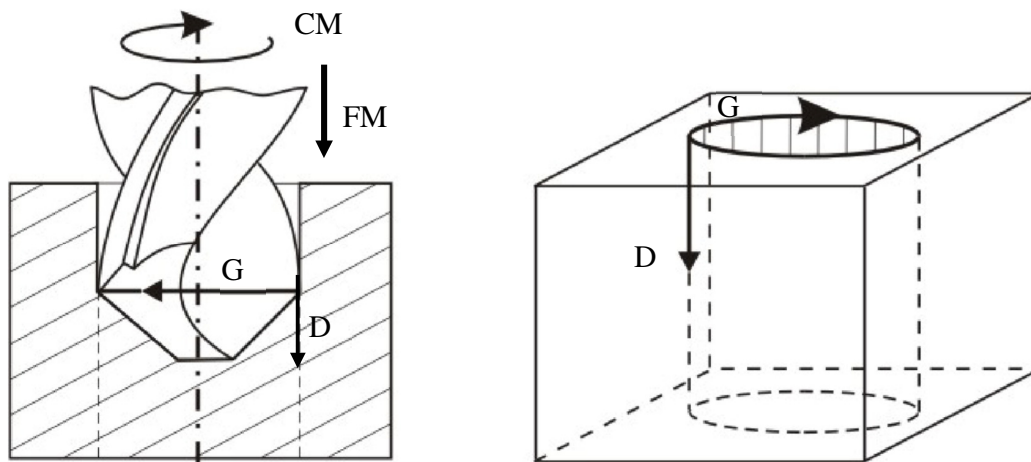


Fig. 2.8 Tool-work motions and G & D in drilling.

Boring machines are mostly used for enlargement and finishing of existing cylindrical holes. Boring machines are of two types:

- Vertical boring machine – low or medium duty and high precision, e.g., Jig boring machine
- Horizontal axis boring machine – medium or heavy duty.

In respect of tool-work motions and G and D, vertical boring and drilling are same. In horizontal boring machine the feed motion is imparted to the work to provide the Directrix by Tracing.

Parameters defining working motions of machine tool

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The working motions of the machine tool are numerically defined by their velocity. The velocity of the primary cutting motion or drive motion is known as *cutting speed*, while the velocity of feed motion is known as *feed*.

The cutting speed is denoted by v and measured in the units m/min. Feed is denoted by s and measured in the following units:

1. mm/rev in machine tools with rotary-drive motion, e.g., lathes, boring machines, etc.,
2. mm/tooth in machine tools using multiple-tooth cutters, e.g., milling machines,
3. mm/stroke in machine tools with reciprocating-drive motion, e.g., shaping and planing machines, and
4. mm/min in machine tools which have a separate power source for feed motion, e.g., milling machines.

In machine tools with rotary primary cutting motion, the cutting speed is determined by the relationship,

$$v = \frac{\pi dn}{1000} \text{ m/min} \quad (1.1)$$

where d = diameter of workpiece (as in lathes) or cutter (as in milling machines), mm

n = revolutions per minute (rpm) of the workpiece or cutter

In machine tools with reciprocating primary cutting motion, the cutting speed is determined as

$$v = \frac{L}{1000T_c} \text{ m/min} \quad (1.2)$$

where L = length of stroke, mm

T_c = time of cutting stroke, min

If the time of the idle stroke in minutes is denoted by T_i , the number of strokes per minute can be determined as

$$n = \frac{1}{T_c + T_i}$$

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Generally, the time of idle stroke T_i is less than the time of cutting stroke; if the ratio T_c/T_i is denoted by K , the expression for number of strokes per minute may be rewritten as

$$n = \frac{1}{T_c(1+T_i/T_c)} = \frac{K}{T_c(1+K)} \quad (1.3)$$

Now, combining Eqs (1.2) and (1.3), the relationship between cutting speed and number of strokes per minute may be written as follows:

$$v = \frac{n \cdot L(K+1)}{1000K} \quad (1.4)$$

The feed per revolution and feed per stroke are related to the feed per minute by the relationship,

$$s_m = s \cdot n \quad (1.5)$$

where s_m = feed per minute
 s = feed per revolution or feed per stroke
 n = number of revolutions or strokes per minute

The feed per tooth in multiple-tooth cutters is related to the feed per revolution as follows:

$$s = s_z \cdot Z \quad (1.6)$$

where s = feed per revolution
 s_z = feed per tooth of the cutter
 Z = number of teeth on the cutter

The machining time of any operation can be determined from the following basic expression:

$$T_m = \frac{L}{s_m} \text{ min} \quad (1.7)$$

where T_m = machining time, min
 L = length of machined surface, mm
 s_m = feed per minute

Mechanical transmission and its elements

Mechanical transmission is employed for transmitting rotary as well as translatory motion to the operative element. This transmission can provide both stepped and stepless regulation of speed and feed rates. Stepless regulation is achieved through special devices called *variators*, which will be discussed in Sec. 2.9.3. A mechanical transmission that provides for stepped regulation of speed and feed rates is made up of elementary drives and mechanisms. For ease in presentation, the elements of mechanical transmission can be classified into the following groups:

1. Elementary transmissions that transfer rotation
2. Elementary transmissions that transform rotary motion into translatory motion
3. Devices for intermittent motion
4. Reversing and differential mechanisms
5. Special mechanisms and devices
6. Couplings and clutches

Elementary transmissions that transfer rotation

The important elementary transmissions which are used for transmitting rotary motion from one shaft to another are described below.

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Gear Transmission In a gear transmission, the rpm of the driven shaft is determined as

$$n_2 = n_1 \cdot \frac{Z_1}{Z_2}$$

where n_2 = rpm of the driven shaft
 n_1 = rpm of the driving shaft
 Z_1 = number of teeth of the driving gear
 Z_2 = number of teeth of the driven gear

The ratio Z_1/Z_2 is known as the transmission ratio of the gear drive and is constant for a particular gear pair.

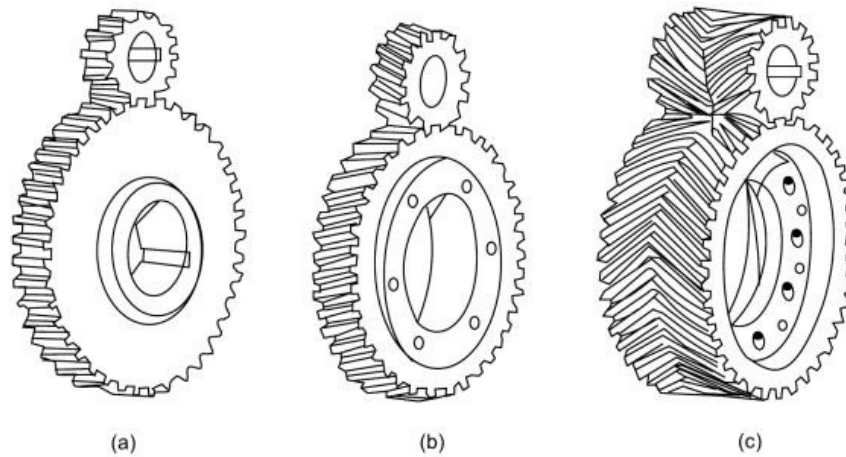


Fig. 1.34 Gears: (a) Spur (b) Helical (c) Herringbone

Rotation is transmitted between parallel shafts by means of spur, helical and herringbone gears (Fig. 1.34). Spur gears have teeth parallel to the axis of rotation, while in helical gears the teeth are inclined with respect to the axis of rotation at an angle known as the helix angle. The herringbone gear is essentially a pair of helical gears in which the helix angle is oppositely directed. Spur gears are used in sliding gear blocks, while helical gears are preferred when the gear pairs are permanently in meshing.

Transmission of rotation between inclined intersecting axes is done with the help of bevel gears. A bevel gear is shown in Fig. 1.35a. The angle between the inclined axes is generally 90° and the bevel-gear transmission (Fig. 1.35b) is commonly employed for transmitting rotation between perpendicular shafts.

Transfer of rotation between skewed axes, i.e., axes that are inclined to each other but do not intersect, is achieved by means of a spiral gear transmission (Fig. 1.36a) or a worm-worm gear transmission (Fig. 1.36b). The spiral gear transmission is characterised by point contact between the meshing gears, and therefore, it cannot be employed for transmitting large torques. In machine tools, the worm-worm gear transmission is commonly employed to achieve heavy speed reduction. Also, since the contact between the worm and worm gear is along a line, this pair can transmit large torques. It should be noted that the worm-worm gear

Module 1

transmission is irreversible and rotation may be transmitted from the worm to the worm gear, but not vice versa. The worm is, in principle, a helical screw and the rpm of the worm gear can be determined by the relationship,

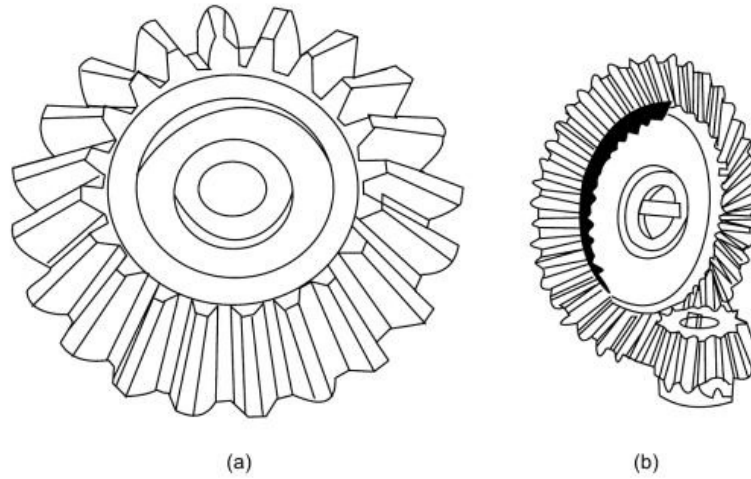


Fig. 1.35 (a) Bevel gear (b) Bevel gear pair

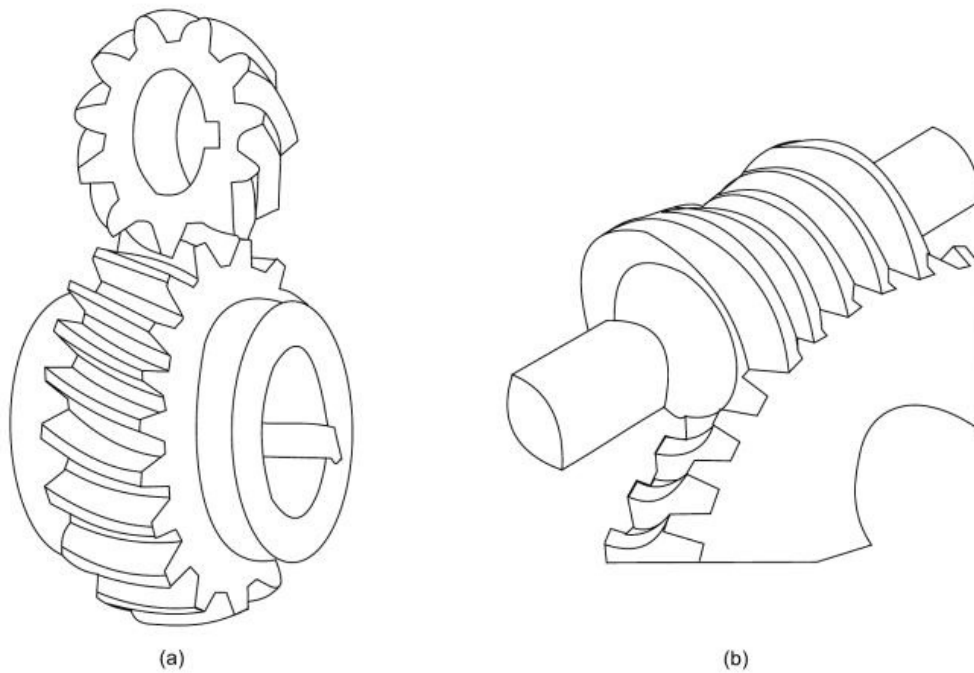


Fig. 1.36 (a) Spiral gear pair (b) Worm-worm gear pair

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$$n_2 = n_1 \cdot \frac{k}{Z}$$

where n_2 = rpm of the worm gear
 n_1 = rpm of the worm
 Z = number of teeth of the worm gear
 k = number of passes of the worm

For a single pass worm, $k = 1$, for a double pass worm, $k = 2$.

If a transmission chain consists of a number of elementary gear transmissions connected in series, the overall transmission ratio of the chain is obtained as the product of transmission ratios of the elementary transmissions. In general, the transmission ratio of a gear drive may be >1 (speed increase) or <1 (speed reduction), except the worm-worm gear transmission which always has a transmission ratio <1 .

Belt Transmission The belt transmission is used for transmitting rotation between shafts that are located at a considerable distance from each other. It is distinguished by smooth and jerk-free rotation which enables its application in high-speed machine tools, e.g., grinding machines. Belt transmission can be employed for transmitting rotation between parallel and skewed shafts. The most commonly used arrangements are shown in Fig. 1.37.

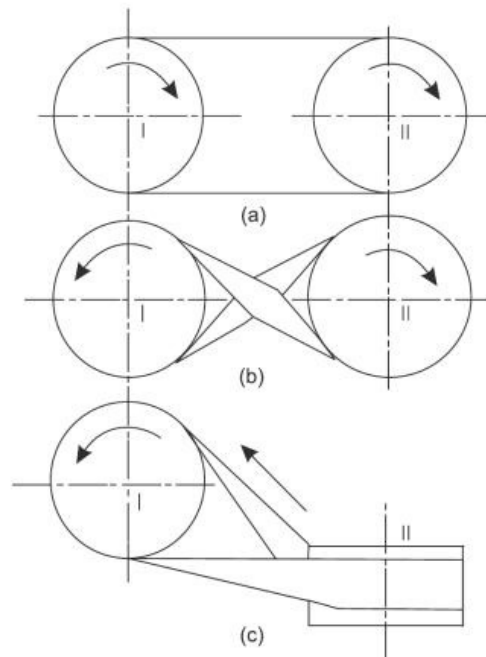


Fig. 1.37 Belt drives: (a) Open-belt arrangement (b) Cross-belt arrangement (c) Quarter-turned arrangement

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