1

TRANSMISSION OF MOTION AND POWER

1.1 INTRODUCTION

A source of power is always needed in various workshop processes particularly in cutting and forming of metals in a machine tool. The electricity as a means of conveying power to machinery is now widely adopted. The power is nearly always supplied to the machine in the form of rotational energy. The electricity or electrical energy is converted to rotational energy by means of an electric motor and the machine converts the input of rotational energy into various forms necessary for doing the job.

1.2 METHODS OF DRIVE

Machines may be driven by any one of the following two methods :

1. Individual drive
2. Group drive

Individual drive : This is also termed *self-contained drive*. The motor may drive the machine shaft through direct coupling or belt, chain, gears or through some multi- or variable-speed transmission. Machine tools use hydraulic actuators, DC motors, AC motor or stepping motors for drives. The type of drive used is determined by the power requirement of the machine tools, the power sources available and the desired dynamic characteristics. Rotational motion of the drive may be transmitted to the machine shaft through direct coupling or belt, chain, gears or through some multi- or variable speed transmission. Machines which require wide speed variations also are best driven by individual drive.

This system has become very popular because of the following advantages :

1. There is considerable economy of power for driving any single

or group of machines as desired for that much of time as is required by a particular machine.

2. In case of drive failure, a particular machine remains idle and this does not affect the working of other machines.
3. Gives a better look and the working hazard being reduced there is practically no chance of any accident. Cleanliness and lighting are also improved for having no overhead shaft and belts in the shop.
4. Gives a wide speed variation and better control of speed range.
5. Power losses are small.
6. Replacement of belt takes very little time as direct-drive motor employs grooved pulleys and V-belts. Layout is very easy.

Group drive : In this system a very powerful motor drives an overhead shaft, called *mainshaft*, that runs from one end to the other end of the shop. This mainshaft drives another shaft called *countershaft* which in turn, drives the machine drive shaft. For starting and stopping the machine spindle, fast and loose pulleys are provided on the countershaft. It also contains a set of cone pulleys to give a wide range of spindle speed. Sometimes, when a machine is driven by a single pulley, and the stop and start arrangements are contained in the machine itself, no countershaft is necessary and the machine gets the drive direct from a pulley on the mainshaft. A diagram showing group drive is shown in Fig.1.1.

The transmission of motion and power from the mainshaft to the countershaft and then to the machines is generally effected through belts and pulleys. The mainshaft is driven from the electric motor by a belt or chain, the motor being placed either on the floor or mounted overhead.

Group drive is most suitable where power consumption of individual machines is extremely variable, with occasional brief high peaks. This is usually more economical in fixed charges, power consumption, and maintenance. But group drive has the following disadvantages :

1. Shafts, pulleys belts, etc. absorb greater power and the efficiency is considerably low.
2. In case of motor failure, all the machines become idle.
3. Gives a very clumsy appearance and there are greater chances of accidents. Cleanliness and lighting are badly affected by the presence of overhead shafts and many belts.
4. Does not give a wide speed variation and better control of speed range.

5. Replacement of belts causes the power to shut down producing great disturbance and annoyance to the workmen.
6. Gives greater power cost for driving the mainshaft even if only one machine works in the whole of the workshop.
7. Overhead traveling cranes cannot be used if required.
8. Layout is difficult.

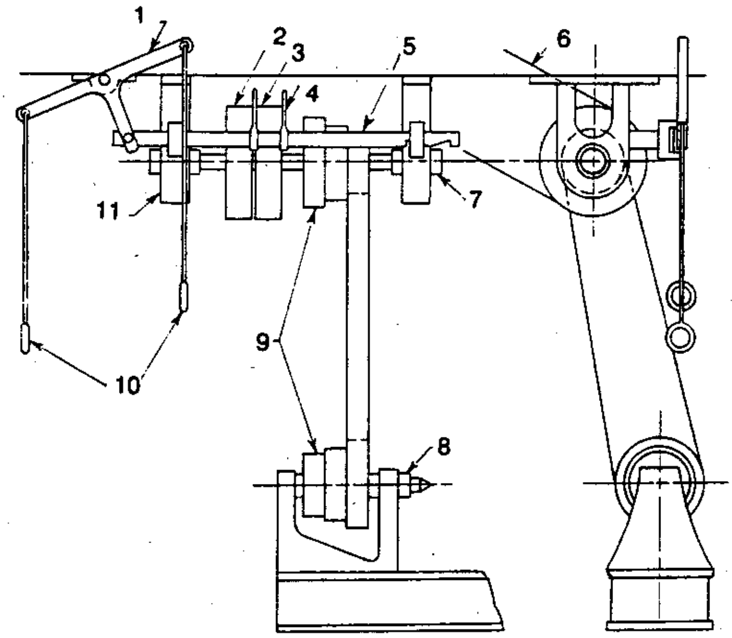


Figure 1.1 Counter shaft drive arrangement
1. Lever, 2. Loose pulley, 3. Fast pulley, 4. Belt fork, 5. Striking bar, 6. Belt drive from main lineshaft, 7. Bearing, 8. Headstock spindle, 9. Cone pulleys, 10. Hanging wire, 11. 'U'-hanger.

1.3 POWER TRANSMISSION ELEMENTS

The elements which are common to all methods of drive, for convenience, may be classified under the following heads :

1. Shafting, bearings, and fixings.
2. Belt-driving.
3. Rope-driving.
4. Chain-driving.

5. Variable speed gear.
6. Clutches.
7. Friction-driving.
8. Toothed gearing.

Belts, ropes, chains, gears, etc. are used for transmitting power from prime mover to machine or from one shaft to the other. The selection of a particular type, of course, depends mostly upon the power required and the distance between the two driving shafts. These are described in the following articles.

1.4 SHAFTING

It may be said that the *shaft* is the essential element for transmitting power in mills and workshops. Under operation a shaft is subject to combined torsion and bending. An *axle* is a stationary shaft on which pulleys and other members rotate. An axle sometimes rotates, but is subjected to bending only. The part of the shaft within the bearing is known as *journal.* Journals *1* and *3* at the end of the shaft or (axle) in Fig.1.2 are called *pivots*, while the intermediate journal 2 is a *neck journal*. A *spindle* is a machine shaft that drives and supports either a cutting tool or the work on which machining and other operations are performed.

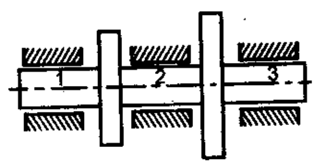


Figure 1.2 Elements of a shaft
1, 3. Journal 2. Neck journal

The shafting used in machine shops is made of mild steel and may be cold-rolled or turned, but it is generally considered amongst metal workers that turned shafting is more desirable. Upto about 125 mm diameter it is generally supplied and used in the cold-drawn or cold rolled bright condition. Cold-drawn shafting is comparatively cheap and the drawing gives a certain amount of work hardening to the outer surface of the shaft which is an advantage. In order to obtain minimum diameter and increased wear resistance of heavily loaded shafts they are sometimes made from alloy steels of various grades treated by heat and case-hardening methods.

Larger shafts are turned from steel forgings, and this applies also if collars or bosses are required. A reduced neck or sunk journal turned out of a shaft causes a serious loss of strength and stiffness and should always be avoided. To avoid unnecessary loss of power due to friction in bearing to facilitate fixing wheels or pulleys at any point, it is important that shafting should be truly round and straight.

Speed of shafting : The speed of shafting varies according to the type of machinery driven in a mill or workshop. At the present time the following speeds are common :

	Revs. per min.
Main shafts and shafting for driving heavy Machinery	100 to 200
Shafting in light machine shop	150 to 300
Countershafts	200 to 600
Shafting for driving textile machinery	300 to 800
Shafting for driving wood working machinery	250 to 750

Power transmitted by shafting : Shafting running at speeds higher than those usually encountered in power-transmission work requires special consideration, but for average conditions the following well-known formulae are useful :

$$h.p. = \frac{2\pi n T}{4{,}500}$$

where, n = speed of the shaft in r.p.m.,
and T = twisting moment of the shaft in metre kilogram

Again, $T = \frac{\pi}{16} d^3 f_s$

where, d = diameter of the shaft
and f = maximum shearing stress induced in the shaft due to twist

1.5 COUPLINGS FOR SHAFTING

Shafting is supplied in reasonable lengths, and to make up a long length several pieces may be joined together by couplings. The coupling should always be placed as close to a bearing as possible and should support and align the two ends of the shaft rigidly so as to give an effect of a continuous shaft. The two principal types of couplings are :

1. Rigid coupling
2. Non-rigid or flexible coupling.

Rigid couplings : Rigid couplings are used to connect two shafts when they are in perfect rigid axial alignment. There are two principal types of rigid coupling : (1) muff coupling, and (2) flange coupling.

A *muff coupling* or *box coupling*, illustrated in Fig.1.3, consists of a solid box or muff made of cast iron, bored out to fit the shafts whose ends are made to butt together inside the box. The box may be secured to the shaft by means of a sunk key which extends the whole length of the box. Sometimes two keys are used to fit the muff on the shafts.

Figure 1.3 Muff coupling

A *flanged shaft coupling*, illustrated in Fig.1.4, is perhaps the most widely used particularly for heavy power transmission at low speeds. Two coupling halves *1* and *3* are keyed to the ends of the shafts and bolted together. To ensure correct alignment, one of the flanges has a circular projection *2* which fits into a corresponding depression in the other flange. To guard against the nuts and bolt heads catching the clothes of workmen, who might be near the couplings, flanges are provided to cover the nuts and bolt heads.

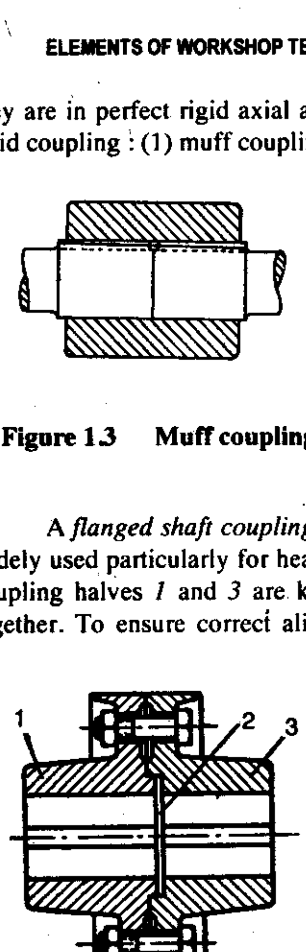


Figure 1.4 Flange coupling
1, 3. Flange coupling, 2. Centering projection

Another type of rigid coupling is the *ribbed coupling* or *split sleeve coupling*. This consists of two longitudinal halves mounted simultaneously on the ends of both shafts and then tightened with bolts. To overcome the possibility of the shaft twisting in the coupling, the ends of both are keyed together.

Flexible couplings : Flexible couplings are used to protect the driving and driven machinery from detrimental effects, which may arise from mis-alignemnt of shafts, vibration, sudden shock loads, end float, or shaft expansion. The most extensively used of all types of flexible couplings is probably the crown-pin type coupling shown in Fig.1.5. One or both halves of the coupling are provided with studs engaging in holes in the other half. Studs have insulating and renewable flexible driving surfaces built up of leather washers or similar materials. This construction permits some axial movement and takes care of starting shock or slight mis-alignment. Another advantage is that it can quickly be disconnected by removing the driving pins.

Other types of flexible couplings are : *belt-type flexible* coupling used to transmit medium power at low speeds ; *internal gear type flexible* coupling used for heavy drives such as in rolling mills, cement mills, etc. and Bibley coupling applied universally to machinery and shafting drives upto the largest powers.

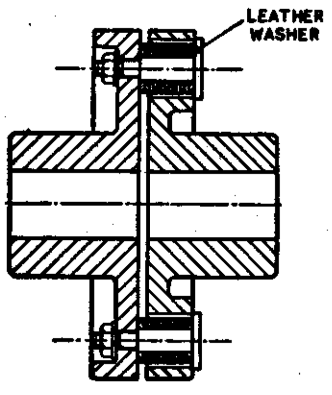


Figure 1.5 Flexible coupling

1.6 BEARINGS FOR SHAFTING

The support in which a shaft or axle rotates is called a bearing. Bearings are classified according to the nature of the applied load and the r.p.m. of the axle or shaft. For different forms of bearings see *Lubricants and Lubrication* in Vol. I.

In practice, the bearings may be in the form of plain bearings, e.g. plummer block, or some form of ball or roller bearings. The use of plain bearings for line shafting is giving way to ball and roller bearings as the latter have many advantages. The outstanding feature of ball and roller bearings is their low starting friction, which is practically the same as running friction. Therefore, if a shaft must frequently be started from rest, it is worthwhile considering the adoption of ball or roller bearings to support it, as they will no doubt effect a considerable saving in power and lubricant. For light duty, ball bearings can be run at higher speeds than plain bearings without danger of overheating and seizing. Other important points in favour of ball bearings are cleanliness and saving in lubricant and attendance. Again, for taking up end-thrust, the ball bearing is indispensable, and has a field of application entirely of its own.

Lubrication of bearing : Proper lubrication of bearing surfaces involves careful consideration of materials comprising of the journal and its bearings. The bearing surfaces in general use come mainly under the following heads : cast iron, steel, various alloys of bronze and babbitt. Cast iron bearing surfaces should only be used for low speeds and light pressures. All normally loaded bearings should have continuous lubrication, and the simplest and cheapest method of obtaining a regular supply of oil is by ring oiling. Heavily loaded or higher speed bearings are sometimes fitted with pumps to force oil on to the surfaces and to keep a large volume of oil in circulation.

Ball and roller bearings, of course, require a small quantity of grease. Although lubrication is only required at intervals of from three to six months, it is an important matter, but it should be understood that it is mainly intended to prevent rusting of the polished working surfaces. A simple way of replenishing the grease when required is by means of a grease gun.

Fixing for shaft bearings : Line shaft bearings are placed at suitable distances and supported by brackets or hangers according to the prevailing condition. Due to subsidence of foundations, deflection of columns, walls, girders, etc. from which the shaft is supported, some displacement will almost inevitably occur after running some time under full load. Shafting in factories is frequently found to be very much out of line and level, and in consequence a considerable amount of power may be absorbed in the drive. It is important, therefore, to ensure that shaft bearings are capable of maintaining the shaft in correct level and alignment, and designed to enable errors in alignment to be easily corrected. A swiveling or self-aligning bearing can only be employed for such adjustment. The bearing automatically adjusts itself to the shaft and is independent of exact level or alignment of fixings on which it is supported. With plain bearings this swiveling movement is achieved by clamping the bearing housing between large spherical ended plugs in the hanger or bracket. In ball and roller bearings, the outside diameter of the outer race is ground to spherical form, and fits a spherical seating in the cast-iron housing. In another type, self-alignment is obtained within the bearing itself by the employment of a double row of balls running in two grooves on the inner race, the spherically ground outer race permitting the required deviation from the normal position.

1.7 BELT-DRIVE

Belt drive is one of the most common and effective devices of transmitting motion and power from one shaft to the other by means of a thin inextensible band running over two pulleys. This is largely used for general purposes in mills and factories specially when the distance between the shafts is not very great. Belts can transmit, however, upto a distance of about 10 m with a maximum surface speed of 1,400, m per min when flat belts are used, while a maximum surface speed of 1,500 m per min can be used with V-belts.

In a belt-drive arrangement, one of the pulleys called *driver* is mounted on the driving shaft while the other, which is mounted on the shaft to which power is to be transmitted is called the *driven pulley* or *follower*. When the belt moves over the pulleys there is always the possibility of some slipping between the belt and the faces of the pulleys, and hence the character of the motion transmitted is *not positive*. Where positive action is required, gears or chains must be used.

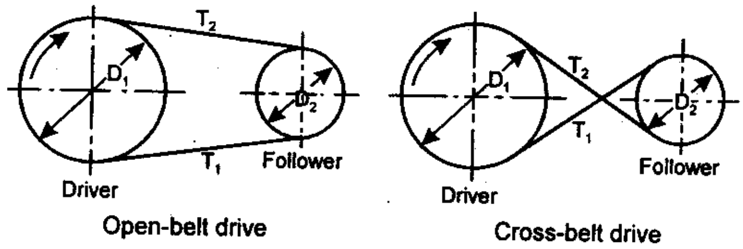


Figure 1.6 Open and cross-belt drive

Types of belt-drive : There are two common types of belt drives : (a) *open-belt drive*, and (b) *crossed-belt drive*. In the open-belt drive the driver and the follower move in the same direction. While in the crossed-belt drive, the sense of rotation of the driven pulley must be opposite to that of the driving pulley. These two arrangements illustrated in Fig.1.6 are used

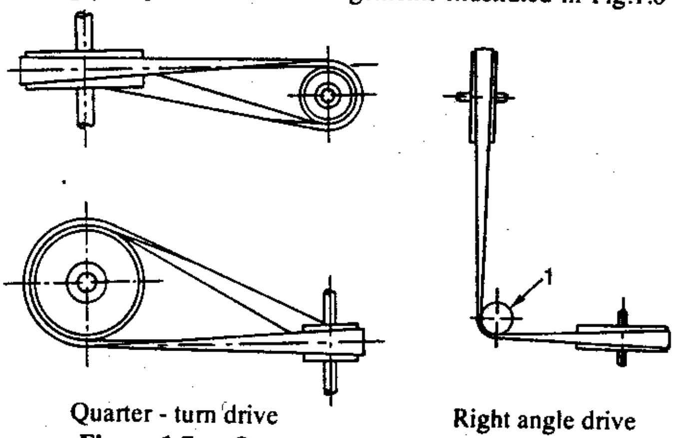


Figure 1.7 Quarter-turn and right angle drive

1. Guide pulley.

to connect shafts which are parallel.

Belt may be used for drives that are not parallel and which do not intersect, provided the pulleys are so located as to conform to a fundamental principle that governs the operation of all belt drives, namely : *the centre line of that part of the belt approaching a pulley must lie in the central plane of that pulley*. The angle at which the belt leaves the pulley is immaterial. Sometimes guide pulleys are necessary to direct the belt. These present no disadvantages and may be used to adjust the belt tension. Belt connections between non-parallel shafts are shown in Fig.1.7. They are known as *quarter-turn drive* and *right angle drive*.

Velocity ratio of belt-drives : The velocity ratio of a belt drive is defined as the ratio of the number of turns of the driving pulley to the number of turns of the driven pulley in a unit of time. This may be determined with sufficient accuracy in the following manner :

In Fig.1.6, let d_1 and d_2 be the diameters of the driver and follower respectively, and let n_1 and n_2 denote their speeds in revolutions per minute. The surface speed of the driver = $\pi d_1 n_1$ and the surface speed of the follower = $\pi d_2 n_2$. If there is no slip between the belt and the pulley, these are equal, i.e.

$$\pi d_1 n_1 = \pi d_2 n_2$$

that is $$d_1 n_1 = d_2 n_2$$

or $$\frac{n_2}{n_1} = \frac{d_1}{d_2} \qquad 1.1$$

or, in words, the velocity ratio

$$= \frac{\text{rev. per minute of the follower}}{\text{rev. per minute of the driver}} = \frac{\text{dia. of the driver}}{\text{dia. of the follower}}$$

The equation (1.1) is true whether the belt is open or crossed. With an open belt the sense of rotation of the two pulleys is same, while with a crossed belt this is opposite.

If t is the thickness of the belt, then,

$$\frac{n_2}{n_1} = \frac{d_1 + t}{d_2 + t} \qquad 1.2$$

When the motion is transmitted from a pulley A to a pulley F

through a number of intermediate pulleys *B, C, D, E,* of which *B* and *C*, are fixed to one shaft and *D* and *E* fixed to another, then,

$$\frac{n_6}{n_1} = \frac{d_1}{d_2} \times \frac{d_3}{d_4} \times \frac{d_5}{d_6} \qquad 1.3$$

Here d_1, d_2, d_3, d_4, d_5, and d_6 are the diameters of the pulley *A, B, C, D, E* and *F* respectively, and n_1 and n_6 are the speed of *A* and *F* respectively. To be exact, the diameters taken should be the effective diameters as explained above.

Hence we can write.

$$\frac{\text{velocity of the last shaft}}{\text{velocity of the first shaft}} = \frac{\text{dia. of the drivers multiplied}}{\text{dia. of the followers multiplied}}$$

Example 1.1 : A 10 kW motor running at 1750 r.p.m. has a pulley of 160 mm diameter fitted to it. It drives a line-shaft at a speed of 800 r. p. m. Three machines are driving by the line-shaft, their speed being 300, 500 and 200 r.p.m. The driving pulleys of the machines are respectively 240, 320 and 400 mm in diameter. Find the size of the pulleys to be fitted on to the line-shaft.

Here $D_1 = 160, n_1 = 1750, n_2 = 800, D_2 = ?$

From equation (1.1), $D_2 = D_1 \times \frac{n_1}{n_2} = \frac{160 \times 1750}{800}$ = **350 mm.**

D_2 is the diameter of the pulley on the line-shaft through which power from the motor is transmitted.

Let d_1, d_2 and d_3 be the diameters of the pulleys fitted on the line shaft for driving machines.

$d_1 \times 800 = 300 \times 240$ or d1 = **90 mm.**
$d_2 \times 800 = 500 \times 320$ or d2 = **200 mm.**
$d_3 \times 800 = 200 \times 400$ or d3 = **100 mm.**

H. P. transmitted by a belt : Let T_1 be the tension in the tight side of the belt and let T_2 be the tension in the slack side. The effective turning force at the circumference of the follower is the difference of the tension in the tight and slack sides of the belt. T_1 being greater than T_2, the difference of tensions is $(T_1 - T_2)$. Therefore, effective pull of the belt is equal to :

$$T_1 - T_2 = P \text{ (say)}$$

This force P is called the driving force or driving tension. If v is the linear velocity in metre per minute, and if P is the driving force in kgf then

$$\text{work transmitted per min} = P \times v \text{ kgfm.}$$

Therefore,

$$h.p. = \frac{Pv}{4500}$$

If the belt passes over a pulley which makes n revolutions per minute, and which has a diameter d in metre, then

$$\text{Speed of the belt, } v = \text{circumference} \times \text{rev. per minute}$$

$$v = \pi dn$$

$$h.p = \frac{\pi dnP}{4{,}500} \quad 1.4$$

In British system h.p. transmitted

$$h.p. = \frac{\pi dnP}{33{,}000}$$

where d is the diameter in ft. and P is the driving force in lb.

Example 1.2 : The width of a belt is 150 mm and the maximum tension per mm of width is not to exceed 1.6 kg. The ratio of tension on the two sides is $2\frac{1}{4}$, the diameter of the driver 1 m, and it makes 220 r.p.m. Find the horse-power that can be transmitted.

In this case, $T_1 = 1.6 \times 150 = 240$ kg.

and $\frac{T_1}{T_2} = 2.25$ *or* $T_2 = \frac{240}{2.25} = 106.7$ kg.

$\therefore$ $P = T_1 - T_2 = (240 - 106.7) = 133.3$ kg.

We know that $v = \pi dn = 3.142 \times 1 \times 220$ m/min.

$$\therefore \quad h.p. = \frac{133.3 \times 3.142 \times 220}{4,500} = 20.5$$

Ratio of driving tensions in a belt : The ratio of driving tensions in a belt just on the point of slipping is given by

$$\frac{T_1}{T_2} = e^{\mu\theta} \qquad 1.5$$

where e is the base of the Napierian log = 2.718, μ = co-efficient of friction for the belt on the pulley, and θ = angle of lap or arc of circumference embraced by the belt in radians.

Taking log on both sides, the equation (1.5) becomes

$$\log \frac{T_1}{T_2} = \mu\theta \log e$$

$$= 0.434\ \mu\theta \text{ in circular measure}$$

$$= 0.007578\ \mu\theta \text{ if } \theta \text{ is in degrees} \qquad 1.6$$

1.8 BELTING

Belting is made of different materials and of varied cross-sections either *flat* or *V-shaped*. The materials of belting in common use for power transmission are : (1) leather, (2) cotton and canvas, (3) India rubber, and (4) steel.

Leather belts are made from the "prime" or "butt" portion of the hide. The method of cutting up the butt for the production of belting of the highest quality is very important. The butt is only about 1.5 m long, but belts of any length can be made by joints about every 1.5 m. Belts are also made of a single and double thickness.

Single belting, i.e. with the thickness composed of one piece only, is now made in four standard thickness denoted by the numbers 1 to 4, and of 4, 5, 6, and 7 mm in thickness respectively. Some makers grade their belting by the weight in gm per sq cm, varying between certain fixed limits according to width.

Double belts, formed by cementing, sewing, or riveting together two thickness of leather are sometimes employed for heavy duty, but should be avoided as far as possible, and should never be used on pulleys less than 900 mm in diameter. Where circumstances will allow, single belts are much to be preferred, as they are more flexible, absorb less power in bending round pulleys, and are in consequence more durable.

Leather belts may preferably be used both in dry and wet places at ordinary temperatures.

Canvas or *woven belts* are manufactured from cotton or camel hair. They are made in two distinct varieties, known commercially as canvas and solid woven respectively. Canvas belting is made from stout canvas or cotton "duck" folded to the required breadth and thickness, the latter dimension being denoted by the number of folds or "plies". This is made in thickness from 3 to 10 ply.

Solid woven belting is produced in the loom in one piece of the required breadth and thickness from yarns spun from long stapled cotton. Hair belting is growing in favour, and may be woven entirely from camel hair or hair may be used in combination with weft and binders of cotton.

The canvas and woven belting are stronger and they are preferable to leather in warm climates, in damp atmosphere, and in exposed positions.

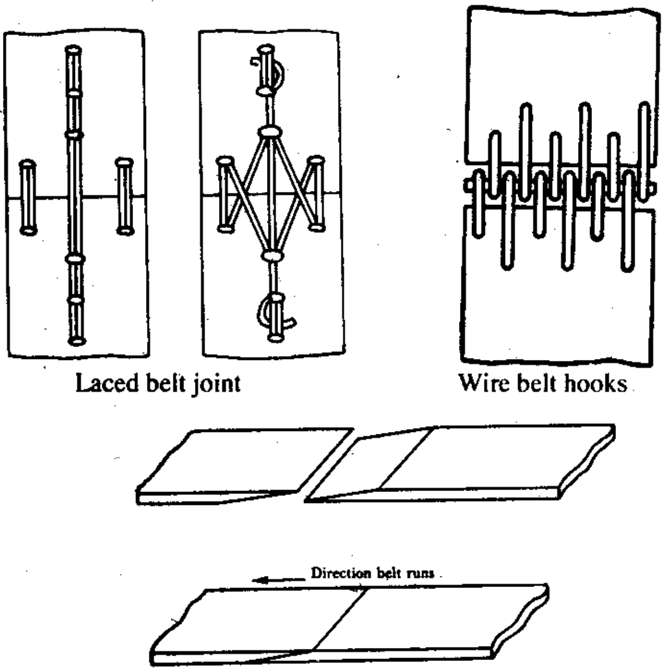
India-rubber belts are made by cementing together the canvas plies with a composition of vulcanized India-rubber. This kind of belting is considered the best in damp situations, but is expensive, and must be kept free from oil or grease, which are ruinous to rubber.

Balata belting has also wide applications in industry. This is primarily a cotton canvas belting prepared in a similar manner with balata in place of rubber. Balata is a gummy substance resembling gutta-percha, obtained from the milky juice of a tree which grows in British Guiana. Balata belting is often preferred in the heavily saturated steam-laden atmosphere of a dyehouse, or when subjected to chemical fumes, or again, for out-of-door use.

Joints in belting : belt fasteners : Belting is generally supplied by the maker in one continuous length ready for use, so that when placed upon the pulleys it only remains to make the closing joint by some form of fastener to produce an endless belt. Three methods are generally used for such fastening, namely, lacing ; metal fastener of various kinds ; and endless, cemented or solutioned joints (Fig.1.8).

Leather belts are often joined by raw hides. For lacing the ends of the belts are cut square and butted together, and the lace is threaded in round or oval holes which are made with a hand-tool known as belt-punch.

Metal belt-fasteners, in common use are : alligator-type fasteners, jackson button fastener, clipper fastener, crescent fastener, etc. The type of lacing depends upon the width of the belt.



Cemented belt splice

Figure 1.8 Belt joints

Leather and balata belts may be made endless by splicing and cementing exactly in the same way as the permanent joints employed in the manufacture of the belt itself. The belt is opened up by heating with a hot iron to enable the plies to be separated. They are then cut to stepped form, so that when the ends are placed together, the thickness of the joint in any part is the same as in the body of the belt. The plies are successively covered with solution, and the joint after thorough heating, is fixed in a clamp or press for ten to thirty minutes until it is set. There are two kinds of belt cements, one for dry and the other for damp conditions. The first is available in cakes or lumps, which dissolve in a glue pot. The other type is sold ready to apply.

V-Belt : When a belt is trapezoidal in section, designed to run in a V-shaped groove, it is known as a V-belt. The modern V-belts are made of fabric and vulcanized rubber with a cotton-cord tension element. The belt runs in 40° V-grooves turned in the pulleys as shown in Fig.1.9. The cross-sectional area varies, depending on the dimensions, the smallest dimensions are 10 and 6 mm, and the largest 50 and 30 mm, respectively.

V-belt drives are used when centre distance between shafts is short and transmission numbers are large. The distance, in general, should not be less than the larger pulley diameter and not more than the sum of the two pulley diameters. V-belt transmits a larger amount of power from a pulley of a given width of face, and being almost positive and slipless in action, it is displacing chain and gear drives for many short-centre distance machine drives. When calculating speed ratios for V-belt drives, pulley diameters measured to the centre of the belt should be taken into account, since contact between belt and pulley extends over an appreciable distance.

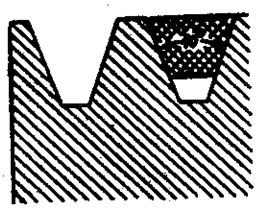


Figure 1.9 Grooved pulley with V-belt

Care and maintenance of belt : The life of a belt will be prolonged and its driving powers kept at capacity by giving it proper attention.

Driving surface of the belt should be kept clean and free from any dirt and other foreign matter. Such dirt, if allowed to get into the surface, forms into lumps, tearing or distorting the driving face of the belt and preventing it from forming proper contact with the face of the pulley.

Care should be taken to prevent oil or grease from getting at the belt. It will cause loss of power by slip, and is particularly harmful to balata or cotton belts, tending to separate the plies. It will also rot a leather belt and rapidly lessen the efficiency. An application of ground chalk will absorb the oil on a leather belt and make it workable for a time.

To keep a leather belt from becoming dry and lifeless, it should be given an occasional washing and brushing in warm water, and afterwards a good greasing with tallow or with one of the patent dressings sold for the purpose.

If belt slip becomes troublesome there are many compositions on the market to increase the friction between the belt and the pulley. A cheaper and better known remedy is powdered resin.

The face of the belt is also very important. The canvas side of a balata belt is the driving face, whether the drive be crossed or open. As regards leather belts, the grain side is the correct driving side. It should transmit nearly twice the power conveyed by the flesh side. The flesh side, which has the greatest tensile strength, will stand the stretching strain necessary in the outside bend around the pulleys.

1.9 PULLEYS

Pulleys are used to transmit power from one shaft to the other at a moderate distance away by means of a belt or strap running over them. They may be made of cast iron, wrought iron, pressed steel or wood. Mainshaft pulleys are generally made of wrought iron, pressed steel or wood which gives them suitable strength combined with lightness, while countershaft pulleys which are usually smaller than mainshaft pulleys are made of cast iron. These pulleys have a thin rim of rectangular section over which the belt runs. Usually, pulleys are provided with arms which may be straight or curved and the cross-section is usually described as "oval", i.e. roughly elliptical. The central part of the pulley is called the "nave", "eye", or "boss". To add strength and stiffness large pulleys are provided with ribs between the rim and the boss. Sometimes these ribs are reinforced with arms for greater stiffness and durability. The rims of all cast iron pulleys are generally : "crowned", i.e. slightly greater in diameter at the centre than at the edges. As the belt seeks the highest point on the pulley, the effect of crowning is to keep the belt in a central position. The crowning of pulleys, in most cases, should not exceed 25 mm on the diameter per metre of width, and the width of the pulley should be one-fourth greater then the width of the belt used. The minimum diameter of pulleys should be at least 24 times the thickness of belt used to run on the pulley.

Fast and loose pulleys : It has already been described in the methods of drive that in workshops and factories, power is in certain cases transmitted to the machines from a main line-shift called mainshaft, through an intermediate shaft, called countershaft, and two pulleys known as fast pulley and loose pulley that are mounted on the countershaft. A fast and loose pulley arrangement enables a machine to be started or stopped at will, without stopping the belt. Loose pulleys should revolve freely on the shaft, but the fast pulley or fixed pulley is firmly keyed on the shaft, as shown in Fig.1.1. To stop the machine shaft, the belt is moved from the fast pulley to the loose pulley by means of a belt shifter. The diameter of the loose pulley is sometimes made slightly smaller than that of the fast pulley so that when the belt is on the loose pulley there is very little tension in the belt. A loose pulley is usually provided with a brass or gun metal bush and needs efficient lubrication for smooth running.

Speed cones or stepped pulleys : Speed cones are cast iron pulleys having several steps of different diameters on which a belt may run (Fig.1.1). Speed cones are used for varying the velocity ratio between a pair of parallel shafts by simply shifting the belt from one step of the pulley to the other. They work in pairs, one on the countershaft and the other on the machine spindle. The diameters of the corresponding steps must be such that the same belt can operate, no matter how many steps are employed.

Guide pulleys : Guide pulleys are used to connect non-parallel shafts those which intersect and those which do not intersect to guide the belt into the proper plane as shown in Fig.1.7. Guide pulleys are also used when the two shafts to be connected are close together. Each portion of the belt, as it passes from one pulley to the other, being taken round part of the periphery of a guide pulley, which is suitably placed.

Jockey pulleys or rider pulleys : Jockey pulleys are used to increase the arc of contact, and also to produce a more tension in the belt as shown in Fig.1.10. They are mounted near the smaller of the two pulleys in a belt drive and always ride on the slack side of the belt. The pulley presses down the slack side due to having loaded bearing in which it runs.

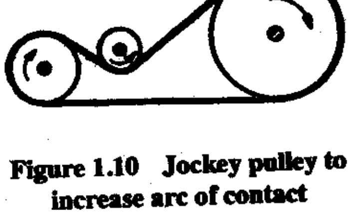


Figure 1.10 Jockey pulley to increase arc of contact

Grooved pulleys : Grooved pulleys for rope, V-belt etc. are generally made entirely of cast iron, but occasionally the arms are made of wrought iron. They are mainly used for the transmission of large powers over great distances and the effect of the groove is to increase the frictional grip of the rope on the pulley and thus reduce the tendency to slip. The grooves on the pulleys are V-shaped, the angle between the two faces being from 40° to 60°. The rope rests on the two sides, and not on the bottom of the groove (Fig.1.9). In guide pulleys, the grooves are semi-circular, and the rope rests on the bottom of the groove. The diameter of a rope pulley is generally not less than thirty times the diameter of the rope.

Wrought-iron pulleys : They are now used in great numbers for several important advantages. Wrought iron pulleys are light, strong, and durable, and are entirely free from the initial strains which exist in cast iron pulleys due to unequal contraction in cooling. In wrought iron pulley the rim is made of sheet wrought iron or pressed steel sheet and riveted to the arms which are made from bar-iron or mild steel. The boss is sometimes also made of wrought iron, but generally it is made of cast iron. To facilitate the erection of pulleys on the main shaft they are usually made in halves, and the parts securely bolted together. Steel often takes the place of wrought iron in the construction of pulleys.

Wooden pulleys : Wooden pulleys are made from 150 to 3000 mm in diameter, the rim built up in thickness, each composed of a number of segments arranged to break joint, the whole properly fitted and nailed and glued together. The arms are put in when the rim is being built up, and extend entirely through to the outside, The smaller sizes are made in block form. The pulleys are made in halves, and are fitted with interchangeable bushings so that they may be clamped tightly upon the shaft, dispensing with the use of a key.

As the coefficient of friction of leather on wood is higher than on the metal, it is claimed that wooden pulley will transmit more power than an iron pulley under the same condition, but they are not so durable as iron. Wooden pulleys can only be used in situations free from excessive dampness or moisture, and not subjected to high or varying temperatures.

1.10 ROPE DRIVE

Rope drive is used to transmit power over a moderately long distance. The horizontal distance apart of the shaft centres in a rope drive should not be less than 9 or 12 m, but may be made as much as 24 or 30 m. The working stress on the rope is usually taken 14 kg/cm^2 of section and they can impart as much as 2,000 h.p. One big advantage of rope drives is that a number of separate drives may be taken from one of the driving pulleys. Ropes for transmitting power are made of cotton, manila, or hemp, cotton ropes being usually considered the best on account of their greater driving power and flexibility. The rope used are endless, being joined by a splice, and fit into circumferential grooves on the pulleys which they connect, and are from 35 to 50 mm in diameter. In transmitting large powers, it is better to use a number of ropes of small diameter rather than a single rope of large diameter. The pulleys or wheels connected by ropes are grooved and the groove angle varies from 40° to 60°, but is generally 45°.

Steel or *wire ropes* are used for transmission of power in cases where the parts to be connected are at a large distance apart, and where extra strength is needed. They are used in lifts, colliery winding and hauling arrangements, mill drives, etc. The ropes run on grooved pulleys, but contrary to the practice adapted with cotton ropes, they rest on the bottom of the grooves and are not wedged between the sides of the grooves.

$$\text{H.P. transmitted by ropes} = \frac{Pv \times N}{4500} = \frac{(T_1 - T_2)v \times N}{4500}$$

where P is driving force in kgf, v the velocity in m per minute, and N the number of ropes in the pulley.

The relation between two tensions T_1 and T_2 is given by :

$$\frac{T_1}{T_2} = e^{\frac{\mu\theta}{\sin\alpha}} \qquad 1.7$$

where e is the base of the napierian log = 2.718, μ = coefficient of friction for the rope on the pulley, θ = angle of lap in radians and 2α = angle of the groove.

Taking log on both sides, the equation (1.7) becomes

$$\log\frac{T_1}{T_2} = 0.434 \times \frac{\mu\theta}{Sin\alpha} \text{ in circular measure}$$

$$= 0.007578 \times \frac{\mu\theta}{Sin\alpha} \text{ if } \theta \text{ is in degrees.} \qquad 1.8$$

Example 1.3 : A rope pulley with 5 ropes and surface speed of 1000 m/min transmits 100 hp. Find the tensions on the tight side and slack side, if the angle of lap is 130°, and the angle between the sides of the groove is 45°. Assume μ = 0.3.

Power transmitted per rope, h.p. = $\frac{100}{5}$ = 20 hp

In case of rope pulleys,

$$\log\frac{T_1}{T_2} = 0.4343 \times \frac{\mu\theta}{\sin\alpha}; \quad \alpha = \frac{45}{2} = 22.5° \; [\quad 2\alpha = 45°]$$

$$\theta = \frac{\pi}{180} \times 130 = 2.27 \text{ radian}$$

$$\therefore \quad \log\frac{T_1}{T_2} = 0.4343 \times \frac{0.3\times 2.27}{\sin 22.5} = 0.77\,; \quad \frac{T_1}{T_2} = 5.888$$

$$\text{h.p.} = \frac{(T_1 - T_2)v}{4500} \quad \text{or} \quad 20 = \frac{(T_1 - T_2)1000}{4500}$$

$$(T_1 - T_2) = \frac{20\times 4500}{1000} = 90 \text{ kgf} = 5.888\,T_2 - T_2$$

or, T_2 = **18.4 kgf**

or T_1 = $5.888\,T_2 = 5.888 \times 18.4$ = **108.3 kgf**

1.11 CHAIN DRIVE

Chains are used for high transmission numbers (up to 15) and can impart as much as 5,000 h.p. They are mostly used when the distance between centres is short. But they are also employed when the center distance is as much as 8 m. They are now in general use for the transmission of power in cycles, motor vehicles, agricultural machinery, road rollers, etc. and for gearing in workshops and factories, and are continually being installed to displace belt or rope drive and wheel gearing.

Well-conceived chain drives are highly effective, are positive in motion, i.e. permit no slip, and may be used where an exact average velocity ratio is essential. A chain drive takes up less space than a belt drive and has no initial tension. For belt or rope drives a certain minimum distance between the shafts is necessary unless jockey pulleys are to be used. This prevents the use of belts or ropes for connecting directly to shafts which are closed together.

A chain may be regarded as a belt built up of rigid links, which are hinged together in order to provide the necessary flexibility for the wrapping action round the driving and driven wheels. Wheels having teeth especially designed for chains are known as *chain sprockets* and bear a superficial resemblance to spur gears.

1.12 VARIABLE SPEED TRANSMISSIONS

It has been observed that a change of speed is obtained with flexible connectors running on a pair of stepped pulley or speed cone of different diameters. For many purposes the arrangement is defective, as only three or four definite speeds can be obtained in this way, and it is impossible to effect a gradual change from one speed to another. There is further disadvantage that it is generally necessary to stop the machine when making the change.

A practical solution of the problem is found in the *Reeves variable-speed transmission* in which the operator is able to control the speed while the speed is running without any interruption of the work in hand, and the change is continuous instead of being abrupt. This consists of a pair of pulleys connected by a V-shaped belt in the manner indicated in Fig.1.11. Each pulley consists of a pair of driving disks with cone-shaped faces, the disks revolving with the shafts, but the same time capable of sliding longitudinally along it to a certain extent. To adjust the diameters of the pulleys, the two conical disks on one shafts forming a pair are caused to approach each other, virtually increasing the diameter or recede from each other when the diameter is reduced. It follows that when the disks of one pair are approaching each other, those of the opposite pair must automatically be made to recede to the same extent. In this manner the ratio of driving diameter to driven diameter is readily and quickly changed, thus securing any desired speed without the necessity of stopping the machine.

Figure 1.11 Variable speed transmission

Variable speed transmission in the case of a chain drive may be secured by a device similar to that described above using *PIV (positive, infinitely variable) gear* which has radial teeth in the conical disk.

1.13 CLUTCHES

A clutch is a form of connection between a driving and a driven member on the same axis. It is so designed that the two members may be engaged or disengaged at will either by a hand-operated device or automatically by the action of some power-driven device. The common types of clutches may be dived into two general classes, namely, the positive clutch and the friction clutch.

Positive clutches : *Claw clutches* are slow-speed positive clutches. A simple form of claw clutch is shown in Fig.1.12. The right-handed marked B is keyed to the driven shaft and rotates with it. The lefthand end marked A is spliced so that it can be moved axially by shifting device that engages it by means of a groove in the flange. The clutch contact surfaces are usually, but not in all cases, made at a slight angle about 3° to 4° to the shaft axis to facilitate disengagement.

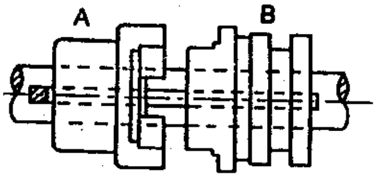


Figure 1.12 Claw clutch

Friction clutches : In friction clutches power is transmitted by friction. They are used to communicate, gradually and without shock, the motion of the driving shaft to the follower shaft at rest. Again, they are used where sudden and complete disconnection of two rotating shafts is necessary, where such shafts are in axial alignment. The frictional surfaces may be *conical* or *cylindrical*, or in the form of one or more *flat rings* of *disks*. A simple form of cone clutch is illustrated in Fig.1.13. It consists of two iron castings marked *A* and *B*. The motion is transmitted from the driving member *A* to the driven member *B* by the frictional resistance of the conical surfaces.

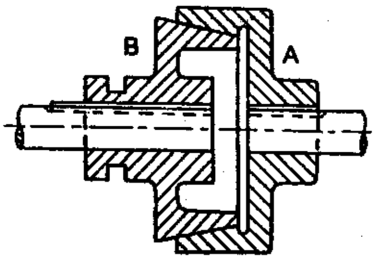


Figure 1.13 Cone clutch

1.14 FRICTION DRIVE

Friction drive is used for light load transmission between parallel shafts or between shafts with intersecting axes. In friction drive one wheel drives another with which it is in contact by reason of the friction between their surfaces, provided the surfaces to the two wheels are sufficiently rough. If the cylindrical friction wheels shown in Fig.1.14 are assumed to operate without slip, the surface speed of both the wheels must be equal. The velocity ratio of a pair of wheels is, therefore, inversely proportional to their diameter, that is :

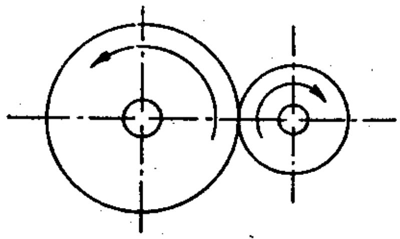


Figure 1.14 Friction drive

$$\frac{d_1}{d_2} = \frac{n_2}{n_1}$$

As in a belt drive, slipping may occur if the power to be transmitted is too great for the frictional grip between the surfaces, and friction wheels do not give a positive drive.

1.15 GEAR DRIVE

It is possible to drive shafts that are parallel, intersecting, or neither parallel not intersecting by the use of toothed gears. Toothed gearing is often used in preference to belting, friction drives, or chain drives, where moderate or large amounts of power must be transmitted at a constant velocity ratio. Many different forms of gears are used and the types most commonly used in industry are :

1. Spur gear.
2. Spiral gear.
3. Helical gear.
4. Bevel gear.
5. Worm and worm wheel.
6. Rack and pinion.

Toothed gear may be classified according to the relation of the axes and pitch surfaces, as in Table 1.1.

TABLE 1.1 . CLASSIFICATION OF TOOTHED GEARING

Name	*Kind*	*Relation of axes*	*Pitch surface*
Spur gears		Parallel	Cylinders
Bevel gears	Straight	Intersecting	Cones
	Spiral	Intersecting	Cones
	Skeew	Not in one plane	Hyperboloids
	Hypoid	Not in one plane	Cones
Helical gears	Parallel	Parallel	Cylinders
	Crossed	Not in one plane	Cylinders
Worm and worm wheel		Not in one plane	Cylinders

1.16 SPUR GEAR

Gears whose axes are parallel and whose teeth are parallel to the centre line of the gear are called spur gears (Fig.1.15). They are used to transmit power from one shaft or element to another in cases where those shafts have their axes parallel. Spur gearing is used over a wide range of articles- from small watches, precision measuring instruments, machine tools to gear boxes fitted in motor cars and aero engines, etc.

Figure 1.15 Spur gear showing straight line teeth

Spur gear elements and toothed parts : A common and usual type of wheel teeth form is shown in Fig.1.16 and the terms in general use in connection with spur gearing are given below :

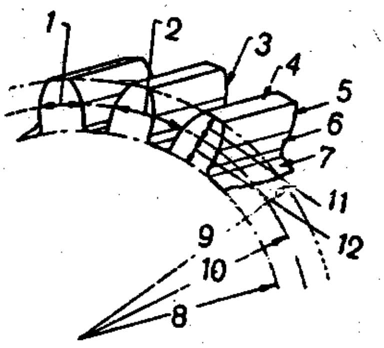


Figure 1.16 Spur gear elements 1. Thickness, 2. Circular pitch, 3, 5. Face 4. Tip or crest, 6. Flank, 7. Bottom or root, 8. Dedendum circle or root circle radius, 9. Addendum circle or Tip circle radius, 10. Pitch circle radius, 11. Addendum, 12. Dedendum.

Addendum : The radial height form the pitch circle to the tip of the tooth.

Dedendum : The radial depth from the pitch circle to the bottom of the tooth space in the mating gear.

Clearance : The radial distance from the top of the tooth to the bottom of the tooth space in the mating gear.

Face of tooth : The surface of a tooth between the pitch line and the top of the tooth.

Flank of tooth : The surface between the pitch line and the bottom of the tooth.

Tooth surface : Includes both face and flank.

Thickness : The thickness of the tooth on the pitch circle.

Working depth : The greatest depth to which a tooth of one gear extends into the tooth space of a mating gear, equals addendum plus dedendum minus the clearance.

Outside circle : The circle that contains the top of the teeth. The diameter of this circle is called outside diameter.

Pitch circle : An imaginary circle through the pitch point having its centre at the axis of the gear. The diameter of pitch circle is called *pitch diameter (d')*

Root circle : The circle that contains the bottoms of the teeth. The diameter of this circle is called *root diameter.*

Pitch point : The point of contact of two pitch circles.

Pitch line : The line of contact of two pitch surfaces.

Circular pitch (p) : The distance measured on the circumference of the pitch circle from a point of one tooth to the corresponding point on the next tooth.

Module (m) : The pitch diameter in millimeter divided by the number of teeth.

Pressure angle or angle of obliquity : The angle which the common normal to the two teeth at the point of contact makes with the common tangent to the two pitch circles at the pitch point.

In the British system the diametral pitch (P) is used instead of the module. It is the ratio of the number of teeth in a gear per inch of pitch diameter.

Relation between diametral pitch and module : By definition,

$$P = \frac{Z}{d'} \text{ and } m = \frac{d'}{Z}$$

Bearing in mind that 1 inch = 25.4 mm, we obtain

$$P = Z : \frac{mZ}{255} = \frac{25.4}{m}$$

We thus see that the module is the reciprocal of diametral pitch.

Relation between circular pitch and diametrical pitch :

$$P = \frac{Z}{d'} \text{ and } p = \frac{\pi d'}{Z}$$

so that $\frac{Z}{d'} = \frac{\pi}{p}$ and $P = \frac{\pi}{p}$ or $P.p = \pi$

Forms of wheel teeth : The standard form of tooth is involute in form except that a slight easing of the point is permissible. It has many advantages, the chief being that involute gears will work well together when the center distances are slightly varied.

The standard pressure angles for teeth are $14\frac{1}{2}°$ and 20°.

Example 1.4 : A large gear has 80 teeth and small mating gear has 10 teeth. If the module is 4 mm, calculate the distance between the centres of the gears.

$$d'_1 = Z_1 m = 80 \times 4 = 320$$

$$d'_2 = Z_2 m = 10 \times 4 = 40$$

$$\therefore \text{ Centre distance the gears} = \frac{d'_1 + d_2}{2} = \frac{320+40}{2} = \mathbf{180\ mm}$$

Example 1.5 : A wheel has 50 teeth of module 5 mm. Find the pitch diameter and the circular pitch.

$$d' = Zm = 50 \times 5 \quad = \mathbf{250\ mm.}$$

$$p = \frac{\pi d'}{Z} = 3.142 \times 5 \quad = \mathbf{15.71\ mm.}$$

1.17 HELICAL GEAR

Helical gears are gears in which the teeth are cut in the form of helix around the gear. Helical gearing is used to connect parallel shafts as well as non-parallel, non-intersecting shafts. The pitch surfaces, are cylindrical as in spur gearing, but the teeth, instead of being parallel to the axes, wind around the cylinders helical like screw threads.

The outstanding advantage of helical gears, as compared with corresponding spur gear, is that helical gears run more smoothly and more quietly at high speeds and under other severe service conditions.

Helical gear for parallel shaft : Helical gears connecting parallel shafts are illustrated in Fig.1.17. The conception of a helical gear is simplified by considering it as a spur gear with the teeth twisted. The teeth of helical gears with parallel axes have line contact, just as do spur gear. This provides gradual engagement and continuous contact of the engaging teeth. The efficiency of transmission with helical form of teeth is high, and there is less noise and less friction

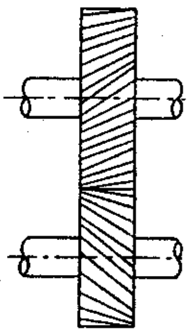


Figure 1.17 Single helical gear

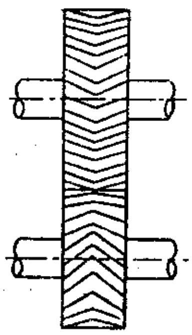


Figure 1.18 Double helical gear

loss. So they can be used to transmit large powers, and larger velocity ratio can be obtained in one step than is possible with ordinary spur gears.

One disadvantage in the use of helical gears is that the teeth impart axial thrust to each other. To obviate this axial thrust the teeth are more often cut in the form of a double helix, as shown in Fig.1.18, when equal and opposite thrusts are produced on each wheel and no axial thrust is transmitted to the shafts. Double helical gears are called *herringbone gears*, which give the smooth-running advantages of helical gears.

Helical gear for non-parallel shafts : Helical gearing for non-parallel, non-intersecting shafts may be designed for any angle between the shafts but the shafts are usually at right angles. The tooth action of this gear is quite different from that of the helical gears for parallel shafts. The former have merely point contact, while the latter have line contact. In the former case, also there is a large amount of sliding in the direction of the common tangent to the tooth elements, which is entirely absent in the latter case. Helical gears for non-parallel, non-intersecting shafts may consequently be used for comparatively light service.

1.18 SPIRAL GEAR

Skew or Spiral gearing illustrated in Fig.1.19 is used to connect non-parallel, non-intersecting shafts. The pitch surfaces are cylindrical and the teeth have point contact. These gears are, therefore, suitable only for transmitting small power. The center distance for a pair of spiral gears is the shortest distance between the two shafts making any angle between them.

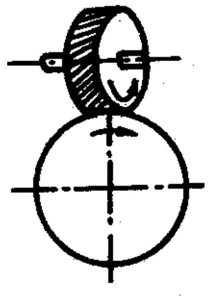


Figure 1.19 Spiral gear

1.19 BEVEL GEAR

When two shafts, the axes of which intersect, are to be connected by gearing, the wheels are known as bevel gears illustrated in Fig.1.20. In a bevel gear the teeth are cut on a conical surface, such as would be represented by a truncated cone. In the great majority of bevel gear drives the shafts are at right angles, but the angles between the shafts may be either greater or less than 90°. In such cases the gears are called *angular bevel gears*. When the angle between the shafts is 90° and two gears of a pair are equal, the gears are called *mitre gears*. When the pitch angle of a bevel gear is 90°, it is called *crown gear*.

Bevel gear may be divided into four classes :

1. *Straight-tooth bevel gears*, in which the elements of the tooth surfaces are straight. The pitch surfaces are cones. Straight-tooth bevel gears are very much used in drilling, shaping and milling machines to transmit power from vertical shafts to the horizontal one.
2. *Spiral bevel gears*, in which the teeth are curved on a spiral. The pitch surfaces are cones. The outstanding advantage of spiral bevel gears as compared with straight-tooth bevel gears is the greater smoothness and quietness of operation of spiral bevel gears, particularly at high speeds. Consequently, these are used in machine tools, motion-picture machinery, sewing machines, etc.
3. *Skew bevel gears* may be used to connect non-parallel and non-intersecting shafts. The teeth surfaces hyperboloids and the teeth are straight. Skew bevel gears are rarely used in machine construction because of the difficulties involved in producing correct tooth forms.
4. *Hypoid gears*, also connect non-parallel and non-intersecting shafts. Hypoid gears possess the main characteristics of skew bevel gears, but they have curved teeth, whereas skew bevel gears have straight teeth.

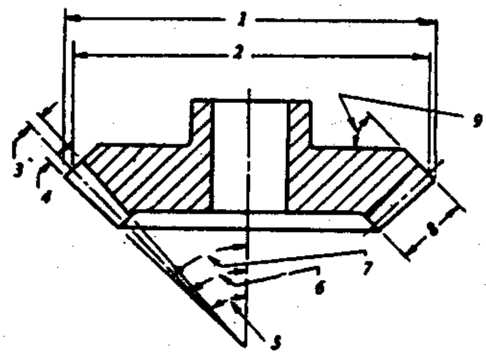


Figure 1.20 Bevel gear elements

1. Outside diameter, 2. Pitch diameter, 3. Dedendum (large end), 4. Addendum (large end), 5. Root angle Cutting angle, 6. Pitch angle, 7. Tip angle or Face angle, 8. Face width, 9. Back angle.

1.20 WORM GEAR

Worm gearing is essentially a special form of helical gearing in which the teeth have line contact and the axes of the driving and driven shafts are usually at right angles and do not intersect. The distinction between helical gearing may be explained as follows : If the number of threads, or teeth is such that no one thread makes a complete turn, the gear is called a helical gear. If on the other hand, a thread makes a complete turn, the result is a worm and the mating gear is called worm wheel. A worm and worm wheel is illustrated in Fig.1.21.

The action of this gearing is like the action of a screw and nut and this class of gearing is, therefore, sometimes called *screw gearing*. In appearance the worm resembles a multiple-threaded screw and its teeth are referred to as threads. Worms are designated like screw threads as right- hand or left-hand *single-thread worm,* right-hand or left-hand *double-thread worm*, etc.

Worm gearing is commonly employed to obtain higher velocity ratios than can conveniently be obtained from other forms of gearing. This velocity ratio in worm gearing, of course, dose not depend upon the diameters of the worm and gear but upon the ratio of the number of teeth on the worm gear to the number of threads on the worm. Machine tools like Lathe, Drill, Milling, etc. are equipped with worm gearing to get large velocity ratio.

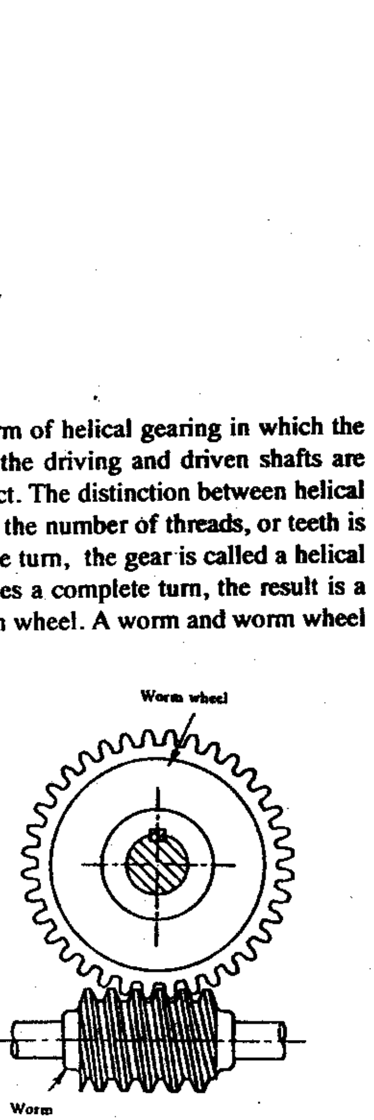


Figure 1.21 Worm and worm wheel

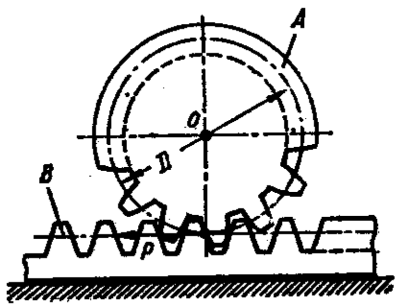


Figure 1.22 Rack and pinion
A. Pinion, B. Rack.

1.21 RACK AND PINION

The function of a rack and pinion, shown in Fig.1.22 is to transform circular motion to rectilinear motion. Small gears are called pinions and racks are a series of teeth on a straight line. They may be considered as spur gears of infinite radii.

Lathe, drill, planer, etc. are fitted with rack and pinion to convert rotary motion to straight-line motion.

1.22 VELOCITY RATIO OF A TOOTHED WHEEL

Let n_1 and n_2 be the speed of the driver and follower respectively in revolutions per minute, d'_1 and d'_2 their pitch circle diameter, and let the driver contain Z_1 teeth and the follower Z_2 teeth.

Then as in belt drive :

$$\pi d'_1 n_1 = \pi d'_2 n_2$$

that is, $d'_1 n_1 = d'_2 n_2$

or $$\frac{n_2}{n_1} = \frac{d'_1}{d'_2}$$

But since the diameters of the pitch circles are proportional to the circumference, and the driver and follower, to work together, must have the same pitch, the circumferences are proportional to the number of teeth in the wheels.

or $$\frac{n_2}{n_1} = \frac{d'_1}{d'_2} = \frac{Z_1}{Z_2} \qquad 1.9$$

It is obvious that the direction of rotation of two gears directly in contact will be opposite to each other. If instead of directly gearing the driver A with the follower B (Fig.1.23) a wheel C is introduced between the driver A and the follower B, the driver A will drive the wheel C, and C will drive B, the effect of C being to make the wheel B turn in the same direction as A instead of in the opposite direction if it is connected directly with A. The wheel C is called the *idle wheel* as it has no effect on the velocity ratio. The function of an idle wheel is, therefore, to change the direction of rotation of the train.

Velocity ratio of worm and worm wheel : As in the case of other gearing, the *velocity ratio of worm gearing* may be expressed as :

$$\frac{\text{r.p.m. of worm shaft}}{\text{r.p.m. of worm wheel}} = \frac{\text{number of teeth in worm wheel}}{\text{number of threads in worm shaft}}$$

The threads in worm shaft are sometimes referred to as teeth and the number of threads in the worm shaft is equal to the lead of the worm shaft divided by the pitch.

Figure 1.23 Diagram showing the function of an idle wheel

Example 1.6 : Find out the r.p.m. of a 50-tooth worm wheel when it is being driven by a worm shaft whose lead is equal to 3 pitch revolving at a speed of 300 r.p.m.

The velocity ratio of worm gearing may be expressed as :

$$\frac{\text{r.p.m. of worm shaft}}{\text{r.p.m. of worm wheel}} = \frac{\text{no. of teeth in worm wheel}}{\text{no of threads in worm shaft}}$$

Lead of the worm shaft being equal to 3 pitch, it is a 3-start thread.

Let n be the r.p.m. of the worm wheel, then

$$\frac{300}{n} = \frac{50}{3} \quad or \quad 50n = 900 \, or \quad n = \frac{900}{50} = \mathbf{18}$$

The worm wheel will revolve at a speed of 18 r.p.m.

1.23 POWER TRANSMITTED BY GEARING

In a train of gear wheels the work put into the train by the first driver must be equal to the work obtained from the last follower, and assuming there is no loss due to friction, this must be equal to the work transmitted.

Then work transmitted

$$= \text{effort applied to the driver} \times \text{distance moved by the effort.}$$

$$= P \times v \text{ kgf-m}$$

$$\therefore \quad \text{h.p.} = \frac{Pv}{4{,}500}$$

or $$\text{h.p.} = \frac{P \times \pi d' n}{4{,}500} \qquad 1.10$$

In British system,

$$\text{h.p.} = \frac{P \times \pi d' n}{33{,}000}$$

where, P is in lb, d' in ft, and n in r.p.m.

1.24 HYDRAULIC SYSTEM

Hydraulic systems are extensively utilised for driving high-power machine tools. This is due to the reason that a relatively small hydraulic system can deliver a high level of power and can develop much higher maximum angular acceleration than DC motors of the same peak power.

A hydraulic system is shown in Fig. 1.24. Maintenance of a hydraulic system is crucial due to high pressure development in the transmission lines. The oil must be kept clear and leakage should be detected and prevented for proper working of the system.

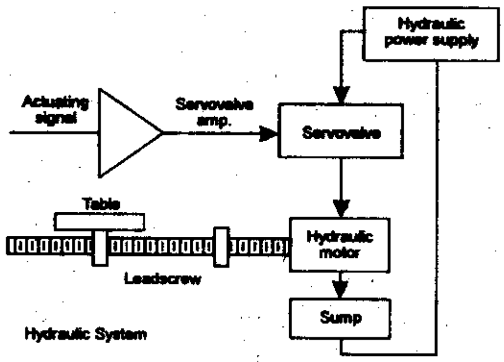


Figure 1.24 Hydraulic system

REVIEW QUESTIONS

1. Name the methods for driving machines in machine shops. Describe them in brief.
2. What are the advantages and disadvantages for (a) individual drive and (b) group drive ?
3. List the various elements used in methods of drive / power transmission.
4. What are the couplings used for shafting ? Describe any two of them with sketches if any.
5. What is the main difference between a shaft and an axle ? Why the shafts are made round in cross section ?
6. What is a bearing ? List the names of bearings used in shaftings. How the bearings are lubricated ? Why ?
7. In which situation you recommend belt drive for power transmission ? What are the common types of belt drives ?
8. Define velocity ratio for belt drive.
9. Name the belt materials and list their merits and demerits.
10. State the different types of pulleys used in power transmission.
11. What is the function of a pulley in transmission of motion ? Name various types of pulleys ? Describe any two of them.
12. What are the advantages and disadvantages of rope drives compared to chain drives ?
13. Describe various elements of a gear. List the different types of gears used in industry.
14. Why helical gears are preferable in certain situations in power transmissions ? Justify your answer.
15. What is worm and a worm wheel ? Describe in brief.
16. What is rack and a pinion ? Discuss their utility.
17. A gear wheel having 40 teeth and running at 100 r.p.m. is driving another wheel having 20 teeth. Find the speed of the driven gear wheel. (200 r.p.m.)
18. Two wheels are connected by a cross belt. The velocity ratio of the drive is 3. The driving wheel runs at 1,000 r.p.m. and has a diameter of 120 cm. Find the speed and the diameter of the driven pulley. (3,000 r.p.m., 40 cm)
19. A pump consuming 5 hp at 200 r.p.m. is drawn by a belt and pulley. If the diameter of the pulley is 375 mm, what is the tension in the belt ? Assume $T_1 = 3\,T_2$. ($T_1 - T_2$ = 94.5 kgf)