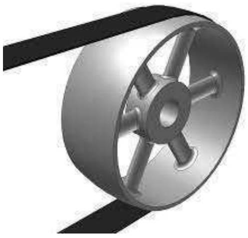
CHAPTER 1

Belts and Pulleys

Outcomes

- Learn advantages and disadvantages of belt and pulley drives over other types of drives
- Belt materials and their properties
- Different types of flat and V belt drives
- Contact angle of belt with pulley for open and cross belts
- Belt tensions and power transmission capacity for flat and V belts
- Initial tension, centrifugal tension, and maximum tension in a belt
- Condition for maximum power
- Slip and creep in a belt
- Design procedure for a flat belt drive
- Center distance, length, and standard lengths of V belts
- Power rating and life of a V belt
- Design procedure for a V belt drive
- Types of pulleys for flat and V belts

1.1 Introduction



In machines, mechanical power is transmitted from one shaft to another shaft. Various types of drive systems are available. Important ones are belt and pulleys, chains and sprockets, and gears. This chapter deals only with belt and pulleys. Pulleys are used to transmit power with the help of belts. A pulley is a circular machine element, having a hub in the center with a key way, which fits on the

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shaft. Pulleys are mounted on shafts, while the belt passes over both the pulleys. The power is transmitted due to the friction between the pulley and the belt. It is suitable, if the center distance between the shafts is large. Some features towards advantages and some towards disadvantages are given below:

1.1.1 Advantages

- It is simple and inexpensive.
- The center distance between the shafts is not that critical as for gears.
- It does not require axially aligned shafts and can tolerate high misalignment.
- The distance between the shafts can be large.
- It needs no lubrication and requires minimal maintenance.
- It protects the machines from overload and jam.
- It damps and isolates noise and vibrations.
- Load fluctuations and shocks are absorbed.
- It does not increase the cost much, even if the shafts are far apart.
- Clutch action can be obtained by releasing / adjusting belt tension.
- It can operate at temperatures ranging from –35° C to 85° C.
- It can work in dusty or corrosive environment.
- Different speeds can be obtained by step or tapered pulleys.
- It offers high transmission efficiency (output / input) 90–98 per cent, usually 95 per cent.

1.1.2 Disadvantages

- Adjustment of center distance or addition of an idler pulley is needed to compensate for wear and stretch.
- Tension of the belt causes bending of the shafts and load on the bearings.
- Short life in comparison to other types of drives.
- A cover, generally of wire mesh is needed on the drive for safety purpose.

1.2 Types of Belts

Belts are of many types as shown in Figure 1.1 and pictures below. Use of a particular type of belt depends on power to be transmitted and type of service:

- Flat belt
- V belt
- Grooved belt
- Ribbed belt
- Film belt
- Circular belt

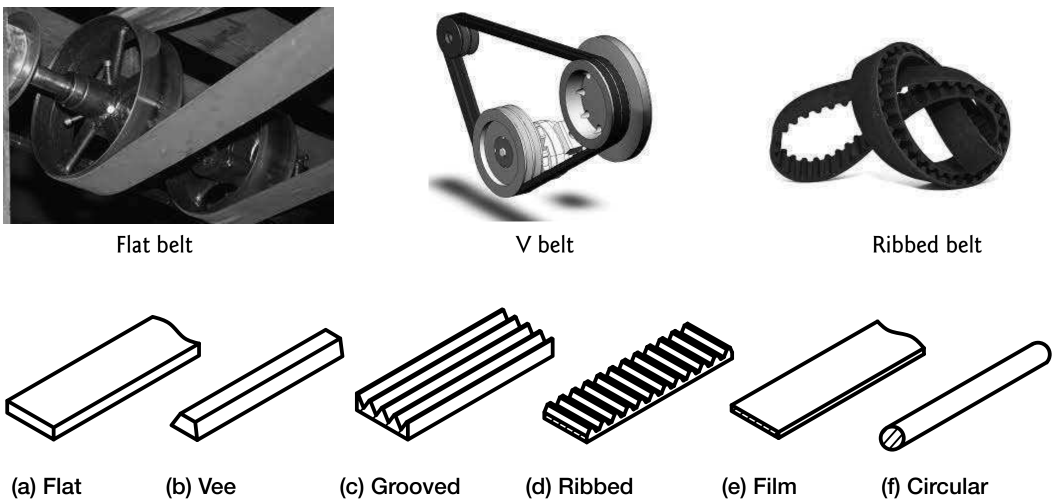

Figure 1.1 Types of belts

Flat and V belts are generally used and hence described below.

1.2.1 Flat belts

Plain flat belts are of rectangular cross section with no teeth or groove as shown in Figure 1.1(a). These belts are used for line shafts in factories, farming, mining applications, saw mills, flour mills, conveyors, etc. These are low cost and used on small pulleys. They need high tension resulting in high bearing loads. They are noisier than other types of belts and have low efficiency at moderate speeds. These are made of leather, fabric, rubberized fabric, nonreinforced rubber / plastic, reinforced leather, etc.

1.2.2 V belts

The V belt was developed in 1917 by John Gates. These are endless, and their cross-sectional shape is trapezoidal. They reduce the slippage and alignment problem. They provide the best combination of power transmission, speed of movement, load of the bearings, and long service life. The belt tends to wedge into the groove, as the load increases. Greater the load, more is the wedging action, thus improving the torque transmission and need lesser width and tension than flat belts. The preferred center distance is larger than the largest pulley diameter, but less than three times the sum of diameter of both the pulleys. Optimal belt speed range is 5–35 m/s.

V belts have long life (3–5 years) and offer quiet operation and low maintenance. These are most commonly used in industry and are available in standard cross-sectional sizes and lengths. They offer more speed than flat belts. The best speed for V belts is between 8 and 30 m/s. V belts are made in two sizes: conventional and narrow. Ideal speed for standard belt is 23 m/s and for narrow belts it is 50 m/s.

Conventional V belts are designated as A, B, C, D, and E. Narrow belts are designated as 3V, 5V, and 8V. Angle for all belts is 40°. Width and thickness of these belts are shown in Figure 1.2. More than one belt is used to increase power transmission capacity. Number of belts on one pulley is limited to eight. If more than eight belts are required, then larger section should be selected.

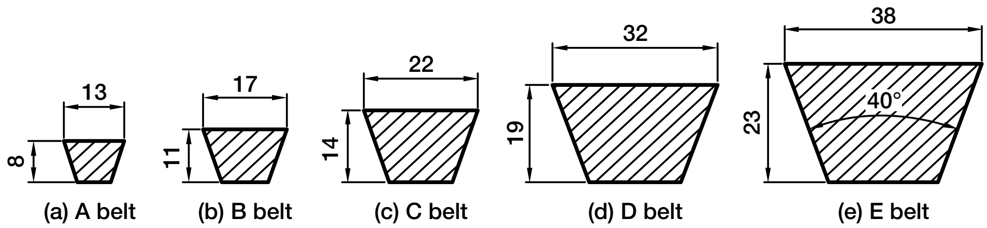

Figure 1.2 V belt cross sections

V belts are designated by its cross-sectional letter A, B, etc., followed by inside length. For example, B 420 means a belt of cross section B and inside length 420. Table 1.1 shows the sizes of various belts.

Table 1.1 Size and Weight of V Belts

Belt Section	Large Width (w) (mm)	Thickness (t) (mm)	Small Width ($w2$) (mm)	Area (mm^2)	Volume per meter (V) (mm^3)	Weight per meter (N)
A	13	8	7.2	81	81,000	1.06
B	17	11	9.0	143	143,000	1.86
C	22	14	11.8	237	237,000	3.43
D	32	19	18.2	477	477,000	5.96
E	38	23	21.3	681	681,000	9.41

Small width of the of the section = Width at large size – $(2 \times \text{thickness} \times \tan 20°)$

$$w2 = w - (2t \times 0.364) = w - 0.728t$$

Area of the trapezoidal cross section $A = \dfrac{\text{Large width} + \text{Small width}}{2 \times \text{Thickness}} = \dfrac{w + w2}{2t}\ \text{mm}^2$

Volume of belt per meter $V = 1{,}000A$
Weight of belt per meter = Volume × density = $V \times \rho$

1.2.3 Construction of V belts

V belts are made of three layers. The outer layer is of polychloroprene as an elastic cover. The central part has load-bearing cords of polyester fabric located near the center of the section

(Figure 1.3). Since the stresses are minimum in the center, these cords have not to bear too much fatigue. In between the outer part and cords is the rubber to transmit force from cords to side walls. Thermoplastic polyurethane, and Elastomers are also used for V belts. Temperature range 0° C – 80° C.

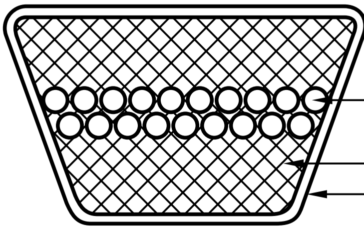

Figure 1.3 V belt construction

1.3 Types of Flat Belt Drive

The open belt drive has parallel shafts rotating in the same direction, whereas the cross-belt drive also have parallel shafts but rotate in the opposite direction. The former is far more common, and the latter is not common, because the pulleys contact both the inner and outer belt surfaces. Non-parallel shafts can be connected, if the belt's center line is aligned with the center plane of the pulley.

Three types of flat belt drives are used; open, crossed, and quarter twist depending on the direction of rotation of shafts, angular position, and distance between shafts.

1.3.1 Open belts

If the direction of rotation of the driver and driven is the same, the open belt arrangement is used as shown in Figure 1.4(a). One side of the belt is called tight side, while the other is called slack side. Tight side should be kept at the bottom as shown in Figure 1.4.

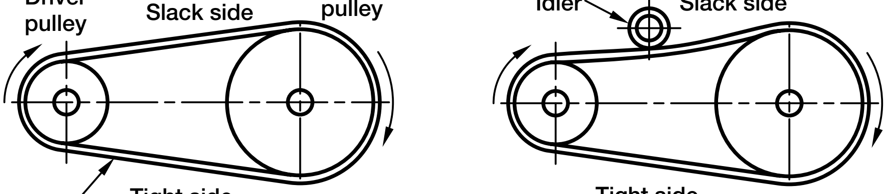

Figure 1.4 Open belt system

The center distance is an important parameter in this drive. Small center distance increases the number of turns of belt per second and hence reduces belt life. Short center distance reduces arc of contact on small pulley, which increases slip. On the other hand, large distance causes sagging of the belt. If the belt is horizontal, sagging causes swinging perpendicular to the belt. Hence, slack side is kept on the upper side so that slackness increases the arc of contact. If loose side is on the lower side, sagging reduces arc of contact and hence increases slipping.

Owing to continuous use of belt, it gets elongated. For shafts, which cannot be moved to tight the belt, an idler is used to keep the belt tight over the pulleys [Figure 1.4(b)].

1.3.2 Crossed belts

If the direction of rotation of the driven is opposite to the driver, then crossed belt arrangement is used [See Figure 1.5(a)]. The belt is twisted 180° such that outside face of belt on one pulley becomes inside face on the other pulley. Since the arc of contact is more, this arrangement can transmit more power than open belts.

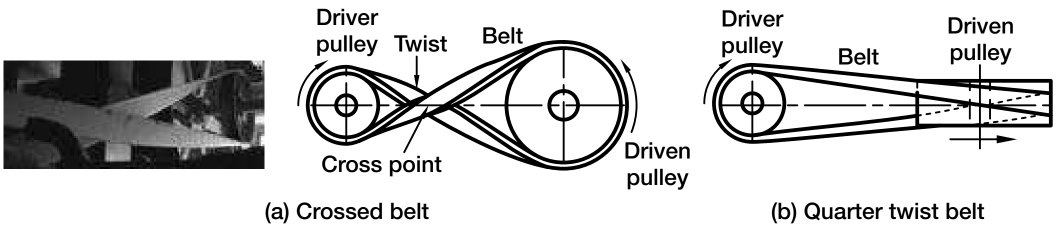

Figure 1.5 Cross and quarter twist belt arrangements

Drawback of this is that the location where two sides of the belts cross each other, rubbing between the belt faces takes place causing excessive wear and tear of the belt. To reduce this rubbing, center distance between the shafts should be about 20 times the width of the belt.

1.3.3 Quarter twist belts

If the axes of the driver and driven shafts are at 90°, quarter twist belt as shown in Figure 1.5(b) is used. Center distance between the pulleys has to be long for this arrangement. To avoid slipping of the belt off the pulley, width of pulley is kept about 1.5 times the width of the belt.

1.3.4 Compound belts

Compound belt is used to obtain high velocity ratios (VR = Driver speed / driven speed). For this type of drive, driver pulley 1 drives the driven pulley 1 mounted on an intermediate shaft as shown in Figure 1.6. Driver pulley 2 is also mounted on intermediate shaft. Belt 2 transmits power from driver pulley 2 to the second driven pulley 2. Overall velocity ratio VR is multiplication of two velocity ratios VR1 and VR2, that is, VR = VR1 × VR2.

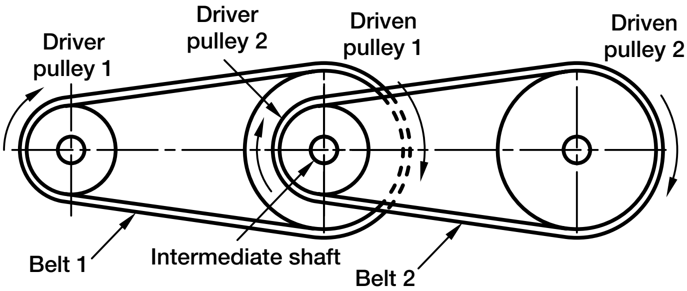

Figure 1.6 Compound belt

1.3.5 Serpentine belts

A belt can drive more than one pulley also as shown in Figure 1.7. In this figure, three pulleys are being driven from a single driver pulley. To increase the arc of contact so that the belt does not slip, idlers are used. Idler is also used to tight the belt by moving it in a direction, which tights the belt.

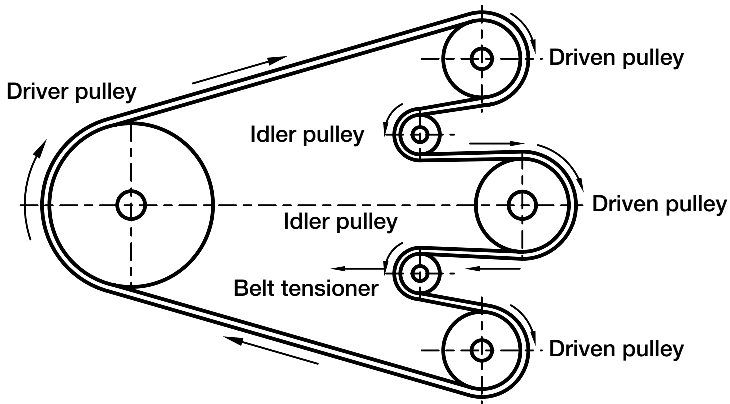

Figure 1.7 Serpentine belt

1.4 Belt Materials and Construction

The belt material is chosen depending on the use and application. Leather oak tanned belts and rubber belts are most commonly used. Plastic belts have almost twice the strength of leather belt. Fabric belts are used for temporary or short-period operations. Belt material should possess the following properties:

- High coefficient of friction for a good grip with the pulley;
- High tensile strength to bear the pull of belt and centrifugal tensions;
- High flexibility, so that it could bend easily when turning over the pulleys;
- High fatigue strength, as the outer and inner surfaces are under varying stresses; and
- High wear resistance for a long life.

Following materials are generally used for the belts:

a. **Leather**

Main advantage of leather belt is high coefficient of friction and hence high power transmitting capacity. Oak-tanned or chrome-tanned leather is used for flat belts. Leather belts of various widths are available in the form of strips up to 1.5 m length. Leather strips have two sides; one is called flash side and the other hair side. Flash side is strong, whereas the hair side is smooth and hard. Hair side is kept for contact on pulley. Tension is maximum on outside of the belt, hence flash side is kept outside. The strips are made into endless loops by making the ends tapered as shown in Figure 1.8(a). Each strip is called a ply.

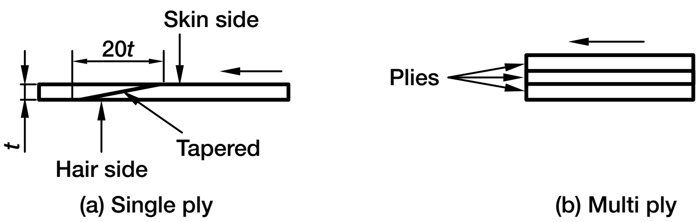

Figure 1.8 Leather flat belts

Thickness of the belt is increased by placing many plies one over the other. Strips of leather are cemented with each other to form a multiply belt [Figure 1.8(b)]. The joints are staggered in steps. These belts need periodic cleaning or dressing with suitable oil to keep them soft.

b. Rubber

Rubber belts are made by joining layers of canvas or cotton duck impregnated with rubber. These belts get easily destroyed under heat or in contact with oil or grease. These belts are suitable for saw mills and paper mills, where the moisture may exist. In some belts, balata (rubber type gum) is used in place of rubber, and it offers 25 per cent higher strength than rubber. For greater tensile strength, the rubber belts are reinforced with steel cords or nylon cords. These belts offer high load-carrying capacity and long life, and can operate at belt speed as high as 300 m/s. Their disadvantages are that they cannot be used over small pulleys and not suitable for oily environment.

c. Fabric

Fabric belts are made of canvas or woven cotton. The thickness of belt is increased either by folding or stitching each layer together. The belt thickness is built up with a number of fabric layers called plies. The plies are impregnated with filler material like linseed oil to make them water proof. These belts are cheaper and suitable for damp and warm environment. These are suitable for agricultural machines, belt conveyors, as they require very little attention. These can be easily made endless. These are manufactured by any one of the methods shown in Figure 1.9.

- **Raw edge belt** Strips are cut and placed one over the other. Edges are visible on sides and hence called raw edge belt [Figure 1.9(a)]. Edges are protected with water proof compound. Rubber is placed in between the plies. These are suitable for small pulley and high speed.

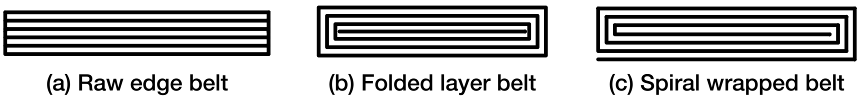

Figure 1.9 Fabric flat belts

- **Folded layer belt** It has a central ply wrapped in rectangular plies [Figure 1.9(b)]. There may not be any rubber between the plies.

- **Spiral wrapped belt** They are made by a single piece of fabric wrapped in a spiral fashion [Figure 1.9(c)]. There may not be any rubber between the plies.

d. Plastics

Thin plastic sheets with rubber layers are also used as flat belt material.

1.5 Properties of Belt Materials

Design strength, endurance strength, and elastic modulus are given in Table 1.2. These values are required to calculate the size of the belt. Table 1.2 also gives density of belt material, which can be used to calculate centrifugal force on the belt.

Table 1.2 Properties of Belt Materials

Material	Design Strength (MPa)	Endurance Strength (MPa)	Elastic Modulus (MPa)	Density (kg/m^3)	Maximum Velocity (m/s)
Leather	2.0	6.0	30.0	1,150	50
Rubber	1.6	6.0	10.0	1,150	30
Fabric	1.5	3.0	15.0	950	25
Plastic	4.0	6.0	60.0	1,050	60

Coefficient of friction depends on pair of belt and pulley material. It is given in Table 1.3.

Table 1.3 Coefficient of Friction for Belt Materials and Different Pulleys

Belt Material	Pulley Material			
	Wood	Cast Iron / Steel		
		Dry	Wet	Greasy
Leather oak tanned	0.30	0.25	0.20	0.15
Leather chrome tanned	0.40	0.35	0.32	0.22
Rubber	0.32	0.30	0.18	–
Canvas	0.23	0.20	0.15	0.12
Woven cotton	0.25	0.22	0.15	0.12

1.6 Flat Belt Specifications

To specify a belt fully, one has to specify the following:

- Material of belt
- Number of plies for flat belt or thickness
- Maximum tensile strength

- Width of flat belt (cross-section size for V belts)
- Power rating in watts per ply per mm width
- Length at pitch diameters of the pulleys
- Timing belts in addition, require size of the teeth.

a. **Material**
Selection of material to be used depends on the type of service, that is, duty hours per day, smooth or shocks, type of environment; dusty, oily, moist, etc.

b. **Number of ply and thickness**
Number of plies is decided depending on the belt tensile strength required for a given power transmission. Standard belt thicknesses are 5, 6.5, 8, 10, and 12 mm.

c. **Maximum belt stress per unit width**
The belts are subjected to only tensile load. The allowable tensile load depends on the allowable stress on the belt and its cross-sectional area. It is customary to provide the belt stress value for a given belt thickness and per unit belt width.

d. **Width**
A designer has to select a belt thickness and then calculate the required belt width. Alternately, one can calculate the belt cross-sectional area and then adjust the belt thickness and the width from the standard widths. Values of standard belt widths are as under:
In R10 series: Width starts from 25 to 63 mm (25, 32, 40, 50, and 63).
In R20 series: Width starts from 71 to 600 mm (71, 80, 90, 100, 112, 125, 140, 160, 180, 200, 224, 250, 280, 315, 355, 400, 450, 500, 560, and 600).

The maximum belt stress also depends on the belt speed. Hence, the maximum belt stress is provided either for different belt speeds or for a specified speed.

1.7 Flat Belt Joints

Strips of the belt material are made into a loop by joining the ends of strip by different methods as described below:

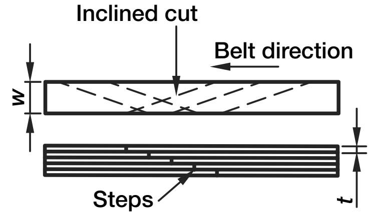

Figure 1.10 Cemented edges

Cemented Leather and fabric belts are joined with a cement by making the ends inclined. The angle is about 1 in 20 (Figure 1.10). The joint can offer strength up to 85 per cent.

Laced Ends of belt are cut squared so that they butt tightly together. Starting from each end, holes are punched. One line of holes is about 20 mm from each end as shown in Figure 1.11(a) and picture on the right. Second set of holes is about 60 mm from the end. The holes are staggered so that the belt does not become weak at the hole section. Finally, a single centered hole is punched 75 mm from the squared end for the knots. Now, similar holes are punched in the second edge as the mirror image of the first end the belt. Butted ends together will show a diamond shape of holes.