MODULE-1
DESIGN OF FLEXIBLE ELEMENTS

Overview

Through the employment of pulleys that rotate either at the same speed or at various speeds, the belts or ropes transfer power from one shaft to another.

The following variables affect how much power is transmitted:

1. The speed of the belt.
2. The tension at which the belt is held on the pulleys.
3. The arc of contact between the belt and the smaller pulley.
4. The circumstances under which the belt is utilized. To ensure uniform strain across the belt segment, keep the shafts perfectly aligned.

(a) The pulleys should not be too close together so that the arc of contact with the smaller pulley is as large as possible.
(c) The pulleys should not be spaced so widely apart that the belt weighs heavily on the shafts, increasing the friction strain on the bearings.
(d) A long belt swings from side to side, causing the belt to exit the pulleys, resulting in crooked places.
(e) The belt's tight side should be toward the bottom, so that any sag on the loose side increases the arc of contact at the pulleys.
(f) For best results with flat belts, the maximum distance between the shafts should not exceed 10 meters and the minimum should not be less than 3.5 times the diameter of the larger pulley.
Selection of a belt drive.

Several major considerations influencing the choosing of a belt drive include:

1. The speed of the driving and driven shafts.
2. Speed reduction ratio,
3. Power transmission,
4. Center distance between shafts
5. Positive driving criteria.
6. Shaft layout,
7. Space availability,
8. Service conditions.

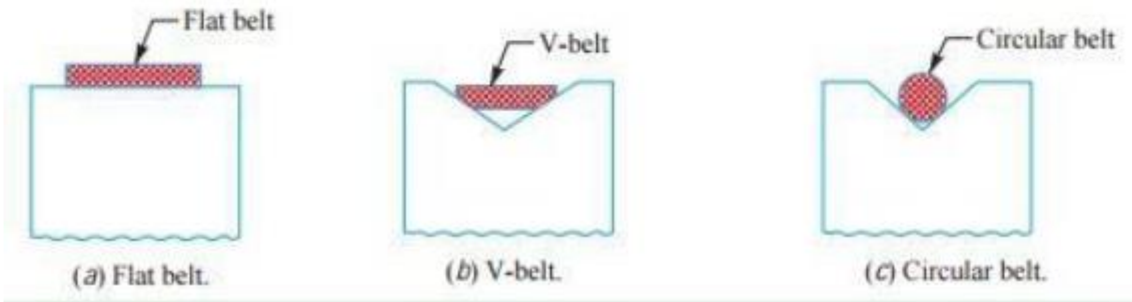
Varieties of Belt Drives:

Belt drives are often grouped into the following three groups:

1. Light drives. These are used to convey modest amounts of power at belt speeds of up to 10 m/s, as in agricultural machines and small machine tools.
2. Medium drives. These are used to transmit medium powers at belt speeds greater than 10 m/s but not exceeding 22 m/s, as seen in machine tools.
3. Heavy drives.

Categories of Belts

1. The flat belt, as seen in Fig(a), is commonly used in factories and workshops to carry a reasonable amount of power from one pulley to another when the two pulleys are no more than 8 metres apart.



(a) Flat belt. (b) V-belt. (c) Circular belt.

2. V-belt. The V-belt depicted in Fig. (b) is commonly used in factories and workshops to carry a large amount of power from one pulley to another when the two pulleys are extremely close together.

3. A belt or rope with a circular shape. The circular belt or rope depicted in Fig. (c) is mostly used in factories and workshops to convey large amounts of power from one pulley to another when the two pulleys are more than 8 meters apart. If a large amount of power needs to be transmitted, a single belt may not be enough. In this instance, wide pulleys with several grooves (for V-belts or circular belts) are employed. Then, in each groove, a belt is installed to transfer the necessary power from one pulley to another.

BELT MATERIALS

Belts and ropes must be made of sturdy, flexible, and long-lasting materials. It must have a large coefficient of friction. Belts are classified as follows based on the material used:

LEATHER BELT:
The most significant belt material is leather. The best leather belts are manufactured from 1.2 to 1.5 metre long strips cut from either side of the backbone of high-quality steer hides. The hair side of the leather is smoother and more durable than the flesh side, but the flesh side is stronger. The fibers on the hair side are perpendicular to the surface, whereas those on the flesh side are interlaced and parallel to the surface. For these reasons, the hair side of a belt should be in touch with the pulley surface, as depicted in Figure.

(a) Single layer belt. (b) Double layer belt

The leather can be tanned with oak or mineral salts, such as chromium. To thicken the belt, the strips are bonded together. Belts are classified based on the number of layers (single, double, or triple ply) and the thickness of the hides (light, medium, or heavy). Leather belts must be cleaned, dressed, or treated on a regular basis using a compound or dressing comprising neat foot or other appropriate oils to keep them supple and flexible.

COTTON OR FABRIC BELTS:
Most fabric belts are created by folding canvas or cotton duck into three or more layers (depending on the desired thickness) and stitching them together. These belts are also woven into a strip of the appropriate width and thickness. They are treated with a filler, such as linseed oil, to make the belts waterproof and prevent fiber damage. Cotton belts are less expensive and more suited to warm temperatures, moist environments, and exposed situations. Cotton belts are commonly used in farm machinery, belt conveyors, and other applications because to their low maintenance requirements.

RUBBER BELT:
The rubber belts are composed of layers of cloth impregnated with rubber compound, with a thin coating of rubber on the faces. These belts are extremely flexible, but they are quickly ruined if exposed to heat, oil, or grease. One of the main advantages of these belts is that they may be easily made infinite. These belts are excellent for sawmills and paper mills that are exposed to moisture.

BALATA BELTS:
These belts are identical to rubber belts, except that balata gum is used instead of rubber. These belts are acid and water proof, and they are not affected by animal oils or alkalis. Balata belts should not be exposed to temperatures exceeding 40° C since the balata softens and becomes sticky at that temperature. Balata belts are 25% stronger than rubber belts.

Types of Flat Belt Drives

Power can be transported from one pulley to another using any of the following belt drives:

Open Belt Drive:

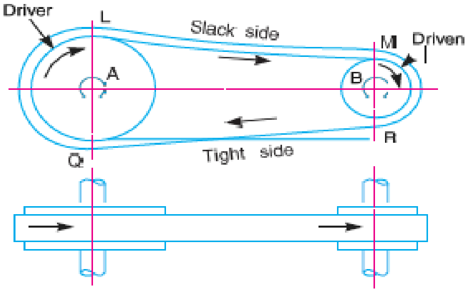


Fig. Open Belt Drive

The open belt drive, depicted in Figure above, uses shafts that are parallel and rotate in the same direction. In this scenario, driver A removes the belt from one side (lower side RQ) and delivers it to the other side (upper side L M). Thus, the tension in the lower side belt will be greater than that in the top side belt. As indicated in Fig., the lower side belt (due to higher tension) is known as the tight side, while the upper side belt (due to lower tension) is known as the slack side.

Cross or Twist Belt Drive:

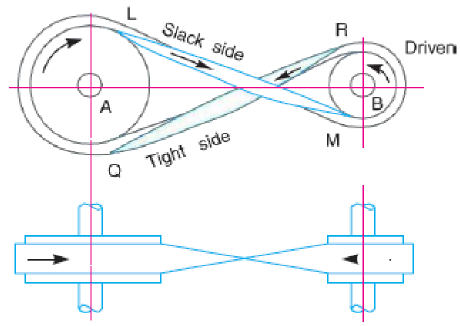


Fig. Cross Belt Drive

The crossed or twist belt drive, as seen in Figure above, is utilized with shafts aligned parallel and rotating in opposite directions. In this scenario, the driver removes the belt from one side (RQ) and delivers it to the opposite side (LM). Thus, the strain in the belt RQ will be greater than that in the belt LM. The belt RQ (due to increased tension) is known as the tight side, whereas the belt LM (due to decreased tension) is known as the slack side, as illustrated in Fig. A closer look reveals that where the belts intersect, they scrape against each other, resulting in severe wear and tear.

Compound Belt Drive:

A compound belt drive, as seen in Fig., is used to transfer power from one shaft to another via a series of pulleys.

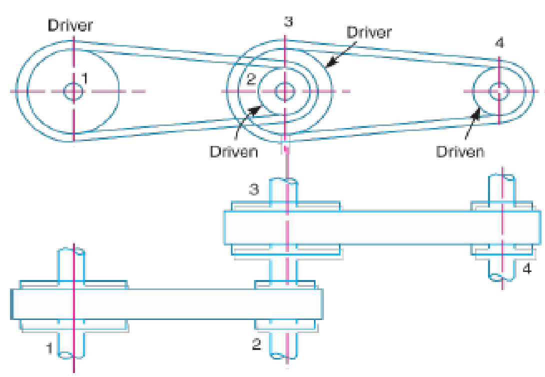


Fig. Compound Belt Drive

Velocity Ratio of a Belt Drive:

It is the ratio of the velocities of the driver and the follower, or driven. It can be stated numerically, as described below:

Let d_1 = Diameter of the driver,

d_2 = Diameter of the follower,

N_1 = Speed of the driver in r.p.m.,

N_2 = Speed of the follower in r.p.m.,

$\therefore$ Length of the belt that passes over the driver, in one minute

$$= \pi d_1 N_1$$

Similarly, length of the belt that passes over the follower, in one minute

$$= \pi d_2 N_2$$

Since the length of belt that passes over the driver in one minute is equal to the length of belt that passes over the follower in one minute, therefore

$$\because \quad \pi d_1 N_1 = \pi d_2 N_2$$

and velocity ratio,

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}$$

When thickness of the belt (t) is considered, then velocity ratio,

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}$$

Notes : 1. The velocity ratio of a belt drive may also be obtained as discussed below:

We know that the peripheral velocity of the belt on the driving pulley,

$$v_1 = \frac{\pi d_1 N_1}{60} \text{ m/s}$$

and peripheral velocity of the belt on the driven pulley,

$$v_2 = \frac{\pi d_2 N_2}{60} \text{ m/s}$$

When there is no slip, then $v_1 = v_2$.

$$\therefore \quad \frac{\pi d_1 N_1}{60} = \frac{\pi d_2 N_2}{60} \quad \text{or} \quad \frac{N_2}{N_1} = \frac{d_1}{d_2}$$

2. In case of a compound belt drive as shown in Fig. 18.7, the velocity ratio is given by

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4} \quad \text{or} \quad \frac{\text{Speed of last driven}}{\text{Speed of first driver}} = \frac{\text{Product of diameters of drivers}}{\text{Product of diameters of drivens}}$$

SLIP OF THE BELT

In previous articles, we discussed the motion of belts and pulleys with a solid frictional grip between them. However, occasionally the frictional grip is insufficient. This may cause the driver to move forward without carrying the belt. This is known as slip of the belt and is typically represented as a percentage.

S1% represents slip between the driver and the belt, and

S2% represents slip between the belt and the follower.

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}\left(1 - \frac{s}{100}\right)$$

CREEP OF BELT:

When the belt moves from the loose side to the tight side, a portion of it expands and then contracts again. The belt and pulley surfaces move relative to one another as their lengths vary. This relative motion is referred to as creep. Creep has the effect of slightly lowering the speed of the driving pulley or follower. Regarding creep, velocity ratio is given by

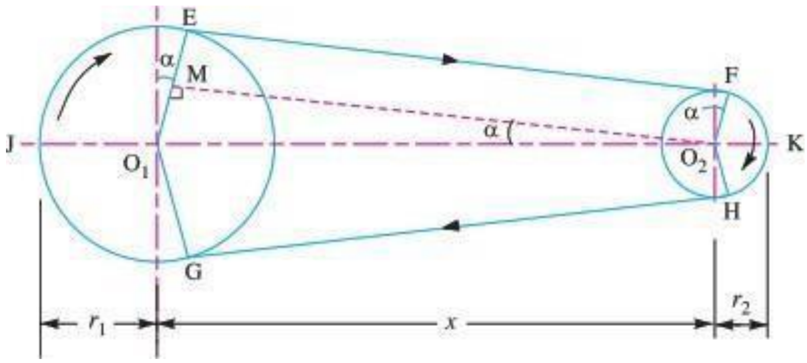
$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \times \frac{E + \sqrt{\sigma_2}}{E + \sqrt{\sigma_1}}$$

Where σ_1 & σ_2 =stress in the belt on the tight and slack side

E = young's modulus for the material of the belt

Note that because the effect of creep is so modest, it is often overlooked.

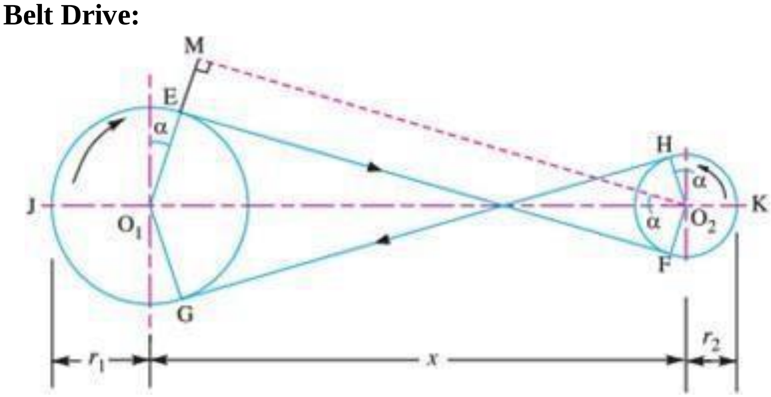
Length of Open Belt Drive:



$$= \pi (r_1 + r_2) + 2x + \frac{(r_1 - r_2)^2}{x} \quad \text{... (in terms of pulley radii)}$$

$$= \frac{\pi}{2} (d_1 + d_2) + 2x + \frac{(d_1 - d_2)^2}{4x} \quad \text{... (in terms of pulley diameters)}$$

Length of a Cross Belt Drive:



$$= \pi (r_1 + r_2) + 2x + \frac{(r_1 + r_2)^2}{x} \quad \text{... (in terms of pulley radii)}$$

$$= \frac{\pi}{2} (d_1 + d_2) + 2x + \frac{(d_1 + d_2)^2}{4x} \quad \text{... (in terms of pulley diameters)}$$

Power Transmitted by a Belt:

T_1 and T_2 are the tensions in the belt's tight and slack sides, r_1 and r_2 are the radii of the driving and driven pulleys, and v is the belt's velocity in meters per second.

$$P = (T_1 - T_2)\,V \;\frac{N-m}{sec}$$

CENTRIFUGAL TENSION:

When the belt is running at a lower speed, the initial tension applied to the belt is adequate to maintain the belt on the pulley with the requisite grip; but, as the belt speed increases, centrifugal action causes the belt to try to fly off the pulley. At the same time, tensions between the tight and slack sides will rise. Centrifugal tension is the force exerted on the shaft as a result of centrifugation.

Let T_1 and T_2 are the tensions in the belt's tight and slack sides,

Centrifugal Tension

$$T_c = mv^2$$

Note: It is known that, the total tensions at tight side and slack side are given by

$T_{t1} = T_1 + T_c$ and $T_{t2} = T_2 + T_c$

Because centrifugal tension is proportional to belt velocity, it is possible to ignore centrifugal action and tension at low speeds. However, for higher speeds, centrifugal stress will be taken into consideration.

$T_{t1} = T_1$ and $T_{t2} = T_2$ at low speeds, but $T_{t1} + T_c = T_2 + T_c$ at high speeds. Also, because the centrifugal force tries to draw the belt away from the pulley, resulting in a decrease in power transmitting capacity, the belt's linear velocity is regulated to 17.5 to 22.5 m/s in order to control the centrifugal strain. If μ is the coefficient of friction between the belt and pulley, and θ is the angle of contact for driving pulley in radians, then the ratio of driving tensions is

$$2.3\log\left(\frac{T_1}{T_2}\right) = \mu\theta$$

$$\left(\frac{T_1}{T_2}\right) = e^{\mu\theta}$$

when the centrifugal tension (T_c) is neglected.

$$\frac{T_1 - T_c}{T_{2} - T_c} = e^{\mu\theta}$$

1. We know that $T_1 = T - T_C$ and for maximum power, $T_C = \frac{T}{3}$.

$$T_1 = T - \frac{T}{3} = \frac{2T}{3}$$

From equation (*iv*), we find that the velocity of the belt for maximum power,

$$v = \sqrt{\frac{T}{3m}}$$

Rope Drives

Rope Drives employ two sorts of ropes:

1. Fibre ropes; 2. Wire ropes.

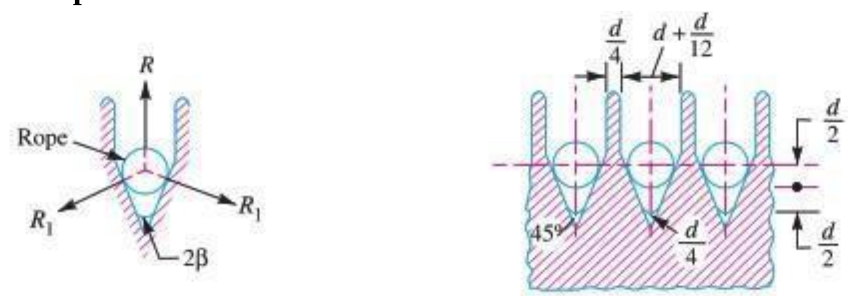
Fibre ropes work well when the pulleys are about 60 metres apart, whereas wire ropes work when the pulleys are up to 150 metres apart.

Benefits of Fibre Rope Drives

Fibre rope drives have the following advantages:

1. They provide seamless, consistent, and silent service.
2. They are relatively unaffected by outdoor conditions.
3. The shafts could be out of precise alignment.
4. The power can be turned off in any direction and in fractions of the total amount.
5. They provide good mechanical efficiency.

Sheave for Fibre Ropes



(*a*) Cross-section of a rope. (*b*) Sheave (grooved pulley) for ropes.

Ratio of driving tensions for fiber rope

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu.\theta \operatorname{cosec} \beta$$

Where μ, θ and β have usual meanings.

Wire Ropes

Wire ropes are used to carry significant amounts of electricity over long distances (up to 150 metres) between pulleys. Wire ropes are commonly employed in elevators, mine hoists, cranes, conveyors, hauling devices, and suspension bridges. The wire ropes run on grooved pulleys, but they rest on the bottom of the grooves, not wedged between the sides of the grooves.