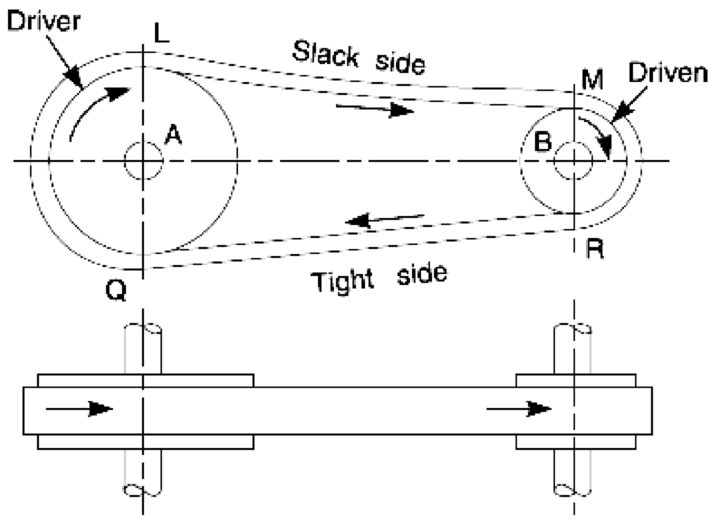
Belt, rope and Chain drives



- Belt drives, rope drives, chain drives and gear drives are power transmission devices.
- Power from one shaft to another can be transmitted by means of belt, ropes, chains, gears etc.
- Belt drives are used when the distance between the shafts do not exceed more than 8m.
- Flat belt drive has basically three components namely driving pulley, flat belt and the driven pulley.

Question: State advantages and limitations of belt drive.

Advantages:

1. Belt drives are used to transmit power from one shaft to another when the ***distance between the shaft is large*** as compared to gear drives where the power can be transmitted between shafts at small distance apart.
2. The ***weight of belts is less*** as compared to chain drives and gear drives.
3. There is ***no need of lubrication in belt drives*** while lubrication is needed in gear drives and chain drives.
4. Repair and maintenance in belt drives is very less as compared to gear drives and chain drives.
5. Manufacturing cost of belt drives is less as compared to gear and chain drives.

Disadvantages:

1. Belt drive is a non-positive drive i.e. slip and creep phenomenon occurs in belt drive.
2. Space required is more.
3. Velocity ratio is not constant due to slip and creep phenomenon.
4. Belts extend after frequent use.

Question: Compare Belt, Rope, Chain and Gear drives.

	Belt drives	Rope drives	Chain drives	Gear drives
Whether slip occurs or not	Slip occurs	Slip occurs	No slip	No slip
Space required	More	More	Compact. i.e. less space required	Less space required.
Weight	less	less	More	More
Velocity ratio	Not constant	Not constant	Constant	Constant
Lubrication	Not required	Not required	Required	Required
Distance between shafts	Upto 8 metre distance	More than 8 metre of distance .	1 to 1.5 metre length	Less distance. If the distance is more gear train used.

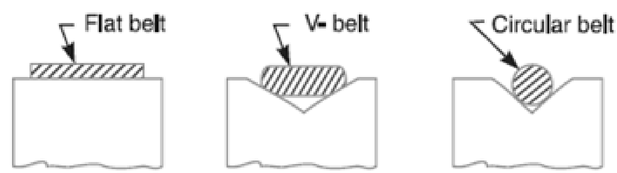
Question: Enlist types of belt drives. Draw neat sketches of belt drives and explain them. OR
Draw neat sketches of Flat Belt drives

1. Light, medium and heavy drives:
2. Flat belt drives, V-belt drives and Circular belt drives
3. Open belt drive and crossed belt drive
4. Compound belt drive
5. Quarter turn belt drive and Quarter turn belt drive with guide pulley.
6. Belt drive with idler pulleys
7. Stepped or cone pulley drive
8. Fast and loose pulley drive

1. ***<u>Light, medium and Heavy drives:</u>*** Light drives transmit small powers at belt speeds upto 10 m/s like in agricultural machines and small machine tools. Medium drives are used to transmit medium power at belt speeds over 10m/s and up to 22 m/s in machine tools. Heavy drives are used to transmit power above 22m/s like in compressors and generators.

<u>2. Flat belts, V-belts and circular belt drives:</u>

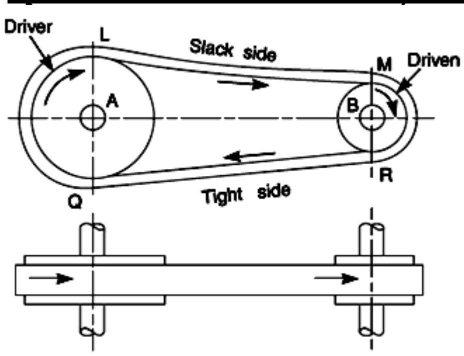
Flat belt drives are used where moderate amount of power is transmitted between two pulleys which are not more than 8 metre apart. *V belt drives* are used to transmit moderate amount of power between two pulleys which are very near to each other. *Circular belt drives or Rope drives* are used to transmit large amount of power between two pulleys which are more than 8 metre apart.

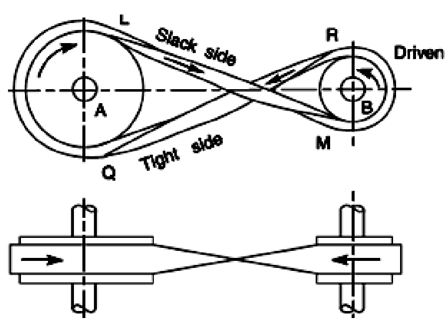


(a) Flat belt. (b) V-belt. (c) Circular belt.

Fig. Types of belts.

<u>3. Open belt drive and Crossed/twist belt drive</u>





Open belt drive is used with shafts arranged in parallel and rotates in same direction. Crossed belt drive is used with shafts rotating in opposite direction. Tension in lower side of belt is more so it is called as tight side of belt.

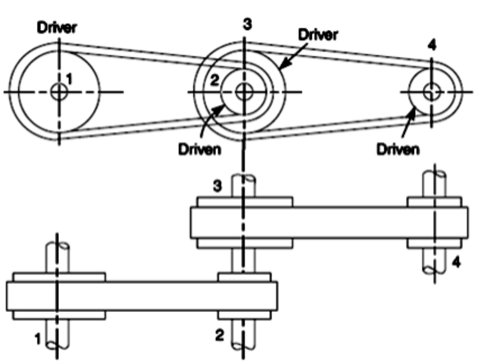
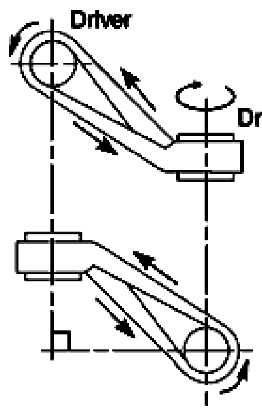


Fig. Compound belt brive.

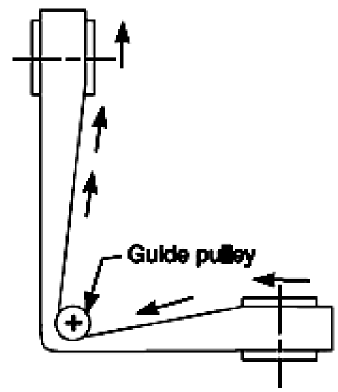
<u>4. Compound belt drive</u>

Compound belt drive is used when power is transmitted from one shaft to another through number of pulleys.

5. Quarter turn belt drive and Quarter turn belt drive with guide pulley.



(*a*) Quarter turn belt drive.

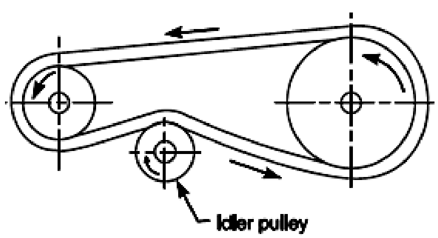


(*b*) Quarter turn belt drive with guide pulley

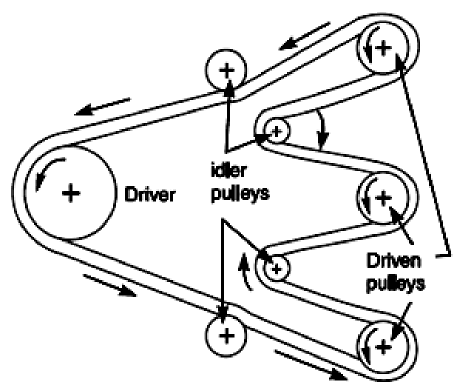
It is also known as right angle belt drive and is used to transmit power between shafts which are not arranged in parallel but between shafts at right angle with each other.

6. Belt drive with idler pulleys

This type of belt drive is to obtain high velocity ratio and when required belt tension cannot be obtained with required means.



(*a*) Belt drive with single idler pulley.



(*b*) Belt drive with many idler pulleys.

7. Stepped or cone pulley drive

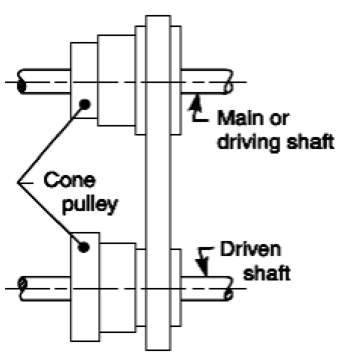


Fig. Stepped or cone pulley drive.

This type of belt drive is used for changing the speed of follower (driven) shaft while the driving shaft rotating at constant speed. This is done by shifting the belt from one step to another step as shown in figure.

8. Fast and loose pulley drive

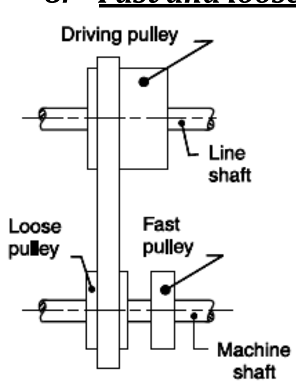


Fig. Fast and loose pulley drive.

It is used when driven/follower shaft is to be started or stopped whenever desired without interfering driving shaft. Pulley keyed to machine shaft is fast pulley and runs at the same speed as that of machine shaft. Loose pulley runs freely over machine shaft and is incapable of transmitting any power . When machine shaft is to be stopped, belt is pushed on the loose pulley so that machine shaft stops but driving shaft keeps rotating.

Velocity Ratio:

Question: Define Velocity Ratio. Derive an expression to find velocity ratio of open belt drive (i) considering thickness, and (ii) Neglecting thickness.

It is the ratio between the velocities of the driver and the follower or driven. It is expressed, mathematically,

peripheral velocity of the belt on the driving pulley, $v_1 = \frac{\pi d_1 . N_1}{60}$ m/s

peripheral velocity of the belt on the driven or follower pulley, $v_2 = \frac{\pi d_2 . N_2}{60}$ m/s

Let d_1 = Diameter of the driver, d_2 = Diameter of the follower,

N_1 = Speed of the driver in r.p.m., and N_2 = Speed of the follower in r.p.m.

$\therefore$ Length of the belt that passes over the driver, in one minute = $\pi d_1 . N_1$

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,

$$\pi d_1 . N_1 = \pi d_2 . N_2$$

$$\therefore \text{ Velocity ratio, } \frac{N_2}{N_1} = \frac{d_1}{d_2}$$

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

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

Velocity ratio of compound Belt drive

Question: Derive an expression to find velocity ratio of compound belt drive.

Sometimes the power is transmitted from one shaft to another, through a number of pulleys as shown in Fig. Consider a pulley 1 driving the pulley 2. Since the pulleys 2 and 3 are keyed to the same shaft, therefore the pulley 1 also drives the pulley 3 which, in turn, drives the pulley 4.

Let d_1 = Diameter of the pulley 1,

N_1 = Speed of the pulley 1 in r.p.m.,

d_2, d_3, d_4, and N_2, N_3, N_4 = Corresponding values for pulleys 2, 3 and 4.

We know that velocity ratio of pulleys 1 and 2,

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad \ldots(i)$$

Similarly, velocity ratio of pulleys 3 and 4,

$$\frac{N_4}{N_3} = \frac{d_3}{d_4} \quad \ldots(ii)$$

Multiplying equations (*i*) and (*ii*),

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_3}{d_4}$$

or

$$\frac{N_4}{N_1} = \frac{d_1 \times d_3}{d_2 \times d_4} \quad \ldots(\because N_2 = N_3, \text{ being keyed to the same shaft})$$

A little consideration will show, that if there are six pulleys, then

$$\frac{N_6}{N_1} = \frac{d_1 \times d_3 \times d_5}{d_2 \times d_4 \times d_6}$$

or

$$\frac{\text{Speed of last driven}}{\text{Speed of first driver}} = \frac{\text{Product of diameters of drivers}}{\text{Product of diameters of drivens}}$$

SLIP in belt:

Question: What is slip of the belt? State the expression for phenomenon of slip.

•During power transmission, driver pulley rotates which carries belt with it.

•Motion of belt and pulley is due to firm frictional grip between belt and pulley but sometimes frictional grip becomes insufficient.

•This causes:

(a) Forward motion of driver pulley without carrying belt with it,

(b) Forward motion of belt without carrying driven pulley with it.

•This is called slip of belt and is expressed in percentage.

•***The slip of belt reduces velocity ratio.***

Let N_1 and N_2 = rpm of driver and driven pulleys respectively, t = thickness of belt

d_1 = dia. of driver pulley and d_2 = dia. of driven pulley,

s_1 = percentage slip of driving pulley

s_2 = percentage slip of driven pulley and belt

$s = s_1 + s_2$, s = total percentage slip between driving and driven pulleys

$$\frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{s_1}{100} - \frac{s_2}{100}\right) \quad \ldots\left(\text{Neglecting } \frac{s_1 \times s_2}{100 \times 100}\right)$$

$$= \frac{d_1}{d_2}\left(1 - \frac{s_1 + s_2}{100}\right) = \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$

... (where $s = s_1 + s_2$, *i.e.* total percentage of slip)

If thickness of the belt (t) is considered, then

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

Creep of belt:

Question: What is creep of the belt and their expression?

- When part of belt moves from driven pulley to driving pulley is known as tight side of belt having tension T_1.
- When part of belt moves from driving pulley to driven pulley is known as slack side of belt having tension T_2.
- Both the tensions are different in magnitude i.e. Tension on tight side T_1 > Tension on slack side T_2.
- The material of belt is elastic and so it elongates on tight side than slack side and this causes unequal stretching on both sides of the drive.
- When belt passes from slack side to tight side, certain portion of belt extends and then it contracts again when belt passes from tight side to slack side.
- Due to this change in length of belt, the *relative motion between the belt and the pulley surface*. This ***relative motion is called creep***.
- Effect of creep is to reduce the velocity ratio.

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

where σ_1 and σ_2 = Stress in the belt on the tight and slack side respectively, and

E = Young's modulus for the material of the belt.

Length of Open (Flat) Belt drive:

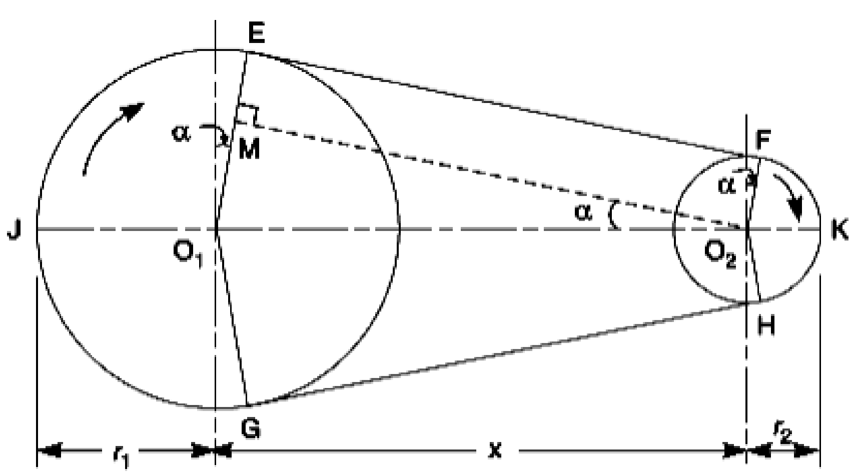


Fig. Length of an open belt drive.

Question: Derive an expression to find the length of open belt drive.

r_1 = radii of larger pulley,

r_2 = radii of smaller pulley,

x = distance between centres of two pulleys i.e. O_1 and O_2.

L = Total length of belt.

Let, belt leave larger pulley at E and G, Let, belt leave smaller pulley at F and H

Through O_2, draw O_2M parallel to FE.

Therefore, now O_2M will be perpendicular to O_1E.

Let the angle $MO_2O_1 = \alpha$ radians.

We know that the length of the belt,

$$L = \text{Arc } GJE + EF + \text{Arc } FKH + HG$$
$$= 2(\text{Arc } JE + EF + \text{Arc } FK) \quad ...(i)$$

From the geometry of the figure, we find that

$$\sin\alpha = \frac{O_1M}{O_1O_2} = \frac{O_1E - EM}{O_1O_2} = \frac{r_1 - r_2}{x}$$

Since α is very small, therefore putting

$$\sin\alpha = \alpha \text{ (in radians)} = \frac{r_1 - r_2}{x} \quad ...(ii)$$

$$\therefore \quad \text{Arc } JE = r_1\left(\frac{\pi}{2} + \alpha\right) \quad ...(iii)$$

Similarly

$$\text{Arc } FK = r_2\left(\frac{\pi}{2} - \alpha\right) \quad ...(iv)$$

and

$$EF = MO_2 = \sqrt{(O_1O_2)^2 - (O_1M)^2} = \sqrt{x^2 - (r_1 - r_2)^2}$$
$$= x\sqrt{1 - \left(\frac{r_1 - r_2}{x}\right)^2}$$

Expanding this equation by binomial theorem,

$$EF = x\left[1 - \frac{1}{2}\left(\frac{r_1 - r_2}{x}\right)^2 + ...\right] = x - \frac{(r_1 - r_2)^2}{2x} \quad ...(v)$$

Substituting the values of arc *JE* from equation (*iii*), arc *FK* from equation (*iv*) and *EF* from equation (*v*) in equation (*i*), we get

$$L = 2\left[r_1\left(\frac{\pi}{2} + \alpha\right) + x - \frac{(r_1 - r_2)^2}{2x} + r_2\left(\frac{\pi}{2} - \alpha\right)\right]$$

$$= 2\left[r_1 \times \frac{\pi}{2} + r_1.\alpha + x - \frac{(r_1 - r_2)^2}{2x} + r_2 \times \frac{\pi}{2} - r_2.\alpha\right]$$

$$= 2\left[\frac{\pi}{2}(r_1 + r_2) + \alpha(r_1 - r_2) + x - \frac{(r_1 - r_2)^2}{2x}\right]$$

$$= \pi(r_1 + r_2) + 2\alpha(r_1 - r_2) + 2x - \frac{(r_1 - r_2)^2}{x}$$

Substituting the value of $\alpha = \frac{r_1 - r_2}{x}$ from equation (*ii*),

$$L = \pi(r_1 + r_2) + 2 \times \frac{(r_1 - r_2)}{x} \times (r_1 - r_2) + 2x - \frac{(r_1 - r_2)^2}{x}$$

$$= \pi(r_1 + r_2) + \frac{2(r_1 - r_2)^2}{x} + 2x - \frac{(r_1 - r_2)^2}{x}$$

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

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

Ratio of Driving tensions for flat belt drive:

Question: Derive an expression $T_1/T_2 = e^{\mu\theta}$ for flat belt drive with usual notations.

Question: Derive an expression to determine ratio of tension on tight side to the tension on slack side for flat belt.

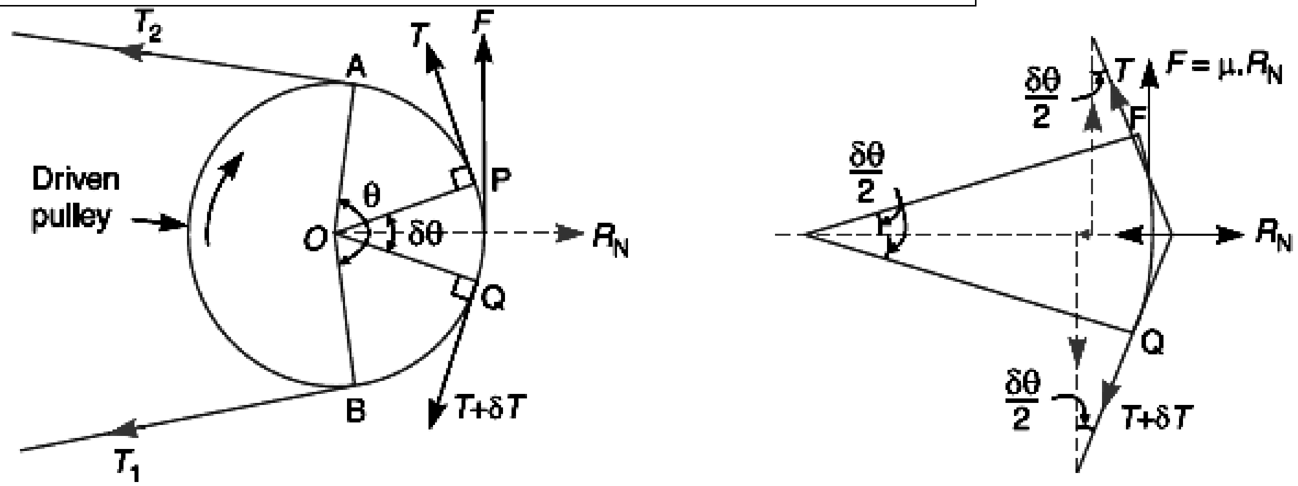


Fig. Ratio of driving tensions for flat belt.

Let T_1 = Tension in the belt on the tight side,

T_2 = Tension in the belt on the slack side, and

θ = Angle of contact in radians (*i.e.* angle subtended by the arc AB, along which the belt touches the pulley at the centre).

Now consider a small portion of the belt PQ, subtending an angle $\delta\theta$ at the centre of the pulley as shown in Fig. The belt PQ is in equilibrium under the following forces :

1. Tension T in the belt at P,
2. Tension $(T + \delta T)$ in the belt at Q,
3. Normal reaction R_N, and
4. Frictional force, $F = \mu \times R_N$, where μ is the coefficient of friction between the belt and pulley.

Resolving all the forces horizontally and equating the same,

$$R_N = (T + \delta T)\sin\frac{\delta\theta}{2} + T\sin\frac{\delta\theta}{2} \quad \text{...}(i)$$

Since the angle $\delta\theta$ is very small, therefore putting $\sin \delta\theta / 2 = \delta\theta / 2$ in equation (*i*),

$$R_N = (T + \delta T)\frac{\delta\theta}{2} + T \times \frac{\delta\theta}{2}$$

$$= \frac{T.\delta\theta}{2} + \frac{\delta T.\delta\theta}{2} + \frac{T.\delta\theta}{2}$$

$$= T.\delta\theta \quad \text{...}(ii) \qquad \text{...}\left(\text{Neglecting } \frac{\delta T.\delta\theta}{2}\right)$$

Now resolving the forces vertically, we have

$$\mu \times R_N = (T + \delta T)\cos\frac{\delta\theta}{2} - T\cos\frac{\delta\theta}{2} \qquad ...(iii)$$

Since the angle $\delta\theta$ is very small, therefore putting $\cos \delta\theta / 2 = 1$ in equation (*iii*),

$$\mu \times R_N = T + \delta T - T$$

$$\mu \times R_N = \delta T$$

$$\text{or} \quad R_N = \frac{\delta T}{\mu} \qquad ...(iv)$$

Equating the values of R_N from equations (*ii*) and (*iv*),

$$T.\delta\theta = \frac{\delta T}{\mu}$$

$$\frac{\delta T}{T} = \mu.\delta\theta$$

Integrating both sides between the limits T_2 and T_1 and from 0 to θ respectively,

i.e.
$$\int_{T_2}^{T_1} \frac{\delta T}{T} = \mu \int_0^{\theta} \delta\theta$$

$$\log_e\left(\frac{T_1}{T_2}\right) = \mu.\theta \quad \text{or} \quad \frac{T_1}{T_2} = e^{\mu.\theta} \qquad ...(v)$$

Centrifugal Tension:

Question: Define Centrifugal Tension. Explain the effect of centrifugal tension in belt drive.

Question: Derive an expression to find centrifugal tension in belt drive.

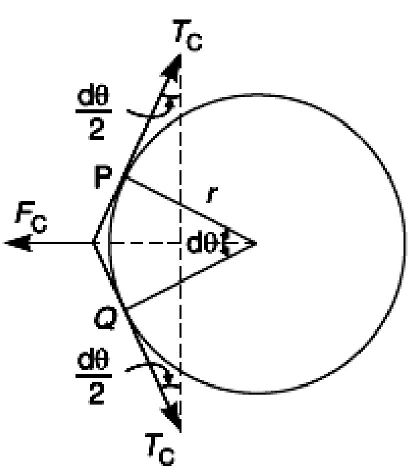


Fig. Centrifugal tension

Since the belt continuously run over the pulleys therefore some centrifugal force is produced whose effect is to increase the tension in both side (tight side and slack side). The tension caused by centrifugal force is called as centrifugal tension. At belt speeds less than 10 m/s, the centrifugal tension is very less but at higher belt speeds effect of centrifugal tension is more and should be taken into consideration.

Consider a small portion PQ of the belt subtending an angle $d\theta$ at the center of the pulley as shown in figure,

Let m = mass of belt per unit length in kg,

v – linear velocity of belt in m/s,

r = radius (metre) of pulley over which belt runs,

Tc = Centrifugal tension acting tangentially at P and Q in

newton,

We know that length of the belt PQ

$$= r.\,d\theta$$

and mass of the belt PQ $= m.\,r.\,d\theta$

∴ Centrifugal force acting on the belt PQ,

$$F_C = (m.r.d\theta)\frac{v^2}{r} = m.d\theta.v^2$$

The centrifugal tension T_C acting tangentially at P and Q keeps the belt in equilibrium.

Now resolving the forces (*i.e.* centrifugal force and centrifugal tension) horizontally and equating the same, we have

$$T_C \sin\left(\frac{d\theta}{2}\right) + T_C \sin\left(\frac{d\theta}{2}\right) = F_C = m.d\theta.v^2$$

Since the angle $d\theta$ is very small, therefore, putting $\sin\left(\frac{d\theta}{2}\right) = \frac{d\theta}{2}$, in the above expression,

$$2T_C\left(\frac{d\theta}{2}\right) = m.d\theta.v^2$$

$$T_C = m\,.\,v^2$$

Power Transmitted:

Power = Workdone / Sec = Force X displacement / Sec = Newton X metre / sec = joule / sec = watts

power transmitted by a belt,

$$P = (T_1 - T_2)\,v$$

where T_1 = Tension in the tight side of the belt in newtons,

T_2 = Tension in the slack side of the belt in newtons, and

v = Velocity of the belt in m/s.

Maximum Power Transmitted:

We know that power transmitted by a belt,

$$P = (T_1 - T_2)\,v \quad \ldots(i)$$

where T_1 = Tension in the tight side of the belt in newtons,

T_2 = Tension in the slack side of the belt in newtons, and

v = Velocity of the belt in m/s.

we also know that the ratio of driving tensions is

$$\frac{T_1}{T_2} = e^{\mu.\theta} \quad \text{or}$$

$$T_2 = \frac{T_1}{e^{\mu.\theta}} \qquad \ldots(ii)$$

Substituting the value of T_2 in equation (*i*),

$$P = \left(T_1 - \frac{T_1}{e^{\mu.\theta}}\right)v$$

$$= T_1\left(1 - \frac{1}{e^{\mu.\theta}}\right)v$$

$$= T_1.v.C \qquad \ldots(iii)$$

where $$C = 1 - \frac{1}{e^{\mu.\theta}}$$

$$T_1 = T_{max} - T_C$$

We know that

where T_{max} = Maximum tension to which the belt can be subjected in newtons, and

T_C = Centrifugal tension in newtons.

Substituting the value of T_1 in equation (*iii*), $P = T_1.v.C$

$$P = (T_{max} - T_C)\,v.C$$

$$P = (T_{max} - m.v^2)\,v.C$$

$$P = (T_{max}.\,v - m\,v^3)\,C \ldots (\text{Substituting } T_C = m.\,v^2)$$

For maximum power, differentiate the above expression with respect to v and equate to zero,

i.e. $\frac{dP}{dv} = 0$ where $P = (T_{max}.\,v - m\,v^3)\,C$ so $\frac{d}{dv}(T_{max}.\,v - m\,v^3)\,C = 0$

$$T_{max} - 3\,m\,.\,v^2 = 0$$

$$T_{max} - 3\,T_C = 0 \quad \text{or}$$

$$T_{max} = 3\,T_C \qquad \ldots(iv)$$

It shows that when the power transmitted is maximum, 1/3rd of the maximum tension is absorbed as centrifugal tension.

Initial Tension:

Question: Define Initial Tension in belt. State the expression of initial tension in belt. State the methods to increase initial tension.

Rope Drives:

Rope Drives

The drives are widely used where a large amount of power is to be transmitted from one pulley to another over a considerable distance. Frictional grip is more than that in v drive. Number of separate drives can be taken from one driving pulley.

Types of Rope Drive

Rope drive is of following two types,

1. **Fiber Rope Drives**

   These operate successfully when the pulleys are about 60 m apart.

2. **Wire Rope Drives**

   These operate successfully when the pulleys are up to 150 m apart.

Advantages of Rope Drive

1. They give smooth, steady and quite service.
2. They are little affected by outdoor conditions.
3. Their shafts may be out of straight alignment.
4. The power may be taken off in any direction and in fractional part of whole amount.

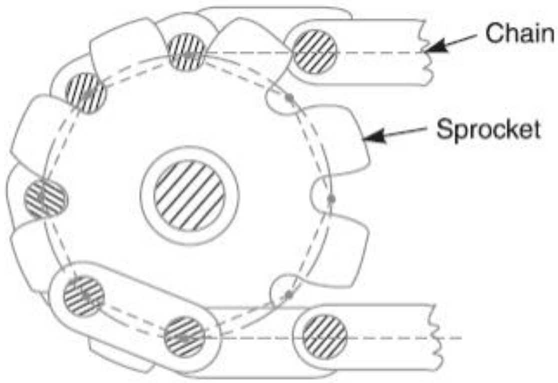
Applications of Rope Drive

1. These are used as haulage ropes in mines, tramways, power transmission.
2. Also used for hoisting purpose in mines, quarries, cranes, dredges, elevators well drilling etc.
3. As hoisting ropes in steel mill ladles, high speed elevators.
4. Used in hand operated hoisting machinery and as tie ropes for fitting tackles, hooks etc.

Chain Drives

We have seen in belt and rope drives that slipping may occur. In order to avoid slipping, steel chains are used. The chains are made up of rigid links which are hinged together in order to provide the necessary flexibility for warping around the driving and driven wheels. The wheels have projecting teeth and fit into the corresponding recesses, in the links of the chain as shown in Fig. The wheels and the chain are thus constrained to move together without slipping and ensures perfect velocity ratio. The toothed wheels are known as *sprocket wheels* or simply *sprockets*. These wheels resemble to spur gears.

The chains are mostly used to transmit motion and power from one shaft to another, when the distance between the centres of the shafts is short such as in bicycles, motor cycles, agricultural machinery, road rollers, etc.



Sprocket and chain.

Advantages and Disadvantages of Chain Drive Over Belt or Rope Drive

Following are the advantages and disadvantages of chain drive over belt or rope drive :

Advantages

1. As no slip takes place during chain drive, hence perfect velocity ratio is obtained.
2. Since the chains are made of metal, therefore they occupy less space in width than a belt or rope drive.
3. The chain drives may be used when the distance between the shafts is less.
4. The chain drive gives a high transmission efficiency (upto 98 per cent).
5. The chain drive gives less load on the shafts.
6. The chain drive has the ability of transmitting motion to several shafts by one chain only.

Disadvantages

1. The production cost of chains is relatively high.
2. The chain drive needs accurate mounting and careful maintenance.
3. The chain drive has velocity fluctuations especially when unduly stretched.

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