Design of Machine Elements-5021

Module- 4

Belts and Types of Belts

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Belt, rope and chain drives

- In many cases the mechanical power is to transmit from different engines, turbines or motors to another machines to do different function.
- The process of transmitting mechanical power from one place to another through various means is called **transmission of power**.
- Commonly using power transmission methods are as follows.

1. Belts and ropes
2. Chains
3. Gears
4. Clutches.

- The shaft from which power is transmitted is called **driver shaft.**
- The shaft to which the power is transmitted is called **driven shaft.**
- The Selection of a suitable drive for transmission of power is depends on many factors such as:

1. Distance between the driver and driven shaft.
2. Amount of power to be transmitted.
3. Speed ratio of shafts.
4. Accuracy required.
5. Maintenance and cost of drive.

Belt and rope drive

Belt and rope drive

- The power has to be transmitted from one shaft to another which are at a considerable distance apart, a belt or rope drive is frequently used.
- Here, pulleys are mounted on the shafts and they are connected by an endless belt or rope passing over them.
- The pulleys have a slight convex on the top surface to keep belt in centre.
- The speed of the driven shaft can be varied by varying the diameters of two pulleys.
- The factor responsible for power transmission is the frictional resistance in between the belt and pulley.
- The amount of power transmitted is depends upon the velocity of belt, belt tension, arc of contact of belt in smaller pulley.

Applications of belt drive

1. A belt drive is used to transfer moderate power.
2. It is commonly used in factories and workshops
3. The belt drive is used in the Mill industry.
4. The belt drive is used in material handling conveyors.

Classification of Belts

- Depending upon the cross section, the belts are classified as:

1. Flat belts
2. V-belts
3. Circular belts (Rope)

- Depending upon the material used, the belts can be classified as:

1. Leather belts
2. Cotton belts
3. Rubber belts
4. Balata belts
5. Steel belts

Flat Belts

- It is rectangular in cross section.
- Used in factories and workshops,where a moderate power is to be transmitted.
- Commonly, it is used to transmit power between the shaft 8-10 meter apart.
- Most of the flat belts are made of leather, canvas and rubber.
- It run over the flat rims if the pulleys.
- The ends of the flat belts may be fastened together by cementing, wire lacing, metal hinges or metal clamps.
- Flat belts are represented by breadth, thickness and length

  Eg:- flat leather belt 25 mm ×6 mm × 3500 mm.

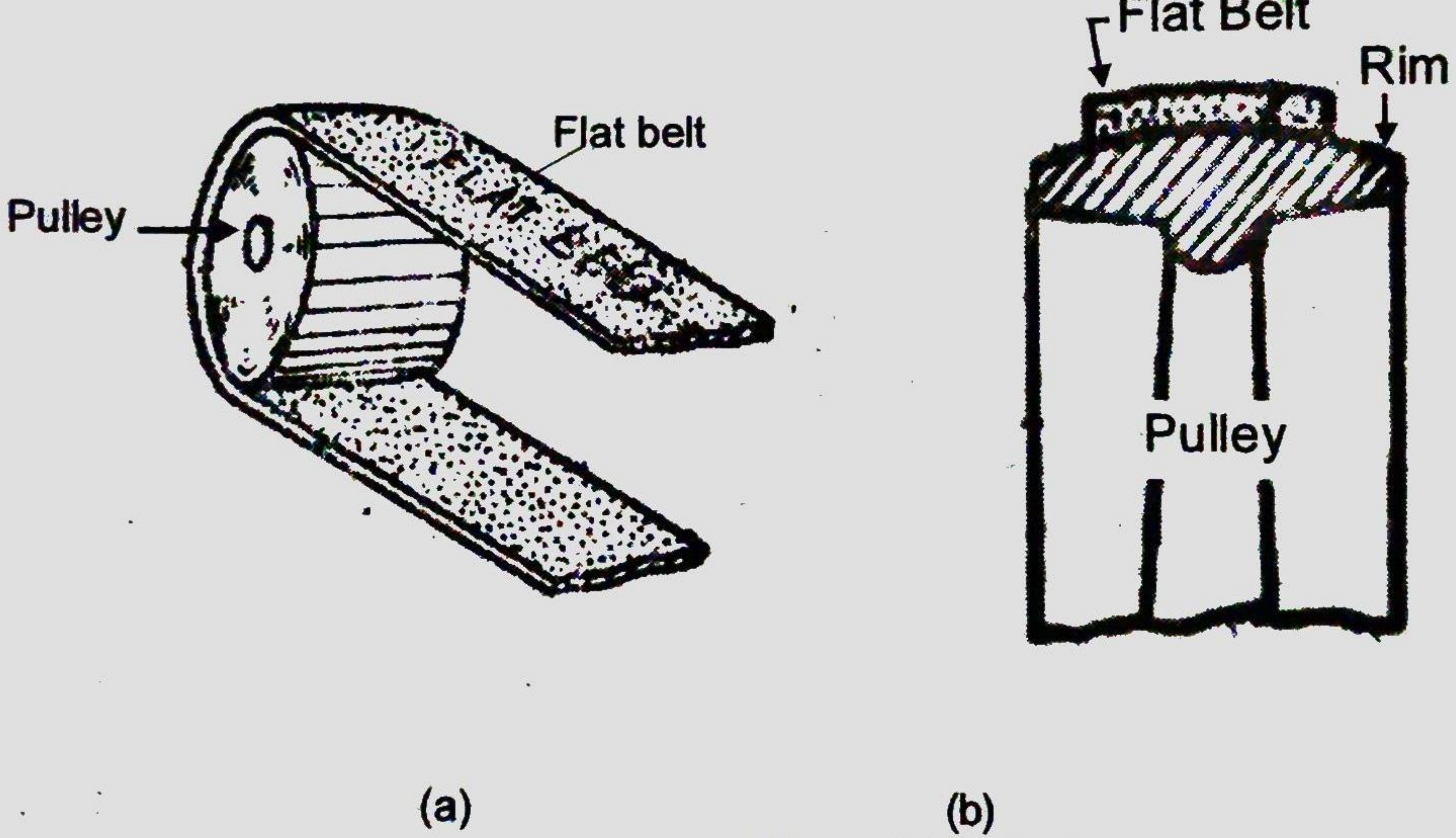
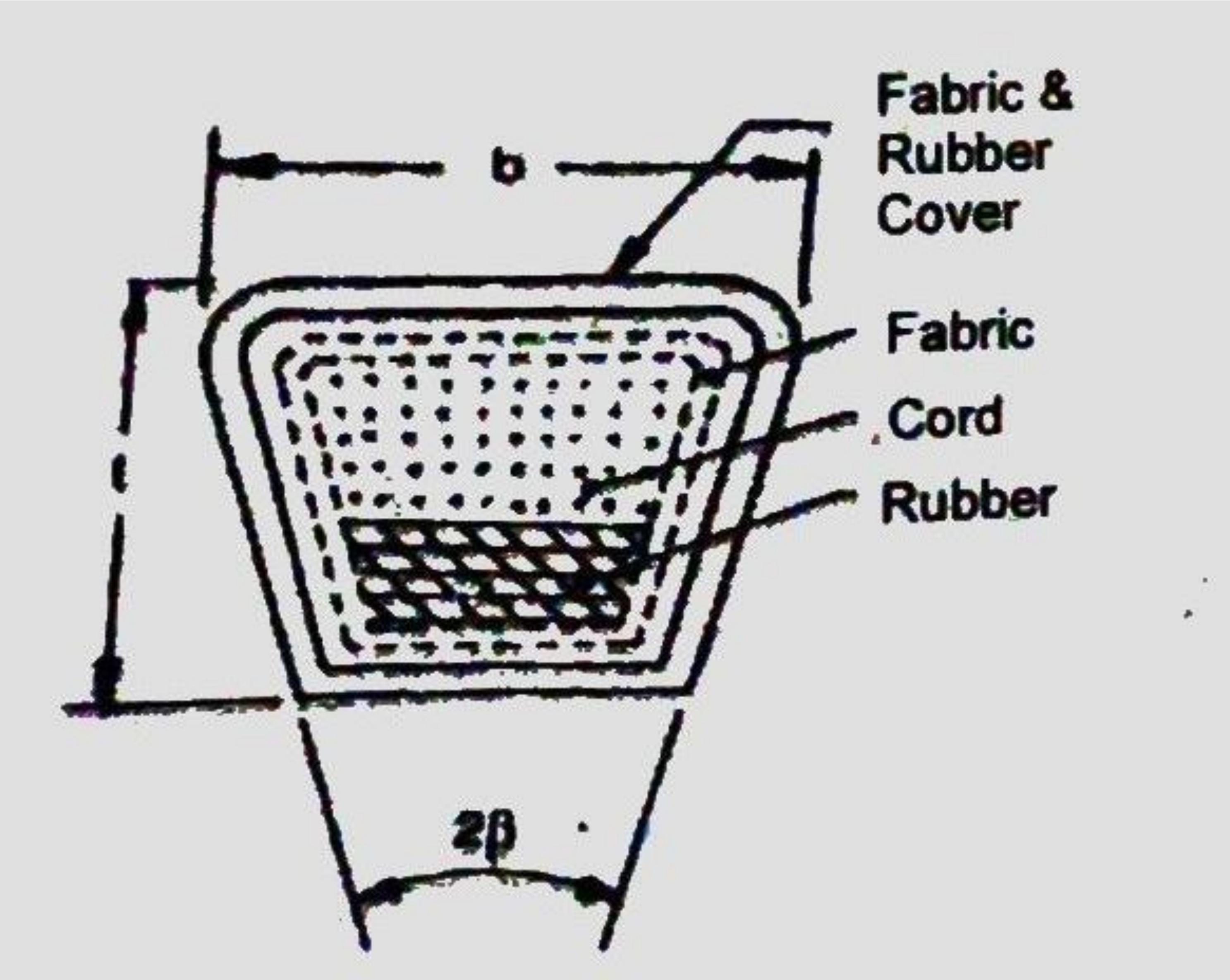


Fig. 9.2 Flat Belt

V- Belts

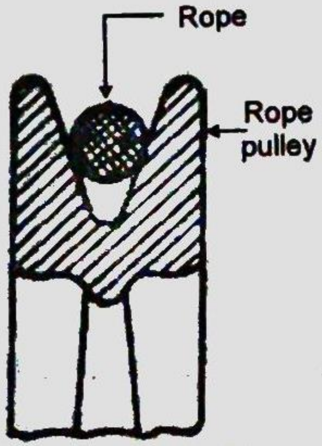
- In V-belts, the cross section is trapezoidal.
- It also used to transmit moderate power. The shaft distance is upto 4m.
- This belts are run in the V-shaped groove provided on the rim of the pulley.
- The V-groove increase the grip between the belt and pulley, so it reduces the slipping tendency.
- Belt is in contact with the side faces of the groove, and belt should not touch the inner surface of the groove of the pulley.
- The groove angle of the V-belt is usually 30°-40°.
- When large amount of power transmitted, two or more belts are used.
- These are made up of cotton, fabric, cord and rubber.
- The length and grades of the beltare stamped on the belt. Eg:- A 50.

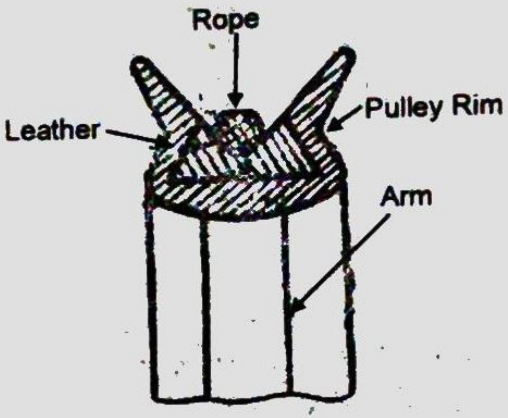
Fabric &
Rubber
Cover
b
t
Fabric
Cord
Rubber
2β

Circular belt (Rope)

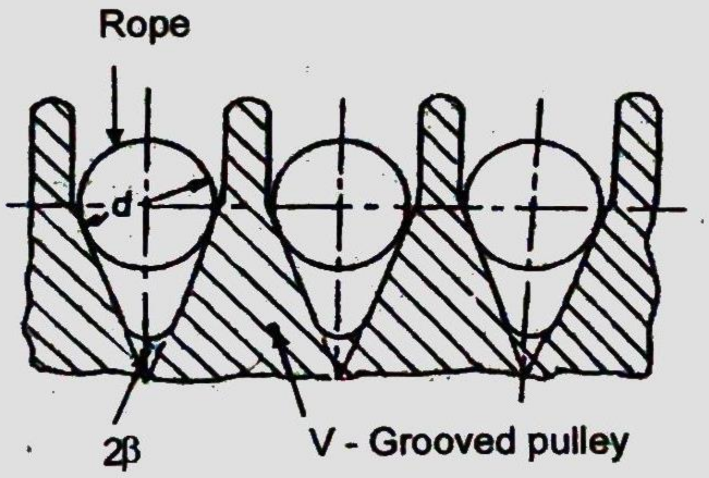
- Here, the cross section is circular.
- Mostly used in factories and workshops where a great amount of power is to be transmitted.
- It run in the groove provided on the rim of the pulley.
- The groove angle is usually 40° - 60°.
- They are used to connect shafts upto 30 m apart. When large amount of power transmitted, two or more ropes are used.
- The materials for ropes are cotton, hemp, manila Or steel.
- Steel or wire ropes are used for transmitting power over very large distances.
- Steel rope doesn’t come in direct contact with the sides of the groove, it rested on a leather or wooden lining provided at the bottom of the groove.



(a) Rope in V - Groove



(b) Rope with leather in V-Groove



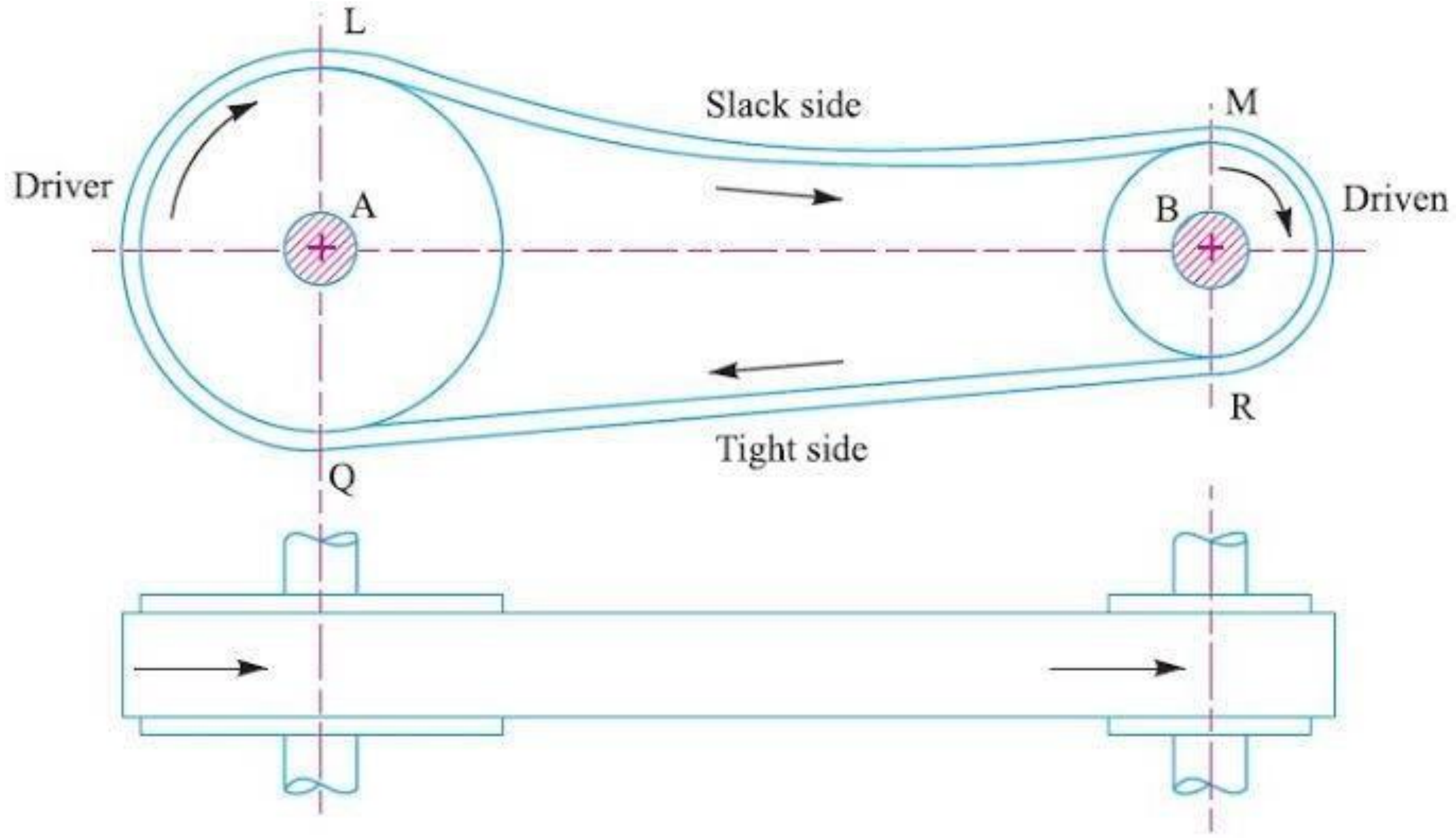
c) Multiple rope

Types of flat Belt Drive

1. Open belt drive

- It is used when shafts arranged in parallel and the driven pulley is desired to be rotated in same direction of driving pulley.
- In this type of belt drive, the driving pulley pulls the belt from one side and delivers to the other side.
- While transmitting power, one side will be more tightened than the other side.
- The side of the belt where the tension is more is called as **Tight side** and other side is called as **Slack side** of the belt. .

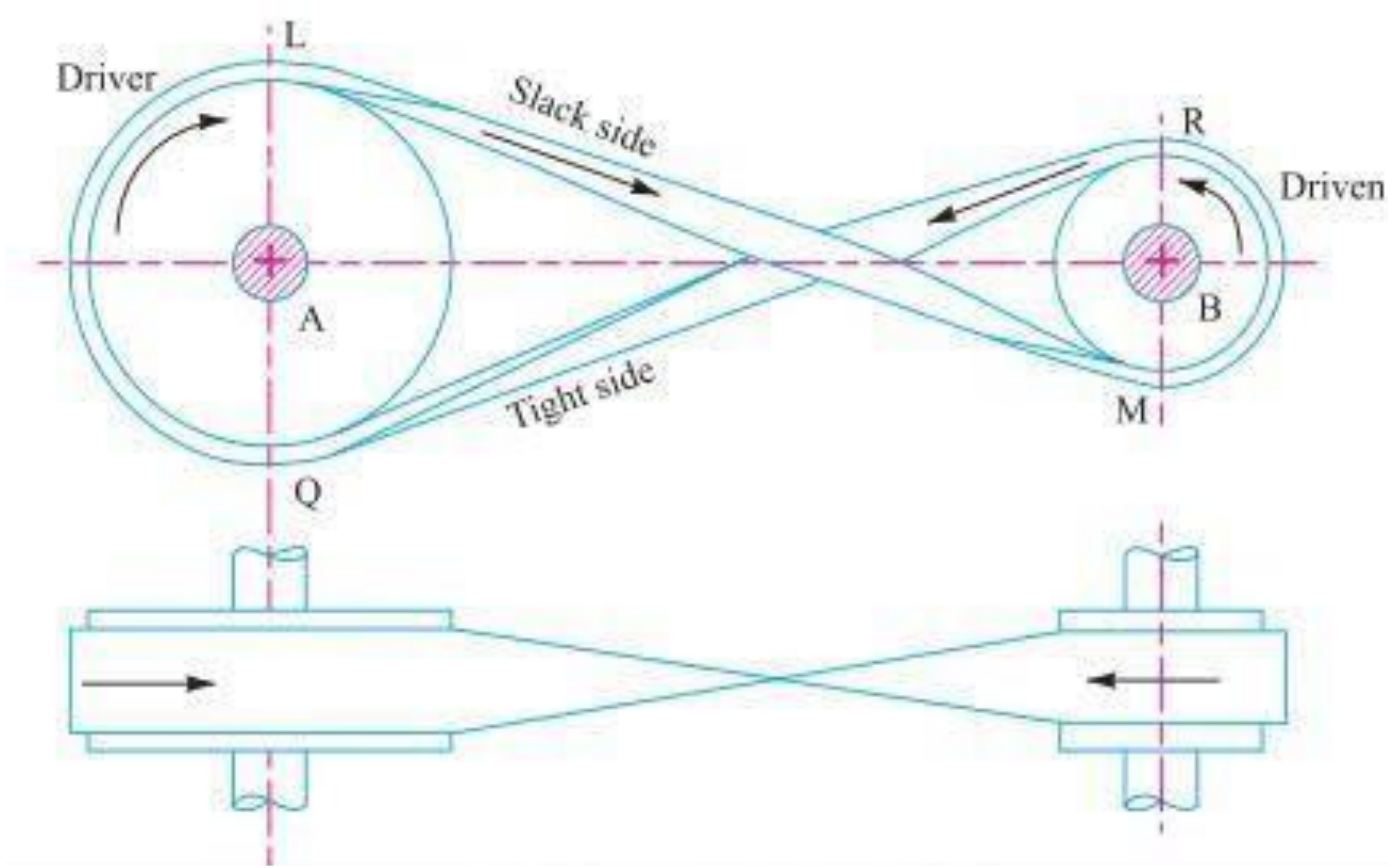
Open Belt Drive



2. Crossed or twist belt drive

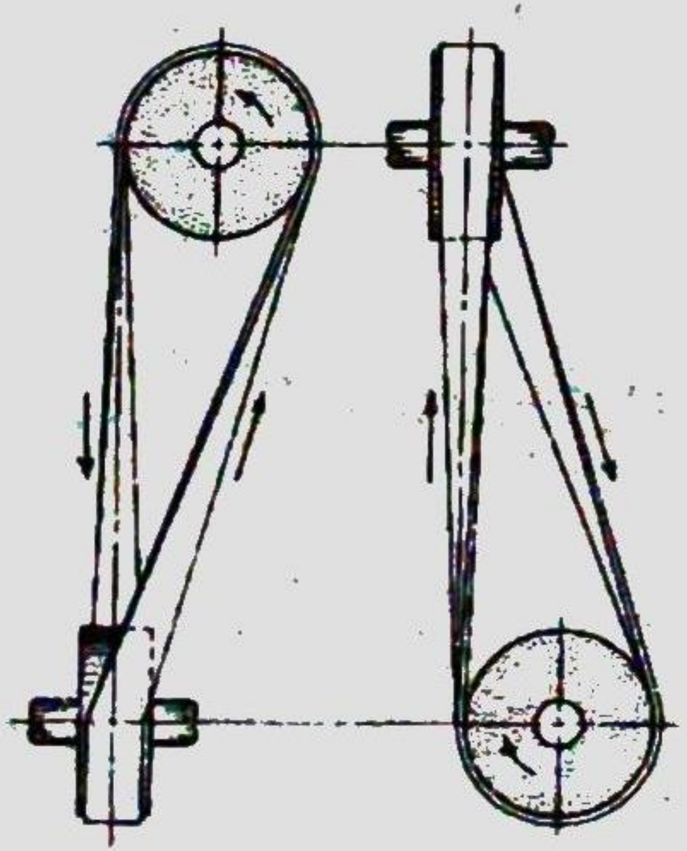
- This type of drive is used when the shafts are arranged in parallel and driven pulley is desired to be rotated in the opposite direction of driving pulley.
- Here, the angle of contact is larger it is used to transmit large powers.
- But at the point of intersection of belt rubs against itself and much wear and tear takes place.
- To minimize this, the distance between the centers of the shafts usually takes as more than 20 b, where b- width of the belt. Also the belt is operated at the speed should be less than 15 m/s.

Crossed belt drive

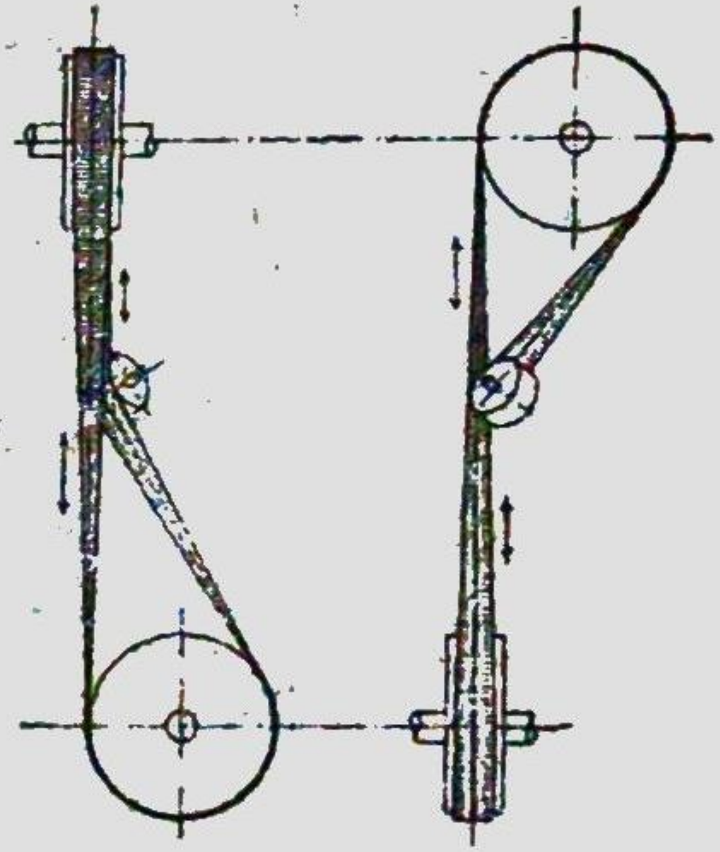


3. Quarter turn belt drive

- Flat belts have often used for drives between shafts which are right angles to each other and the pulleys are rotating in one definite direction.
- So this type of belt drive is also called **right angle belt drive.**
- If the direction of belt motion is reversed, the belt will run off from pulleys.
- When the reversible motion is desired, a guide pulley is used.
- To avoid the slipping of belt away from the pulley, the width of the face of the pulley takes greater than or equal to 1.4b, where b is the belt width.



(a) Quarter - turn belt drive

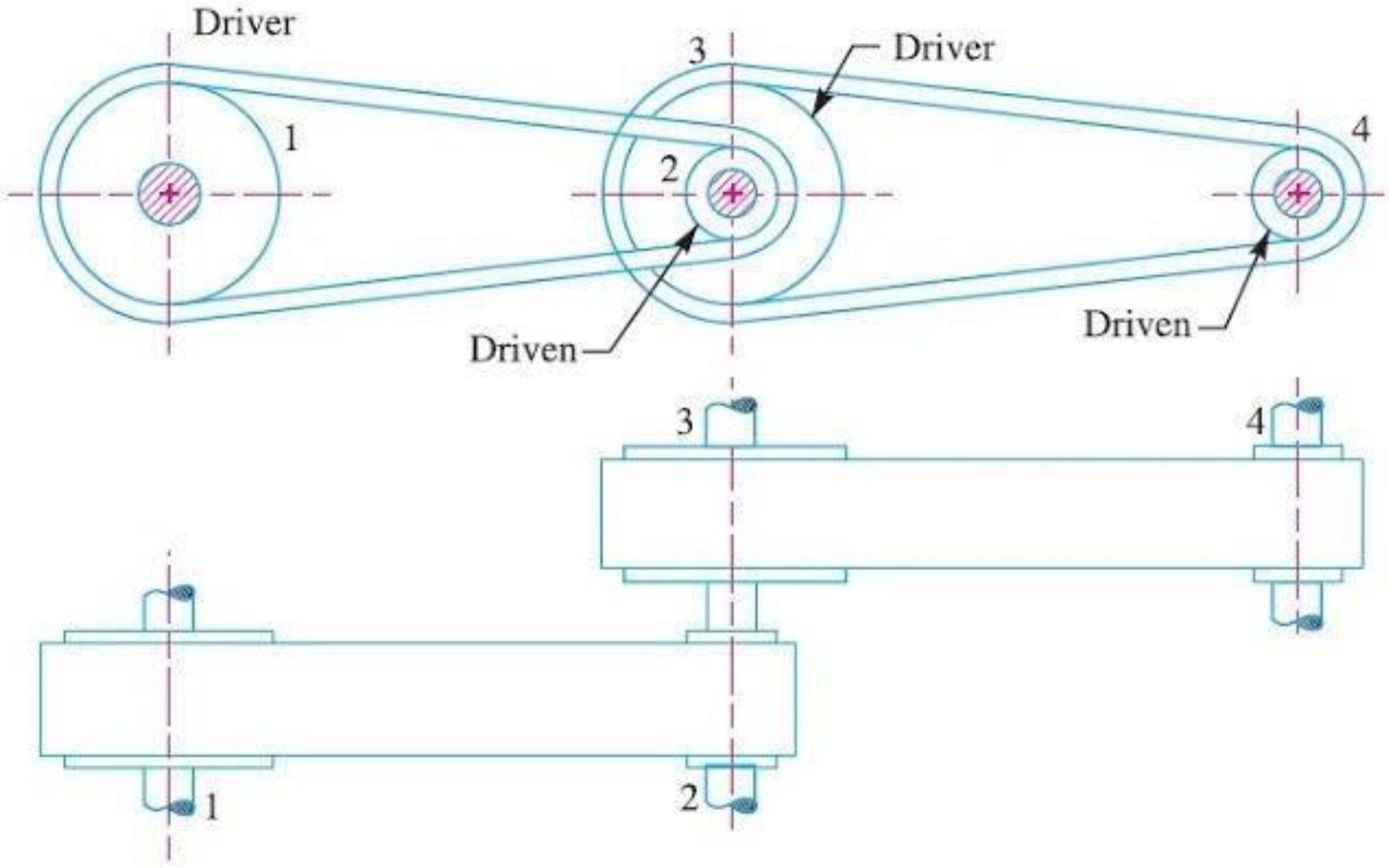


(b) Quarter - turn belt drive with guide pulley

4. Compound belt drive

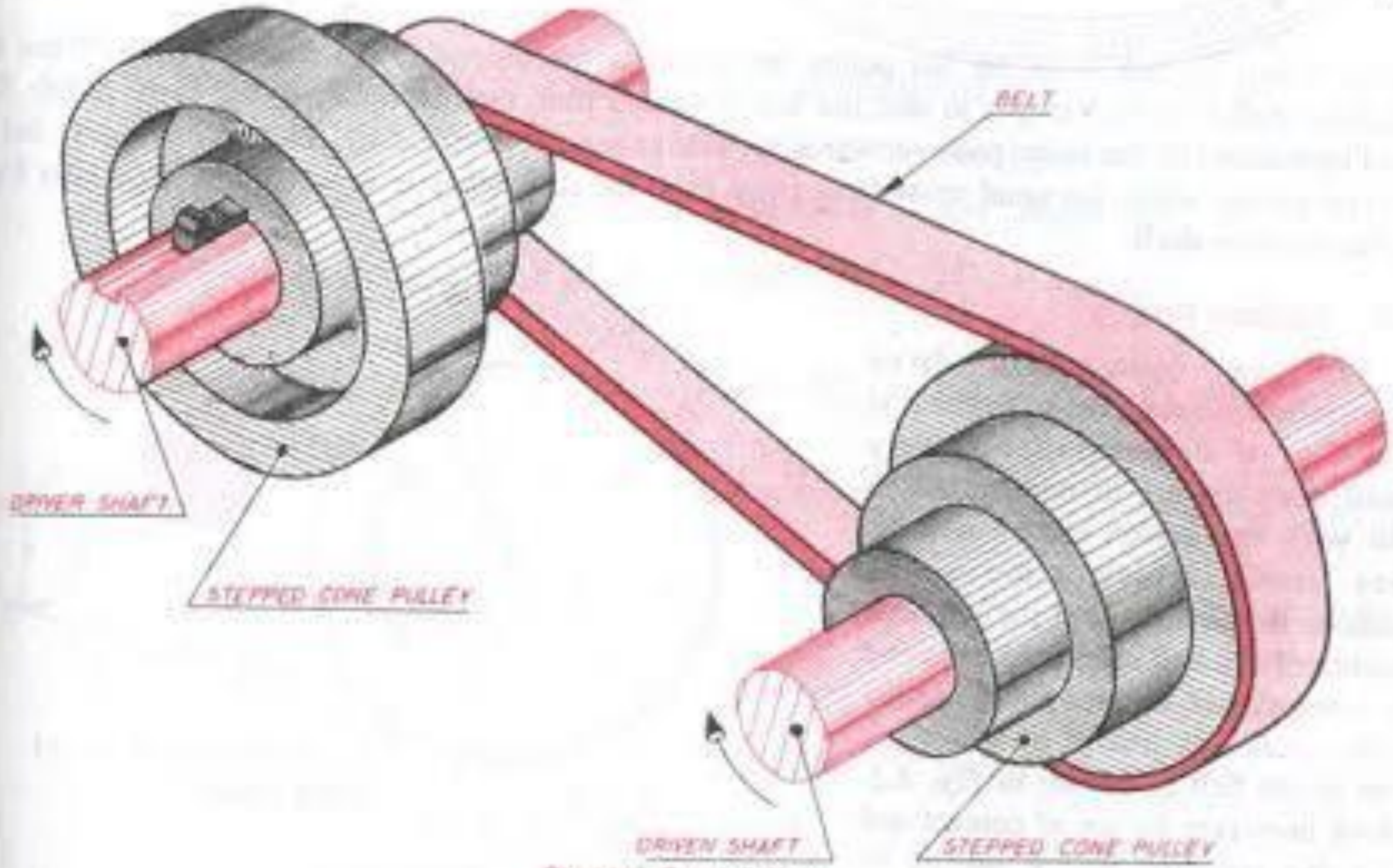
- A **compound belt drive** is used when power is transmitted from one shaft to another through a number of pulleys.
- In the figure, pulley 1 drives the pulley 2 and pulley 3, because pulley 2 and 3 are keyed on the same shaft.
- Also pulley 3 drives the pulley 4.
- Therefore, pulley 1 and 3 are the drivers and pulley 2 and 4 are driven or followers.

Compound belt drive

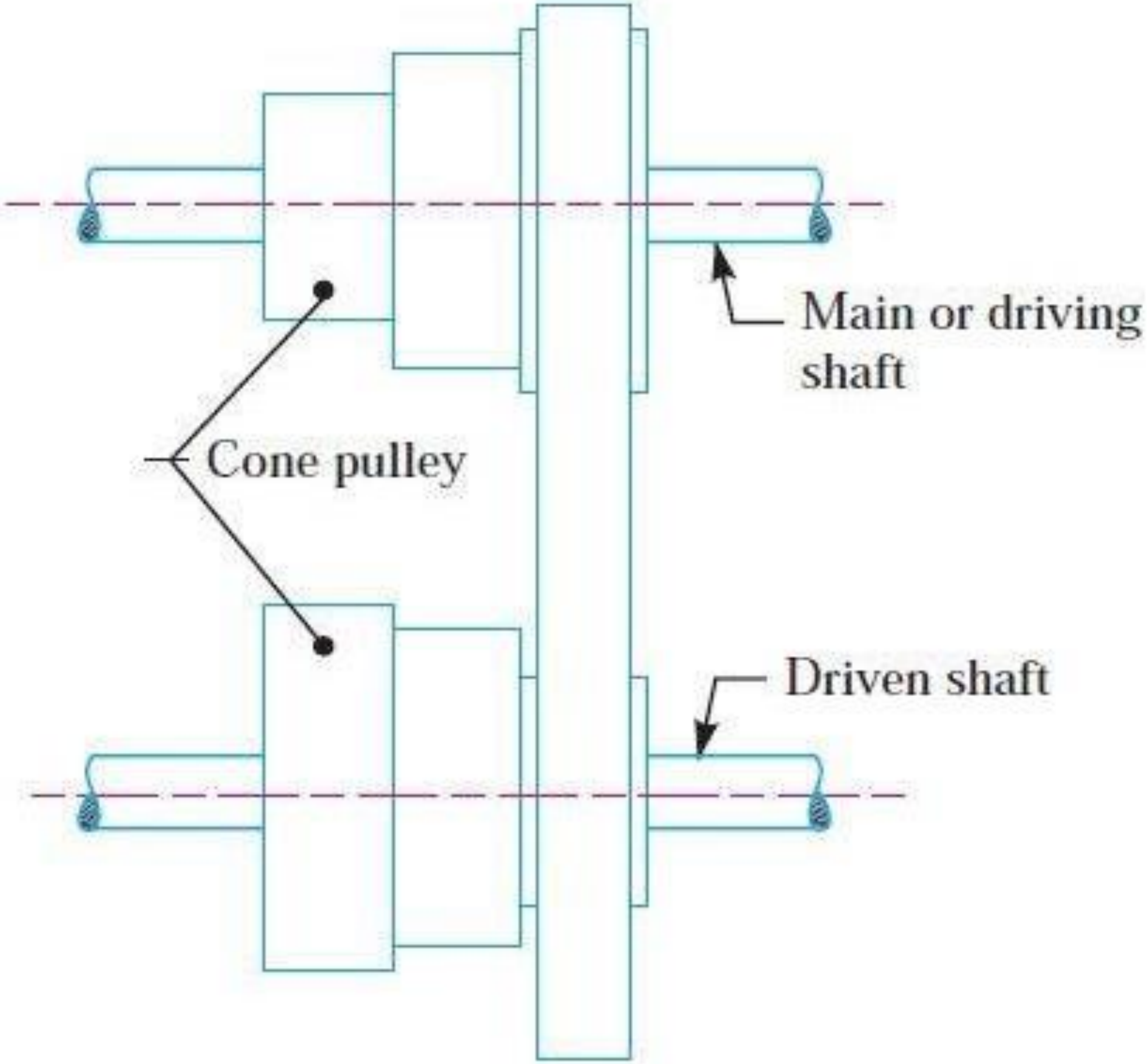


5. Stepped or cone pulley drive

- If we want to change the speed of the shaft which is driven by another shaft rotating at constant speed, then we use a pair of stepped pulleys or cone pulleys.
- The driving cone pulley has a uniform rotational speed and the driven cone pulley is altered to the requirements by shifting the belt from one step to the other.



Stepped Cone Pulley
Fig. 8.38


Main or driving
shaft
Cone pulley
Driven shaft

Velocity ratio of Belt drive

- It gives the relation between the speed of driven and driver pulleys.
- It is defined as the ratio of speed of driven pulley to that of the driving pulley.
- Due to occurrence of slip between belt and pulleys, the velocity ratio of the drive is never exact. So it is not a positive drive.
- If N_1, N_2 are the rotational speed of the driving and driven pulleys in rpm.
- d1, d2 are the diameters of driving and driven pulleys respectively in mm.
- Then velocity ratio, $V.R = \frac{N_2}{N_1} = \frac{d_1}{d_2}$

$$V.R = \frac{\text{Speed of follower}}{\text{Speed of driver}} = \frac{\text{Diameter of driver}}{\text{Diameter of follower}}$$

- If the thickness of the belt is considered, the velocity ratio will be,

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

Where, t – thickness of the belt in mm.

- When power transmitted from driver to driven pulley through number of intermediate pulleys (Compound belt drive),
- Then the velocity ratio $V.R = \frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{d_1}{d_2} \times \frac{d_3}{d_4}$

Here, N_2=N_3, Speed of the same shaft. Then,

$$V.R = \frac{N_4}{N_1} = \frac{d_1 d_3}{d_2 d_4}$$

Where d1, d2, d3 and d4Are the diameters of pulleys 1,2,3,4 respectively

And N_2 and N_4, are the speed of first driver and last driven.

- So we can write, Velocity ratio as,

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

Slip of the Belt

- The power transmission by belt is possible only with sufficient frictional grip between the belt and its pulleys.
- Some times, this frictional grip becomes insufficient.
- Due to this, some forward motion of driving pulley without carrying the belt with it, also some forward motion of belt without carrying the driven pulley with it.
- This relative motion between the pulleys and belt is called **slip of the belt.**
- Slip is defined as insufficient frictional grip between pulley (driver/driven) and belt.
- Slip will decrease the speed of the driven shaft. Power loss occurs.
- The difference in linear speed of pulleys and belt is the measure of slip and it is expressed in percentage.

- Let, S_1 – percentage slip between the driver pulley and belt.
- S_2 – percentage slip between the belt and driven pulley.
- Then Total percentage of slip, $S = S_1 + S_2$
- We have, Surface speed of driver per minute, $v_1 = \pi d_1 N_1$
- Speed of the belt passing over the driver per minute $= \pi d_1 N_1 - \pi d_1 N_1 \times (S_1/100)$.

$$= \pi d_1 N_1 \{1-(S_1/100)\}$$

Similerly, surface speed of the driven pulley per minute, $v_2 = \pi d_2 N_2$

$$= \text{Speed of the belt} - \text{Speed of the belt} \times S_2/100$$

$$= \text{Speed of the belt} \times \{1-(S_2/100)\}$$

$$= \pi d_1 N_1 \left(1 - \frac{S_1}{100}\right)\left(1 - \frac{S_2}{100}\right)$$

$$= \pi d_1 N_1 \left(\frac{100 - S_1}{100}\right)\left(\frac{100 - S_2}{100}\right) = \pi d_1 N_1 \left(\frac{(100 - S_1)(100 - S_2)}{100 \times 100}\right)$$

$$= \pi d_1 N_1 \left(\frac{100 \times 100 - 100S_1 - 100S_2 + S_1 S_2}{100 \times 100}\right) = \pi d_1 N_1 \left(\frac{100\left(100 - (S_1 + S_2)\right) + S_1 S_2}{100 \times 100}\right)$$

$$= \pi d_1 N_1 \left(1 - \frac{S}{100} + \frac{S_1 S_2}{10000}\right)$$

Where S is equal to the total percentage of slip (i.e., $S_1 + S_2$). Neglecting the term $\frac{S_1 S_2}{10000}$ because it is very small, then the above equation becomes.

$$\pi d_2 N_2 = \pi d_1 N_1 \left(1 - \frac{S}{100}\right)$$

$$\therefore \qquad V.R = \frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{S}{100}\right) \qquad ...(9.4)$$

If thickness of the belt 't' is taken into consideration, then

$$V.R = \frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}\left(1 - \frac{S}{100}\right) \qquad ...(9.5)$$

Creep of the belt

- Creep in belt drives is a phenomenon where a flexible belt experiences gradual and undesired elongation over time under the influence of sustained tension and load.

- Thus the creep is from the slack side to the tight side.

- Due to creep, the belt on the driving pulley travels at a slower linear velocity than the rim of the driving pulley and rim velocity of the driven pulley is less than that of the belt on it.
- The rim velocity of the driven pulley is thus less than that of driving pulley.
- Hence the effect of creep is to reduce slightly the speed of the driven pulley.
- Considering creep, the velocity ratio, $$V.R = \frac{N_2}{N_1} = \frac{d_1}{d_2} \times \frac{E + \sqrt{\sigma_2}}{E + \sqrt{\sigma_1}}$$
- Where,
- σ_1 – Stress in the belt on tight side in MPa.
- σ_2 – Stress in the belt on slack side in MPa.
- E – Young's modulus of the material of the belt in MPa.

?. A shaft running at 90 rpm is driving another parallel shaft having 400 mm diameter pulley. The pulley on the driving shaft has its diameter 600 mm. Find (i) Speed of the driven shaft and

(ii) Linear speed of the belt.

Given,

Speed of the driving shaft, N_1 = 90 rpm

Diameter of the driven pulley, d_2 = 400 mm.

Diameter of the driver pulley, d_1 = 600 mm

Using the relation for velocity ratio of belt drive,

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

$\therefore$ Speed of the driven shaft,

$$N_2 = \frac{d_1}{d_2} \times N_1 = \frac{600 \times 90}{400} = 135 \text{ rpm}$$

Using the relation for linear speed of the belt, i.e., $v = \pi d_1 N_1$ or $\pi d_2 N_2$

$$= \pi \times 600 \times 90 \text{ or } \pi \times 400 \times 135 = 169646 \text{ mm/min} = \frac{169646}{1000 \times 60} = 2.83 \text{ m/s}$$

Result :

Speed of the driven shaft is **135 rpm** and the linear speed of belt is **2.83 m/s**.

?. A shaft running at 90 rpm is to drive a parallel shaft at 150 rpm. The pulley on the driving shaft is 750 mm diameter. Calculate the diameter of the pulley on the follower shaft when,

(i) Neglecting the belt thickness

(ii) Taking the thickness of belt as 6 mm.

- Given,

Rotational speed of the driving shaft, $N_1 = 90$ rpm

Rotational speed of the driving shaft, $N_2 = 150$ rpm

Diameter of the driver pulley, $d_1 = 750$ mm.

Thickness of the belt, $t = 6$ mm.

Case (*i*): *Neglecting the belt thickness.*

Using the relation for velocity ratio of drive

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

∴ Diameter of the pulley on the follower shaft, $d_2 = d_1 \times \frac{N_1}{N_2} = \frac{750 \times 90}{150} = 450 \text{ mm}$

Case (*ii*): *Taking belt thickness as 6 mm.*

Using the relation for velocity ratio of belt drive

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

∴ Diameter of the pulley on the follower shaft, $d_2 = \left((d_1 + t) \times \frac{N_1}{N_2}\right) - t$

$$= \left((750 + 6) \times \frac{90}{150}\right) - 6 = 447.6 \text{ mm}$$

Result :

Diameter of the pulley on the follower shaft is **450 mm** without considering thickness of the belt and **447.6 mm** when considering the thickness of the belt.

- An engine shaft running at 120 rpm is required to drive a machine shaft by a belt. The pulley on the engine shaft is 2 m diameter and that of the machine shaft is 1m diameter. If the belt thickness is 5mm, determine the speed of the machine shaft, when

  (i) There is no slip

  (ii) There is a total slip of 3%.

Given, Speed of the engine shaft, $N_1 = 120$ rpm

Diameter of the engine pulley, $d_1 = 2$ m $= 2\times10^3$ mm

Diameter of the pulley on machine shaft, $d_2 = 1$ m $= 1\times10^3$ mm.

Thickness of the belt, t= 5 mm

Total slip of the drive, S = 3%

Case (*i*): ***Assuming there is no slip***

Using the relation for velocity ratio of belt drive.

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

$\therefore$ Speed of the machine shaft, $N_2 = \frac{d_1 + t}{d_2 + t} \times N_1 = \left(\frac{2 \times 10^3 + 5}{1 \times 10^3 + 5}\right) \times 120 = 239.4 \text{ rpm}$

Case (*ii*): ***Assuming a total slip of 3%***

Using the relation for velocity ratio of belt drive

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

$\therefore$ Speed of the machine shaft, $N_2 = \frac{d_1 + t}{d_2 + t}\left(1 - \frac{S}{100}\right) \times N_1$

$$= \left(\frac{2 \times 10^3 + 5}{1 \times 10^3 + 5}\right)\left(1 - \frac{3}{100}\right) \times 120 = 232.22 \text{ rpm}$$

?. An engine running at 150 rpm drives a line shaft by means of a belt. The engine pulley is 750 mm diameter and the pulley on the line shaft is 450 mm. A 900 mm diameter pulley on the line shaft drives a 150 mm diameter pulley keyed to the dynamo shaft. Find the speed of the dynamo shaft, when

(i) There is no slip

(ii) There is a total percentage slip of 4%.

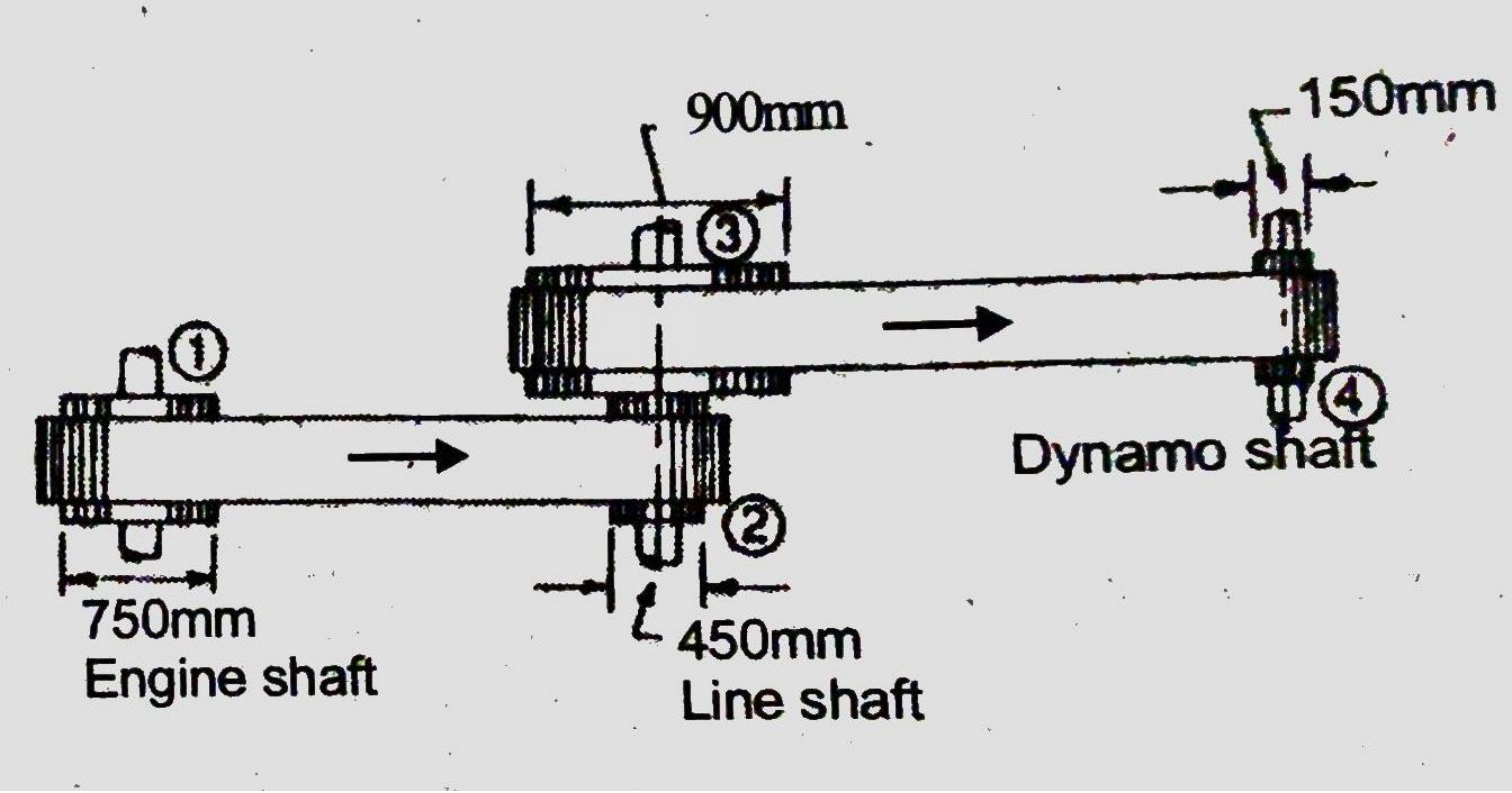
Given, Speed of the engine shaft, N_1 = 150 rpm

Diameter of the engine pulley, d_1 = 750 mm

Diameter of the pulley on the line shaft, d_2 = 450 mm.

Diameter of the another pulley on the line shaft, d_3 = 900 mm.

Diameter of the pulley on the dynamo shaft, d_4 = 150 mm.



900mm
150mm
③
①
④
Dynamo shaft
②
750mm
Engine shaft
450mm
Line shaft

Case (*i*): *Assuming there is no slip.*

Using the relation for velocity ratio of belt drive.

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

$\therefore$ Speed of dynamo shaft, $N_4 = \frac{d_1 d_3}{d_2 d_4} \times N_1 = \frac{750 \times 900}{450 \times 150} \times 150 = 1500$ rpm.

Case (*ii*): *When there is a total slip of* 4%.

Using the relation

$$\frac{N_4}{N_1} = \frac{d_1 d_3}{d_2 d_4}\left(1 - \frac{S}{100}\right)$$

$\therefore$ Speed of dynamo shaft,

$$N_4 = \frac{d_1 d_3}{d_2 d_4}\left(1 - \frac{S}{100}\right) \times N_1 = \frac{750 \times 900}{450 \times 150}\left(1 - \frac{4}{100}\right) \times 150 = 1440 \text{ rpm}$$

Result :

Speed of dynamo shaft is **1500 rpm** and **1440 rpm** when considering no slip and a total slip of 4% respectively.

- The power is transmitted from a pulley 1m diameter running at 300 rpm to a pulley 2.5 m diameter by means of a belt. Find the speed lost by the driven pulley as a result of creep. If the stress on the tight side and slack side of the belt is 1 MPa and 0.4 Mpa respectively. The Young's modulus of belt material is 100 MPa.

Given, Speed of the driving pulley, N_1 = 300 rpm

Diameter of the driving pulley, $d_1 = 1$ m = 1×10^3 mm

Diameter of the driven pulley , $d_2 = 2.5$ m = 2.5×10^3 mm.

Stress in tight side, = 1 MPa = 1 N/mm^2

Stress in slack side, = 0.4 MPa = 0.4 N/mm^2

Young's modulus, E= 100 Mpa = 100 N/mm^2.

Using velocity ratio equation of belt drive, neglecting the effect of creep ,i.e.,

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

$\therefore$ Speed of the driven pulley, $N_2 = \frac{d_1}{d_2} \times N_1 \quad = \frac{1 \times 10^3}{2.5 \times 10^3} \times 300 \quad = 120 \text{ rpm}$

Considering creep, velocity ratio of drive

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

$\therefore$ Speed of the driven pulley, $N_2 = \frac{d_1}{d_2} \times \frac{E + \sqrt{\sigma_2}}{E + \sqrt{\sigma_1}} \times N_1$

$$= \frac{1 \times 10^3}{2.5 \times 10^3} \times \left(\frac{100 + \sqrt{0.4}}{100 + \sqrt{1}} \right) \times 300 = 119.56 \text{ rpm}$$

$\therefore$ Speed lost by driven pulley due to creep $= 120 - 119.56 \quad = 0.44 \text{ rpm}$

Result :

Loss in speed due to creep of belt is **0.44 rpm** .

Length of an open belt drive

- The total length of an open belt comprises three portions,

  (i) The length in contact with the smaller pulley.

  (ii) The length in contact with the larger pulley.

  (iii) The length not in contact with either of the pulleys.

- Let, L_o – Length of belt for an open belt drive in mm.

  r_1 – Radius of smaller pulley in mm.

  r_2 – Radius of larger pulley in mm.

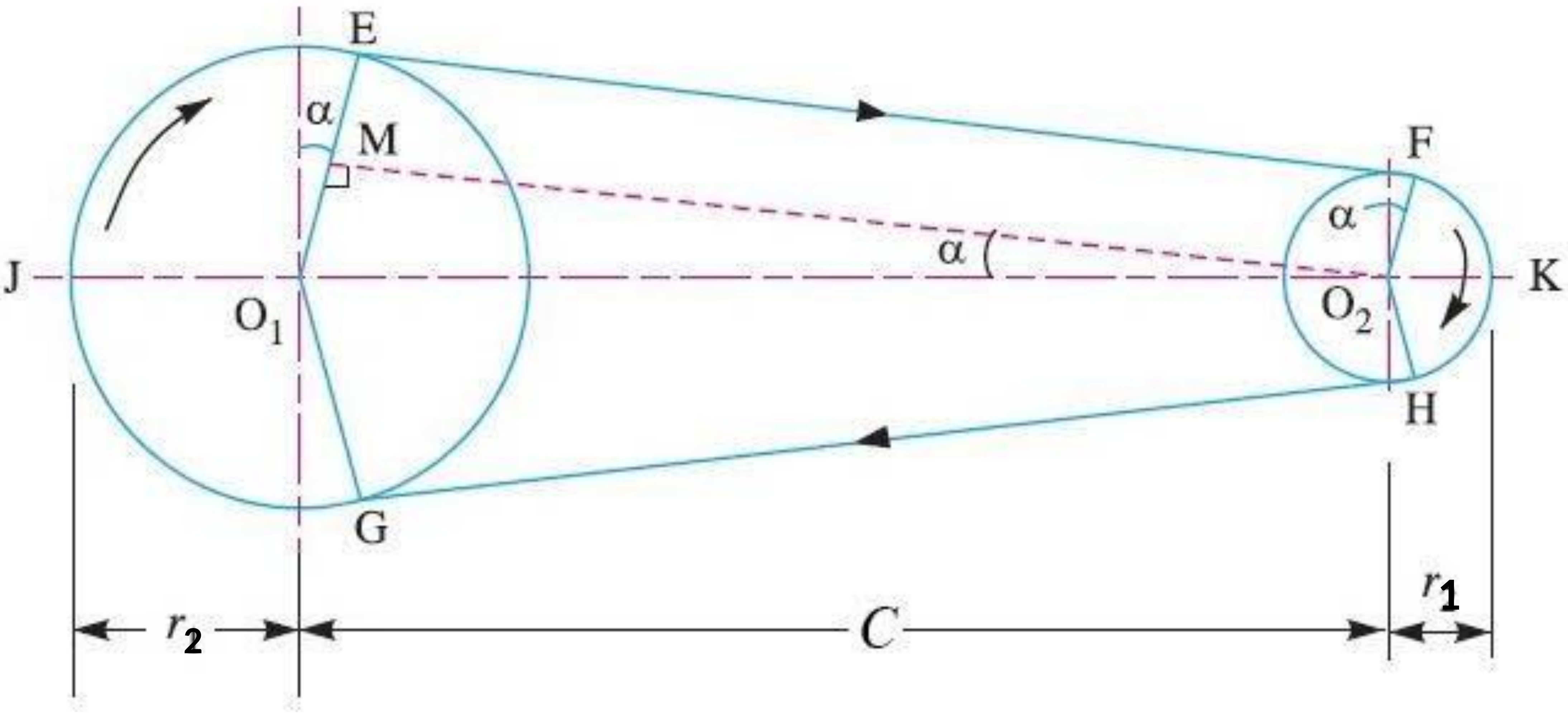
  C – Distance between the centers of two pulleys in mm

Then, Length of an open belt,

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

or

$$L_o = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 - d_1)^2}{4C}$$



E
α
M
F
α
α
J
O1
O2
K
H
G
r2
C
r1

Length of crossed belt drive

- Let, L_c – Length of belt for an open belt drive in mm.

  r_1 – Radius of smaller pulley in mm.

  r_2 – Radius of larger pulley in mm.

  C – Distance between the centers of two pulleys in mm
- Then, the length of belt is

$$L_c = \pi(r_2 + r_1) + 2C + \frac{(r_2 + r_1)^2}{C}$$

or

$$L_c = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 + d_1)^2}{4C}$$

?. Two parallel shafts 5 meters apart are provided with pulleys 500 mm and 750 mm in diameter. Find the length of the belt

(i) for turning the two shafts in the same direction

(ii) for turning the two shafts in the opposite direction.

Given, Distance between two parallel shafts, $C = 5\text{ m} = 5\times10^3\text{ mm}$

Diameter of smaller pulley, $d_1 = 500\text{ mm}$

Diameter of larger pulley, $d_2 = 750\text{ mm}$

Case (i) : shafts rotates in the same direction.

- We know that, for turning two shaft in same direction, we can use open belt.
- So the length of the belt obtained by using the relation.

$$L_o = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 - d_1)^2}{4C}$$

$$= \frac{\pi}{2}(750 + 500) + 2 \times 5 \times 10^3 + \frac{(750 - 500)^2}{4 \times 5 \times 10^3} = 11966.62 \text{ mm} \quad = 11.97 \text{ m}$$

Case (ii) shafts rotates in the opposite direction.

- We know that, for turning two shaft in opposite direction, we can use crossed belt.

$$L_c = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 + d_1)^2}{4C} \quad = \frac{\pi}{2}(750 + 500) + 2 \times 5 \times 10^3 + \frac{(750 + 500)^2}{4 \times 5 \times 10^3}$$

$$= 12041.62 \text{ mm} \quad = 12.04 \text{ m}$$

- ?. A 300 mm diameter pulley running at 200 rpm is connected by belt to another pulley at a distance of 3 m. The second pulley has to rotate at 120 rpm. If the belt is 5 mm thick and slip between belt and pulley is 3% at each stage, determine the diameter of the second pulley. Also find the length of the belt if the drive is an open belt drive.

- Given, Speed of the driving pulley, N_1 = 200 rpm
  Speed of the driven pulley, N_2 = 150 rpm Diameter of the driving pulley, d_1 = 300 mm. Distance between pulleys, C = 3 m = 3×10^3 mm. Thickness of the belt, t = 5 mm.

  Slip at each stage, S_1 and S_2 = 3%

Total percentage of slip, $S = S_1 + S_2$

$$= 3 + 3 \quad = 6\%$$

Using the relation for velocity ratio considering thickness and slip, i.e.,

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

Diameter of second pulley,

$$d_2 = \left((d_1 + t)\left(1 - \frac{S}{100}\right) \times \frac{N_1}{N_2}\right) - t \quad = \left((300 + 5)\left(1 - \frac{6}{100}\right) \times \frac{200}{120}\right) - 5$$

$$= 472.83 \text{ mm}$$

Using the relation for length of belt in open belt drive

$$L_o = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 - d_1)^2}{4C}$$

$$= \frac{\pi}{2}(472.83 + 300) + 2 \times 3 \times 10^3 + \frac{(472.83 - 300)^2}{4 \times 3 \times 10^3}$$

$$= 7216.45 \text{ mm} \quad = 7.22 \text{ m}$$

- Two parallel shaft, connected by a crossed belt drive are provided with pulleys 800 mm and 600 mm in diameters. The distance between center lines of the shafts is 6m. Find by how much the length of the belt should be changed to alter the direction of rotation of the driven shaft.

- Given, Diameter of larger pulley, $d2 = 800$ mm

  Diameter of smaller pulley, $d1 = 600$ mm

  Distance between center lines of the shaft, $C = 6$ m 6×10^3 mm.

Analysis :

Using the relation for length of crossed belt

$$L_c = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 + d_1)^2}{4C}$$

$$= \frac{\pi}{2}(800 + 600) + 2 \times 6 \times 10^3 + \frac{(800 + 600)^2}{4 \times 6 \times 10^3} = 14280.78 \text{ mm} \quad = 14.28 \text{ m}$$

Using the relation for length of belt in open belt drive

$$L_o = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 - d_1)^2}{4C} \quad = \frac{\pi}{2}(800 + 600) + 2 \times 6 \times 10^3 + \frac{(800 - 600)^2}{4 \times 6 \times 10^3}$$

$$= 14200.78 \text{ mm} \quad = 14.20 \text{ m}$$

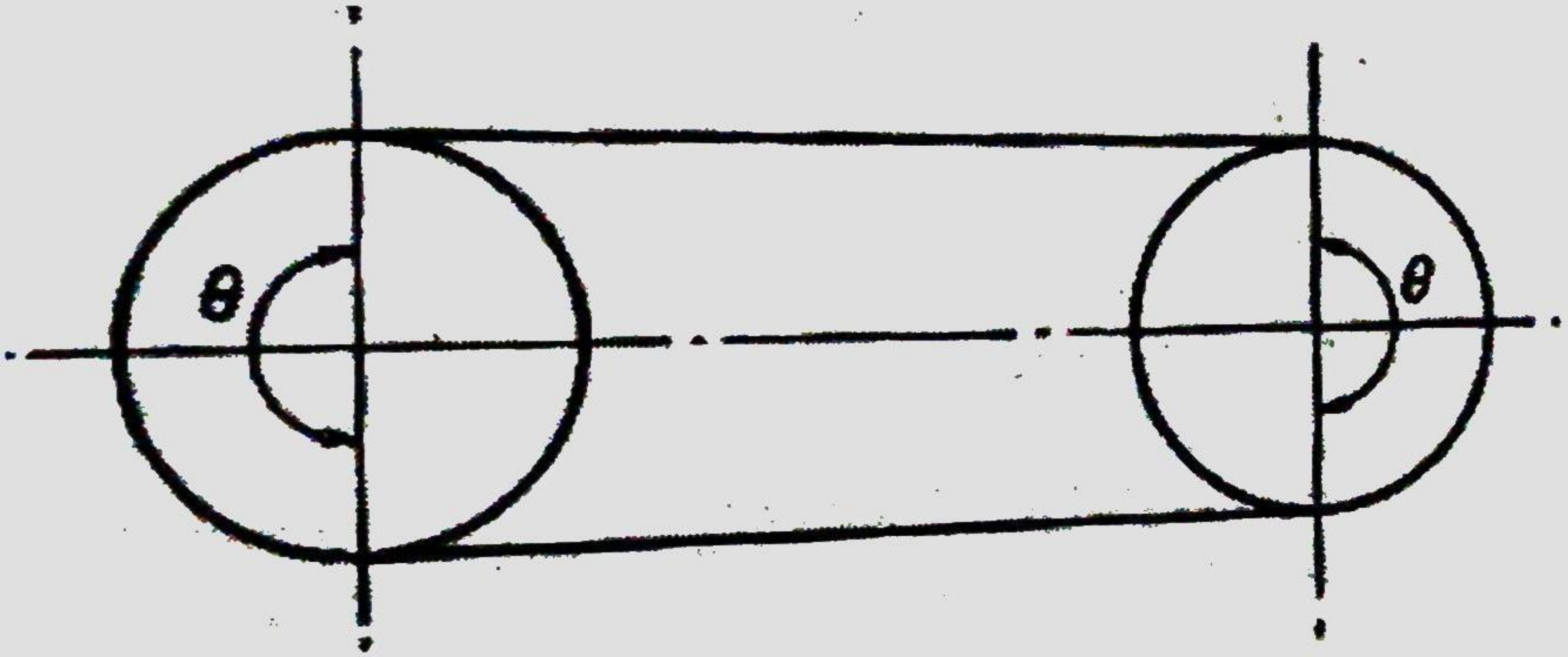
$\therefore$ Length of the belt reduced $= 14.28 - 14.20 = 0.08$ m

Result :

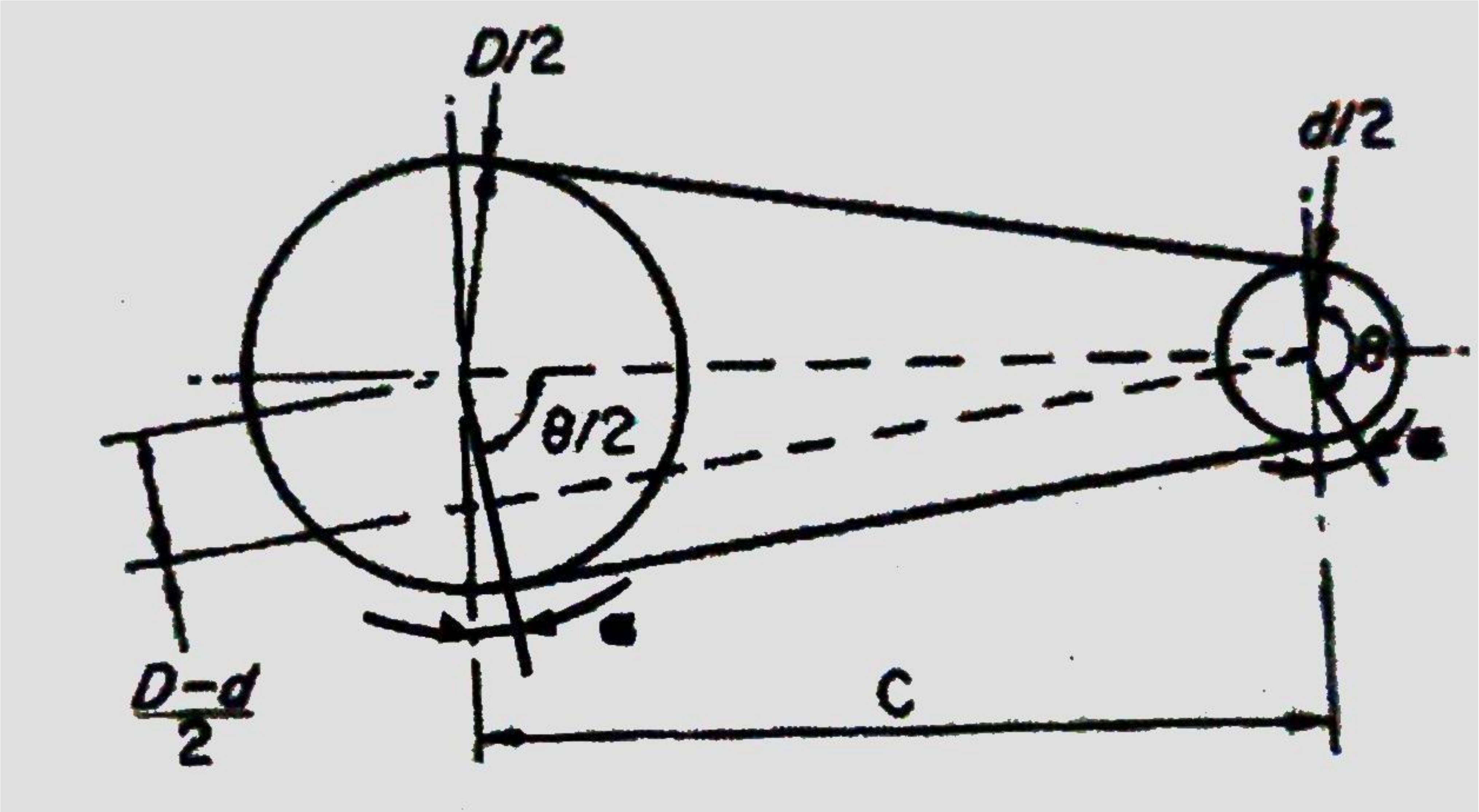
Length of the belt should be changed by reducing **0.08 metres** of crossed belt.

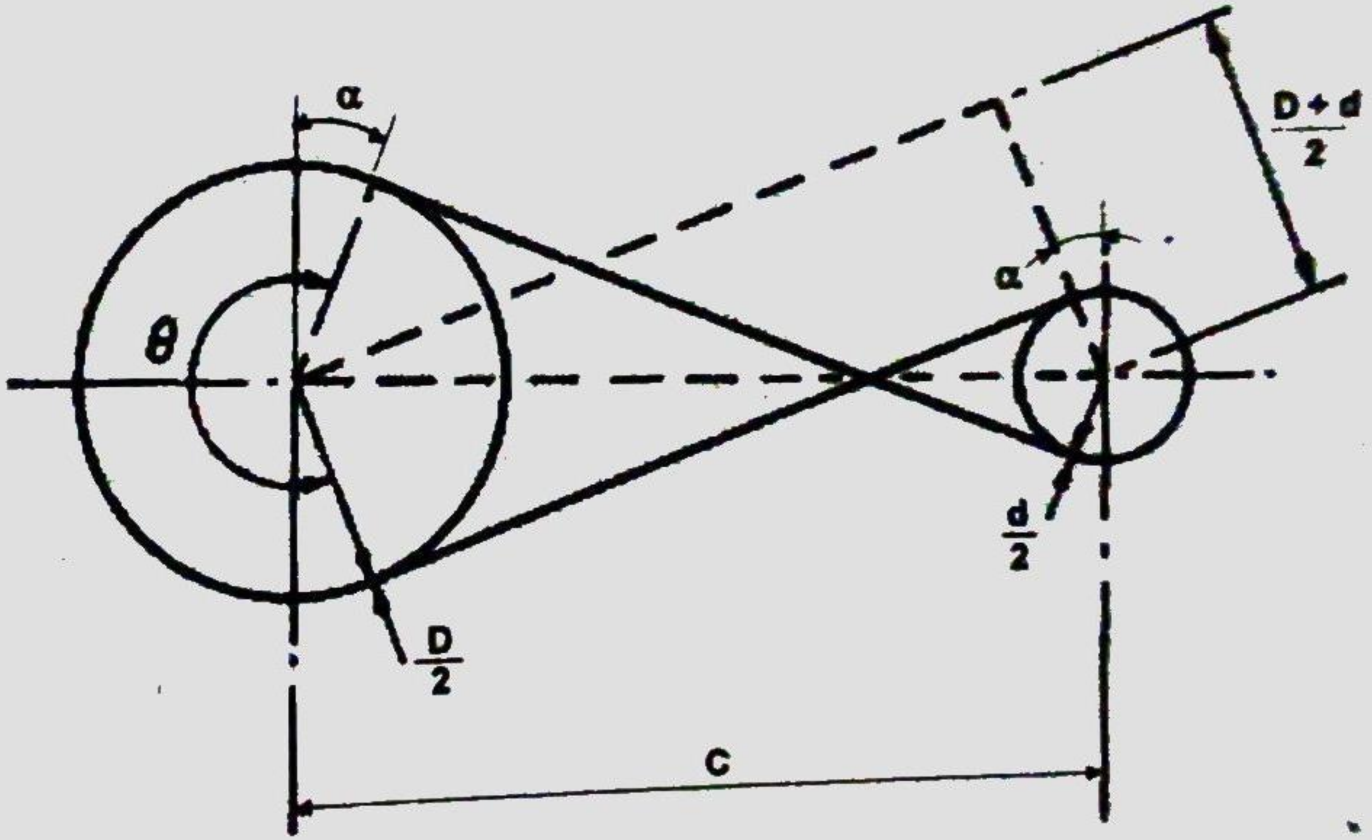
Angle of lap or angle of arc of contact

- This is the angle substended at the center of the pulley by the arc over which the belt is in contact with the pulley.
- It is denoted by θ.
- If the pulleys gave equal diameters, then the angle of lap or contact for both pulleys is 180° or π radian.
- If the pulleys are unequal diameters, the angle of lap on the smaller pulley is smaller than the angle of lap on the larger pulley.
- Therefore, the possibility of slip is more on the smaller pulley due smaller angle of arc of contact.
- Hence angle of lap on the smaller pulley is the limiting factor.



(a) Pulleys of equal diameter


D/2
d/2
θ/2
θ
α
α
C
$\frac{D-d}{2}$



(c) Crossed belt

Fig. 9.13 Angle of lap

- In the case of open belt drive, the angle of lap on smaller pulley is the limiting factor

Angle of contact or lap, $\theta = \pi - 2\alpha$

$$\therefore \quad \theta = \pi - 2\sin^{-1}\left(\frac{r_2 - r_1}{C}\right)$$

$$\theta = \pi - 2\sin^{-1}\left(\frac{d_2 - d_1}{2C}\right)$$

- In case of cross belt drive, the angle of lap on both pulleys are same

Angle of contact or lap, $\theta = \pi + 2\alpha$

$$\therefore \quad \theta = \pi + 2\sin^{-1}\left(\frac{r_2 + r_1}{C}\right)$$

$$\therefore \quad \theta = \pi + 2\sin^{-1}\left(\frac{d_2 + d_1}{2C}\right)$$

- Two pulleys of 250 mm and 500 mm diameter are connected by a flat belt. Calculate the angle of lap if the center distance is 1.5 m. When,

1. An open belt drive is used
2. A crossed belt drive is used.

- Given, Diameter of smaller pulley, $d1 = 250$ mm

  Diameter of larger pulley, $d2 = 500$ mm

  Center distance between the pulleys, $C = 1.5$ m $= 1.5\times10^{3}$ mm.

Analysis : Using the relations for angle of lap.

(i) Open belt drive .

$$\text{Angle of lap, } \theta = \pi - 2\sin^{-1}\left(\frac{d_2 - d_1}{2C}\right) = 180^0 - 2\sin^{-1}\left(\frac{500-250}{2\times1.5\times10^3}\right)$$

$$= 170.44^0 = 170.44\times\frac{\pi}{180} = 2.97 \text{ radians .}$$

(ii) Crossed belt drive.

$$\text{Angle of lap, } \theta = \pi + 2\sin^{-1}\left(\frac{d_2 + d_1}{2C}\right) = 180^0 + 2\sin^{-1}\left(\frac{500+250}{2\times1.5\times10^3}\right)$$

$$= 208.96^0 = 208.96\times\frac{\pi}{180} = 3.65 \text{ radians .}$$

Result :

Angle of lap in an open belt drive is **2.97 radians** and crossed belt drive is **3.65 radians** .

Ratio of belt tension in flat belt

- Belt is subjected to an initial tension when itvis connected over the pulleys which are at rest.
- The rotation of driver leads to increase the tension on one side (tight side) and decrease it on other side (slack side).
- The ratio of belt tensionsvin tight and slack sides of the belt is mathematically written as

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

Where

T_1 = Tension in the belt on tight side in N.

T_2 = Tension in the belt on slack side in N.

θ = Angle of lap of the belt over the pulley in radians.

μ = Coefficient of friction between the belt and the pulley.

Power transmitted by the belt

- The tension in tight side of the belt is more that that of slack side of the belt.
- Due to this difference in tension, the belt exerts a tangential force on the circumference of the pulley. The effective tension is equal to $(T_1 - T_2)$ N.
- The effective turning force at the circumference of the pulley exerts torque on the pulley.
- Torque exerted on the pulley = $(T_1 - T_2)r$ Nm.
- So work done/s or power = Torque × angular velocity.

$$P = (T_1 - T_2)r \times \text{angular velocity.}$$

$$\mathbf{P = (T_1 - T_2) \times v} \text{ or } \mathbf{P = (T_1 - T_2) \times \pi dN/60} \text{ watts.}$$

?. A 400 mm diameter pulley is driven at 750 rpm by a flat belt with a tight side tension of 300 N and slack side tension of 45.35 N. Determine the power transmitted by the belt.

- Given, Diameter of the pulley, d = 400 mm = 0.4 m

  Speed of the pulley, N = 750 rpm

  Tension on tight side, T1 = 300 N

  Tension on slack side, T2 = 45.35 N

- Using the expression for power transmitted, $P = (T_1 - T_2) \times \pi d N/60$

  $P = (300-45.35)\,(\pi\times0.4\times750)\,/60$

  P= 4000.03 We = 4 kW.

- A flat belt make contact with a 350 mm diameter pulley over an angle of 160°. The coefficient of friction is 0.3 and the speed of the pulley is 1200 rpm. If the maximum allowable tension in the belt is 550 N., calculate the maximum torque and maximum power that can be transmitted by the belt.

- Given, Diameter of the pulley d = 350 mm = 0.35 m

  Angle of contact, $\theta = 160° = 160 \times (\pi/180) = 2.79$ radians.

  Coefficient of friction, $\mu = 0.3$

  Speed of the pulley, N = 1200 rpm

  Maximum allowable tension, $T_1 = 550$ N

Using the relation for ratio of flat belt tensions , i.e., $\frac{T_1}{T_2} = e^{\mu\theta}$

Or, Tension on slack side, $T_2 = \frac{T_1}{e^{\mu\theta}} = \frac{550}{e^{0.3\times2.79}} = 238.15 \text{ N}$

$\therefore$ Maximum torque exerted on the pulley,

$$T = (T_1 - T_2)\frac{d}{2} = (550 - 238.15)\frac{350\times10^{-3}}{2} = 54.57 \text{ N - m}$$

Using the relation for power transmitted,i.e.,

$$P = (T_1 - T_2)\frac{\pi dN}{60} = (550 - 238.15)\frac{\pi\times350\times10^{-3}\times1200}{60}$$

$$= 6857.94 \text{ W} = 6.86 \text{ kW}$$

Result :

Maximum torque and power transmitted by the belt are **54.57 N - m** and **6.86 kW**

Example 9.20 : Determine the maximum torque and power that can be transmitted by a flat belt if the maximum tension is 500 N, the coefficient of friction is 0.25, the angle of contact is 150^0 and the diameter of the pulley is 300 mm. The speed of the pulley is 1150 rpm.

Example 9.21 : A pump consuming 3.5 kW at 200 rpm is drawn by a belt and pulley. If the diameter of the pulley is 375 mm. The ratio of belt tensions is 3. Determine the angle of lap and the belt tensions, if coefficient of friction is 0.35.

Example 9.22 : A belt drive must transmit 15 kW at a belt speed of 11.5 m/s. The tension in the tight side of the belt drive must not exceed 2.25 times that in slack side. Determine the angle of lap and belt tensions if coefficient of friction is 0.3. (***March*** **2007**)

- Two pulleys 450 mm diameter and 200 mm diameter are on parallel shafts. 1.95 m apart and are connected by a cross belt. Find the length of the belt required and the angle of contact between the belt and each pulley. What power can be transmitted by the belt when larger pulley rotates at 200 rpm, if the maximum permissible tension in the belt is 1kN, and the coefficient of friction between the belt and pulley is 0.25.

- Given, Diameter of the larger pulley, d_2 = 450 mm = 0.45 m

  Diameter of the driving pulley, d_1 = 200 mm = 0.2 m Speed

  of the larger pulley, N_2 = 200 rpm

  Distance between pulleys, C= 1.95 m =1950 mm

  Maximum permissible tension in the belt, T1= 1kN = 1×10^3 N.

  Coefficient of friction between the belt and pulley, μ= 0.25

Using the relation for length of crossed belt

$$L_c = \frac{\pi}{2}(d_2 + d_1) + 2C + \frac{(d_2 + d_1)^2}{4C} = \frac{\pi}{2}(450 + 200) + 2 \times 1.95 \times 10^3 + \frac{(450 + 200)^2}{4 \times 1.95 \times 10^3}$$

$$= 4975.18 \text{ mm} \quad = 4.98 \text{ m}$$

Using the relation for angle of contact or lap for crossed belt

Angle of lap, $\theta = \pi + 2\sin^{-1}\left(\frac{d_2 + d_1}{2C}\right) = 180^0 + 2\sin^{-1}\left(\frac{450 + 200}{2 \times 1.95 \times 10^3}\right) = 199.19^0$

$$= 199.19 \times \frac{\pi}{180} \quad = 3.48 \text{ rad.}$$

Using the power equation for belt drive $P = T_1\left(1 - \frac{1}{e^{\mu\theta}}\right)\frac{\pi d N}{60}$

$$= 1 \times 10^3\left(1 - \frac{1}{e^{0.25 \times 3.48}}\right) \times \frac{\pi \times 450 \times 10^{-3} \times 200}{60}$$

$$= 2738.13 \text{ W} \quad = 2.74 \text{ kW}$$

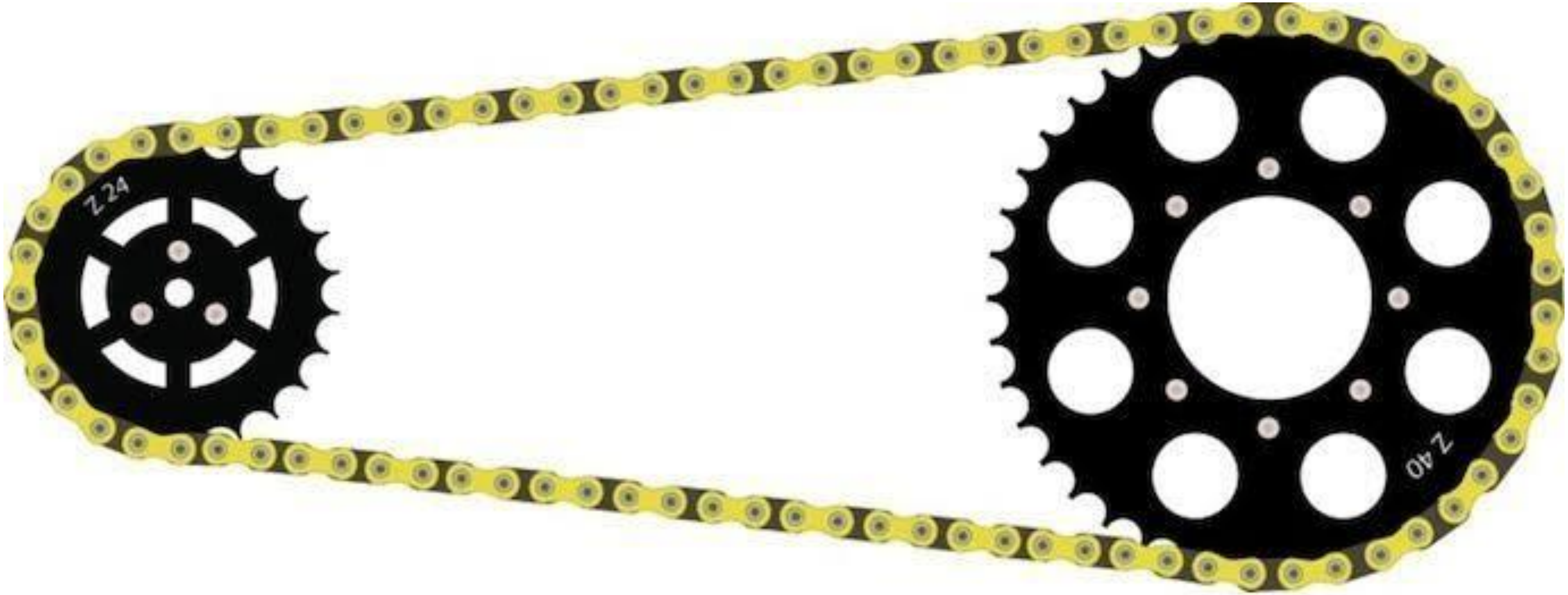
Centrifugal tension

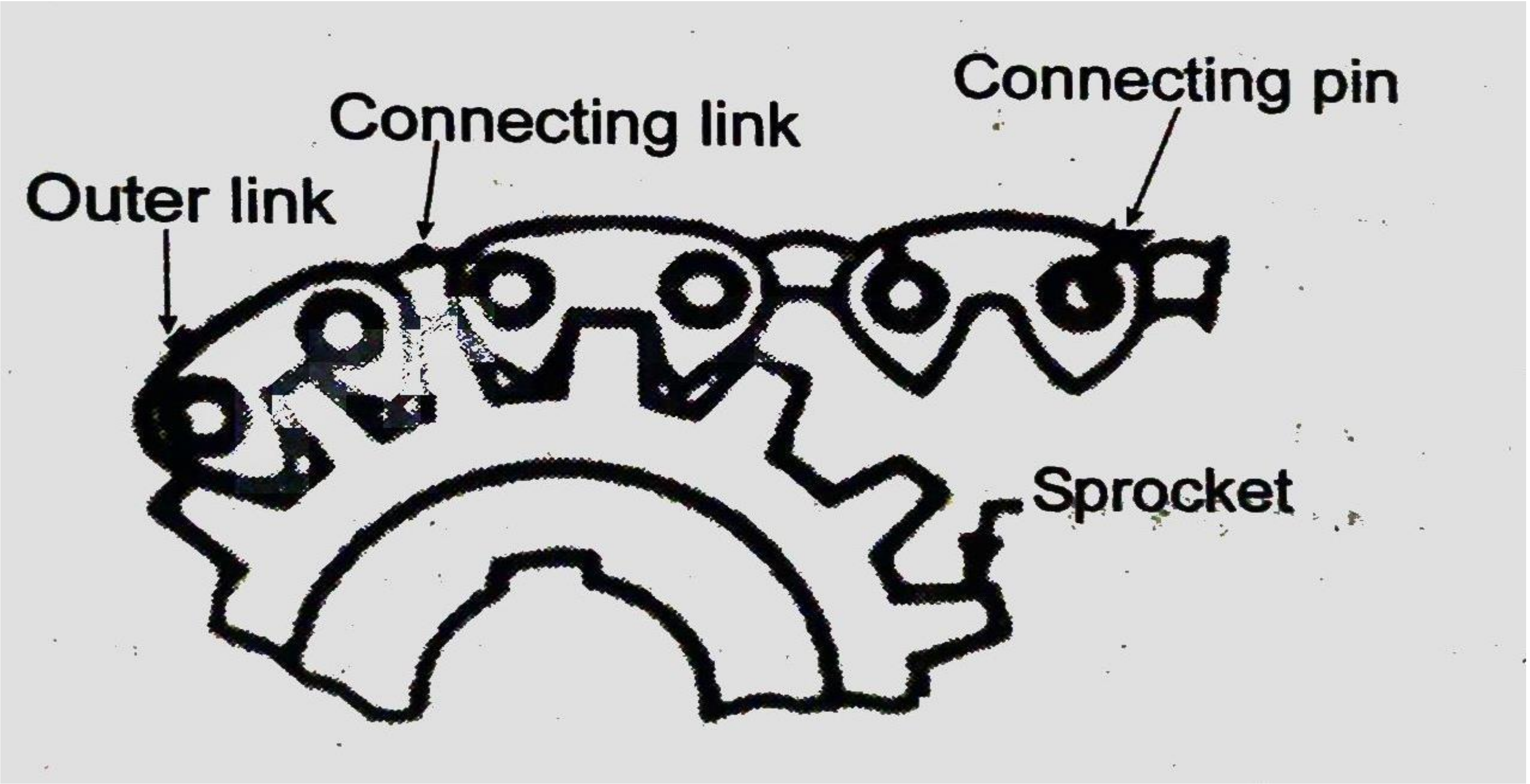
- When a belt or a rope passes over its pulley continuously run in a circular path, it is subjected to centrifugal force, this centrifugal effects tends to lift the belt from the rim of the pulley.
- Hence it reduce the friction force between the belt and pulley.
- So it reduces the capacity of power transmission.
- Due to centrifugal forces, an additional tension is induced in the belt.
- This additional tension produced is known as centrifugal tension.
- It is negligible for low speed (less than 10 m/s)
- Mathematically, $\mathbf{T_c = mv^2}$ Where, T_c – Centrifugal tension in the belt in N
- m – Mass of the belt per unit length in kg.

  v – Linear velocity of belt in m/s

V-belt	Flat belt
1. Suitable for shorter distances between the shafts	1. Suitable for comparatively longer centre distances
2. Trapezoidal in cross section	2. Rectangular in cross section
3. High frictional grip between belt and pulley	3. Less frictional grip between belt and pulley
4. No possibility of belt coming out of the grooves	4. Possibility of belt coming out of the pulley
5. Occurrence of slip is seldom possible i.e., low percentage of slip	5. Slip occurs easily i.e., high percentage of slip
6. Velocity ratio is high	6. Velocity ratio is low
7. Number of drives can be taken from a single pulley by providing a number of grooves on the pulley	7. Only single drive can be taken from a single pulley
8. Since more than one belt can be used, power transmitted will be more	8. Since single belt can be used power transmitted is less

Chain drive





- Chain drive is a way of transmitting mechanical power from one place to another.
- It is often used to convey power to the wheels of a vehicle,
  particularly bicycles and motorcycles.

Advantages of chain drive over belt drive

1. No slip takes place, hence perfect velocity ratio occurs.
2. More compact than belt drive.
3. It occupies less space due to metallic construction.
4. It can be used where exact timing in movement is desired.
5. No initial tension is required for its operation.
6. It used with sprockets which are less costly than pulleys.
7. Less load on shafts compared to belt drives.
8. Unaffected by temperature and efficiency of transmission is high.
9. Possible to transmit power or motion to several shafts with one chain.
10. It is more durable.

Disadvantages of chain drive over belt drive

1. Production cost is comparatively high.
2. More noisy operation.
3. Need for accurate mounting and careful maintenance.
4. More complicated design than belts.
5. Due to metallic constructions, these are heavy.
6. These can get stretched occasionally, therefore, the links have to be removed.

Rope Drive

- A rope drive is a form of belt drive, used for mechanical power transmission.
- Rope drives use a number of circular section ropes, rather than a single flat or V-belt.

Advantages of the rope drive

- Significant power transmission.
- It can be used for long distance.
- Ropes are strong and flexible.
- Provides smooth and quiet operation.
- It can run any direction.
- Low-cost and economic.
- Precise alignment of the shaft not required.

Disadvantages of the rope drive

- Internal failure of the rope has no sign on external, so it if often get unnoticed.
- Corrosion of wire rope.