∴ Centrifugal tension,

$$T_C = m.v^2 = 0.253\,(23.56)^2 = 140.4 \text{ N}$$

Let T_1 = Tension in the tight side of the belt, and

T_2 = Tension in the slack side of the belt.

We know that maximum tension in the belt,

$$T = \text{Stress} \times \text{area} = \sigma \times a = 2.1 \times 230 = 483 \text{ N}$$

We also know that maximum or total tension in the belt,

$$T = T_1 + T_C$$

$$\therefore \quad T_1 = T - T_C = 483 - 140.4 = 342.6 \text{ N}$$

We know that

$$2.3 \log \left(\frac{T_1}{T_2}\right) = \mu.\theta_2 = 0.2 \times 3.8 = 0.76$$

$$\log \left(\frac{T_1}{T_2}\right) = 0.76 / 2.3 = 0.3304 \quad \text{or} \quad \frac{T_1}{T_2} = 2.14 \quad \text{...(Taking antilog of 0.3304)}$$

and

$$T_2 = T_1 / 2.14 = 342.6 / 2.14 = 160 \text{ N}$$

∴ Power transmitted per belt

$$= (T_1 - T_2)\, v = (342.6 - 160)\, 23.56 = 4302 \text{ W} = 4.302 \text{ kW}$$

We know that number of belts required

$$= \frac{\text{Total power transmitted}}{\text{Power transmitted per belt}} = \frac{20}{4.302} = 4.65 \text{ say } 5 \quad \textbf{Ans.}$$

20.7 Rope Drives

The rope drives are widely used where a large amount of power is to be transmitted, from one pulley to another, over a considerable distance. It may be noted that the use of flat belts is limited for the transmission of moderate power from one pulley to another when the two pulleys are not more than 8 metres apart. If large amounts of power are to be transmitted, by the flat belt, then it would result in excessive belt cross-section.

The ropes drives use the following two types of ropes :

1. Fibre ropes, and **2.** *Wire ropes.

The fibre ropes operate successfully when the pulleys are about 60 metres apart, while the wire ropes are used when the pulleys are upto 150 metres apart.

20.8 Fibre Ropes

The ropes for transmitting power are usually made from fibrous materials such as hemp, manila and cotton. Since the hemp and manila fibres are rough, therefore the ropes made from these fibres are not very flexible and possesses poor mechanical properties. The hemp ropes have less strength as compared to manila ropes. When the hemp and manila ropes are bent over the sheave, there is some sliding of the fibres, causing the rope to wear and chafe internally. In order to minimise this defect, the rope fibres are lubricated with a tar, tallow or graphite. The lubrication also makes the rope moisture proof. The hemp ropes are suitable only for hand operated hoisting machinery and as tie ropes for lifting tackle, hooks etc.

The cotton ropes are very soft and smooth. The lubrication of cotton ropes is not necessary. But if it is done, it reduces the external wear between the rope and the grooves of its sheaves. It may be noted that the manila ropes are more durable and stronger than cotton ropes. The cotton ropes are costlier than manila ropes.

* Wire ropes are discussed in Art. 20.12.

Notes : 1. The diameter of manila and cotton ropes usually ranges from 38 mm to 50 mm. The size of the rope is usually designated by its circumference or ***'girth'***.

2. The ultimate tensile breaking load of the fibre ropes varies greatly. For manila ropes, the average value of the ultimate tensile breaking load may be taken as 500 d^2 kN and for cotton ropes, it may be taken as 350 d^2 kN, where d is the diameter of rope in mm.

20.9 Advantages of Fibre Rope Drives

The fibre rope drives have the following advantages :

1. They give smooth, steady and quiet service.

2. They are little affected by out door conditions.

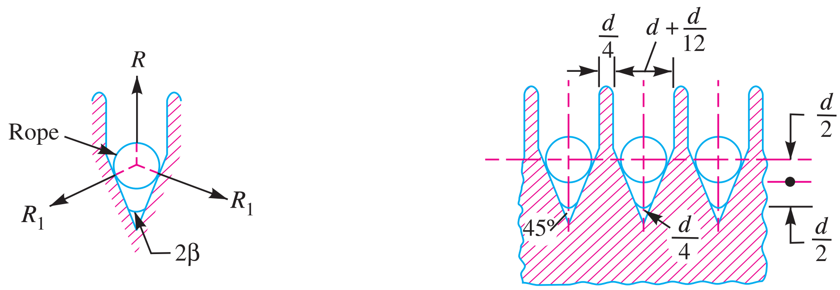
3. The shafts may be out of strict alignment.

4. The power may be taken off in any direction and in fractional parts of the whole amount.

5. They give high mechanical efficiency.

20.10 Sheave for Fibre Ropes

The fibre ropes are usually circular in cross-section as shown in Fig. 20.6 (*a*). The sheave for the fibre ropes, is shown in Fig. 20.6 (*b*). The groove angle of the pulley for rope drives is usually 45°.



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

Fig. 20.6. Rope and sheave.

The grooves in the pulleys are made narrow at the bottom and the rope is pinched between the edges of the *V*-groove to increase the holding power of the rope on the pulley. The grooves should be finished smooth to avoid chafing of the rope. The diameter of the sheaves should be large to reduce the wear on the rope due to internal friction and bending stresses. The proper size of sheave wheels is 40 *d* and the minimum size is 36 *d*, where *d* is the diameter of rope in cm.

Note : The number of grooves should not be more than 24.

Rope drives

20.11 Ratio of Driving Tensions for Fibre Rope

A fibre rope with a grooved pulley is shown in Fig. 20.6 (*a*). The fibre ropes are designed in the similar way as *V*-belts. We have discussed in Art. 20.5, that the ratio of driving tensions is

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

where μ, θ and β have usual meanings.

Example 20.6. *A pulley used to transmit power by means of ropes has a diameter of 3.6 metres and has 15 grooves of 45° angle. The angle of contact is 170° and the coefficient of friction between the ropes and the groove sides is 0.28. The maximum possible tension in the ropes is 960 N and the mass of the rope is 1.5 kg per metre length. Determine the speed of the pulley in r.p.m. and the power transmitted if the condition of maximum power prevail.*

Solution. Given : d = 3.6 m ; n = 15 ; 2 β = 45° or β = 22.5° ; θ = 170° = 170 × π / 180 = 2.967 rad ; μ = 0.28 ; T = 960 N ; m = 1.5 kg / m

Speed of the pulley

Let N = Speed of the pulley in r.p.m.

We know that for maximum power, speed of the pulley,

$$v = \sqrt{\frac{T}{3m}} = \sqrt{\frac{960}{3 \times 1.5}} = 14.6 \text{ m/s}$$

We also know that speed of the pulley (v),

$$14.6 = \frac{\pi d . N}{60} = \frac{\pi \times 3.6 \times N}{60} = 0.19\ N$$

∴ N = 14.6 / 0.19 = 76.8 r.p.m. **Ans.**

Power transmitted

We know that for maximum power, centrifugal tension,

$$T_C = T / 3 = 960 / 3 = 320 \text{ N}$$

∴ Tension in the tight side of the rope,

$$T_1 = T - T_C = 960 - 320 = 640 \text{ N}$$

Let T_2 = Tension in the slack side of the rope.

We know that

$$2.3 \log \left(\frac{T_1}{T_2}\right) = \mu.\theta \operatorname{cosec} \beta = 0.28 \times 2.967 \times \operatorname{cosec} 22.5° = 2.17$$

∴ $$\log \left(\frac{T_1}{T_2}\right) = \frac{2.17}{2.3} = 0.9435 \quad \text{or} \quad \frac{T_1}{T_2} = 8.78$$ ...(Taking antilog of 0.9435)

and $T_2 = T_1 / 8.78 = 640 / 8.78 = 73$ N

∴ Power transmitted,

$$P = (T_1 - T_2)\, v \times n = (640 - 73)\, 14.6 \times 15 = 124\,173 \text{ W}$$
$$= 124.173 \text{ kW}$$ **Ans.**

Example 20.7. *A rope pulley with 10 ropes and a peripheral speed of 1500 m / min transmits 115 kW. The angle of lap for each rope is 180° and the angle of groove is 45°. The coefficient of friction between the rope and pulley is 0.2. Assuming the rope to be just on the point of slipping, find the tension in the tight and slack sides of the rope. The mass of each rope is 0.6 kg per metre length.*

Solution. Given : n = 10 ; v = 1500 m/min = 25 m/s ; P = 115 kW = 115 × 10^3 W ; θ = 180° = π rad ; 2 β = 45° or β = 22.5° ; μ = 0.2 ; m = 0.6 kg / m

Let T_1 = Tension in the tight side of the rope, and

T_2 = Tension in the slack side of the rope.

We know that total power transmitted (P),

$$115 \times 10^3 = (T_1 - T_2)\, v \times n = (T_1 - T_2)\, 25 \times 10 = 250\,(T_1 - T_2)$$

∴ $$T_1 - T_2 = 115 \times 10^3 / 250 = 460$$ ...(*i*)

We also know that

$$2.3 \log \left(\frac{T_1}{T_2}\right) = \mu.\theta \operatorname{cosec} \beta = 0.2 \times \pi \times \operatorname{cosec} 22.5° = 1.642$$

$$\therefore \quad \log \left(\frac{T_1}{T_2}\right) = \frac{1.642}{2.3} = 0.714 \quad \text{or} \quad \frac{T_1}{T_2} = 5.18 \qquad \text{...(Taking antilog of 0.714) ...}(ii)$$

From equations *(i)* and *(ii)*, we find that

$$T_1 = 570 \text{ N, and } T_2 = 110 \text{ N}$$

We know that centrifugal tension,

$$T_C = m\, v^2 = 0.6\,(25)^2 = 375 \text{ N}$$

∴ Total tension in the tight side of the rope,

$$T_{t1} = T_1 + T_C = 570 + 375 = 945 \text{ N}$$ **Ans.**

and total tension in the slack side of the rope,

$$T_{t2} = T_2 + T_C = 110 + 375 = 485 \text{ N}$$ **Ans.**

Example 20.8. *A rope drive transmits 600 kW from a pulley of effective diameter 4 m, which runs at a speed of 90 r.p.m. The angle of lap is 160°; the angle of groove 45°; the coefficient of friction 0.28; the mass of rope 1.5 kg / m and the allowable tension in each rope 2400 N. Find the number of ropes required.*

Solution. Given : P = 600 kW ; d = 4 m ; N = 90 r.p.m. ; θ = 160° = 160 × π/180 = 2.8 rad ; 2β = 45° or β = 22.5° ; μ = 0.28 ; m = 1.5 kg / m ; T = 2400 N

We know that velocity of the pulley or rope,

$$v = \frac{\pi\, d\, N}{60} = \frac{\pi \times 4 \times 90}{60} = 18.85 \text{ m/s}$$

∴ Centrifugal tension,

$$T_C = m.v^2 = 1.5\,(18.85)^2 = 533 \text{ N}$$

and tension in the tight side of the rope,

$$T_1 = T - T_C = 2400 - 533 = 1867 \text{ N}$$

Let T_2 = Tension in the slack side of the rope.

We know that

$$2.3 \log \left(\frac{T_1}{T_2}\right) = \mu.\theta \operatorname{cosec} \beta = 0.28 \times 2.8 \times \operatorname{cosec} 22.5° = 0.784 \times 2.6131 = 2.0487$$

$$\log \left(\frac{T_1}{T_2}\right) = \frac{2.0487}{2.3} = 0.8907 \quad \text{or} \quad \frac{T_1}{T_2} = 7.78 \qquad \text{...(Taking antilog of 0.8907)}$$

$$\therefore \quad T_2 = T_1 / 7.78 = 1867 / 7.78 = 240 \text{ N}$$

We know that power transmitted per rope

$$= (T_1 - T_2)\, v = (1867 - 240)\, 18.85 = 30\,670 \text{ W} = 30.67 \text{ kW}$$

∴ Number of ropes required

$$= \frac{\text{Total power transmitted}}{\text{Power transmitted per rope}} = \frac{600}{30.67} = 19.56 \text{ say } 20$$ **Ans.**

Example 20.9. *A rope drive is to transmit 250 kW from a pulley of 1.2 m diameter, running at a speed of 300 r.p.m. The angle of lap may be taken as π radians. The groove half angle is 22.5°. The ropes to be used are 50 mm in diameter. The mass of the rope is 1.3 kg per metre length and each rope has a maximum pull of 2.2 kN, the coefficient of friction between rope and pulley is 0.3. Determine the number of ropes required. If the overhang of the pulley is 0.5 m, suggest suitable size for the pulley shaft if it is made of steel with a shear stress of 40 MPa.*

Solution. Given : $P = 250$ kW $= 250 \times 10^3$ W ; $d = 1.2$ m ; $N = 300$ r.p.m ; $\theta = \pi$ rad ; $\beta = 22.5°$; $d_r = 50$ mm ; $m = 1.3$ kg / m ; $T = 2.2$ kN $= 2200$ N ; $\mu = 0.3$; $\tau = 40$ MPa $= 40$ N/mm^2

We know that the velocity of belt,

$$v = \frac{\pi d.N}{60} = \frac{\pi \times 1.2 \times 300}{60} = 18.85 \text{ m/s}$$

and centrifugal tension, $T_C = m.v^2 = 1.3\,(18.85)^2 = 462$ N

∴ Tension in the tight side of the rope,

$$T_1 = T - T_C = 2200 - 462 = 1738 \text{ N}$$

Let T_2 = Tension in the slack side of the rope.

We know that

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu.\theta.\text{cosec}\,\beta = 0.3 \times \pi \times \text{cosec } 22.5° = 0.9426 \times 2.6131 = 2.463$$

$$\therefore \quad \log\left(\frac{T_1}{T_2}\right) = \frac{2.463}{2.3} = 1.071 \quad \text{or} \quad \frac{T_1}{T_2} = 11.8 \qquad \text{...(Taking antilog of 1.071)}$$

and

$$T_2 = \frac{T_1}{11.8} = \frac{1738}{11.8} = 147.3 \text{ N}$$

Number of ropes required

We know that power transmitted per rope

$$= (T_1 - T_2)\,v = (1738 - 147.3) \times 18.85 = 29\,985 \text{ W} = 29.985 \text{ kW}$$

∴ Number of ropes required

$$= \frac{\text{Total power transmitted}}{\text{Power transmitted per rope}} = \frac{250}{29.985} = 8.34 \text{ say } 9$$ **Ans.**

Diameter for the pulley shaft

Let D = Diameter for the pulley shaft.

We know that the torque transmitted by the pulley shaft,

$$T = \frac{P \times 60}{2\pi N} = \frac{250 \times 10^3 \times 60}{2\pi \times 300} = 7957 \text{ N-m}$$

Since the overhang of the pulley is 0.5 m, therefore bending moment on the shaft due to the rope pull,

$$M = (T_1 + T_2 + 2T_C)\,0.5 \times 9 \qquad \text{...(}\because \text{ No. of ropes = 9)}$$

$$= (1738 + 147.3 + 2 \times 462)\,0.5 \times 9 = 12\,642 \text{ N-m}$$

∴ Equivalent twisting moment,

$$T_e = \sqrt{T^2 + M^2} = \sqrt{(7957)^2 + (12\,642)^2} = 14\,938 \text{ N-m}$$

$$= 14.938 \times 10^6 \text{ N-mm}$$

We know that the equivalent twisting moment (T_e),

$$14.938 \times 10^6 = \frac{\pi}{16} \times \tau \times D^3 = \frac{\pi}{16} \times 40 \times D^3 = 7.855\,D^3$$

$$\therefore \quad D^3 = 14.938 \times 10^6 / 7.855 = 1.9 \times 10^6 \quad \text{or} \quad D = 123.89 \text{ say } 125 \text{ mm}$$ **Ans.**