19.8 Design of Cast Iron Pulleys

The following procedure may be adopted for the design of cast iron pulleys.

1. *Dimensions of pulley*

(*i*) The diameter of the pulley (D) may be obtained either from velocity ratio consideration or centrifugal stress consideration. We know that the centrifugal stress induced in the rim of the pulley,

$$\sigma_t = \rho . v^2$$

where ρ = Density of the rim material

= 7200 kg/m^3 for cast iron

v = Velocity of the rim = $\pi DN / 60$, D being the diameter of pulley and N is speed of the pulley.

The following are the diameter of pulleys in mm for flat and V-belts.

20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 71, 80, 90, 100, 112, 125, 140, 160, 180, 200, 224, 250, 280, 315, 355, 400, 450, 500, 560, 630, 710, 800, 900, 1000, 1120, 1250, 1400, 1600, 1800, 2000, 2240, 2500, 2800, 3150, 3550, 4000, 5000, 5400.

The first six sizes (20 to 36 mm) are used for V-belts only.

(*ii*) If the width of the belt is known, then width of the pulley or face of the pulley (B) is taken 25% greater than the width of belt.

$\therefore$ $B = 1.25\, b$; where b = Width of belt.

According to Indian Standards, IS : 2122 (Part I) – 1973 (Reaffirmed 1990), the width of pulley is fixed as given in the following table :

Table 19.2. Standard width of pulley.

Belt width in mm	*Width of pulley to be greater than belt width by (mm)*
upto 125	13
125-250	25
250-375	38
475-500	50

The following are the width of flat cast iron and mild steel pulleys in mm :

16, 20, 25, 32, 40, 50, 63, 71, 80, 90, 100, 112, 125, 140, 160, 180, 200, 224, 250, 315, 355, 400, 450, 560, 630.

(*iii*) The thickness of the pulley rim (t) varies from $\frac{D}{300} + 2$ mm to $\frac{D}{200} + 3$ mm for single belt and $\frac{D}{200} + 6$ mm for double belt. The diameter of the pulley (D) is in mm.

2. *Dimensions of arms*

(*i*) The number of arms may be taken as 4 for pulley diameter from 200 mm to 600 mm and 6 for diameter from 600 mm to 1500 mm.

Note : The pulleys less than 200 mm diameter are made with solid disc instead of arms. The thickness of the solid web is taken equal to the thickness of rim measured at the centre of the pulley face.

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(*ii*) The cross-section of the arms is usually elliptical with major axis (a_1) equal to twice the minor axis (b_1). The cross-section of the arm is obtained by considering the arm as cantilever *i.e.* fixed at the hub end and carrying a concentrated load at the rim end. The length of the cantilever is taken equal to the radius of the pulley. It is further assumed that at any given time, the power is transmitted from the hub to the rim or ***vice versa,*** through only half the total number of arms.

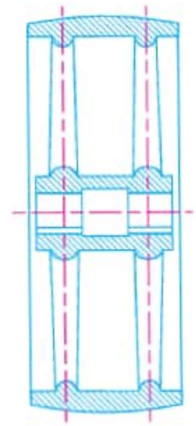

Fig. 19.4. Cast iron pulley with two rows of arms.

Let T = Torque transmitted,

R = Radius of pulley, and

n = Number of arms,

∴ Tangential load per arm,

$$W_T = \frac{T}{R \times n/2} = \frac{2\,T}{R \cdot n}$$

Maximum bending moment on the arm at the hub end,

$$M = \frac{2\,T}{R \times n} \times R = \frac{2\,T}{n}$$

and section modulus,

$$Z = \frac{\pi}{32} \times b_1\,(a_1)^2$$

Now using the relation,

σ_b or σ_t = M/Z, the cross-section of the arms is obtained.

(*iii*) The arms are tapered from hub to rim. The taper is usually 1/48 to 1/32.

(*iv*) When the width of the pulley exceeds the diameter of the pulley, then two rows of arms are provided, as shown in Fig. 19.4. This is done to avoid heavy arms in one row.

3. *Dimensions of hub*

(*i*) The diameter of the hub (d_1) in terms of shaft diameter (d) may be fixed by the following relation :

$$d_1 = 1.5\,d + 25 \text{ mm}$$

The diameter of the hub should not be greater than 2 d.

(*ii*) The length of the hub,

$$L = \frac{\pi}{2} \times d$$

The minimum length of the hub is $\frac{2}{3}$ B but it should not be more than width of the pulley (B).

Example 19.1. *A cast iron pulley transmits 20 kW at 300 r.p.m. The diameter of pulley is 550 mm and has four straight arms of elliptical cross-section in which the major axis is twice the minor axis. Find the dimensions of the arm if the allowable bending stress is 15 MPa. Mention the plane in which the major axis of the arm should lie.*

Solution. Given : P = 20 kW = 20 × 10³ W ; N = 300 r.p.m. ; *d = 550 mm ; n = 4 ; σ_b = 15 MPa = 15 N/mm²

Let b_1 = Minor axis, and

a_1 = Major axis = $2b_1$ ...(Given)

We know that the torque transmitted by the pulley,

$$T = \frac{P \times 60}{2\,\pi\,N} = \frac{20 \times 10^3 \times 60}{2\,\pi \times 300} = 636 \text{ N-m}$$

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∴ Maximum bending moment per arm at the hub end,

$$M = \frac{2T}{n} = \frac{2 \times 636}{4}$$

$$= 318 \text{ N-m} = 318 \times 10^3 \text{ N-mm}$$

Cast iron pulley.

and section modulus,

$$Z = \frac{\pi}{32} \times b_1 (a_1)^2 = \frac{\pi}{32} \times b_1 (2b_1)^2$$

$$= \frac{\pi (b_1)^3}{8}$$

We know that the bending stress (σ_b),

$$15 = \frac{M}{Z} = \frac{318 \times 10^3 \times 8}{\pi (b_1)^3} = \frac{810 \times 10^3}{(b_1)^3}$$

∴ $(b_1)^3 = 810 \times 10^3 / 15 = 54 \times 10^3$ or $b_1 = 37.8$ mm **Ans.**

and $a_1 = 2\, b_1 = 2 \times 37.8 = 75.6$ mm **Ans.**

The major axis will be in the plane of rotation which is also the plane of bending.

Example 19.2. *An overhung pulley transmits 35 kW at 240 r.p.m. The belt drive is vertical and the angle of wrap may be taken as 180°. The distance of the pulley centre line from the nearest bearing is 350 mm. μ = 0.25. Determine :*

1. *Diameter of the pulley ;*
2. *Width of the belt assuming thickness of 10 mm ;*
3. *Diameter of the shaft ;*
4. *Dimensions of the key for securing the pulley on to the shaft ; and*
5. *Size of the arms six in number.*

The section of the arm may be taken as elliptical, the major axis being twice the minor axis.

The following stresses may be taken for design purposes :

Shaft }	*Tension and compression*	— *80 MPa*
Key }	*Shear*	— *50 MPa*
Belt : Tension		— *2.5 MPa*
Pulley rim : Tension		— *4.5 MPa*
Pulley arms : Tension		— *15 MPa*

Steel pulley.

Solution. Given : $P = 35$ kW $= 35 \times 10^3$ W ; $N = 240$ r.p.m. ; $\theta = 180° = \pi$ rad ; $L = 350$ mm $= 0.35$ m ; $\mu = 0.25$; $t = 10$ mm ; $n = 6$; $\sigma_{ts} = \sigma_{tk} = 80$ MPa $= 80$ N/mm^2 ; $\tau_s = \tau_k = 50$ MPa $= 50$ N/mm^2 ; $\sigma = 2.5$ MPa $= 2.5$ N/mm^2 ; $\sigma_t = 4.5$ MPa $= 4.5$ N/mm^2 ; $\sigma_b = 15$ MPa $= 15$ N/mm^2

1. *Diameter of the pulley*

Let D = Diameter of the pulley,

σ_t = Centrifugal stress or tensile stress in the pulley rim $= 4.5$ MPa $= 4.5 \times 10^6$ N/m^2 ...(Given)

ρ = Density of the pulley material (*i.e.* cast iron) which may be taken as 7200 kg/m^3.

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We know that centrifugal stress (σ_t),

$$4.5 \times 10^6 = \rho.v^2 = 7200 \times v^2$$

$$\therefore \quad v^2 = 4.5 \times 10^6 / 7200 = 625 \quad \text{or} \quad v = 25 \text{ m/s}$$

and velocity of the pulley (v),

$$25 = \frac{\pi\, D.\, N}{60} = \frac{\pi\, D \times 240}{60} = 12.568\, D$$

$$\therefore \quad D = 25 / 12.568 = 2 \text{ m} \quad \textbf{Ans.}$$

2. ***Width of the belt***

Let b = Width of the belt in mm,

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

T_2 = Tension in the slack side of the belt.

We know that the power transmitted (P),

$$35 \times 10^3 = (T_1 - T_2)\, v = (T_1 - T_2)\, 25$$

$$\therefore \quad T_1 - T_2 = 35 \times 10^3 / 25 = 1400 \text{ N} \qquad ...(i)$$

We also know that

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu.\theta = 0.25 \times \pi = 0.7855$$

$$\therefore \quad \log\left(\frac{T_1}{T_2}\right) = \frac{0.7855}{2.3} = 0.3415 \quad \text{or} \quad \frac{T_1}{T_2} = 2.195 \qquad ...(ii)$$

... (Taking antilog of 0.3415)

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

$$T_1 = 2572 \text{ N} \; ; \text{ and } T_2 = 1172 \text{ N}$$

Since the velocity of the belt (or pulley) is more than 10 m/s, therefore centrifugal tension must be taken into consideration. Assuming a leather belt for which the density may be taken as 1000 kg/m^3.

We know that cross-sectional area of the belt,

$$= b \times t = b \times 10 = 10\, b \text{ mm}^2 = \frac{10\, b}{10^6} \text{ m}^2$$

Mass of the belt per metre length,

$$m = \text{Area} \times \text{length} \times \text{density}$$

$$= \frac{10\, b}{10^6} \times 1 \times 1000 = 0.01\, b \text{ kg / m}$$

We know that centrifugal tension,

$$T_C = m.v^2 = 0.01\, b\, (25)^2 = 6.25\, b \text{ N}$$

and maximum tension in the belt,

$$T = \sigma.b.t = 2.5 \times b \times 10 = 25\, b \text{ N}$$

We know that tension in the tight side of the belt (T_1),

$$2572 = T - T_C = 25\, b - 6.25\, b = 18.75\, b$$

$$\therefore \quad b = 2572 / 18.75 = 137 \text{ mm}$$

The standard width of the belt (b) is 140 mm. **Ans.**

3. ***Diameter of the shaft***

Let d = Diameter of the shaft.

We know that the torque transmitted by the shaft,

$$T = \frac{P \times 60}{2\, \pi\, N} = \frac{35 \times 10^3 \times 60}{2\, \pi \times 240} = 1393 \text{ N-m} = 1393 \times 10^3 \text{ N-mn}$$

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and bending moment on the shaft due to the tensions of the belt,

$$M = (T_1 + T_2 + 2T_C)\,L = (2572 + 1172 + 2 \times 6.25 \times 140) \times 0.35 \text{ N-m}$$

$$= 1923 \text{ N-m} \qquad \text{... } (\because T_C = 6.25\, b)$$

We know that equivalent twisting moment,

$$T_e = \sqrt{T^2 + M^2} = \sqrt{(1393)^2 + (1923)^2} = 2375 \text{ N-m}$$

$$= 2375 \times 10^3 \text{ N-mm}$$

We also know that equivalent twisting momnt (T_e),

$$2375 \times 10^3 = \frac{\pi}{16} \times \tau_s \times d^3 = \frac{\pi}{16} \times 50 \times d^3 = 9.82\, d^3$$

$$\therefore \quad d^3 = 2375 \times 10^3 / 9.82 = 242 \times 10^3 \quad \text{or} \quad d = 62.3 \text{ say } 65 \text{ mm } \textbf{Ans.}$$

4. Dimensions of the key

The standard dimensions of the key for 65 mm diameter shaft are :

Width of key, w = 20 mm **Ans.**

Thickness of key = 12 mm **Ans.**

Let l = Length of the key.

Considering shearing of the key. We know that the torque transmitted (T),

$$1393 \times 10^3 = l \times w \times \tau_k \times \frac{d}{2} = l \times 20 \times 50 \times \frac{65}{2} = 32\,500\, l$$

$$\therefore \quad l = 1393 \times 10^3 / 32\,500 = 42.8 \text{ mm}$$

The length of key should be atleast equal to hub length. The length of hub is taken as $\frac{\pi}{2} \times d$.

$$\therefore \quad \text{Length of key} = \frac{\pi}{2} \times 65 = 102 \text{ mm } \textbf{Ans.}$$

5. Size of arms

Let b_1 = Minor axis, and

a = Major axis = $2b_1$ ... (Given)

We know that the maximum bending moment per arm at the hub end,

$$M = \frac{2\,T}{n} = \frac{2 \times 1393}{6} = 464.33 \text{ N-m} = 464\,330 \text{ N-mm}$$

and section modulus,

$$Z = \frac{\pi}{32} \times b_1\,(a_1)^2 = \frac{\pi}{32} \times b_1\,(2b_1)^2 = 0.393\,(b_1)^3$$

We know that bending stress (σ_b),

$$15 = \frac{M}{Z} = \frac{464\,330}{0.393 \times (b_1)^3} = \frac{1.18 \times 10^6}{(b_1)^3}$$

$$\therefore \quad (b_1)^3 = 1.18 \times 10^6 / 15 = 78.7 \times 10^3 \quad \text{or} \quad b_1 = 42.8 \text{ say } 45 \text{ mm } \textbf{Ans.}$$

and

$$a_1 = 2b_1 = 2 \times 45 = 90 \text{ mm } \textbf{Ans.}$$