Design of Clutch

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Introduction

- **Definition:**

  A clutch is a machine member used to connect a driving shaft to a driven shaft so that the driven shaft may be started or stopped at will, without stopping the driving shaft.

- **Types of Clutches:**

  1. Positive clutches:

  The positive clutches are used when a positive drive is required. The simplest type of a positive clutch is a ***jaw*** or ***claw clutch***.

  2. Friction clutches:

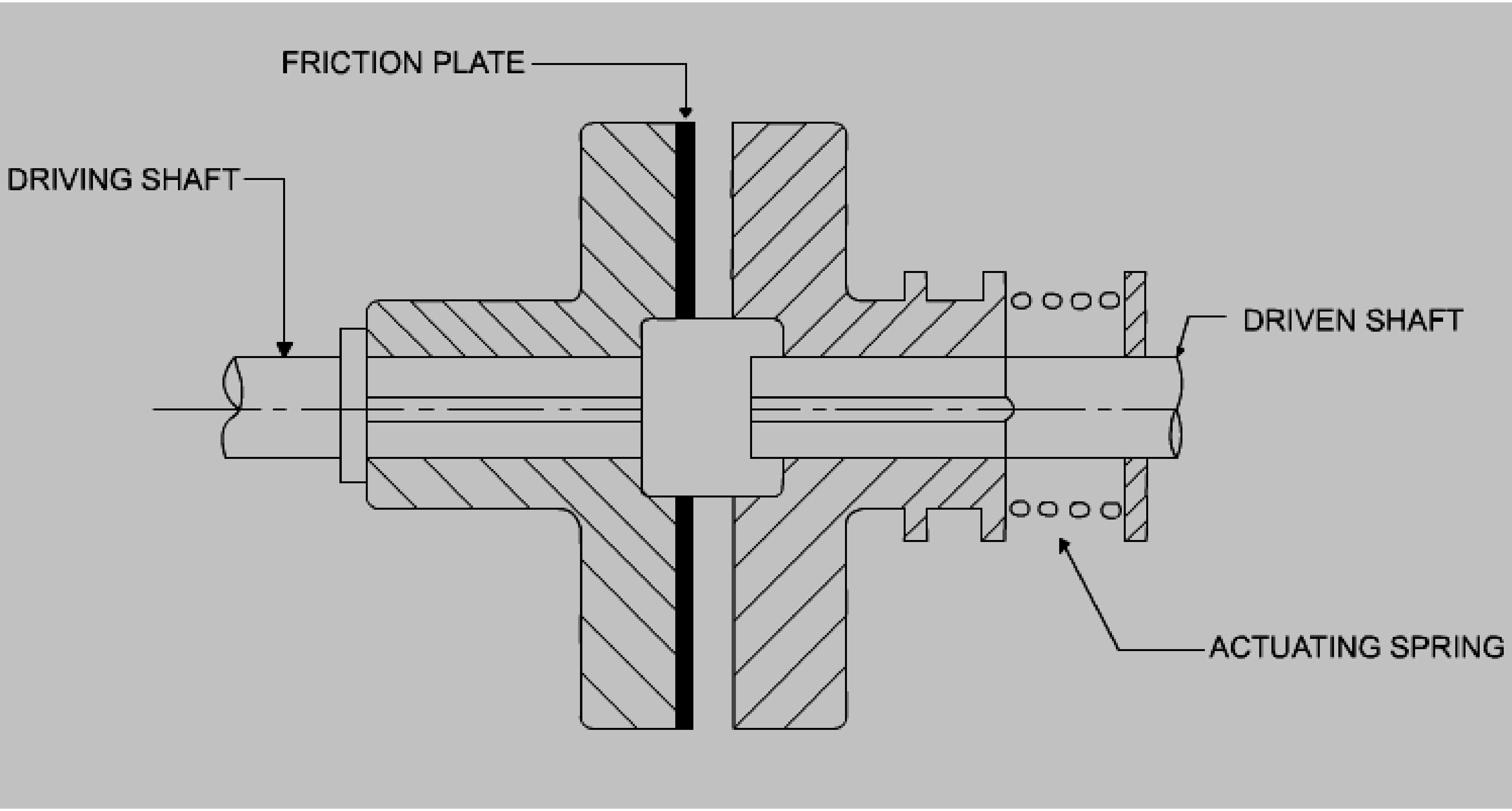
  These clutches are more common; in which two or more rotating surfaces are pressed to gather with normal force to create a friction torque.

  Types of Friction Clutches:

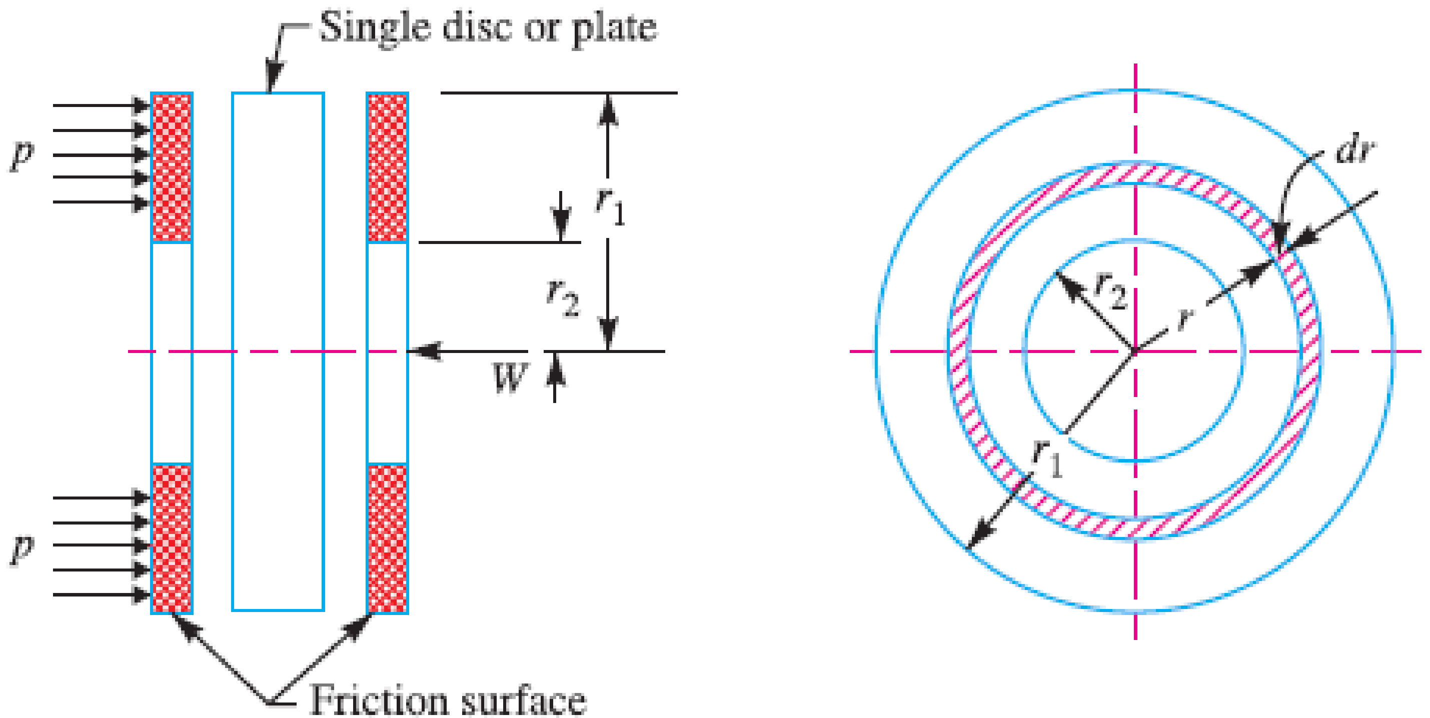
  1. Disc or plate clutches

  2. Cone clutches

  3. Centrifugal clutches


FRICTION PLATE
DRIVING SHAFT
DRIVEN SHAFT
ACTUATING SPRING

Design of a Disc or Plate Clutch



T = Torque transmitted by the clutch,

p = Intensity of axial pressure with which the contact surfaces are held together,

r_1 and r_2 = External and internal radii of friction faces,

r = Mean radius of the friction face, and

μ = Coefficient of friction.

Considering an elementary ring of radius r and thickness dr as shown in Fig.

We know that area of the contact surface or friction surface = $2\pi\, r.dr$

Normal or axial force on the ring,

δW = Pressure × Area = $p \times 2\pi\, r.dr$

Frictional force on the ring acting tangentially at radius r,

$F_r = \mu \times \delta W = \mu.p \times 2\pi\, r.dr$

Frictional torque acting on the ring,

$T_r = F_r \times r$

$= \mu.p \times 2\pi\, r.dr \times r =$ **$2\pi\mu p.\, r^2.dr$**

1. *Considering uniform pressure: (p = C)*

$$p = \frac{W}{\pi\left[(r_1)^2 - (r_2)^2\right]}$$

W = Axial thrust with which the friction surfaces are held together

Total frictional torque acting on the friction surface or on the clutch,

$$T = \int_{r_2}^{r_1} 2\pi\,\mu.p.r^2.dr = 2\pi\,\mu.p\left[\frac{r^3}{3}\right]_{r_2}^{r_1}$$

$$= 2\pi\,\mu.p\left[\frac{(r_1)^3 - (r_2)^3}{3}\right] = 2\pi\,\mu \times \frac{W}{\pi\,[(r_1)^2 - (r_2)^2]}\left[\frac{(r_1)^3 - (r_2)^3}{3}\right]$$

... (Substituting the value of *p*)

$$= \frac{2}{3}\,\mu.\,W\left[\frac{(r_1)^3 - (r_2)^3}{(r_1)^2 - (r_2)^2}\right] = \mu\,.W.R$$

$$R = \frac{2}{3}\left[\frac{(r_1)^3 - (r_2)^3}{(r_1)^2 - (r_2)^2}\right]$$ = Mean radius of the friction surface.

2. *Considering uniform axial wear: (pr = C)*

$$p.r = C \text{ (a constant) or } p = C / r$$

and the normal force on the ring,

$$\delta W = p.2\pi r.dr = \frac{C}{r} \times 2\pi r.dr = 2\pi C.dr$$

∴ Total force acing on the friction surface,

$$W = \int_{r_2}^{r_1} 2\pi C \, dr = 2\pi C \, [r]_{r_2}^{r_1} = 2\pi C (r_1 - r_2)$$

or

$$C = \frac{W}{2\pi (r_1 - r_2)}$$

$$T_r = 2\pi \mu . p.r^2 .dr = 2\pi \mu \times \frac{C}{r} \times r^2 .dr = 2\pi \mu .C.r.dr$$

Total frictional torque acting on the friction surface (or on the clutch),

$$T = \int_{r_2}^{r_1} 2\pi\,\mu\, C.r.dr = 2\pi\,\mu\, C\left[\frac{r^2}{2}\right]_{r_2}^{r_1}$$

$$= 2\pi\mu\,.C\left[\frac{(r_1)^2 - (r_2)^2}{2}\right] = \pi\,\mu.C\,[(r_1)^2 - (r_2)^2]$$

$$= \pi\mu \times \frac{W}{2\pi\,(r_1 - r_2)}\,[(r_1)^2 - (r_2)^2] = \frac{1}{2} \times \mu.W\,(r_1 + r_2) = \mu.W.R$$

$$R = \frac{r_1 + r_2}{2}$$ = Mean radius of the friction surface.

$T = n.\mu.W.R$

n = Number of pairs of friction (or contact) surfaces, and

R = Mean radius of friction surface

$$= \frac{2}{3}\left[\frac{(r_1)^3 - (r_2)^3}{(r_1)^2 - (r_2)^2}\right] \quad \text{... (For uniform pressure)}$$

$$= \frac{r_1 + r_2}{2} \quad \text{... (For uniform wear)}$$

In case of multiple disc clutch;

Let n_1 = Number of discs on the driving shaft, and

n_2 = Number of discs on the driven shaft.

$\therefore$ Number of pairs of contact surfaces,

$$n = n_1 + n_2 - 1$$

and total frictional torque acting on the friction surfaces or on the clutch,

$$T = n.\mu.W.R$$

where R = Mean radius of friction surfaces

$$= \frac{2}{3}\left[\frac{(r_1)^3 - (r_2)^3}{(r_1)^2 - (r_2)^2}\right] \quad \text{... (For uniform pressure)}$$

$$= \frac{r_1 + r_2}{2} \quad \text{... (For uniform wear)}$$

Example: 1

- *A single plate clutch, effective on both sides, is required to transmit 25 kW at 3000 r.p.m. Determine the outer and inner diameters of frictional surface if the coefficient of friction is 0.255, ratio of diameters is 1.25 and the maximum pressure is not to exceed 0.1 N/mm2. Also, determine the axial thrust to be provided by springs. Assume the theory of uniform wear.*

Given :

- $n = 2$;
- $P = 25$ kW $= 25 \times 10^3$ W ;
- $N = 3000$ r.p.m. ;
- $\mu = 0.255$;
- $d1 / d2 = 1.25$ or $r1 / r2 = 1.25$;
- $pmax = 0.1$ N/mm^2

SOLUTION HINTS:

$$T = n.\mu.W.R$$

$$T = \frac{P \times 60}{2\,\pi\,N}$$

$$R = \frac{r_1 + r_2}{2}$$

$$W = 2\pi\,C\,(r_1 - r_2)$$

$$p_{max} \times r_2 = C$$

The intensity of pressure is maximum at the inner radius (*r*2)

Axial thrust to be provided by springs:

$$W = 2\pi\,C\,(r_1 - r_2)$$

Example: 2

- *A multi-disc clutch has three discs on the driving shaft and two on the driven shaft. The inside diameter of the contact surface is 120 mm. The maximum pressure between the surface is limited to 0.1 N/mm2. Design the clutch for transmitting 25 kW at 1575 r.p.m. Assume uniform wear condition and coefficient of friction as 0.3.*

Given :

- *n*1 = 3 ; *n*2 = 2 ;
- *d*2 = 120 mm or *r*2 = 60 mm ;
- *pmax* = 0.1 N/mm2 ;
- *P* = 25 kW = 25 × 103 W ;
- *N* = 1575 r.p.m. ;
- μ = 0.3
- Design the clutch; i.e.Cal. of r1 = ?

SOLUTION HINTS:

$$T = n.\mu.W.R$$

$$T = \frac{P \times 60}{2\,\pi\,N}$$

$$n = n_1 + n_2 - 1$$

$$R = \frac{r_1 + r_2}{2}$$

$$W = 2\pi\,C\,(r_1 - r_2)$$

$$p_{max} \times r_2 = C$$

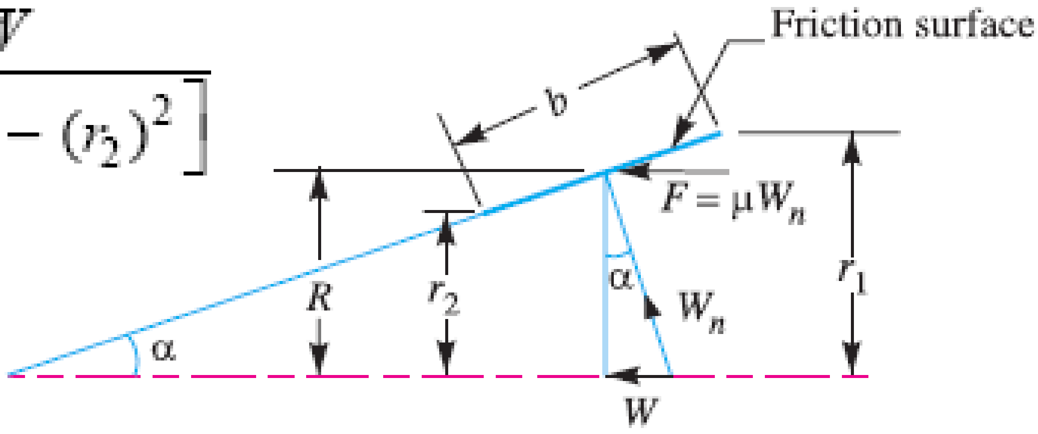
The intensity of pressure is maximum at the inner radius (*r*2)

Design of a Cone Clutch

$$T = \mu\, W_n\, R$$

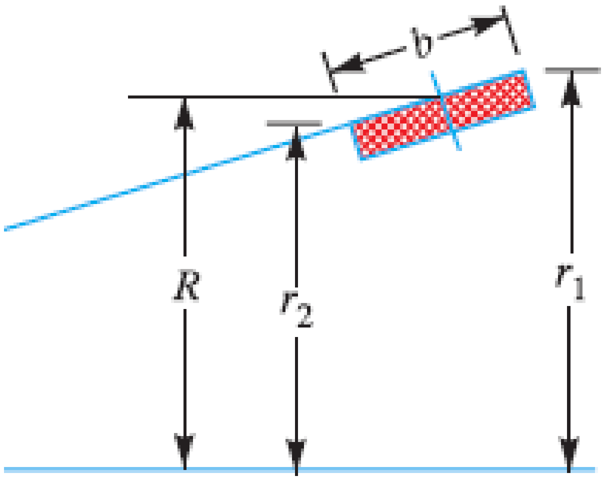
$$W_n = W \operatorname{cosec} \alpha,$$

$$p_n = \frac{W}{\pi\left[(r_1)^2 - (r_2)^2\right]}$$



From Fig.

$$r_1 - r_2 = b \sin \alpha \quad \text{and} \quad R = \frac{r_1 + r_2}{2} \quad \text{or} \quad r_1 + r_2 = 2R$$



$$r_1 = R + \frac{b}{2} \sin \alpha$$

$$r_2 = R - \frac{b}{2} \sin \alpha$$

$$p_n = \frac{W}{\pi\,[(r_1)^2 - (r_2)^2]} = \frac{W}{\pi\,(r_1 + r_2)\,(r_1 - r_2)} = \frac{W}{2\,\pi\,R.b\,\sin\,\alpha}$$

$$W = p_n \times 2\pi\,R.b\,\sin\alpha = W_n\,\sin\alpha$$

W_n = Normal load acting on the friction surface = $p_n \times 2\pi R.b$

$$T = \mu\,(\,p_n \times 2\pi\,R.\,b\,\sin\,\alpha)\,R\,\text{cosec}\,\alpha = 2\pi\,\mu.p_n\,R^2.b$$

face width of the clutch = $b = D\,/\,6$

Example: 3

- *Determine the principal dimensions of a cone clutch faced with leather to transmit 30 kW at 750 r.p.m. from an electric motor to an air compressor. Sketch a sectional front view of the clutch and provide the main dimensions on the sketch.*
- *Assume : semi-angle of the cone =* $12^1/_2°$;
- μ *= 0.2 ;*
- *allowable normal pressure for leather and cast iron = 0.075 to 0.1 N/mm2;*
- *load factor = 1.75*
- *mean diameter to face width ratio = 6.*

Given : $P = 30$ kW $= 30 \times 10^3$ W ;

- $N = 750$ r.p.m. ;
- $\alpha = 12^1/_2°$;
- $\mu = 0.2$;
- $p_n = 0.075$ to 0.1 N/mm2 ;
- $K_L = 1.75$;
- $D / b = 6$
- Design means; Cal. of D, b, r1, r2 = ???

SOLUTION HINTS:

$$T = \frac{P \times 60}{2\pi N} \times K_L$$

$$T = 2\pi \mu . p_n R^2 . b$$

$$D = 2R$$

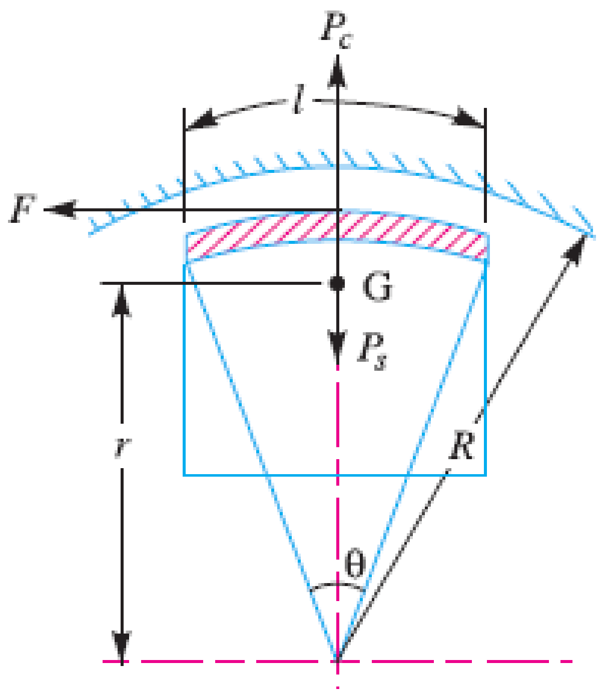
$$b = D / 6$$

$$r_1 = R + \frac{b}{2} \sin \alpha$$

$$r_2 = R - \frac{b}{2} \sin \alpha$$

Design of a Centrifugal Clutch

1. *Mass of the shoes*



m = Mass of each shoe,

n = Number of shoes,

r = Distance of centre of gravity of the shoe from the centre of the spider,

R = Inside radius of the pulley rim,

N = Running speed of the pulley in r.p.m.,

ω = Angular running speed of the pulley in rad / s $= 2\pi N / 60$ rad/s,

ω_1 = Angular speed at which the engagement begins to take place, and

μ = Coefficient of friction between the shoe and rim.

Centrifugal Force; $P_c = m.\omega^2.r$

Spring Force; $P_s = m\,(\omega_1)^2\,r = m\left(\frac{3}{4}\omega\right)^2\,r$

$$= \frac{9}{16}\,m.\omega^2 \cdot r$$

The engagement begins to take place is generally taken as 3/4th of the running speed

Net radial Force; $= P_c - P_s = m.\omega^2.r - \frac{9}{16}\,m.\omega^2.r = \frac{7}{16}\,m.\omega^2.r$

the frictional force acting tangentially on each shoe,

$$F = \mu\,(P_c - P_s)$$

$\therefore$ Frictional torque acting on each shoe

$$= F \times R = \mu\,(P_c - P_s)\,R$$

total frictional torque transmitted,

$$T = \mu\,(P_c - P_s)\,R \times n = n.F.R$$

2. *Size of the shoes*

l = Contact length of the shoes,

b = Width of the shoes,

R = Contact radius of the shoes. It is same as the inside radius of the rim of the pulley,

θ = Angle subtended by the shoes at the centre of the spider in radians, and

p = Intensity of pressure exerted on the shoe. In order to ensure reasonable life, it may be taken as 0.1 N/mm^2.

$$\theta = \frac{l}{R} \text{ or } l = \theta . R = \frac{\pi}{3} R \qquad \text{...(Assuming } \theta = 60° = \pi / 3 \text{ rad)}$$

$\therefore$ Area of contact of the shoe

$$= l \cdot b$$

and the force with which the shoe presses against the rim

$$= A \times p = l.b.p$$

Since the force with which the shoe presses against the rim at the running speed is (*Pc* – *Ps*),

So;

l.b.p = Pc – Ps

From this expression, the width of shoe (*b*) may be obtained

3. *Dimensions of the spring*

We have discussed above that the load on the spring is given by

$$P_s = \frac{9}{16} \times m.\omega^2.r$$

The dimensions of the spring may be obtained as usual.

Example: 4

- *A centrifugal clutch is to be designed to transmit 15 kW at 900 r.p.m. The shoes are four in number. The speed at which the engagement begins is 3/4th of the running speed.*
- *The inside radius of the pulley rim is 150 mm. The shoes are lined with Ferrodo for which the coefficient of friction may be taken as 0.25. Determine: 1. mass of the shoes, and 2. size of the shoes.*

Given :

- P = 15 kW = 15 × 103 W ;
- N = 900 r.p.m. ;
- n = 4 ;
- R = 150 mm = 0.15 m ;
- μ = 0.25

SOLUTION HINTS:

$$T = \mu\,(P_c - P_s)\,R \times n = n.F.R$$

$$T = \frac{P \times 60}{2\pi N}$$

$$\omega = \frac{2\pi N}{60}$$

$$\omega_1 = \frac{3}{4}\,\omega$$

$$P_c = m.\omega^2.r$$

$$P_s = m(\omega_1)^2\,r$$

Assuming that the centre of gravity of the shoe lies at a distance of 120 mm (30 mm less than *R*) from the centre of the spider, *i.e.*
***r* = 120 mm = 0.12 m**

THANKS