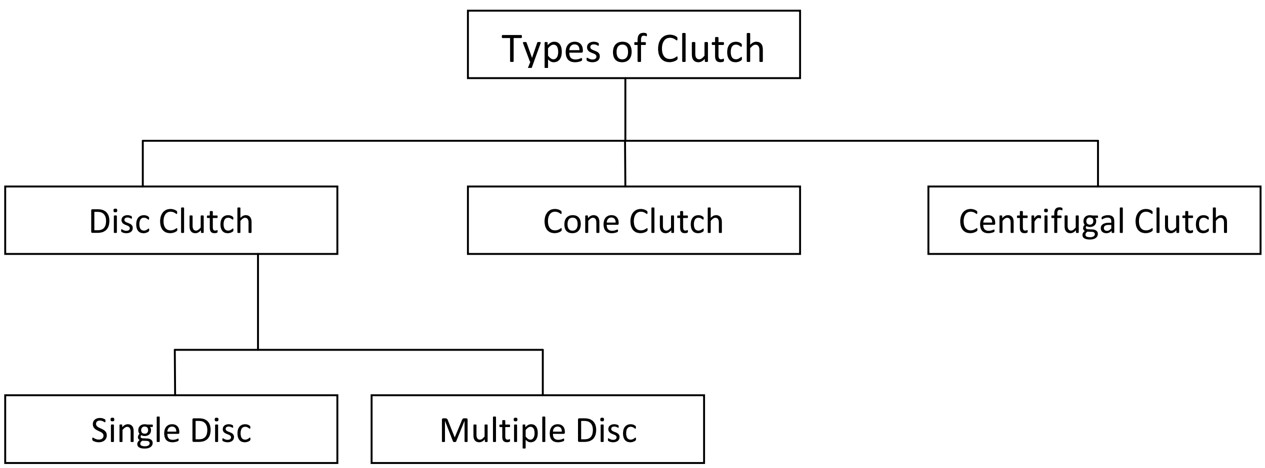
FRICTION CLUTCHES

A Friction clutch has it principal application in the transmission of power of shafts and machines which must be started and stopped frequently. Its application is also found in cases in which power is to be delivered to machines partially or fully loaded. The force of friction is used to start the driven shaft from the rest and gradually brings it up to the proper speed without excessive shipping of the friction surfaces. In automobile, friction clutch is used to connect the engine to the driven shaft. In operating such a clutch, care should be taken so that the friction surface engage easily and gradually brings the driven shaft up to proper speed. The proper alignment of bearing must be maintained and it should be located as close to the clutch as possible. It may be noted that:

1. The contact surfaces should develop a frictional force and may pick up and hold the load with reasonable low pressure between the contact surfaces.
2. The heat of friction should be rapidly dissipated and tendency to grab should be at a minimum.
3. The surface should be backed by a material stiff enough to ensure a reasonable uniform distribution of power.



- **<u>Single Disc or Plate Clutch:</u>** A single disc or plate clutch consists of a clutch plate whose both sides are faced with a friction material (usually ferrods). It is mounted on the hub which is free to move axially along the splines of the driven shaft. The pressure plate is mounted inside the clutch body, which is bolted to the flywheel. Both the pressure plates & flywheel rotate with the engine crank shaft or the driving shaft. The pressure plate pushes the clutch plates towards the flywheel; by a set of strong springs which are arranged radially inside the body. The three levers (also known as release lever or fingures) are carried on pivot suspended from the case of the body. These are arranged in such a manner so that the pressure plates moves away from the flywheel by the inward movement of a thrust bearing. The bearing is mounted upon a forked shaft and moves forward when the clutch pedal is pressed.

  When the Clutch pedal is pressed down, its linkage forces the thrust release bearing to move in towards the flywheel and pressing the longer ends of the lever inwards. The levers are forced to turn on their suspended pivot and the flywheel by the knife edges, thereby compressing the clutch springs. The action removes the pressure from the clutch plate and thus moves back from the flywheel and the driven shaft becomes stationary. On the other hand, when the foot is taken off from the clutch pedal, the thrust bearing moves back by the lever. This allows the spring to extend and thus the pressure plate pushes the clutch plate back towards the flywheel.

  Fig.: Refer any single disc or plate clutch from Google/Youtube.

The Axial pressure exerted by the spring provides a frictional force in circumferential direction when the relative motion between the driving and driven members tends to take place. If the torque due to this friction force exceeds the torque to be transmitted, then no slipping takes place and the power is transmitted from the driving shaft to the driven shaft.

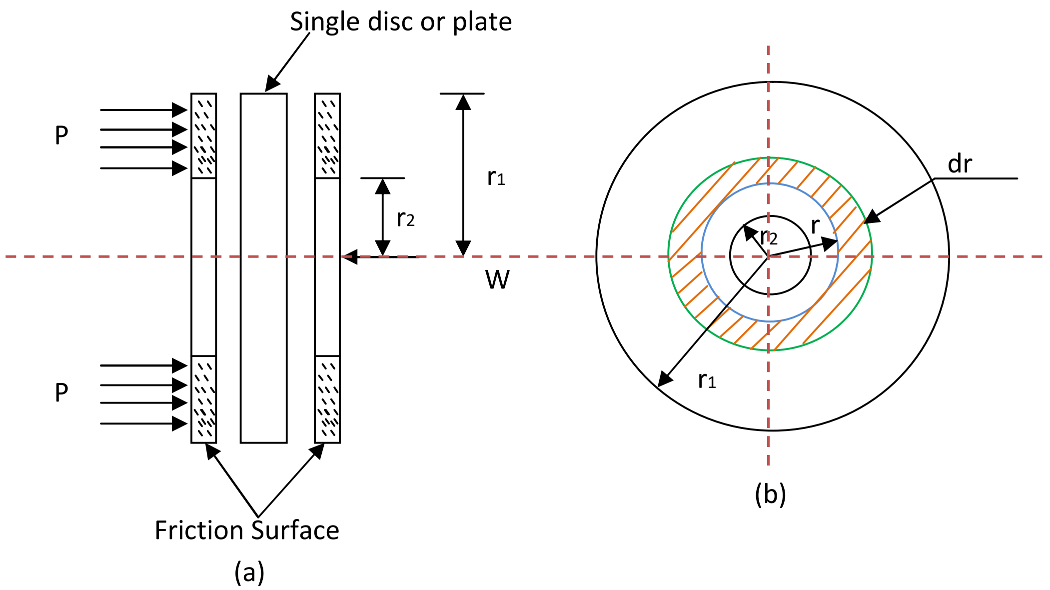


Fig. (2): Forces on a single disc or plate clutch.

Now consider two friction surfaces, maintained in contact by an axial thrust W, as shown in Fig.(2)

Let T= Torque transmitted by clutch

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

r1 and r2=External & internal radiuses of friction surface.

μ=Co-efficient of frictions

Let us consider an elementary ring of radius "r" and thickness is "dr" as shown in fig.(2)

Therefore area of contact surface of friction surface = $2\pi r.dr$

Therefore Normal or axial force on ring

∂W = Pressure X area

= $P \times 2\pi r.dr$

Also, frictional force on the ring acting tangentially at radius "r".

$F_t = \mu \times \partial W = \mu \times p \times 2\pi r.dr$

Therefore Frictional torque $T_t = F_t \times r$

⇒ $T_t = \mu \times p \times 2\pi r.dr \times r$

⇒ $T_t = 2\pi r.\mu.p.r2.dr$ ——— (1)

Now we will consider the following two cases:

- When there is uniform pressure
- When there is uniform wear

1. **Considering uniform pressure:-**

   When the pressure is uniformly distributed over the entire area of the friction face, then the intensity of pressure

   $$P=W/\pi[r1^2 - r2^2] \text{ ——— } (2)$$

   Where W = Axial thrust with which the contact or surfaces are held together

   With help of eqn. (1), integrating within limit from r_2 to r_1 for the total friction torque.

   ∴Total frictional torque acting on the friction surface or on clutch.

$$T = \int_{r2}^{r1} 2\pi\mu.\rho.r^2 dr = 2\pi\mu\rho \int_{r2}^{r1} r^2 dr$$

$$= 2\pi\mu p.\left[\frac{r^3}{3}\right]_{r2}^{r1} = 2\pi\mu\rho[\frac{r1^3-r2^3}{3}]$$

Putting value of ρ from eqn. (2)

$$T = 2\pi\mu \text{ X } \frac{\omega}{\pi[r1^2-r2^2]} X \frac{(r1)^3-(r2)^3}{3}$$

$$= \frac{2}{3}.\mu.\omega\left[\frac{r1^3-r2^3}{r1^2-r2^2}\right] = \mu.\omega.R \text{ ——— } (3)$$

Where R = mean radius of friction surface

$$= \frac{2}{3}.\frac{r1^3-r2^3}{r1^2-r2^2}$$

2. **Consider uniform wear:-**

   As per Fig(2), let ρ be the normal intensity of pressure at a distance "r" form the axis of the clutch. Since the intensity of pressure varies inversely with the distance.

$$∴\rho.r = C \text{ [C=constant]}$$

$$=> \rho = C/r \text{ ——— } (4)$$

∴ Normal force on the ring

$$\partial\omega = \rho.2\pi r.dr = \frac{C}{\cancel{r}}.2\pi\cancel{r}.dr$$

$$=2\pi C.dr$$

∴ Total force acting on friction surface

$$\omega = \int_{r2}^{r1} 2\pi c.dr = 2\pi C.[r]_{r2}^{r1}$$

$$= 2\pi C.[r1 - r2]$$

$$=> C = \frac{\omega}{2\pi(r1-r2)}$$

Total frictional torque on friction surface:

$$T_r = 2\pi\mu\rho r^2 dr$$

$$=> T_r = 2\pi\mu.\frac{C}{\cancel{r}} r^{\cancel{2}}.dr$$

$$=> T_r = 2\pi\mu.C.r.dr$$

∴ Total frictional torque

$$T=\int_{r2}^{r1} 2\pi\mu.C.r.dr$$

$$\Rightarrow T= 2\pi\mu.C[\frac{r^2}{2}]_{r2}^{r1}$$

$$\Rightarrow T= \cancel{2}\pi\mu.C.\frac{r1^2-r2^2}{\cancel{2}}$$

$$\Rightarrow T= \cancel{\pi}\mu.\frac{\omega}{2\cancel{\pi}(r1-r2)}.(r1^2-r2^2)$$

$$\Rightarrow T= \frac{\mu.\omega}{2\cancel{(r1-r2)}} X(r1+r2)\cancel{(r1-r2)}$$

$$\Rightarrow T=\frac{1}{2} X\ \mu.\omega\ (r_1+r_2)$$

$$\Rightarrow T=\mu.\omega.R \quad \text{———} \quad (5)$$

Notes:-

1. In general, total frictional torque acting on the frictional surface is given by

$$\Rightarrow T=\mu.\omega.R$$

Where η=n. of pairs of friction or contact surface

$$R=\frac{2}{3}[\frac{r1^3-r2^3}{r1^2-r2^2}]$$

$$=\frac{r1+r2}{2} \quad \text{(for uniform pressure)}$$

2. For a single disc or plate clutch, normally both side of the disc are effective. Therefore a single disc clutch has two pairs of surface in contact, i.e., η=2
3. Since the intensity of pressure is max. at the inner radious (r_2)of the friction surface, therefore

$$P_{max}\ X\ r_2=C \Rightarrow P_{max} = C/r_2$$

4. Since the intensity of the pressure is min. at the outer radius (r_1) of friction surface

$$P_{min}\ X\ r_1=C \Rightarrow P_{min} = C/r_1$$

5. The average pressure (P_{av}) given by

$$P_{av} = \frac{\text{Total force on friction surface}}{\text{cross section area of friction surface}}$$

$$= \frac{\omega}{\pi(r1^2-r2^2)}$$

- **Multiple Disc Clutch:-** A Multiple Disc Clutch as per Fig. may be used when a large torque is to be transmitted. The inside discs are fastened to the driven shaft to permit axial motion (except for the last disc). The outside discs (usually of bronze) are held by bolts and are fastened to the housing which is keyed to the driving shaft. The multiple disc clutches are extensively used in motion cars, machine tools etc.

  Let, n_1= No. of discs on the driving shaft

  n_2= No. of discs on driven shaft

  ∴Number of pairs of contact surface

  $\eta = n_1 + n_2$ ———— (1)

  Total frictional torque acting on the frictional surface or on the clutch.

  $T = \eta.\mu.\omega.R$

  Where R= mean radius of friction surfaces

  $= \frac{2}{3}[\frac{r1^3 - r2^3}{r1^2 - r2^2}]$ (for uniform pressure)

  $= \frac{r1+r2}{2}$ (for uniform wear)

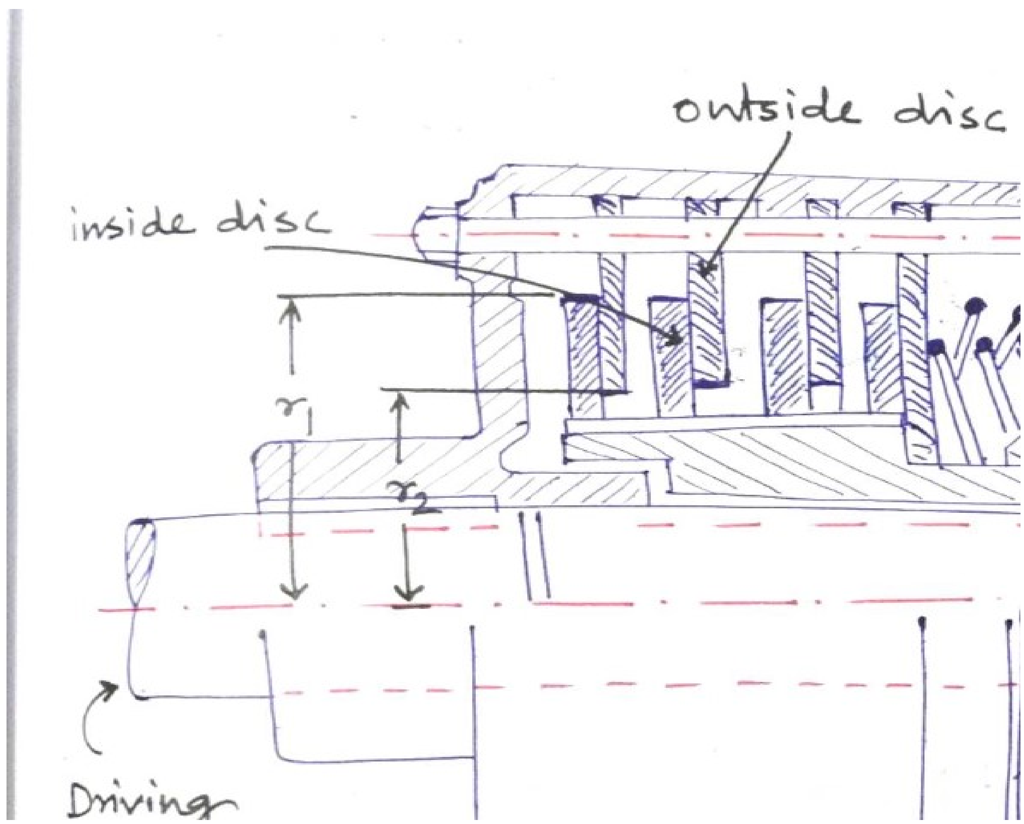


Fig (3): Multiple disc clutch

- Cone clutch :-

A Cone clutch as shown in fig.(4) was extensively used in automobile industries.

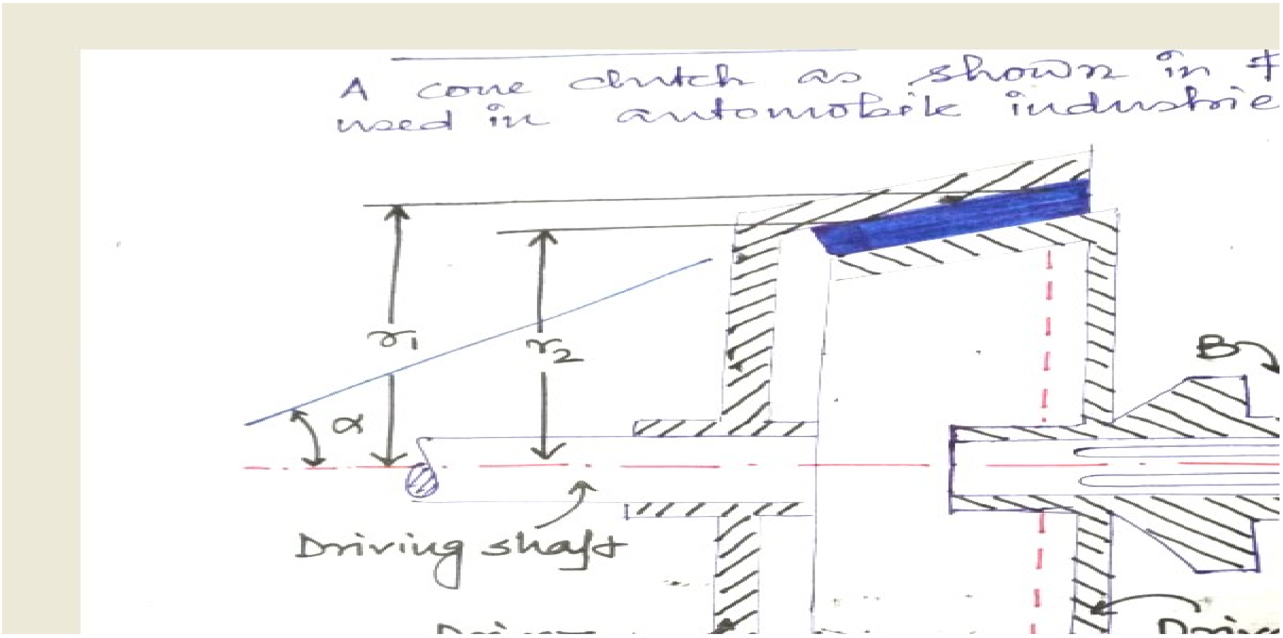


Fig.(4): Cone Clutch

It consists of one pair of friction surface only. In a cone clutch, driver is keyed to the driving shaft by a sunk key and has an inside conical surface or face which exactly fits in to the outside conical surface of the driven. The driven member resting on the feather key in the driven shaft, may be shifted along the shaft by a forced lever provided at "B", in order to engage the clutch by bringing the tow conical surface in contact. Due to frictional reasistance setup at this contact surface, the torque is transmitted from one shaft to another. In some cases, a spring is placed arround the driven shaft in contact with the hub of the driven. This springs holds the clutch faces in contact and maintains the pressure between them and the forced lever is used only for disengagement of the clutch. The contact sutfaces of the clutch may be metal to metal contact, but more often the driven member is linked with some material like wood, leather, cork, asbestor etc. The material of the clutch face (contact surface) depends upon the allowable normal pressure and co-efficient of friction.

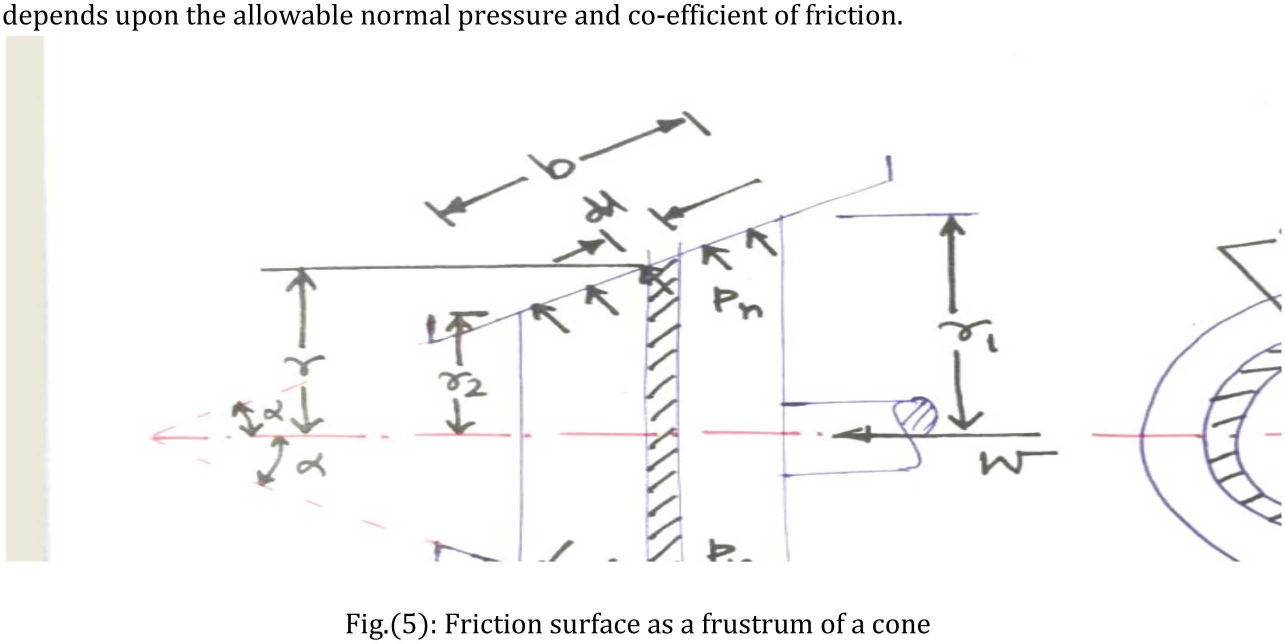


Fig.(5): Friction surface as a frustrum of a cone

Consider a pair of friction surface, as shown in fig.5(a). Since the area of contact of pair of friction surface is a frustrum of a cone, therefore the torque tranmitted by the cone clutch may be determined in the similar manner as discussed for conical pivot.

Let, P_n = intensity of pressure with which the clinical friction surface are held together.

r_1 & r_2 = Outer & Inner radius of friction surface respectively.

R = mean radius of friction surface

$= \frac{r1+r2}{2}$

$\boldsymbol{\alpha}$ = Semi angle of the cone or the angle of friction surface with the axis of friction of the clutch.

μ = Co-efficient of friction between the contact surfaces.

b = Width of contact surfaces.

Now considering a small ring of radius "r" and thickness "dr", as shown in fig. 5(b). Let "dl" is the length of the ring – of the friction surface.

$\therefore$ dl = dr. cosec$\boldsymbol{\alpha}$

$\therefore$ Area of ring "A" = 2πr. dl

=> A = 2πr. dr. cosec$\boldsymbol{\alpha}$

Now we will consider two cases:-

1. When there is uniform pressure
2. When there is uniform wear

1. **Considering uniform pressure**: Consider, normal load acting on ring

$\partial\omega_n$ = normal pressure X area of ring

$= p_n \times 2\pi r.dr.\text{cosec}\,\boldsymbol{\alpha}$

and the axial load acting on the ring

$\partial\omega$ = Horizontal component of $\partial\omega_n$

$= \partial\omega_n \times \text{Sin}\,\boldsymbol{\alpha}$

$= p_n \times 2\pi r.dr.\text{cosec}\,\boldsymbol{\alpha}.\ \text{Sin}\,\boldsymbol{\alpha}$

$= p_n \times 2\pi r.dr$

$\therefore$ Total axial load transmitted to the clutch or the axial spring force required

$$\omega = \int_{r2}^{r1} 2\pi r.\text{pn}.dr = 2\pi\text{pn} \int_{r2}^{r1} r.dr$$

$$= 2\pi\, p_n.\left[\frac{r2}{2}\right]_{r2}^{r1} = 2\pi\, p_n\left[\frac{r1+r2}{2}\right]$$

$$= \pi\, p_n\,(r_1^2 - r_2^2)$$

$$\therefore p_n = \frac{\omega}{\pi(r1^2 - r2^2)}$$

We know that the friction force on the ring acting tangentially at rad r.

$F_t = \mu\, \partial\omega_n = \mu.2\pi r.dr.\ \text{pn.Cosec}\boldsymbol{\alpha}$

$\therefore$ Friction torque $T_t = F_t \times r$

$= 2\pi r\mu\ p_n.\text{Cosec}\boldsymbol{\alpha}.\ r^2.\ dr$

$\therefore$ Total frictional torque T

$$= \int_{r2}^{r1} 2\pi r\mu\ \text{pn}.\ \text{Cosec}\alpha.\ r2.\ dr$$

$=> T = 2\pi\mu.\rho_n \text{cosec}\alpha\{\frac{r2}{3}\}_{r2}^{r1}$

$= 2\pi\mu.\rho_n \text{cosec}\alpha\ [\frac{r1^3 - r2^3}{3}]$

Putting the value of ρ_n from Equ (1)

$$T = 2\cancel{\pi}\mu.\frac{\omega}{\cancel{\pi}(r1^2 - r2^2)}.\ \text{Cosec}\alpha\ .\frac{r1^3 - r2^3}{3}$$

$$= \frac{2}{3} X\ \mu.\omega.\ \text{Cosec}\alpha.\frac{r1^3 - r2^3}{r1^2 - r2^2} \quad \text{———} \quad (2)$$

2. **Consider Uniform wear:-** In Fig.(5), let p_r be the normal intensity of pressure at a distance "r" from the axis of the clutch. We know that in case of uniform wear, the intensity of pressure, varies inversly with the distance.

$\therefore p_r X r = c$ [c=constant]

$=> p_r = c/r$

$\therefore \partial\omega_n$ = normal pressure X area of ring

(Normal load)

$= p_r X\ 2\pi r.dr.\text{cosec}\alpha$

And axial load

$\partial\omega = \partial\omega_n X \sin\alpha$

$= p_r X\ 2\pi r.dr.\text{cosec}\alpha\ X \sin\alpha$

$= p_r X\ 2\pi r.dr$

$= \frac{c}{r} X\ 2\pi r.dr$

$= 2\pi\ X\ c\ X\ dr$

$\therefore$ Total axial load transmitted to the clutch

$$w = \int_{r2}^{r1} 2\pi c.\ dr = 2\pi.c.\ [r]_{r2}^{r1}$$

$$= 2\pi c\ (r_1 - r_2)$$

$$=> c = \frac{\omega}{2\pi\ (r1 - r2)} \quad \text{———} \quad (3)$$

Now the friction force acting on the wheel or ring

$$F_r = \pi\partial\omega_n = \mu.p_r\ X\ 2\pi r\ X\ dr.\ \text{cosec}\boldsymbol{\alpha}$$

And frictional torque on the ring

$$T_r = F_r\ X\ r = \mu.p_r\ X\ 2\pi r\ X\ dr.\ \text{cosec}\boldsymbol{\alpha}.\ r$$

$$= \mu.\frac{c}{\cancel{r}}.\ 2\pi r.dr.\ \text{cosec}\boldsymbol{\alpha}.\cancel{r}$$

$\therefore$ Total frictional torque acting on clutch

$$T = \int_{r2}^{r1} 2\pi\mu.c.cosec\alpha.r.dr$$

$$= 2\pi\mu.c.cosec\alpha.r.[\frac{r2}{2}]_{r2}^{r1}$$

$$= 2\pi\mu.cosec\alpha.c.[\frac{r1^2 - r2^2}{2}]$$

Putting value of "c" from equ. (3)

$$T = 2\cancel{\pi}\mu.cosec\alpha.c.\frac{\omega}{\cancel{2\pi(r1 - r2)}} X \frac{(r1+r2)\cancel{(r1-r2)}}{2}$$

$$=> T = \mu.\omega.\text{cosec}\boldsymbol{\alpha}.\frac{(r1+r2)}{2} = \mu.\omega.\text{cosec}\boldsymbol{\alpha}.R \quad \text{———} \quad (4)$$

- **Centrifugal Clutch:**

  The centrifugal clutches are usually incorporated into the motor pulleys. It consists of a number of shoes on the inside of a rimof the pulley, as shown in fig.(6). The outer surface of the shoes are covered with a frictional material. These shoes which can move radially in guides, are held against the boss on the driving shaft by means of springs.

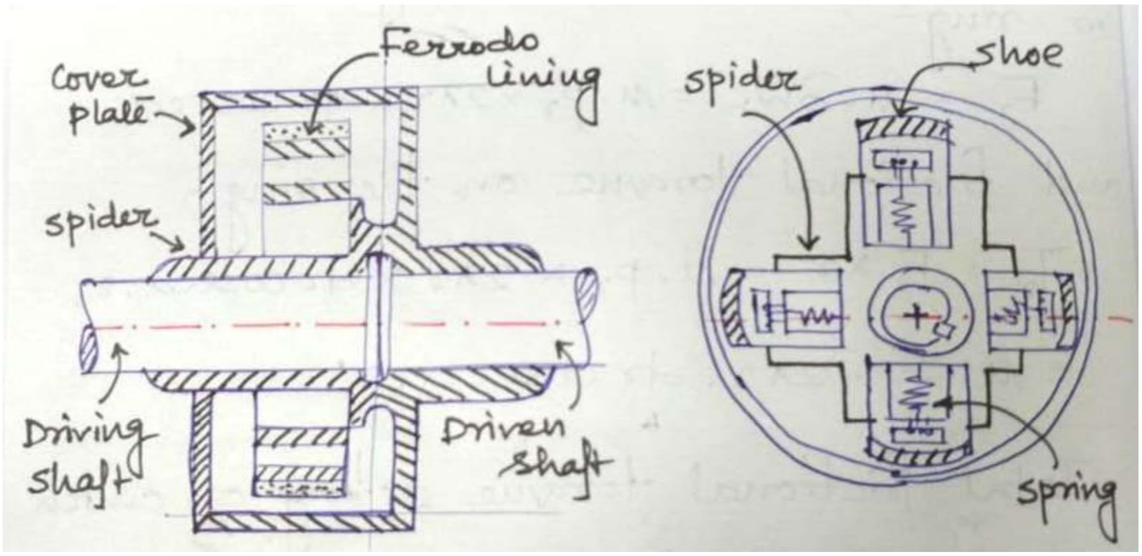


Fig.(6) centrifugal clutch

The springs exert a radially inward force which is assumed constant. The mass of shoe, when revolving causes it to exert a radially outward force (centrifugal force). The magnitude of this cebtrifugal force depends upon the shoe is revolving. A little consideration will show that when the centrifugal force is less than the springs force, the shoe remains in the same position as when the driving shaft was stationary, but when the centrifugal force is equal to spring force, the shoe is just floating. When the centrifugal force exceeds the spring force, the shoe moves outwards and comes in contact with the driven member is the diffrence of the centrifugal force and the spring force. The increase of speed causes the shoe to press harder and enables more torque to be transmitted.

In order to determine the mass and size of the shoes, the following procedure is adopted –

1. Mass of the shoes:-

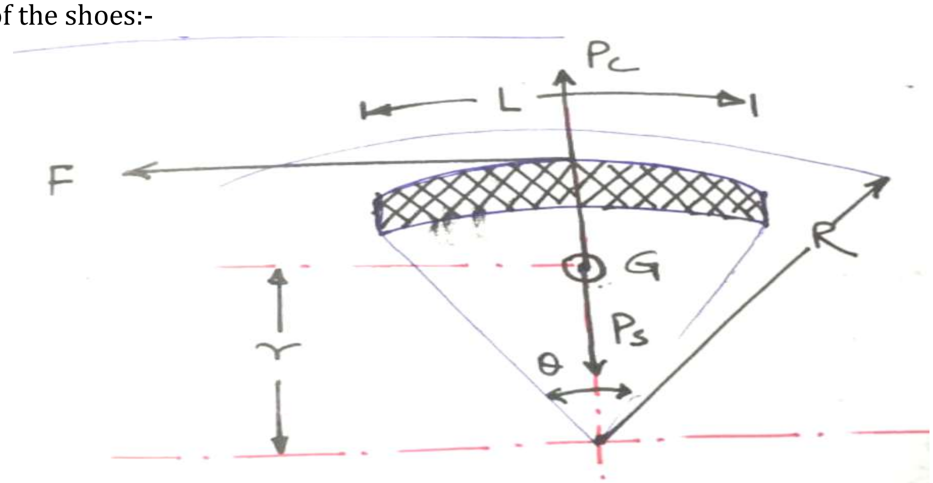


Fig. (7) Forces on a shoe of centrifugal clutch

Consider one shoe of a centrifugal clutch as shown in fig.(7)

Let, m = Mass of each shoes

N = Number of shoes

r = Distance of C.G of shoes from center of spider

R = Inside radius of pulley rim

N = Running speed of pulley in rpm

ω = Angular running speed of the pulley in rad/s = $\frac{(2\pi N)}{60}$ rad/s

ω_1 = co-efficient of friction between shoe & rim

We know tha the centrifugal force acting on each shoe

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

And the inward force on each shoe exerted by the spring at the speed at which engagement begins to take place

$$P_s = m\ (\omega_1).r$$

∴ The net outward radial force (centrifugal force) with which the shoe presses against the rim at running speed

$$P = P_c - P_s$$

Now the tangential frictional force on each shoe

$$F = \mu \times P = \mu\ (P_c - P_s)$$

∴ Frictional torque on single shoe = F X R = $\mu\ (P_c - P_s) \times R$

Total friction torque

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

Form this, mass of shoe (m) may be evaluated

2. Size of the shoe:

Let L = contact length of shoe

B = width of shoe

R = contact radius of shoe. It is issame as the inside radius of the centero of spider in radians.

θ = angle subtended by the shoes st the centre of spider in radians

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

We know that $\theta = L/R$, rad => $L = \theta R$

∴ Are of contact of the shoe A = l X b

∴ force with which the shoe presses against the rim = A X p =lbp

Since the forces with which the shoe presses against the rim at running speed is $(P_c - P_s)$

∴ lbp = $(P_c - P_s)$

Form this expression, width of shoe (b) may be obtained.