LECTURE NOTES

ON

THEORY OF MACHINE

FOR

DIPLOMA IN MECHANICAL ENGINEERING

(4TH SEMESTER STUDENTS)

AS PER SCTE&VT SYLLABUS

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THEORY OF MACHINES

CHAPTER – 1 : SIMPLE MECHANISMS

Theory of m/c is a branch of science which deals with the study of relative motion between the various parts of a m/c, & the forces which are acting upon them.

It is broadly divided into two parts.

Kinematics

It deals with the study of relative motion between the various parts of the machine, but the various forces involved in the motion, are not considered.

Dynamics

It deals with the study of various forces involved in the various parts of the m/c. The forces may be static or dynamic.

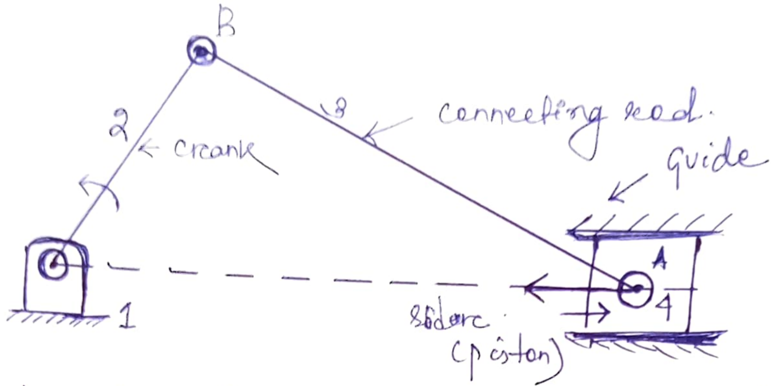
Mechanism & Machine

① Mechanism → If a no. of rigid bodies are assembled in such a way that the motion of one causes ~~constraint~~ constrained and predictable motion to the another, is known as a m/c. mechanism.

A mechanism also transmitts & modify motion.

② Machine → A machine is a mechanism or combination of mechanisms which not only imparts definite motions to the parts but also transmitts & modify the available mechanical energy into some kind of useful energy. This useful energy may be in the shape of some kind of desired work.

for example :- Slider crank mechanism



The above fig. shows a mechanism which is known as slider - crank mechanism. It is a combination of rigid bodies namely crank, connecting rod & slider. They are also so shaped & connected that they move upon each other with definite relative motion.

The slider - crank mechanism will become a m/c become a m/c when it is used in automobile engine by adding valve mechanism etc. In that case it will convert the available energy (force on the piston) into the desired energy (torque on the crank shaft). This torque will move the vehicle.

Link

A link is defined as a member or a combination of members, connecting other members & having motion relative to them. A Slider - crank mechanism consist of following four links.

i) frame
ii) crank
iii) connecting rod
iv) slider

The slider (4) reciprocates in guide, which is connected to frame. Hence guide also becomes link 1.

Types of link → Rigid link
Flexible link
Fluid link

Kinematic Pair

Two links or element of a machine, when in contact with each other they said to form a paire.

Types of kinematic pair

1. According to nature of contact.

- Lower pair
- Higher pair

Lower pair – A pair of link having surface or area contact between them known as lower paire. The contact surface of two links are similar.

eg. shaft rotating in bearing
Nut turning in a screw.

Higher pair – When a pair has a point or line contact between the links, is known as higher paire. The contact surface betn two surface are dissimilar.

eg. cam followere paire

*

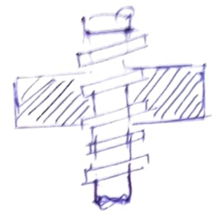
2. Acc. to nature of Mechanical constraint

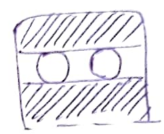
closed paire – When the elements of a paire of link are held together mechanically, it is known as closed paire. The two elements are geometrically identical & are one element envelope the other one. eg.

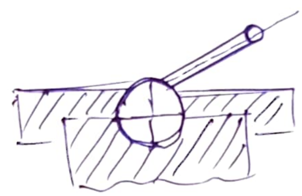
unclosed paire – When two links of a paire are in contact either due to gravity are called unclosed paire.

3. Acc. to nature of relative motion

Sliding pair -  eg. piston & cylinder

Turning pair -  lathe spindle supported in head stoke

Rolling pair -  Roller bearing

Spherical pair -  ball & socket Joint attachment of care mirror.

Degree of freedom

It can be defined as the no. of independent motion both translational & rotational a body can have.

→ Translation motion along x, y & z axis.

→ Rotational motion along x, y, z axis.

$$n = 3(l-1) - 2j - h$$

l → no. of links
j – no. of binary Joint
h → no. of higher pair.

It is called as kutzbach criterion, for a mechanism.

Kinamatic chain

When a kinamatic pairs are coupled in such a way that the last link is joined to the first link to transmit definite motion, it is called as a kinematic chain.

* The relation betn no. of link (L) & pair (p) is given by

$$L = 2p - 4 \quad \text{—— (1)}$$

* The relation betn no. of link (L) & Joints (J) is given by

$$j = \frac{3}{2}L - 2 \quad \text{—— (2)}$$

The equation ① & ② if

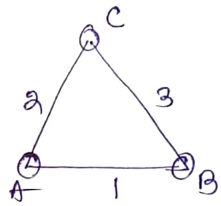
LHS > RHS → then the chain is locked

LHS < RHS → then the chain is unconstrained

LHS = RHS → " " is constrained

<u>example - 1</u>

A 3 link ~~Joi~~ chain with 3 Joints.
Prove the chain is locked



$j = 3$

$L = 3$

$P = 3$

① $L = 2P - 4$

$\Rightarrow 3 = 6 - 4 = 2$

$\Rightarrow 3 > 2$ LHS > RHS

② $j = \frac{3}{2}L - 2$

$\Rightarrow 3 = \frac{3}{2} \times 3 - 2$

$\Rightarrow 3 > 2.5$ LHS > RHS

Hence proved.

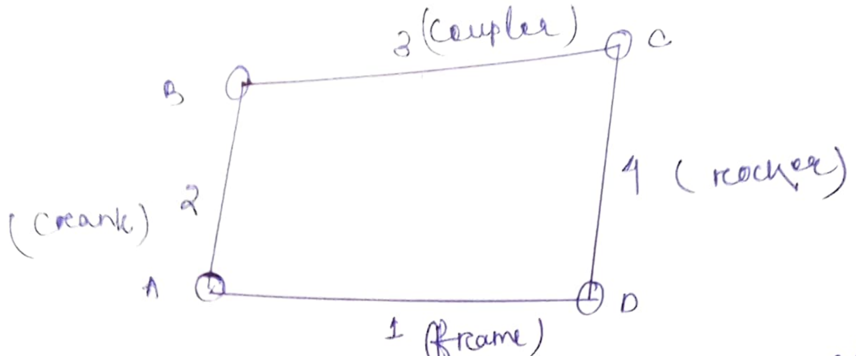
Inversion Mechanism

Mechanism is a kinematic chain whose one link is fixed. As there are many link in a chain, by fixing one at a time, we can obtain a no. of Mechanism. & This method is known as inversion.

1) Four bar chain Mechanism & its inversion.

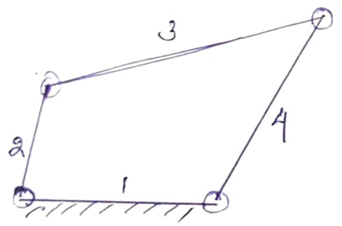
This is the simplest kinematic chain. It consist of four rigid links which are connected in the form of a quadrilateral by 4 pin Joints.

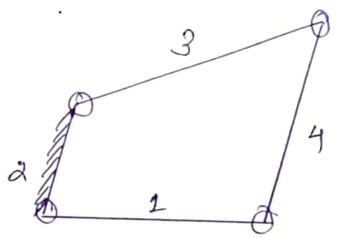
It consists of four turning pairs. Link 1 & link 2. forms first turning pair, link 2 & link 3 form second turning pair. link 3 & 4 3rd & 4 & 1 4th turning pair respectively.

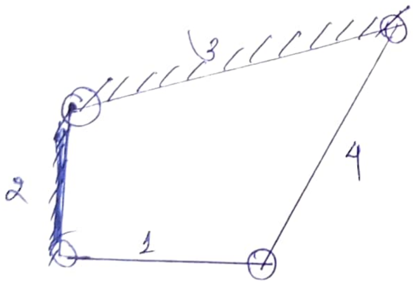


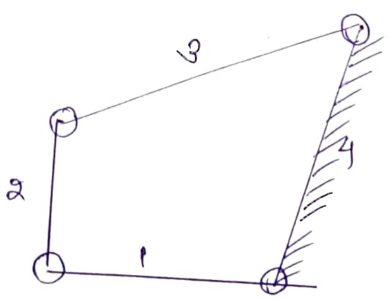
A link that makes complete revolution is known as crank. The fixed link is known as frame of the mechanism. The link opposite to the fixed link is known as connecting rod. The forth link is known as lever, or rocker (if oscillates) or an another crank (if it rotates).

If different links of the four bar mechanism are fixed, four diff. mechanism will be obtained.









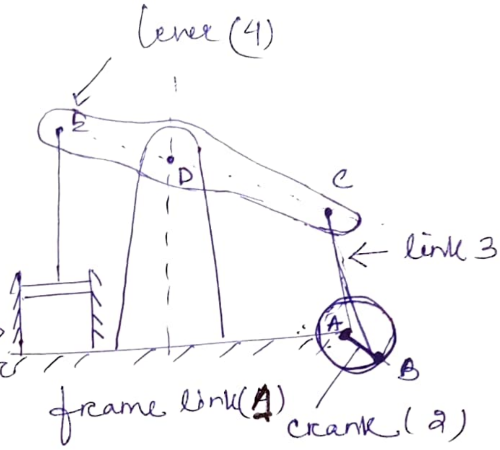
Conditions for four bar Mechanism / (Grashof condition)

- The length of one link should not be greater then the sum of the ~~other~~ other three links.
- One of the shortest link should make a complete revolution relative to other 3 link.
- The sum of the longest & shortest link should not be greater than the sum of the other 2 links.

Examples of inversions

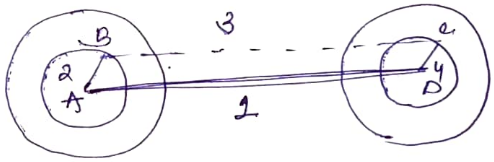
1. Beam engine (crank lever mechanism)

It is also known as crank lever mechanism. which consist of 4 links. As shown in the figure, when the crank rotates about pt A the lever oscillates about fixed centre D. The end 'E' of the lever EDC is connected to a piston rod which reciprocates due to revolution of crank. Means the rotary motion is converted into reciprocating motion.



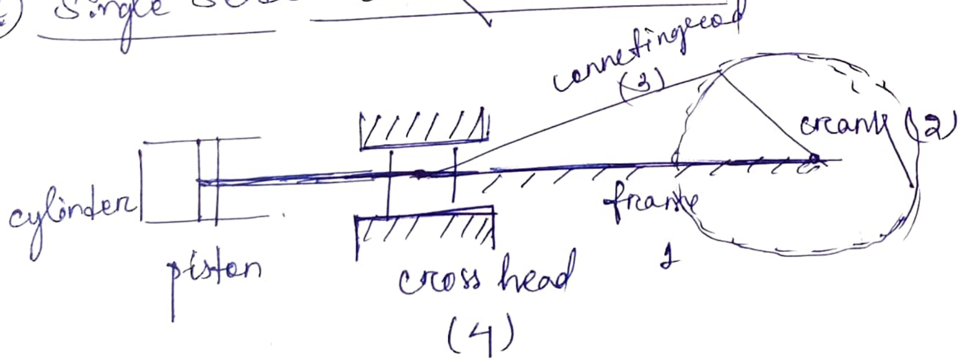
2. coupling rod of locomotive (double crank mechanism)

Here the links AB & CD are act as cranks & connected to the respective wheels. The link BC act as coupling rod. & AD act as frame or fixed.



- used to transmit rotary motion from one wheel to another wheel.

3) Single slider crank chain



- It consist of 4 links having one sliding pair & 3 turning pair.
- It converts rotary motion into reciprocating motion & vice versa.

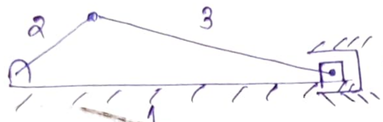
1-2, 2-3, 3-4 → turning pair
4-1 → sliding pair

Inversion of single slider crank chain

1) 1st inversion

It is obtained when 1 link is fixed & link 2 is the crank & link 4 becomes slider.

Application – reciprocating engine

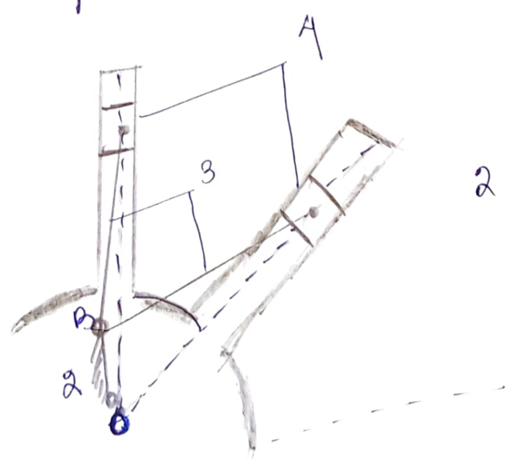


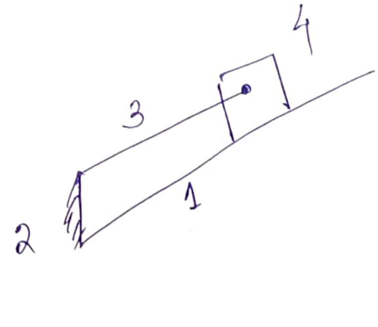
Here link 1 is fixed & 2 is the crank & link 4 is the slider.

2) 2nd inversion

It is obtained when link 2 is fixed. When link 2 is fixed instead of link 1, the link 3 along with slider 4 will become the crank. It causes link 1 to rotates about pt. O, with the slider reciprocating.

Application – Rotary engine.





The fig shows the rotary engine mechanism. In this mechanism link 2 is fixed. Link 4 is made as the piston arrangement. & link 1 made as the cylinder, which reciprocates about link 4. Here instead of one cylinder, seven or nine cylinders are symmetrically placed in regular intervals in the same plane. All the cylinders rotates about the common fixed center O. The fixed link 2 is common to all cylinders. The only difference between the 1st & 2nd inversion is that, in 1st inversion, the body is fixed & crank is rotating where as in 2nd inversion, the crank is fixed & body rotates.

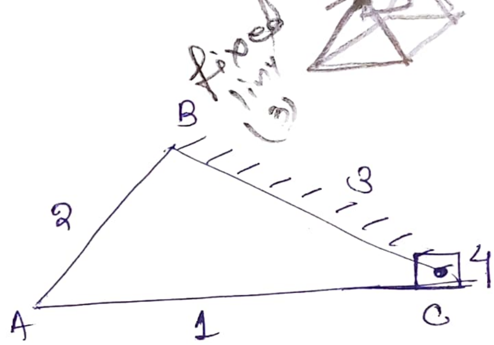
3) 3rd inversion

When link 3 is fixed and link 2 act as crank & link 4 oscilates.

Application – Oscillating cylinder
Crank & slotted lever mechanism

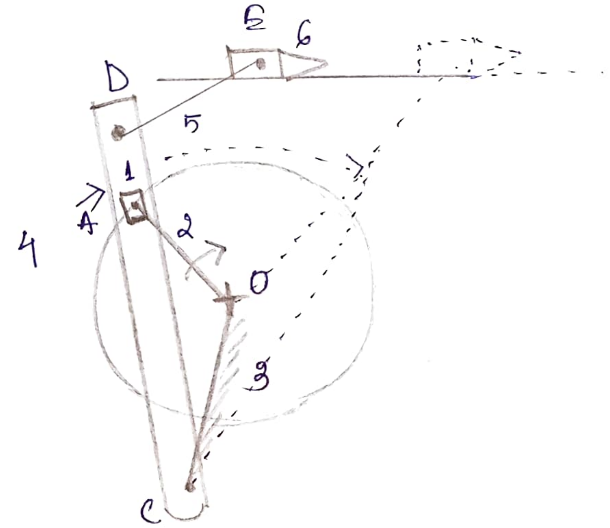
i) Oscillating cylinder

The piston reciprocates inside the cylinder pivoted to the fixed link 3. when the piston reciprocates the crank rotates. about O.



ii) crank & slotted lever Mechanism

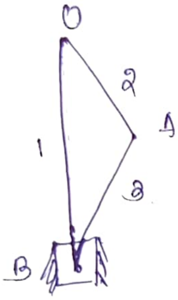
In the fig , link 1 is the slider which slides upon link 4. Link 3 is fixed and link 2 is the crank which rotes counter clockwise about a fixed center O. The link 4 is extented to pt. D which is another link, link, 5. At the end to link 5 link 6 is attached, which is the cutting tool.

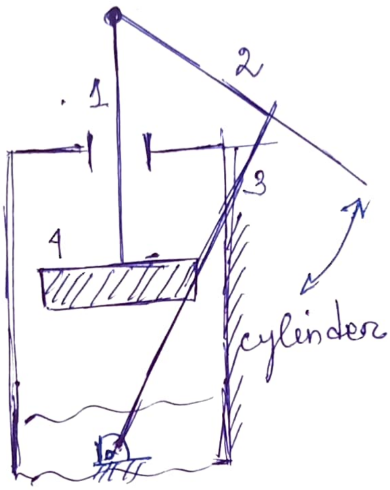


4) 4th inversion

When the 4th link is fixed, the 4th inversion is obtained. Link 3 can oscillates about the fixed point B on the link 4. It causes link 2 to oscillates about B & the end O. to reciprocates along the axis of the fixed link. 4.

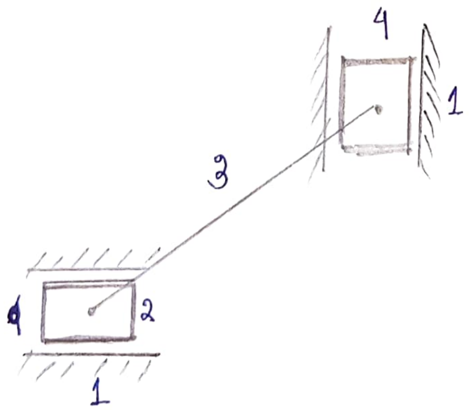
Application - hand pump.





3) Double slider crank chain

A four bar chain having 2 turning pair & 2 sliding pair such that two pairs of same kind are adjacent is called double slider crank chain.



link 1-2, 4-1 } sliding pair

link 2-3, 3-4 } turning pair

i) 1st inversion

It is obtained when link 1 is fixed & 2-3, 3-4 are turning pair and 1-2 & 4-1 are sliding pair.

Application - Elliptical trammel

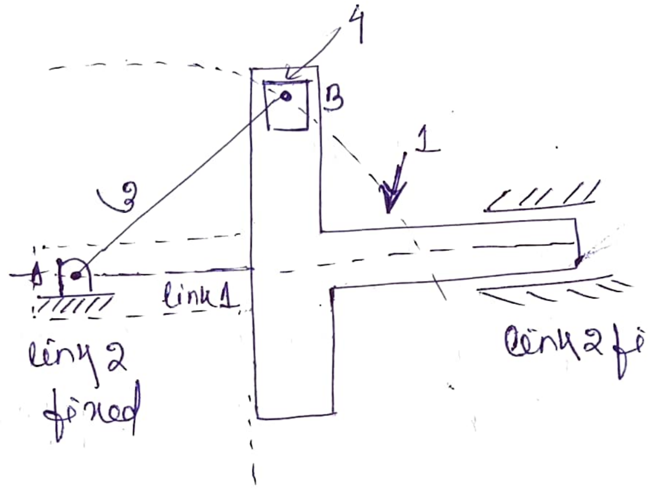
It is an instrument used to draw ellips.

ii) 2nd inversion

It is obtained when any slide block in the 1st inversion is fixed. ~~taken~~

Application : Scotch yoke mechanism.

Here link 2 is fixed and 'B' end link of 3 rotates about pt A. and link 1 reciprocates, in the horizontal direction. The link 1 reciprocates about fixed link 2.



iii) 3rd inversion

When link 3 is fixed it is called as the 3rd inversion.

Application - oldham's coupling.

It is used for connecting 2 parallel shaft whose axes are at a small distance apart. The shaft s are coupled such that if one shaft rotates, the other shaft also rotates with the same speed.

* ## Types of constrained motion

1) Completely constrained motion

→ when the motion between the two elements of a pair is in a definite direction irrespective of the direction of the force applied.

→ It may be linear or rotary.

eg. piston & cylinder of the steam engine.

Here the motion of the piston is limited to definite direction.

2) incompletely constrained motion

When motion between two elements of a pair is possible in more than one direction & depends on the direction of force applied.

Eg. shaft in circular hole.
(It can slide as well as rotates)

3) Successfully constrained motion

When the motion between two elements of a pair is possible in more than one direction but is made to have motion only in one direction by using some external means.

Eg. shaft in a foot step bearing, the vertical motion is restricted in upward direction by applying load, apart from rotary motion.

FRICTION

When a solid body slides over a stationary solid body, a force is exerted at the surface of contact by the stationary body on the moving body. This force is called as friction.

Types

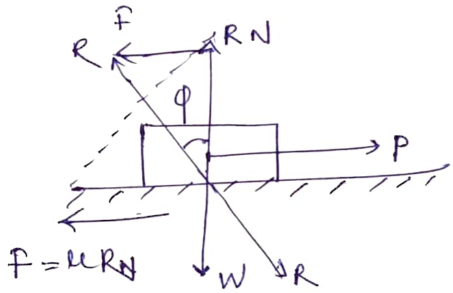
→ Static friction → It is the friction, experiend by a body, when at rest.

→ Dynamic friction → experienced by a body, when it is in motion.

Coefficient of friction (μ)

$$\mu = \frac{\text{limiting friction}}{\text{Normal reaction}} = \frac{F}{R_N}$$

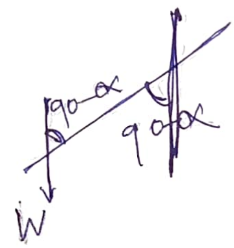
$$\Rightarrow \boxed{F = \mu R_N} \quad \text{—— ①}$$



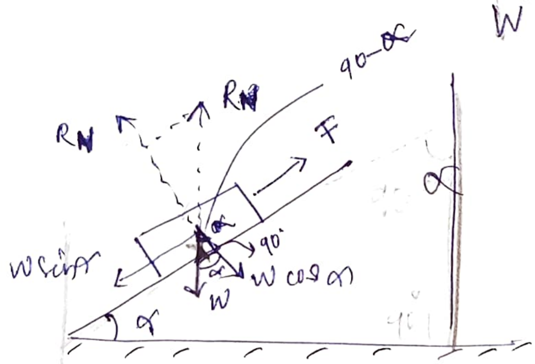
angle of friction (ϕ)

$$\tan\phi = \frac{F}{R_N} = \frac{\mu R_N}{R_N}$$

$$\boxed{\tan\phi = \mu} \quad \text{—— ②}$$



Angle of repose (α)



$$W\sin\alpha = F$$
$$= \mu R_N$$
$$= \mu W\cos\alpha$$

$$\Rightarrow \mu = \tan\alpha$$

$$\Rightarrow \boxed{\tan\phi = \tan\alpha} \quad \text{—— ③}$$

$$\boxed{\alpha = \phi}$$

Screw Friction

Screws, bolts, studs, nuts etc are widely used in various and structures for temporary fastening. These fastening have screw threads, which is made of cutting a continuous helical groove on a cylindrical surface. If the cuts are outside it is called as external threads & if the cuts are internal it is called as internal threads. Screw thread are 2 types. square thread.
& V. thread.

Terms related to threads

Helix – It is the curve traced by a particle, while ~~describing~~ ~~a circular path~~ moving along a screw thread.

pitch – It is the distance from a point of a screw to a corresponding point on the next thread measured parallel to the axis of the screw.

lead – It is the distance which a screw thread advances axially in one turn. (P)

Helix angle – Slope of thread with the horizontal.

$$\tan\alpha = \frac{\text{Lead}}{\text{circumference of screw}} = \frac{P}{\pi d} \quad \text{—— (4)}$$

Screw Jack

It is a device used for lifting of heavy loads, with very small effort. It ~~consi~~ consist of a nut, screw & a handle fitted to the head of the screw. The nut also forms the body of the Jack.

W = Weight placed on the screw head.

P = Effort applied at the end of handle.

L = Length of the handle.

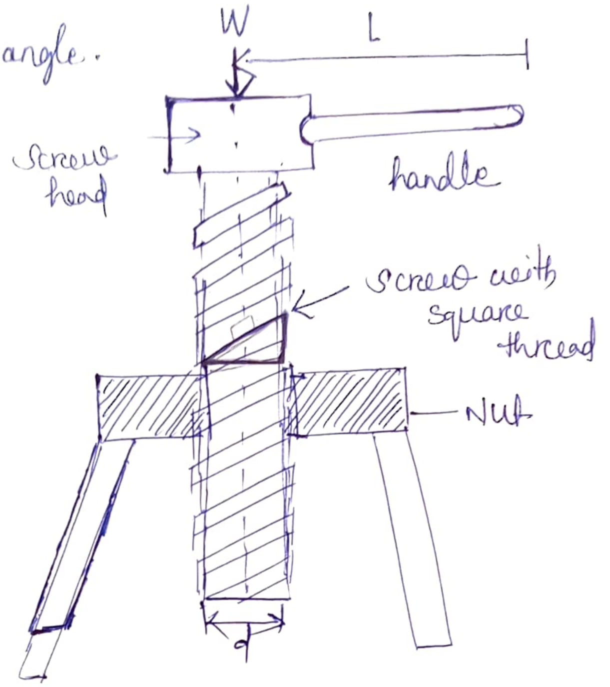
p = pitch of the screw

d = mean dia of the screw

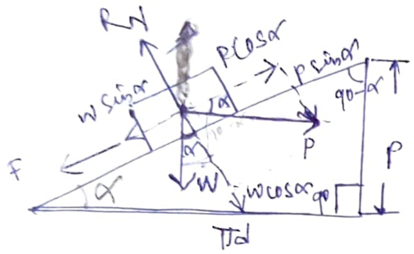
α = angle of the screw i.e. helix angle.

ϕ = angle of friction

μ = co-efficient of friction.



Torque required to lift the load



Since the load is being lifted, therefore force of friction will act downward.

from the above fig

$$P\cos\alpha = W\sin\alpha + F$$

$$\Rightarrow P\cos\alpha = W\sin\alpha + \mu R_N \quad \text{--- (5)}$$

($\because$ $F = \mu R_N$)

(Resolution along horizontal)

$$R_N = P\sin\alpha + W\cos\alpha \quad \text{--- (6)}$$

putting R_N in eqn (5)

$$P\cos\alpha = W\sin\alpha + \mu(P\sin\alpha + W\cos\alpha)$$

$$\Rightarrow P\cos\alpha = W\sin\alpha + \mu P\sin\alpha + \mu W\cos\alpha$$

$$\Rightarrow P\cos\alpha - \mu P\sin\alpha = W\sin\alpha + \mu W\cos\alpha$$

$$\Rightarrow P(\cos\alpha - \mu\sin\alpha) = W(\sin\alpha + \mu\cos\alpha)$$

$$\Rightarrow P = W\left[\frac{\sin\alpha + \mu\cos\alpha}{\cos\alpha - \mu\sin\alpha}\right]$$

putting $\mu = \tan\phi$

$$\Rightarrow P = W\left[\frac{\sin\alpha + \tan\phi\cos\alpha}{\cos\alpha - \tan\phi\sin\alpha}\right]$$

$$= W\left[\frac{\sin\alpha + \frac{\sin\phi}{\cos\phi}\cdot\cos\alpha}{\cos\alpha - \frac{\sin\phi}{\cos\phi}\sin\alpha}\right]$$

$\Rightarrow P = W \times \frac{\sin\alpha \cdot \cos\phi + \sin\phi \cdot \cos\alpha}{\cos\alpha \cdot \cos\phi - \sin\alpha \sin\phi}$

$\Rightarrow P = W \frac{\sin(\alpha+\phi)}{\cos(\alpha+\phi)}$

$\Rightarrow \boxed{P = W\tan(\alpha+\phi)}$ —— (7)

Torque required to over come friction between screw & nut

$T = P \times \frac{d}{2}$

$\boxed{T = W\tan(\alpha+\phi)\frac{d}{2}}$ —— (8)

$d \rightarrow$ Mean diameter of thread $d = d_o - P/2$

$d_o \rightarrow$ ext dia $d = d_c + P/2$.

$d_c \rightarrow$ int dia

without friction

$\boxed{P = W\tan\alpha}$

* speed of screw (N) = $\frac{\text{speed of nut}}{\text{pitch of screw}}$

Torque required to lower the load by a screw Jack.

$\boxed{T = W\tan(\phi - \alpha)\frac{d}{2}}$ —— (9)

When axial load is given Torque $T_2 = \mu_1 W R$

Total torque = $T_1 + T_2$

$= P \times \frac{d}{2} + \mu_1 W R$

Bearing

A bearing is a m/c element that constraints relative motion to only the desired motion and reduces friction between moving parts. For example rotary bearings hold rotating components such as shafts & axles with in mechanical system.

R = Mean dia of bearing.

Types – ball bearing

Roller bearing

plain bearing

needle bearing

ne wo... can be ... provide ... a ...

the rotating shaft are subjected to axial thrust. These shafts can be kept in correct axial position if bearing surface are provided. The bearing surface which is placed at the end of a shaft are known as pivots. (2)

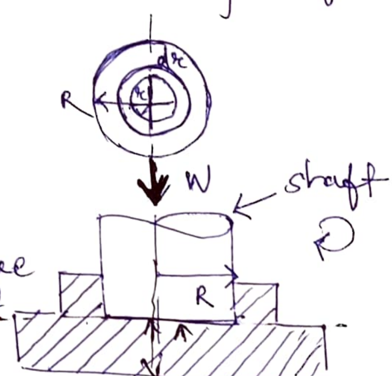
- A pivot may be of flat or conical surface.

For describing friction in bearing, two assumption has to be taken.

UPT ① The pressure is uniformly distributed throughout the bearing surface.

UWT ② The wear is uniform throughout the bearing surface.

Flat pivot bearing / Foot step bearing



flat pivot bearing

It is also known as footstep bearing.

W → load transmitted over bearing surface due to shaft.

R → Radius of bearing surface.

P → Pressure (intensity of) per unit area.

μ → co-efficient of friction.

T → Total frictional torque.

Consider a small ring having radius r & thickness dr.

Area of bearing surface $dA = 2\pi r \cdot dr$. Area of bearing surface for ring

$= 2\pi \times 2d \cdot dr$

$= 4\pi d \cdot dr$

i) uniform pressure

Total pressure $p = \frac{W}{\pi R^2}$

$A = 2\pi r \cdot dr$

load transmitted at the ring $\delta W = p \times A$

$= p \times 2\pi r \cdot dr$

Frictional resistance to sliding acting at the ring

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

$F_r = 2\pi \mu p \, r \cdot dr$

Frictional torque $T_r = F_r \times r$

$T_r = 2\pi \mu p \, r^2 dr$

Total torque. $T = \int_0^R T_r = \int_0^R 2\pi \mu p r^2 dr$

$\Rightarrow T = 2\pi \mu p \int_0^R r^2 dr$

$= 2\pi \mu p \left. \frac{r^3}{3} \right|_0^R = 2\pi \mu p \frac{R^3}{3}$

$\Rightarrow T = \frac{2}{3} \pi \mu \times \frac{W}{\pi R^2} \times \frac{R^3}{3} \quad (\because p = \frac{W}{\pi R^2})$

$\Rightarrow \boxed{T = \frac{2}{3} \times \mu \times W \times R}$ ——— (10)

power lost in friction $P = T \times \omega$

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

ii) uniform wear

The rate of wear depends upon the intensity of pressure & the velocity of the rubbing surface (v). This rubbing velocity increases with the distance from the axis of bearing (i.e radius)

(→ constant)

(1) $P = \frac{C}{r}$

$$\delta W = P \times 2\pi r \times dr$$

$$= \frac{C}{r} \times 2\pi r \times dr$$

$$= 2\pi C \cdot dr.$$

Total load transmitted to the bearing $W = \int_0^R dW$

$$= 2\pi C \, r \Big|_0^R$$

$$W = 2\pi C R$$

Total torque

$$T_r = 2\pi \mu p r^2 dr \quad (F_r \times r)$$

$$= 2\pi \mu \frac{C}{r} r^2 dr$$

$$= 2\pi \mu \, C \cdot r \cdot dr$$

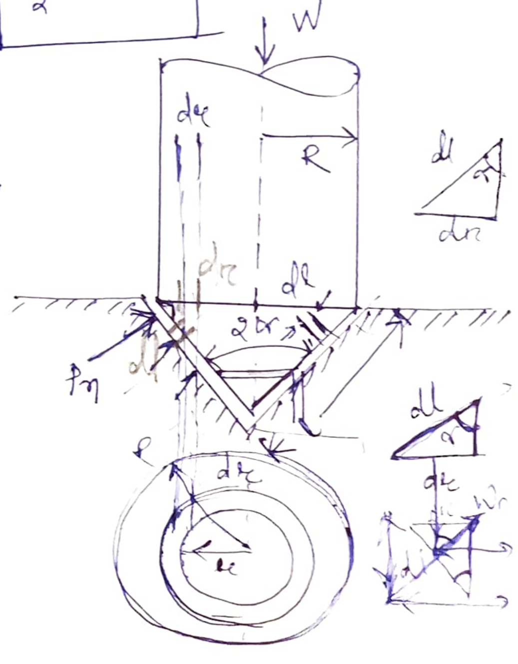
$$\text{Total } T = \int_0^R T_r = \int_0^R 2\pi \mu C \, r \cdot dr = 2\pi \mu C \int_0^R r \cdot dr = 2\pi \mu C \frac{r^2}{2}\Big|_0^R$$

$$\Rightarrow T = 2\pi \mu C \frac{R^2}{2}$$

$$\Rightarrow \boxed{T = \pi \mu C R^2} \quad \text{— (11)}$$

$$\Rightarrow T = \pi \times \frac{W}{2\pi R} R^2 \times \mu = \boxed{\frac{1}{2} \mu W R}$$

CONICAL PIVOT BEARING



P_n → intensity of pressure normal to cone.

α → semi angle of cone.

R → radius of shaft.

consider a small ring having radius r & thickness dr. & length dl on the length of cone.

$dl = dr \cdot \text{cosec}\,\alpha$ (∗ load acting on the circular ring, nor to the conical surface,

$A = 2\pi r \cdot dl$ (Area of the small element)

$= 2\pi r \cdot dr \cdot \text{cosec}\,\alpha$

i) uniform pressure

$\delta W_n = p_n \times A$ (normal load)

$\Rightarrow \delta W_n = p_n \times 2\pi r \cdot dr \cdot \text{cosec}\,\alpha$.

Vertical load will be

$\delta W_v = \delta W_n \cdot \sin\alpha$

$= p_n \times 2\pi r \cdot dr \cdot \text{cosec}\,\alpha \cdot \sin\alpha$

$\delta W_v = p_n \times 2\pi r \cdot dr$. ($\because \text{cosec} = \frac{1}{\sin}$)

total vertical load.

$W = \int_0^R p_n \times 2\pi r \cdot dr$

$= p_n 2\pi \int_0^R \frac{r^2}{2}$

$= 2\pi p_n \times \frac{R^2}{2}$

$W = \pi p_n R^2$

$\Rightarrow \boxed{p_n = W/\pi R^2}$

Frictional force acting tangentially

$F_r = \mu \times \delta W_n$

$= \mu \times p_n \times 2\pi r \cdot dr \cdot \text{cosec}\,\alpha$

$= 2\pi \mu p_n \cdot \text{cosec}\,\alpha \cdot r \cdot dr$.

Torque $T_r = F_r \times r$

$= 2\pi \mu p_n \,\text{cosec}\,\alpha\, r^2 dr$.

integrating T_r

$T = \int^R 2\pi \mu p_n \,\text{cosec}\,\alpha \cdot r^2 dr$

$T = 2\pi \mu p_n \,\text{cosec}\,\alpha \frac{R^3}{3}$

$T = \frac{2}{3} \times \pi R^3 \mu p_n \,\text{cosec}\,\alpha$

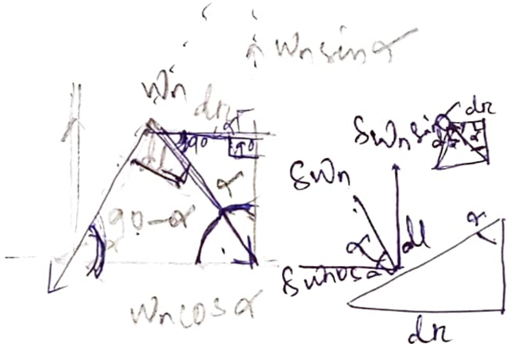
putting $p_n = \frac{W}{\pi R^2}$

$\Rightarrow T = \frac{2}{3} \times \pi R^3 \times \mu \times \frac{W}{\pi R^2} \,\text{cosec}\,\alpha$

$T = \frac{2}{3} \times \mu W R \,\text{cosec}\,\alpha$

$$\boxed{T = \frac{2}{3} \times \mu W l} \quad \text{—— (12)}$$

($R\,\text{cosec}\,\alpha = l$)



As we derived previously

$p_r \times r = C$

$\delta W = p_r \times 2\pi r . dr$ $\quad (A = 2\pi r . dr)$

$W = \int_0^R 2\pi C . dr$

$W = 2\pi C . R$

$\Rightarrow C = W / 2\pi R$

Frictional torque acting on the ring.

$T_r = 2\pi \mu p_r . \operatorname{cosec} \alpha . r^2 . dr$

$= 2\pi\mu \times \frac{C}{r} \times \operatorname{cosec} \alpha \, r^2 dr$

$T_r = 2\pi\mu C \operatorname{cosec} \alpha \, r . dr$

$T = \int_0^R T_r = \int_0^R 2\pi\mu C . \operatorname{cosec} \alpha \, r . dr$

$= 2\pi\mu C . \operatorname{cosec} \alpha \left. \frac{r^2}{2} \right|_0^R$

$= 2\pi\mu C . \operatorname{cosec} \alpha \frac{R^2}{2}$

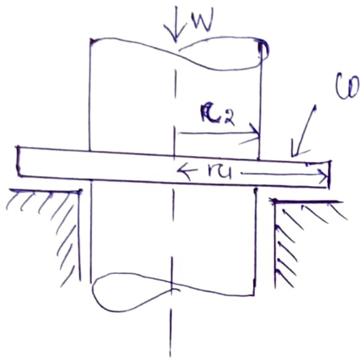
$T = \pi\mu C . \operatorname{cosec} \alpha . R^2$

$\Rightarrow T = \frac{1}{2} \mu . W . R \operatorname{cosec} \alpha$ $\quad$ (putting $C = W / 2\pi R$)

$\Rightarrow \boxed{T = \frac{1}{2} \mu W \times l}$ —— (13)

Flat collar bearing

The bearing surface provided at any position along the shaft but not in the end of the shaft to carry axial thrust known as collar. Aslo called as thrust bearing.



(Single collar)

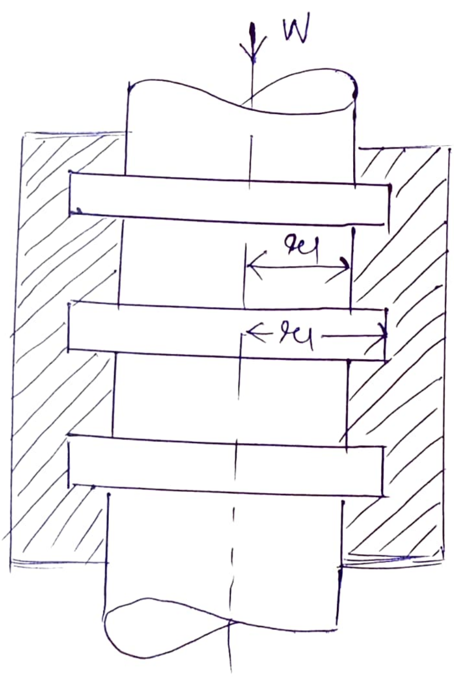
Formula for uniform pressure = $T = \frac{2}{3} \mu W \left[\frac{r_1^3 - r_2^3}{r_1^2 - r_2^2} \right]$

uniform wear = $T = \frac{\mu W}{2} (r_1 + r_2)$ — 15

power in friction.

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

Multiple collar

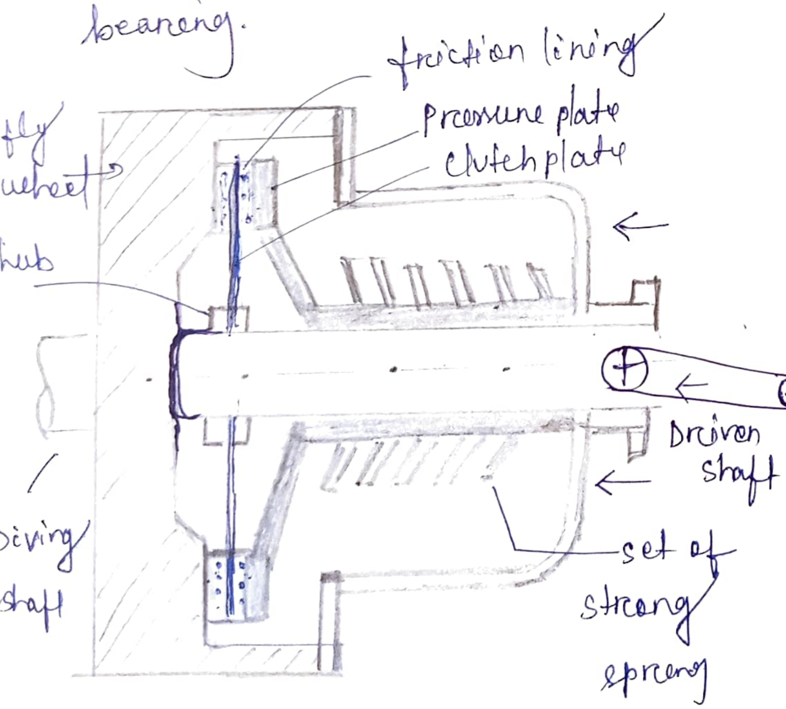


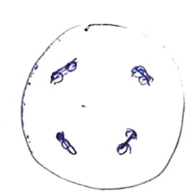
Friction clutch

The device used to transmit the rotary motion of one shaft to another or driver shaft to driven shaft is known as friction clutch or "clutch." The engine shaft and the gear box shaft is connected with the help of friction clutch.

1. Single plate clutch

A single plate clutch consist of a single clutch plate with friction lining on both side. This plate is attached to a hub which is free to move axially along the splines of the driven shaft. There is a pressure plate inside the clutch body. This pressure plate pushes the clutch plate towards the flywheel by a set of strong springs. The total clutch body is bolted to the flywheel. The pressure plate & the flywheel rotate with the driving shaft. The movement of the clutch pedal is transfered to the pressure plate through thrust bearing.





Engaged position

When the foot is taken away from the pedal, the set of strong & will move forward to the pressure plate & a contact is made [frictional] the clutch plate and the flywheel with both side friction lining. Due to the friction lining a tight grip is created between the pressure plate & flywheel, thus the power from the driving shaft is transmitted to the driven shaft. And when the pedal is pressed the both shaft got detached from each other & power transⁿ stops.

Torque transmitted

let r_1 = ext. radius of friction lining

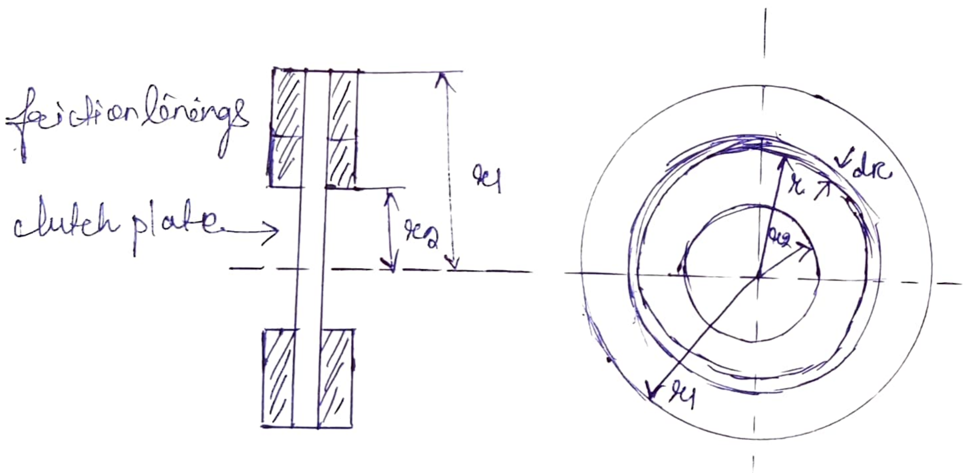
r_2 = int. " "

p = intensity of pressure

W = total axial load.

μ = co-effi. of friction

T = Torque transmitted.



* For a new clutch the intensity of pressure is approximately ~~high over~~ ~~at~~ uniform over the entire surface where in an old clutch the uniform wear theory is more approximate.

Area of the ring $dA = 2\pi r \cdot dr$

Axial load in the ring $dW = p \times 2\pi r \cdot dr$

Frictional force " $dF = \mu \times$ load in the ring

$= \mu \times p \times 2\pi r \cdot dr$.

...ional torque dT = frictional force × Radius

$= dF \times r$

$= \mu p \times 2\pi r\, dr \times r$

$= \mu p\, 2\pi r^2\, dr$

i) For uniform pressure.

p = constant

$= \frac{\text{Load}}{\text{Area}} = \frac{W}{\pi(r_1^2 - r_2^2)}$ (average pressure)

$$T = \int_{r_2}^{r_1} dT = \int_{r_2}^{r_1} \mu p\, 2\pi r^2\, dr$$

$$= 2\pi \mu p \left[\frac{r^3}{3}\right]_{r_2}^{r_1} = 2\pi \mu p \left[\frac{r_1^3 - r_2^3}{3}\right]$$

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

$$\boxed{T = \frac{2}{3}\mu W \left[\frac{r_1^3 - r_2^3}{r_1^2 - r_2^2}\right]} \quad \text{—— (16)}$$

The above torque for a single singe friction plate.

So the total torque on the total clutch plate will be

$$\boxed{T_c = 2T}$$

ii) For uniform wear

$p \times r$ = const.

$p \times r = C$ (∵ $W = 2\pi C(r_1 - r_2)$)

$\Rightarrow p = C/r$

We know $dW = 2\pi r\, dr \times p$

total axial load $W = \int_{r_2}^{r_1} dW = \int_{r_2}^{r_1} 2\pi r\, dr \times \frac{C}{r} = 2\pi C[r_1 - r_2]$

$$\Rightarrow \boxed{C = \frac{W}{2\pi[r_1 - r_2]}}$$

Total frictional torque.

$$T = \int_{r_2}^{r_1} dT = \int_{r_2}^{r_1} \mu \times p \times 2\pi r^2 \, dr$$

$$= \int_{r_2}^{r_1} \mu \times \frac{C}{r} \times 2\pi r^2 \, dr = \int_{r_2}^{r_1} \mu C \times 2\pi r \, . dr$$

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

$$= \mu \times \frac{W}{2\pi (r_1 - r_2)} \times \frac{r_1^2 - r_2^2}{2} \times \pi$$ {putting value of $C = \frac{W}{2\pi(r_1 - r_2)}$}

$$= \frac{\mu \times W}{2} (r_1 + r_2)$$

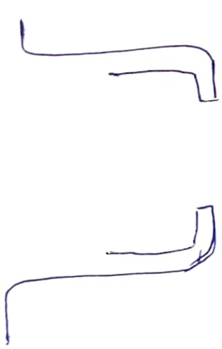
$$\boxed{T = \frac{\mu \times W (r_1 + r_2)}{2}} \quad \text{——— (17)}$$

Total torque on clutch plate $\boxed{T_c = 2T}$

Multiplate clutch

The working & construction is same as the single plate clutch except, the friction lining & disc plate. As the name suggest it contains a no. of friction & disc plate.

diagram.



Torque is same.

$$T = n \times \mu \times W \times \frac{2}{3} \left[\frac{r_1^3 - r_2^3}{r_1^2 - r_2^2} \right]$$

$$T = \frac{n \times \mu \times W \times (r_1 + r_2)}{2}.$$

$n = n_1 + n_2 - 1$

$n_1 \rightarrow$ no. of friction plate

$n_2 \rightarrow$ " " disc.

BRAKES

brake is a mechanical device by means of which artificial frictional [resis]tance is provided or applied to a moving machine, in order to [ret]ard or stop the motion of the machine. The energy absorbed by brake is dissipated in the form of heat. The heat is dissipated to the surrounding air.

The capacity of a brake depends upon the following factors.

- The unit pressure betn the breaking surface.
- The co-efficient of friction betn the breaking surfaces.
- The projected area of the friction surface
- The ability of ~~break~~ brake to relese heat.

Material for brakes

The material used for brake lining should have following characteristic.

- It should have high co-efficient of friction.
- It should have low weare rate.
- It should have high heat resistant.
- It should have enough mechanical strength.
- It should not be effected by moisture & oil.

Some important type of Mechanical brakes are.

1) simple shoe / block brake
2) Double block brake
3) Band brake
4) Internal expanding brake etc.