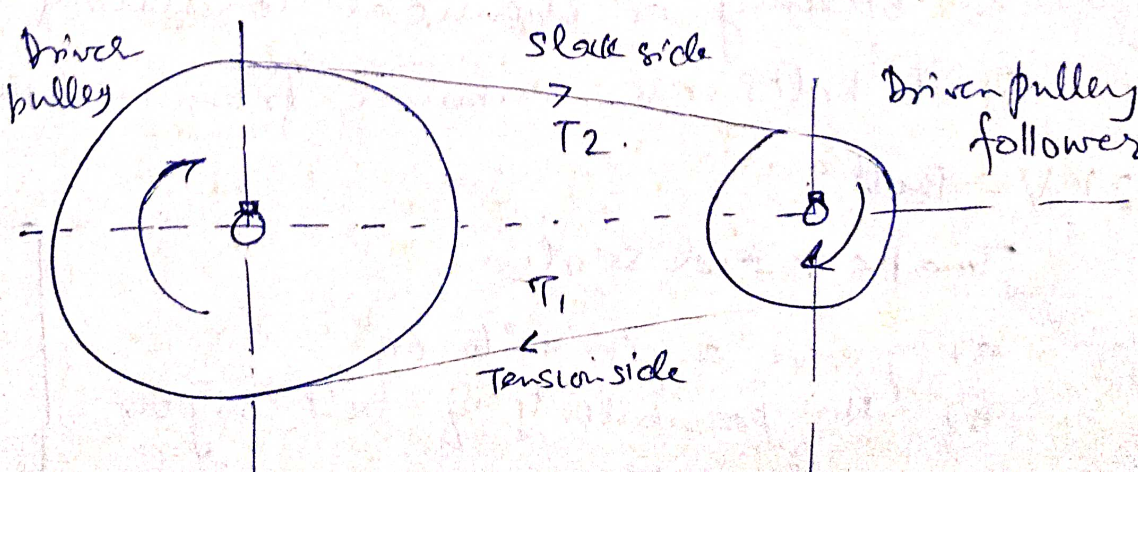
Unit – VI

Power Transmission

In order to transform power from one shaft to another we have;

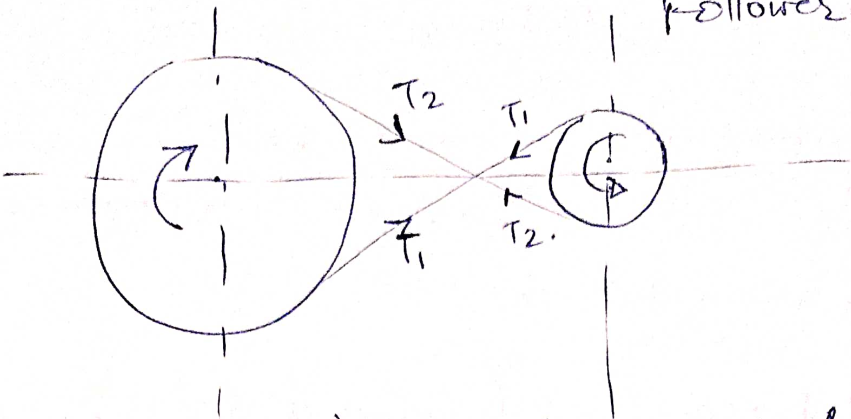
1. Belts & ropes ⇒ Distance is large, such devices are non-rigid & undergo strain while transferring ~~(movement)~~ power, hence called non-positive drive because the possibility of slip is always there
2. Chain drive ⇒ when the distance between two parallel shafts is less & no slip is required.
3. Gears ~~drive~~ ⇒ ~~are~~ when the distance is too short & a constant velocity ratio is desired. for power & mot
4. clutches are used for power transmission between co-axial shafts.

Belt & rope drive; The shafts are fitted with pulle the belt is wrapped round the pulleys & its ends are connected to form an endless connector. The belts & pulley remain in contact by frictional grip.



Cross type

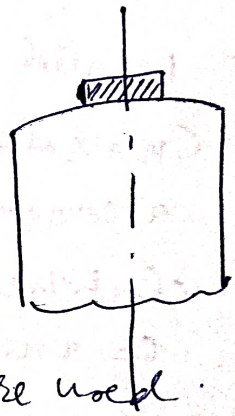
opposite direction



Angle of contact in this system is more & according it can transmit more power than open type, However the belt wears at centre.

Belt Material & sections

1) Flat Belt ; Load carrying capacity depends on it's width.



Material ; Leather

UTS = 4.5 ~ 7 N/m

For heavy duty 2 or 3 ply belts are used.

Can be used in dry & wet places at ordinary temperat

Costly.

Stitched canvas treated with rubber or balatagum

Rubber belts are acid & water proof & are used in steamy or chemical conditions

Steel belts are immune from stretching & slipping

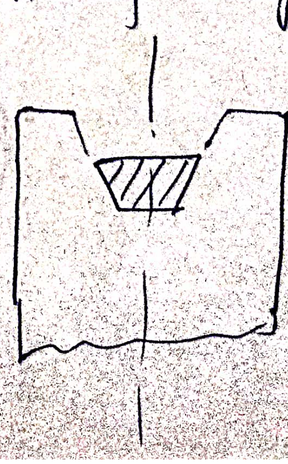
2) V - Belts ;

Trapezoid section

a) groove angle 40° to 60°.

b) No possibility of belt coming out of groove.

c) Short distance & large power.



d). Multiple V-belts for greater power
e) high speed & shock absorber
f). larger reduction in speed possible
g). Initial installation & replacement is easy due to standardisation of V-belts.

h) available in five sections 'A' 'B' 'C, D & E
light load → heavy load

Velocity Ratio

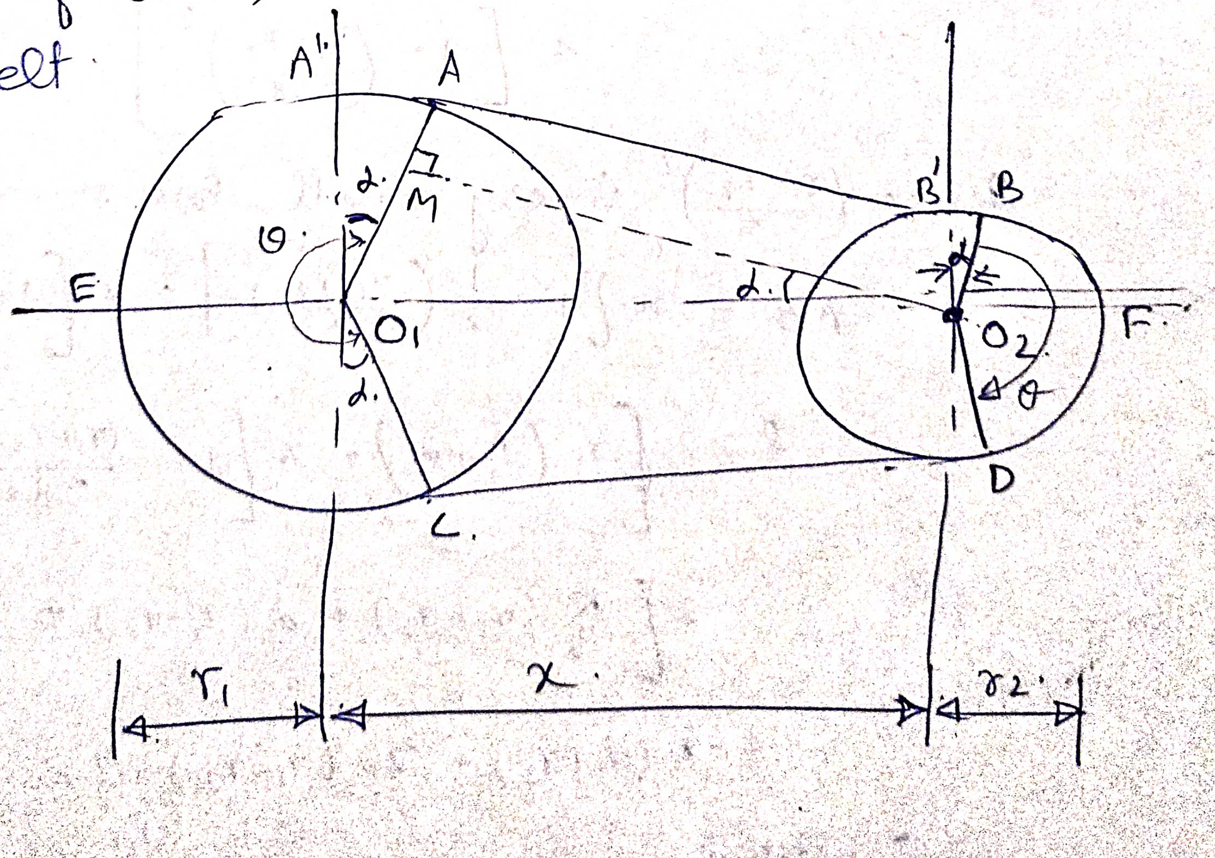
Linear speed of driver = driven

$$\omega_1 \times \frac{d_1}{2} = \omega_2 \times \frac{d_2}{2}.$$

or $$2\pi N_1 \times \frac{d_1}{2} = 2\pi N_2 \frac{d_2}{d} \Rightarrow \boxed{\frac{N_2}{N_1} = \frac{d_1+t}{d_2+t}}$$

Length of Belt ;

1 Open Belt.



$\angle A'O_1A = \angle B'O_2B = \angle O_1O_2M = \alpha$

$\sin\alpha = \dfrac{r_1 - r_2}{x}$

Since 'α' is very small :

$\sin\alpha = \alpha = \dfrac{r_1 - r_2}{x}$.

Length of belt

$l = \text{arc } EA \times 2 + AB \times 2 + \text{arc } BF \times 2$

$\text{arc } EA = r_1 \times \left(\frac{\pi}{2} + \alpha\right)$ & $\text{arc } BF = r_2 \times \left(\frac{\pi}{2} - \alpha\right)$

$AB = MO_2 = \sqrt{(O_1O_2)^2 - (O_1M)^2}$

$= \sqrt{x^2 - (r_1 - r_2)^2}$

$= x\sqrt{1 - \left(\frac{r_1 - r_2}{2}\right)^2}$

$= x\left[1 - \left(\frac{r_1 - r_2}{x}\right)^2\right]^{1/2}$

Since $\left(\frac{r_1 - r_2}{x}\right)^2$ is very small, Binomial expansion ;

$AB = x\left[1 - \frac{1}{2}\left(\frac{r_1 - r_2}{x}\right)^2\right] = x\left[1 - \frac{(r_1 - r_2)^2}{2x}\right]$

$l = 2\left[r_1\left(\frac{\pi}{2} + \alpha\right) + x\left[1 - \frac{(r_1 - r_2)^2}{2x^2}\right] + r_2\left(\frac{\pi}{2} - \alpha\right)\right]$

$= 2\left[\frac{\pi}{2}(r_1 + r_2) + \alpha(r_1 - r_2) + \left\{x - \frac{(r_1 - r_2)^2}{2x}\right\}\right]$

$= \pi(r_1 + r_2) + 2\alpha(r_1 - r_2) + 2x - \frac{(r_1 - r_2)^2}{x}$.

Substituting ; $\alpha = \frac{r_1 - r_2}{x}$ we have ;

$l = \pi(r_1 + r_2) + 2\frac{(r_1 - r_2)}{x} \times (r_1 - r_2) + 2x - \frac{(r_1 - r_2)^2}{x}$

$$\boxed{l = \pi(r_1+r_2) + \frac{(r_1-r_2)^2}{x} + 2x}$$

Round belt

The round x-section belts are employed when low power is to be transmitted such as in instruments, house hold appliances, table top machines etc & machinery of the clothing industry.
These belts are made of leather, canvas & rubber. Their diameter is usually within the range 4mm to 8mm, & the allowable ratio of the diameter of smaller pulley to the belt diameter is about 20.

-

Slip & its effect on VR; when the frictional grip between the belt & pulley becomes insufficient, there occurs some forward motion of the driver without carrying the belt with it. The relative motion between the pulley & belt is called slip. The difference between the linear speeds of the pulley rim & belt is the measure of slip.

Let S_1 = percentage slip between driver & the belt.
S_2 = percentage slip between belt & the follower (driven pulley)

Linear velocity of driving pulley:

$$v_1 = \omega_1 \times \frac{d_1}{2}.$$

Due to slip between the driving pulley & the belt, the velocity of belt will decrease.

Velocity of belt $= v_1 - v_1 \times \frac{S_1}{100} = v_1\left[1 - \frac{S_1}{100}\right]$

This will also be the velocity of belt as it passes over the driven pulley. As there is slip at the driven pulley also, the velocity of the follower pulley will become less.

Linear speed of the driven pulley

$$= v_1\left[1-\frac{S_1}{100}\right] - v_1\left[1-\frac{S_1}{100}\right]\times\frac{S_2}{100}.$$

$$= v_1\left[1-\frac{S_1}{100}\right]\left[1-\frac{S_2}{100}\right].$$

$$= v_1\left[1-\frac{S_1+S_2+0.01S_1S_2}{100}\right].$$

$$= v_1\left[1-\frac{S}{100}\right]$$

$$= \omega_1\times\frac{d_1}{2}\left[1-\frac{S}{100}\right]$$

where $S = S_1+S_2+0.01\,S_1S_2$ is the percentage of total effective slip.

The linear speed of the driven pulley is also given by;

$$v_2 = \omega_2\times\frac{d_2}{2}.$$

$$\therefore\ \omega_2\times\frac{d_2}{2} = \omega_1\times\frac{d_1}{2}\left[1-\frac{S}{100}\right]$$

or $$\frac{\omega_2}{\omega_1} = \frac{d_1}{d_2}\left[1-\frac{S}{100}\right]$$

or $$\frac{2\pi N_2}{2\pi N_1} = \frac{d_1}{d_2}\left[1-\frac{S}{100}\right]$$

or VR ; $$\frac{N_2}{N_1} = \frac{d_1}{d_2}\left[1-\frac{S}{100}\right]$$

It is apparent from the above equation that the VR decreases due to slipping of belt.

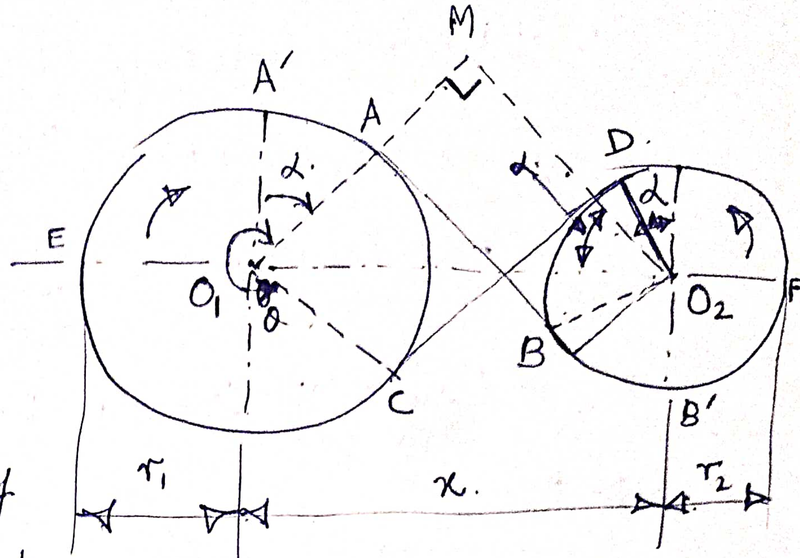
If thickness of 't' of the belt is taken into consideration

$$\boxed{\frac{N_2}{N_1} = \frac{d_1+t}{d_2+t} \times \left[1 - \frac{S}{100}\right]}$$

Creep; When the belt passes from the slack side to the tight side a certain portion of the belt extends & when the belt passes from the tight to slack side the belt contracts. Due to these changes in length, there is relative motion between the belt & pulley surfaces. The relative motion is termed as creep of the belt. Like slip, creep also reduces the velocity of the belt drive system.

Length of Belt;

2) Cross belt System



→ Driving & driven wheel rotate in opposite direction

The belt leaves the bigger pulley at 'A' & 'C' & the smaller pulley at 'B' & D. A line O_2M drawn parallel at AB will be perpendicular to ~~O_1A~~ O_1A also.

$$\angle A'O_1A = \angle B'O_2B = \angle O_1O_2M = \alpha,$$

$$\sin\alpha = \frac{O_1M}{O_1O_2} = \frac{O_1A + AM}{O_1O_2} = \frac{r_1+r_2}{x}$$

$O_1M = O_1A + AM = r_1 + r_2$

$AM \parallel BO_2$

& $AM = BO_2 = r_2$.

Since 'α' is very small;

$$\sin\alpha = \alpha = \frac{r_1+r_2}{x}$$

Length of Belt;

$$l = 2(\text{arc } EA + AB + \text{arc } FB)$$

$$\text{arc } EA = r_1\left(\frac{\pi}{2}+\alpha\right) \text{ \& arc } FB = r_2\left(\frac{\pi}{2}+\alpha\right).$$

$$AB = MO_2 = \sqrt{(O_1O_2)^2 - (O_1M)^2} = \sqrt{x^2 - (r_1+r_2)^2}$$

$$= x\sqrt{1-\left(\frac{r_1+r_2}{x}\right)^2} = x\left[1-\left(\frac{r_1+r_2}{x}\right)^2\right]^{1/2}$$

Thru Binomial Expansion

$$AB = x\left[1-\frac{1}{2}\left(\frac{r_1+r_2}{x}\right)^2\right]$$

$$= x\left[1-\frac{(r_1+r_2)^2}{2x^2}\right]$$

$$\therefore\ l = 2\left[r_1\left(\pi/2+\alpha\right) + x\left\{1-\frac{(r_1+r_2)^2}{2x^2}\right\} + r_2\left(\pi/2+\alpha\right)\right]$$

$$= 2\left[\pi/2\,(r_1+r_2) + \alpha(r_1+r_2) + \left\{x - \frac{(r_1+r_2)^2}{2x}\right\}\right].$$

$$= \pi(r_1+r_2) + 2\alpha(r_1+r_2) + 2x - \frac{(r_1+r_2)^2}{x}$$

Substituting the value of $\alpha = \frac{r_1+r_2}{x}$ we get;

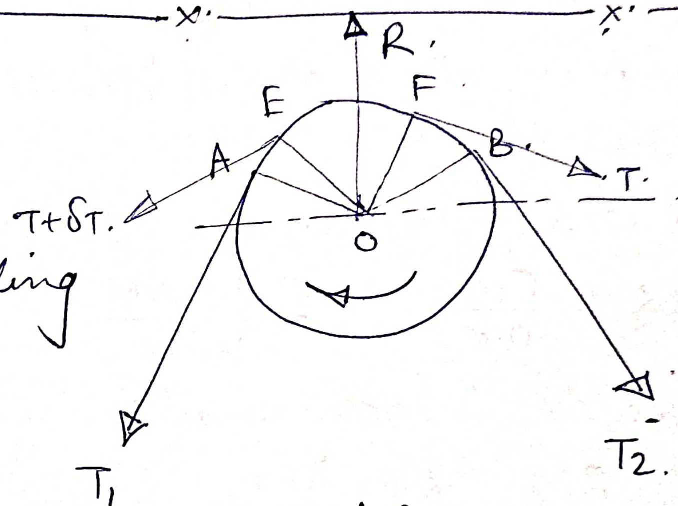
$$l = \pi(r_1+r_2) + 2\left(\frac{r_1+r_2}{x}\right)\times(r_1+r_2) + 2x - \frac{(r_1+r_2)^2}{x}$$

$$\boxed{l = \pi(r_1+r_2) + \frac{(r_1+r_2)^2}{x} + 2x}$$

→ Length of Crossed belt is higher than that of open belt.

→

Ratio of Tensions;



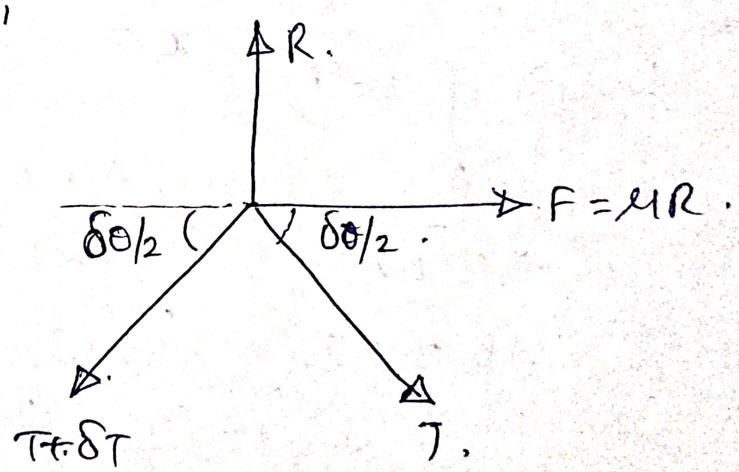
Tension $T_1 > T_2$

When the motion is impending (About to start)

$\angle AOB = \theta$

$\angle EOF = \delta\theta$

Angle of Contact or Angle of lap; $\theta = AOB$.



Considering small element EF;

1) Tension 'T' acting tangentially at 'F'.

2). Tension $(T+\delta T)$ acting tangentially at 'E'

3). Normal reaction 'R' exerted by the pulley rim.

4). Friction force; $F = \mu R$; acts against the tendency to slip & is perpendicular to normal reaction 'R'

Considering Equillibrium of forces in the radial(vertical) direction;

$$R = (T+\delta T)\sin\frac{\delta\theta}{2} + T\sin\frac{\delta\theta}{2}$$

For small values of $\delta\theta$; $\sin\frac{\delta\theta}{2} \to \frac{\delta\theta}{2}$.

Hence;

$$R = (T+\delta T)\times\frac{\delta\theta}{2} + T\times\frac{\delta\theta}{2}.$$

$$\Rightarrow \quad R = T\times\frac{\delta\theta}{2} + \delta T\times\frac{\delta\theta}{2} + T\times\frac{\delta\theta}{2}.$$

Since $\delta T\times\frac{\delta\theta}{2}$ is very small hence can be neglected.

$$R = T\times\frac{\delta\theta}{2} + T\times\frac{\delta\theta}{2}$$

$$\boxed{R = T\times\delta\theta}.$$

Resolving tangentially (horizontal);

$$\mu R = (T+\delta T)\cos\frac{\delta\theta}{2} + T\cos\frac{\delta\theta}{2}$$

For $\delta\theta$ being very small; $\cos\frac{\delta\theta}{2} \to 1$.

$$\mu R = (T+\delta T)\times 1 - T\times 1.$$

$$\Rightarrow \quad \boxed{R = \frac{\delta T}{\mu}}.$$ Equating; $T\times\delta\theta = \frac{\delta T}{\mu}$.

Seperating variables;

$$\mu.\delta\theta = \frac{\delta T}{T}.$$

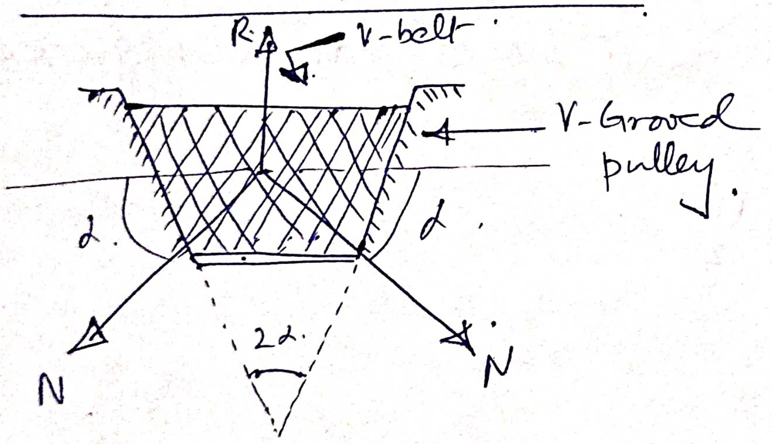
Now Integrating from T_2 to T_1 & 0 to θ for limits;

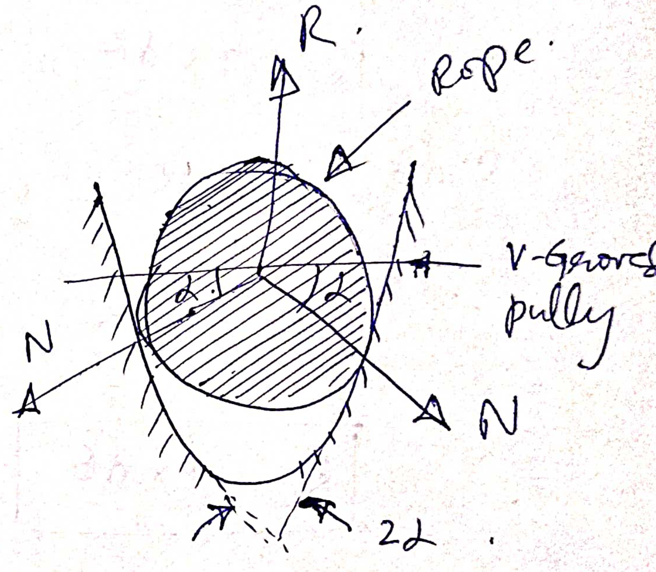
$$\int_{T_2}^{T_1} \frac{\delta T}{T} = \mu \int_0^{\theta} \delta\theta$$

$$\Rightarrow \boxed{\log_e \frac{T_1}{T_2} = \mu\theta} \quad \text{or} \quad \boxed{\frac{T_1}{T_2} = e^{\mu\theta}}$$

→ When '2' pulley of unequal diameters are connected by open belt drive, the slip occurs first on the smaller pulley where the force of friction is less.

V-belt & rope drive;





Considering equillibrium between 'R' & 'N', we have;

$$R = N\sin\alpha + N\sin\alpha = 2N\sin\alpha$$

$$N = \frac{R}{2\sin\alpha} = \frac{R}{2}\operatorname{cosec}\alpha$$

Friction reaction;

$$\text{Friction resistance} = \mu N + \mu N = 2\mu N = 2\mu \times \frac{R}{2}\operatorname{cosec}\alpha$$

$$= \mu R \operatorname{cosec}\alpha$$

We know that;

$$R = (T + \delta T)\sin\frac{\delta\theta}{2} + T\sin\frac{\delta\theta}{2}$$

$R = \frac{T\delta\theta}{2} + \frac{\delta T \cdot \delta\theta}{2} + \frac{T\delta\theta}{2}$ (Since $\delta\theta$ is small)

$R = T.\delta\theta$

Also; $\mu R \operatorname{cosec}\alpha = (T + \delta\theta)\cos\frac{\delta\theta}{2} - T\cos\frac{\delta\theta}{2}$

$= (T + \delta T) - T$ Since $\frac{\delta\theta}{2}$ is small hence $\cos\frac{\delta\theta}{2} \to 1$.

$\mu(T\delta\theta)\operatorname{cosec}\alpha = \delta T \cdot$ Since, $R = T\delta\theta$

or $(\mu \operatorname{cosec}\alpha)\,\delta\theta = \frac{\delta T}{T}$.

$\mu \operatorname{cosec}\alpha \int_0^{\theta} \delta\theta = \int_{T_2}^{T_1} \frac{\delta T}{T}$.

or $(\mu \operatorname{cosec}\alpha) \times \theta = \log_e \frac{T_1}{T_2}$

or $\boxed{\frac{T_1}{T_2} = e^{\mu \operatorname{cosec}\alpha\,\theta}}$

Power Transmitted;

Effective Turning Force $= (T_1 - T_2)$

WD = force x distance moved

$\boxed{WD = (T_1 - T_2) \times V}$ Nm/s where $V \Rightarrow$ velocity of belt

Power $= (T_1 - T_2)V$ in watts.

Gears & Gear Drive.

A toothed wheel or gear is essentially a wheel with teeth cut on its periphery.

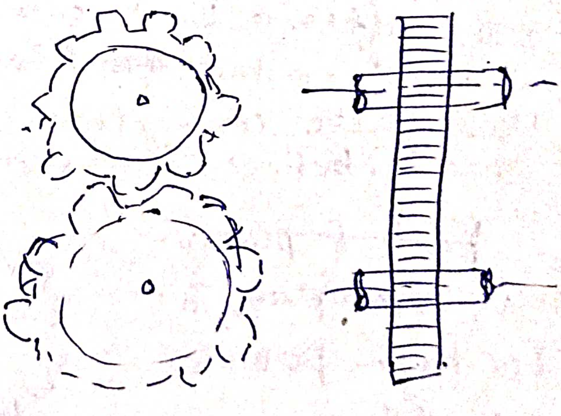
Power or motion is transmitted from one shaft to another with gear drive when;

→ Centre distance are relatively short
→ Speed of the shaft is low & the use of belt drive is not recommed.
→ positive drive is necessary i.e. VR is fixed.
→ No need to stepup or step down the speed.
→ High torque is to be transmitted
→ precise timing is required.

The gear of drive has a compact layout & it provides a highly efficient & reliable service.

Types of Gear.

1) spur gear;



Cylinderical gear having SL teeth parallel to gear axis

The axes are parallel & Co-planer.

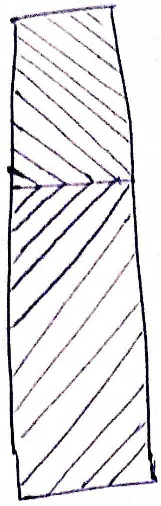
Efficiency 96-98%.

Sliding gears used for speed changing mechanism in gear boxes of lathe.

Noisy, wear out readily & develop backlash.

Helical gears :-

Cylindrical gear whose tooth traces are straight helices.
Teeth are inclined at an angle of the gear axis. Teeth are thus helical or screw form. This ensures smooth action & accurate maintenance of VR.
Used in automobiles where Large power is transmitted



Axes are parallel & co-planer

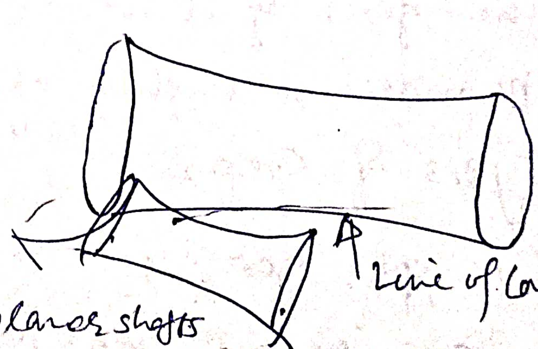
Bevel Gear :-

~~Bevel gear~~
The bevel gear wheels conforming of cones having a common vertex; tooth traces are straight line generators of the cone.
Shafts are at right angles & the wheels are equal in size are called mitre gears.

Axes are coplaner but intersecting

Spiral Geare :-

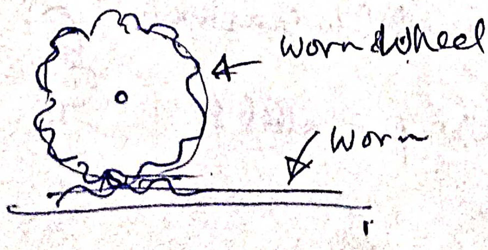
Identical to helical gears with difference ~~the~~ these gears are have pt. contact ~~than line contact~~.
Used where connection is to be made between intersecting & n-coplaner shafts



~~Rack & pinion~~

Worm Gear :-

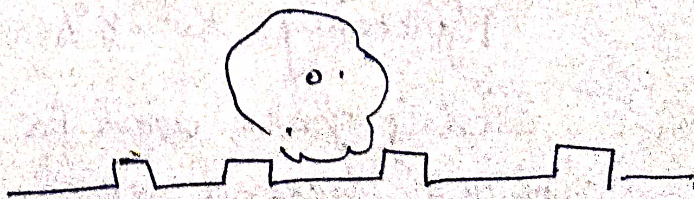
For high power reduction 10:1



Shafts are Non parallel
Non-intersecting at right angles.

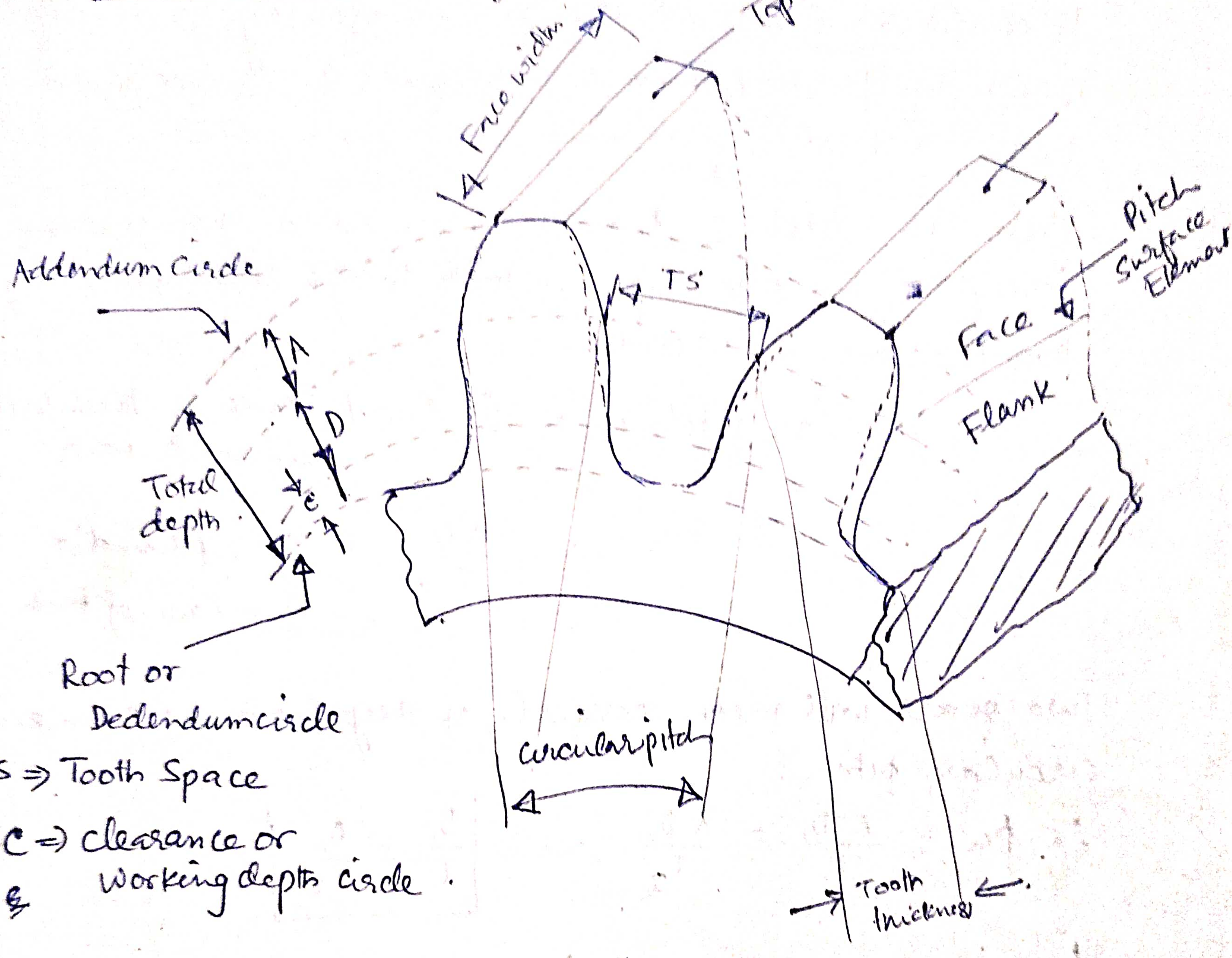
Rack & Pinion :-

~~Rack & pinion~~
Rack is a SL spur gear of infinite diameter. It meshes both internally & externally.



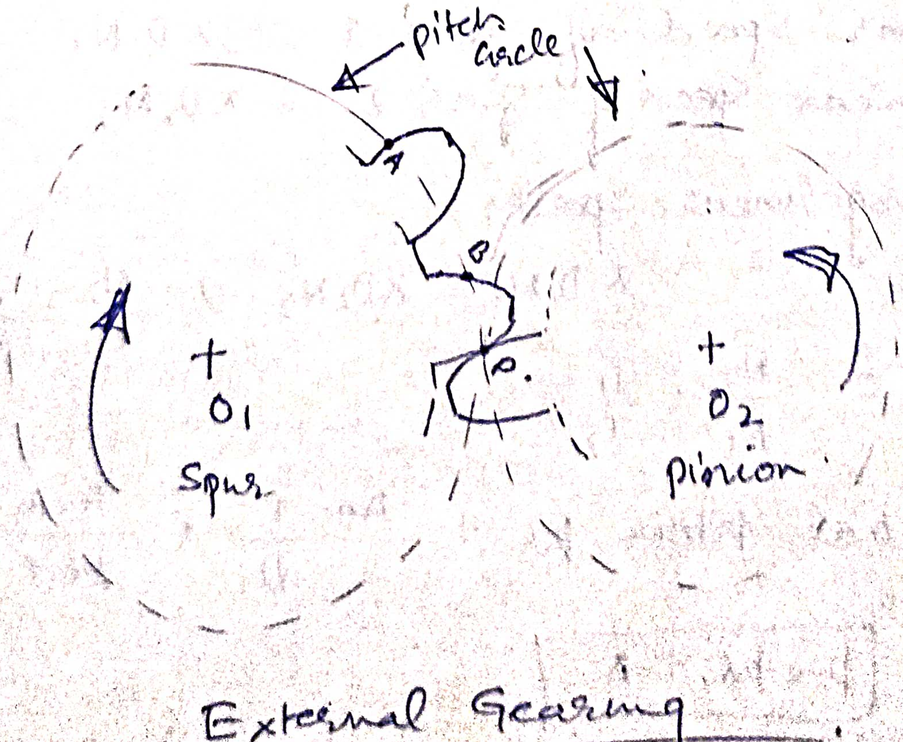
Internal & External gearing

Gear Terminology



TS ⇒ Tooth Space

C ⇒ clearance or working depth circle.



External Gearing

Pitch circle is essentially an imagenery circle which by pure rolling action gives the same motion as the actual gear.

Circular Pitch; Distance measured on the circumference of the pitch of one tooth to the corresponding point on the next tooth.

$$\text{circular pitch } p_c = \frac{\text{Circumference of pitch circle}}{\text{number of teeth}}$$

$$= \frac{\pi D}{T}.$$

$D \Rightarrow$ pitch dia
$T \Rightarrow$ no. of teeth.

Two gears will mesh correctly if they have the same circular pitch.

$$\therefore p_c = \frac{\pi D_1}{T_1} = \frac{\pi D_2}{T_2} \Rightarrow \boxed{\frac{D_1}{T_1} = \frac{D_2}{T_2}}$$

Linear speed of gear 1 $= \pi D_1 N_1$
Linear speed of gear 2 $= \pi D_2 N_2$.

Equating linear speeds;

$$\pi D_1 N_1 = \pi D_2 N_2 \Rightarrow \frac{N_2}{N_1} = \frac{D_1}{D_2}.$$

$$VR = \frac{N_2}{N_1} = \frac{T_1}{T_2}.$$

$$\text{Diametral pitch } p_d = \frac{T}{D} = \frac{\text{Teeth}}{\text{pcd}}.$$

$$\Rightarrow \boxed{p_c \times p_d = \pi}.$$

Module ; Ratio of pcd (mm) to no. of teeth ;
Module is reciprocal of diametral pitch.

$$\text{Module } m = \frac{D}{T}.$$

Addendum circle ; circle bounding outer ends of teeth & concentric with pitch.
Addendum => radial distance between pitch circle & addendum circle.
Dedendum => Circle ; Circle bounding the bottom of the tooth & concentric with pitch circle.
Dedendum =>. The radial distance between the pitch circle & the dedendum circle is called dedendum.

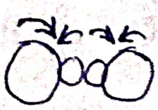
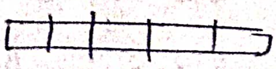
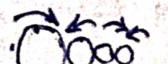
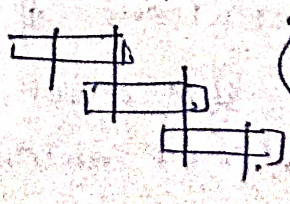
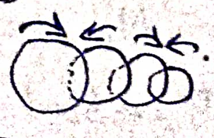
Working depth equals the sum of addends of the two mating gears. The radial distance from the top of tooth to the bottom of tooth is called clearance.
The standard value of clearance equals 0.157 m where 'm' is the module.
Then ;

$$\text{Dedendum} = \text{Addendum} + \text{clearance}$$
$$= m + 0.157\,m$$
$$= 1.157\,m.$$

Addendum equals module & is always less than dedendum.

Types of ~~gle~~ gear Trains ;

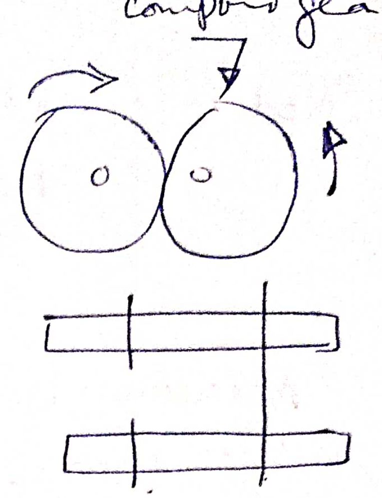
$$\boxed{\text{Train Value} = \frac{N_4}{N_1} = \frac{T_1}{T_4}}$$

1) Simple  
2) Compound   
~~3) Reverted~~.
~~4) Epicyclic~~.

$$\boxed{VR = \frac{N_1}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}} \quad \boxed{\frac{N_1}{N_2} \times \frac{N_3}{N_4} \times \frac{N_5}{N_6}}$$

$$\frac{D_1+D_2}{2} = \frac{D_3+D_4}{2} \quad D_1+D_2 = D_3+D_4$$

Compound gear



Reverted Gear Train

When First (driver) & Second (driven) are on the same axis.

Speed Ratio $\frac{N_1}{N_4} = \frac{T_2 \times T_4}{T_1 \times T_3}$.

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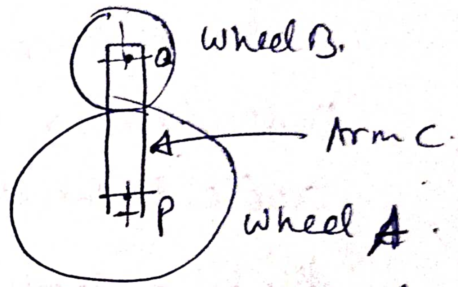
(4) Epicyclic gear

$$\boxed{\frac{N_B}{N_C} = 1 + \frac{T_A}{T_B}}$$



In simple & compound gear trains, the axis of the wheel remain fixed relative to one another. The epicyclic gear train is a special type of gear train in which axis of rotation of one or more of the two wheels is carried on an arm & this arm is free to rotate about the axis of rotation of one or the other wheels in the train.

· Gear 'A' & arm 'C' can rotate about the axis at 'P'. The gear 'B' meshes with gear 'A' & has its axis of rotation on the arm at 'Q'.

When the gear 'A' is fixed & the arm 'C' is made to rotate about 'P' the gear 'B' would be forced to roll around the outside of the gear 'A'.

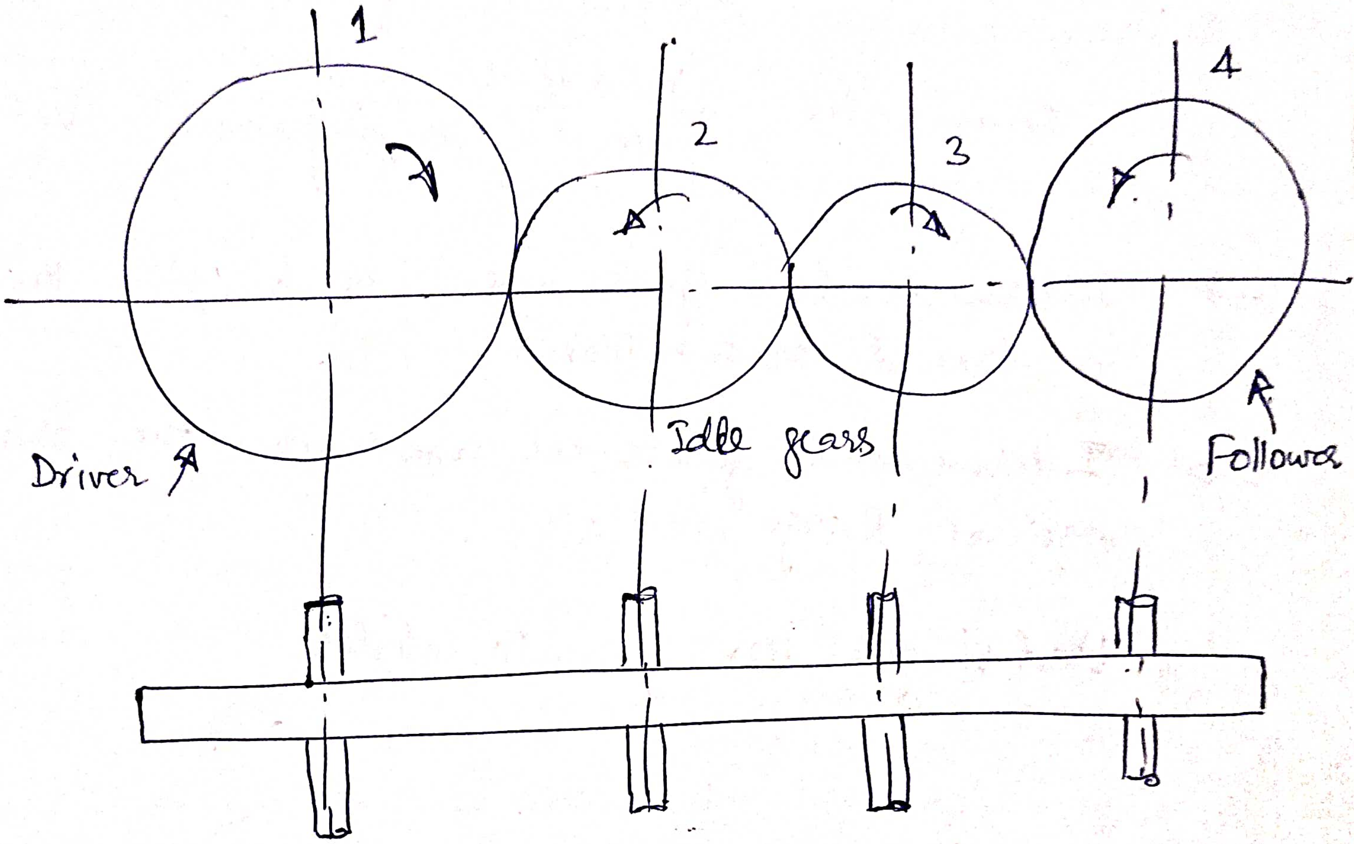
With 'Nc' revolutions of the arm, the gear wheel 'B' rotates about it's axis by speed N_B:

e.g. Wrist watches, automobiles, hoists & pulley blocks

Gear Trains :- Combination of gear wheels by means of which power & motion is transmitted from one shaft to another :-

Types :-

① Simple gear Train :-



For Gear No - 1 & 2 ; $\frac{N_1}{N_2} = \frac{T_2}{T_1}$

For Gear No 2 & 3 $\frac{N_2}{N_3} = \frac{T_3}{T_2}$

For Gear No 3 & 4 $\frac{N_3}{N_4} = \frac{T_4}{T_3}$.

&- ~~Similarly for gear~~ Speed Ratio is given by ;

~~Gear~~ $\frac{N_1}{N_2} \times \frac{N_2}{N_3} \times \frac{N_3}{N_4} = \frac{T_2}{T_1} \times \frac{T_3}{T_2} \times \frac{T_4}{T_3}$

$$\boxed{\frac{N_1}{N_4} = \frac{T_4}{T_1}}$$

→ Speed Ratio is independent of intermediate or idle gears teeth

$$\text{Speed ratio} = \frac{\text{Speed of driving wheel}}{\text{Speed of ~~follower~~ wheel}} = \frac{\text{Teeth of driven wheel}}{\text{Teeth of driver wheel}}$$

→ Train value is reciprocal of Speed or velocity Ratio.

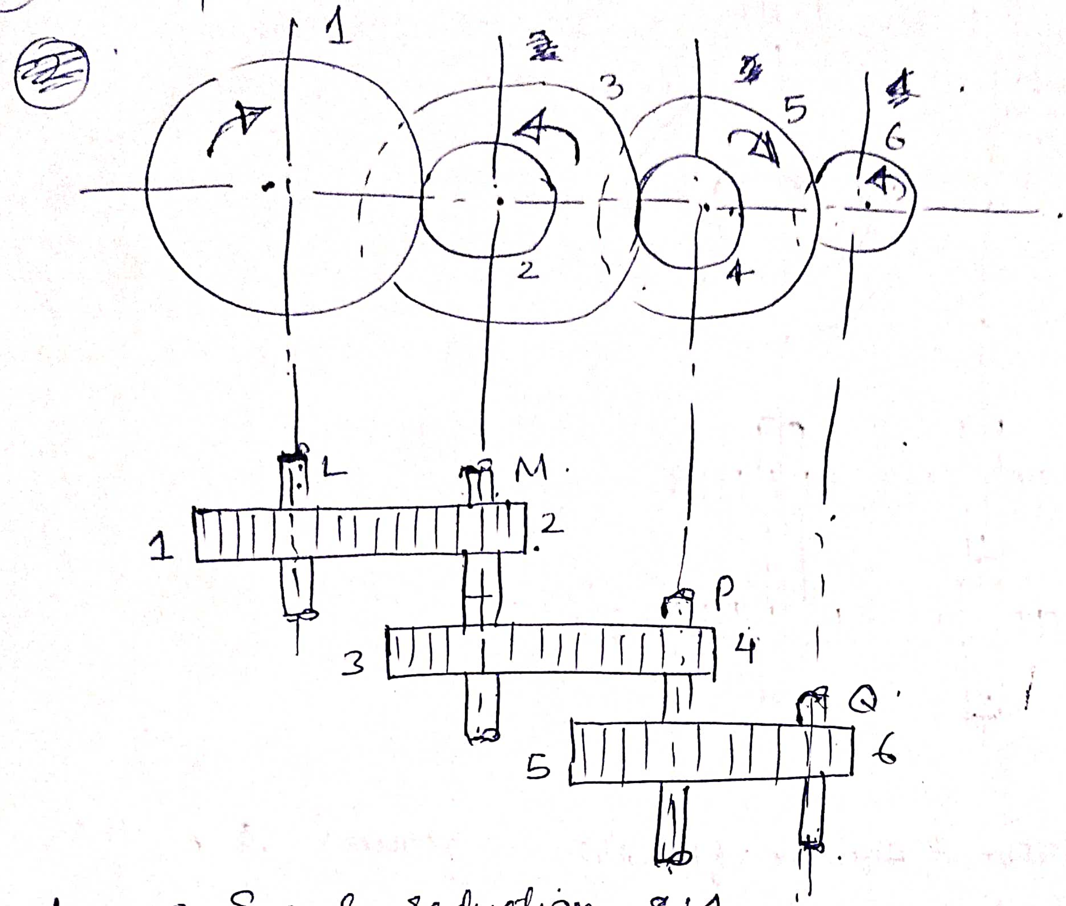
$$\text{Train value} = \frac{\text{Speed of driven wheel}}{\text{Speed of driving wheel}} = \frac{\text{Teeth of driving wheel}}{\text{Teeth of driven wheel}}$$

→ Intermediate gears are used to give the motion in desired orientation.

→ Intermediate gears are used when the shafts are at large distance.

Used in gear box of automobiles.

(2) Compound Gears :-



→ Large Speed reduction 8:1
Two wheels are mounted on the same shaft which are identified by 'M' & 'P'

$$\frac{N_1}{N_2} = \frac{T_2}{T_1} \; ; \quad \frac{N_3}{N_4} = \frac{T_4}{T_3} \quad \& \quad \frac{N_5}{N_6} = \frac{T_6}{T_5}.$$

Speed ratio ;

$$\frac{N_1}{N_2} \times \frac{N_3}{N_4} \times \frac{N_5}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}.$$

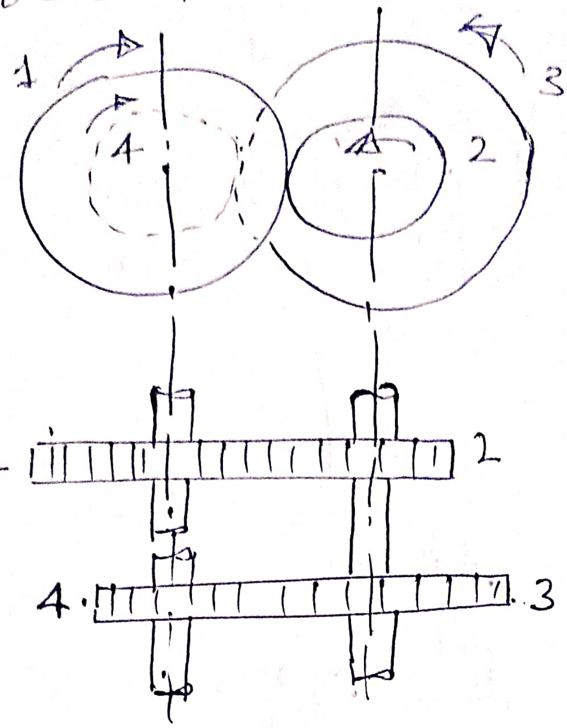
Gears '2' & '3' are mounted on the same shaft hence;

$N_2 = N_3$. & Similary; $\boxed{N_4 = N_5}$

hence VR; $\frac{N_1}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}$.

$= \frac{\text{Product of teeth on driven}}{\text{Product of teeth on drivers.}}$

(3) Reverted Gear Train :-



Driving & driven are shafts are co-axial & in the same direction

Centre distance between the shafts is equal : Hence;

$$\frac{D_1 + D_2}{2} = \frac{D_3 + D_4}{2} \Rightarrow \boxed{D_1 + D_2 = D_3 + D_4}$$

Hence; $\boxed{T_1 + T_2 = T_3 + T_4}$.

Assuming circular pitch or module of all the gear wheels is same.

Speed Ratio ; $\frac{N_1}{N_4} = \frac{\text{no. of teeth on drivers}}{\text{no. of teeth on drivers}} = \frac{T_2 \times T_4}{T_1 \times T_3}$

Hour hand to minute hand is connected by reverted gear train.

CLUTCH

Clutch is a connection between the driving and driven shafts with the provision to disconnect the driven shafts instantaneously as and when desired by the operator. The clutch can engage or disengage the two shafts either by a hand operated device or automatically by some power driven device.

The clutches are used mostly in automobile practice when the vehicle has to be stopped for a while with the engine still running. The clutch also permits gradual engagement of the fast running engine to the stationary wheel and thus ensure smooth start to the vehicle. Further, a clutch permits easy engagement of the different gears.

What is a friction clutch ?

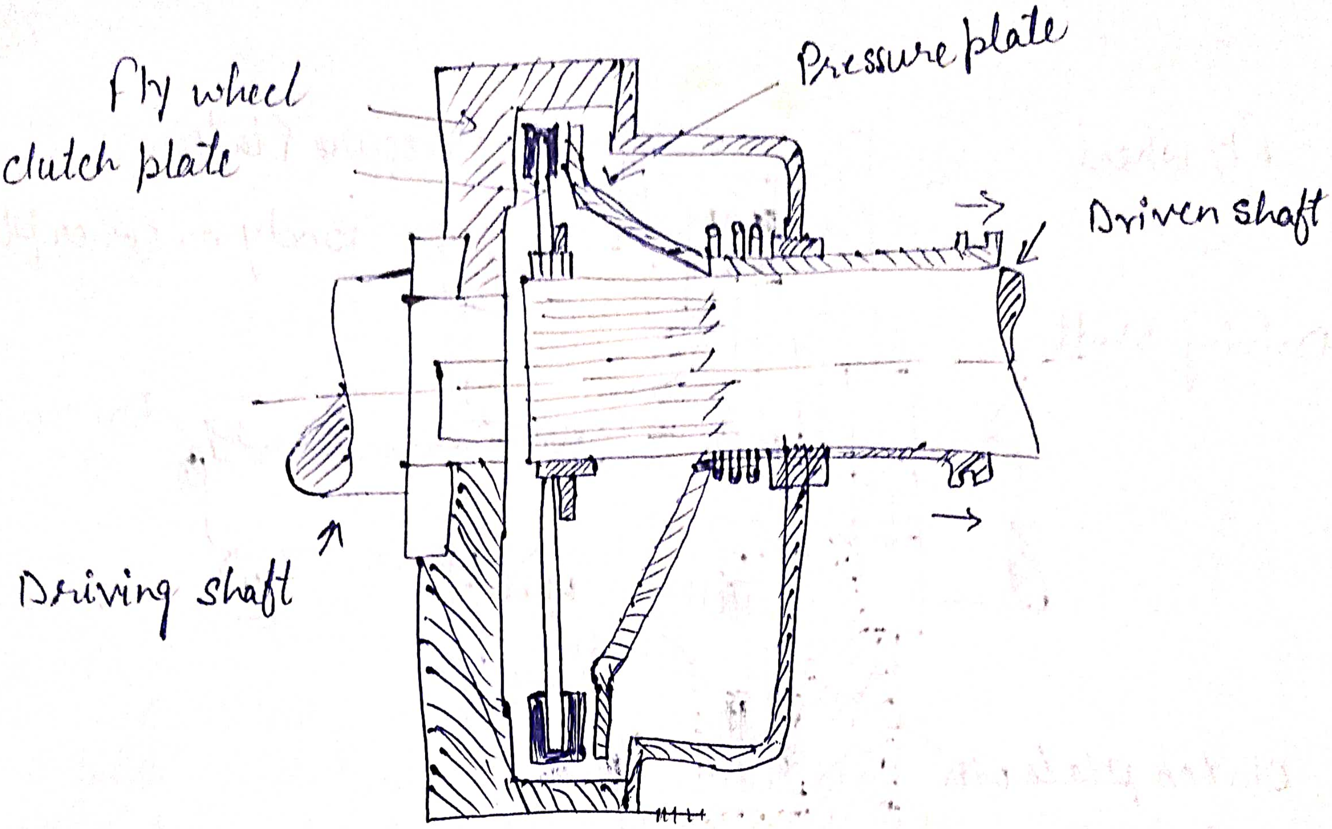
A friction clutch ~~transmits~~ transmits the power by friction without shock. It is used where sudden and complete disconnection of two rotating shafts are necessary, and the shafts are in axial alignment. Frictional surfaces may be conical or cylindrical or in the form of disc.

A single plate clutch essentially consists of three main parts: the driving plate or flywheel, clutch plate or driven plate, and the pressure plate. The clutch plate can be regarded as the "cheese between the sandwich", the flywheel and the pressure plate representing the two pieces of bread. Essentially it consists of a steel plate whose both sides are

(2) lined with a friction material. The success of the clutch largely depends on the constitution of friction material. The clutch permits a certain amount of slip on engagement. Friction caused by slipping generates heat which would tend to burn any material used for clutch lining. The basis of most clutch lining is asbestos suitably bonded with gum or resin. A wire is sometimes included in the bonding process to increase the resistance to wear. The clutch plate is mounted on a hub which is splined from inside and is thus free to slide over the shaft of gear box. There are springs arranged circumferentially, which provide axial force to keep the clutch in engaged position. A pedal is provided to pull the pressure plate against the spring force whenever it is required to be disengaged.

The clutch is a disengaged or withdrawn by forcing the pressure plate against the springs. This is achieved by pressing the clutch pedal down by foot. The set of springs get compressed and this action removes the pressure from the clutch plate. There is then no contact between the clutch plate and the pressure plate, and the clutch plate moves away from the flywheel. The friction linings on the clutch plate ar free of contact with the pressure plate as well as the fly wheel. Even though the flywheel and the pressure plate may be rotating, the clutch plate (and hence the driven shafts remains stationary.)

(3.)



Single plate clutch disengaged

The clutch is engaged when the foot is taken off from the clutch pedal. The set of springs force the pressure plate to bring it in contact with the clutch plate which is attached to the hub. The hub moves axially along the splines of the driven shaft. The clutch plate gets tightly gripped between the pressure plate and the flywheel. The friction lining on one side of the clutch plate is in contact with the pressure plate whereas the friction lining on the other side of the clutch plate is squeezed against the flywheel. Due to the tightly gripping of clutch plate between the pressure plate and flywheel, the clutch plate and hence the driven shaft starts rotating. A certain amount of slip always occurs before the clutch is fully engaged. This is done intentionally so that the drive will be taken up without shock.

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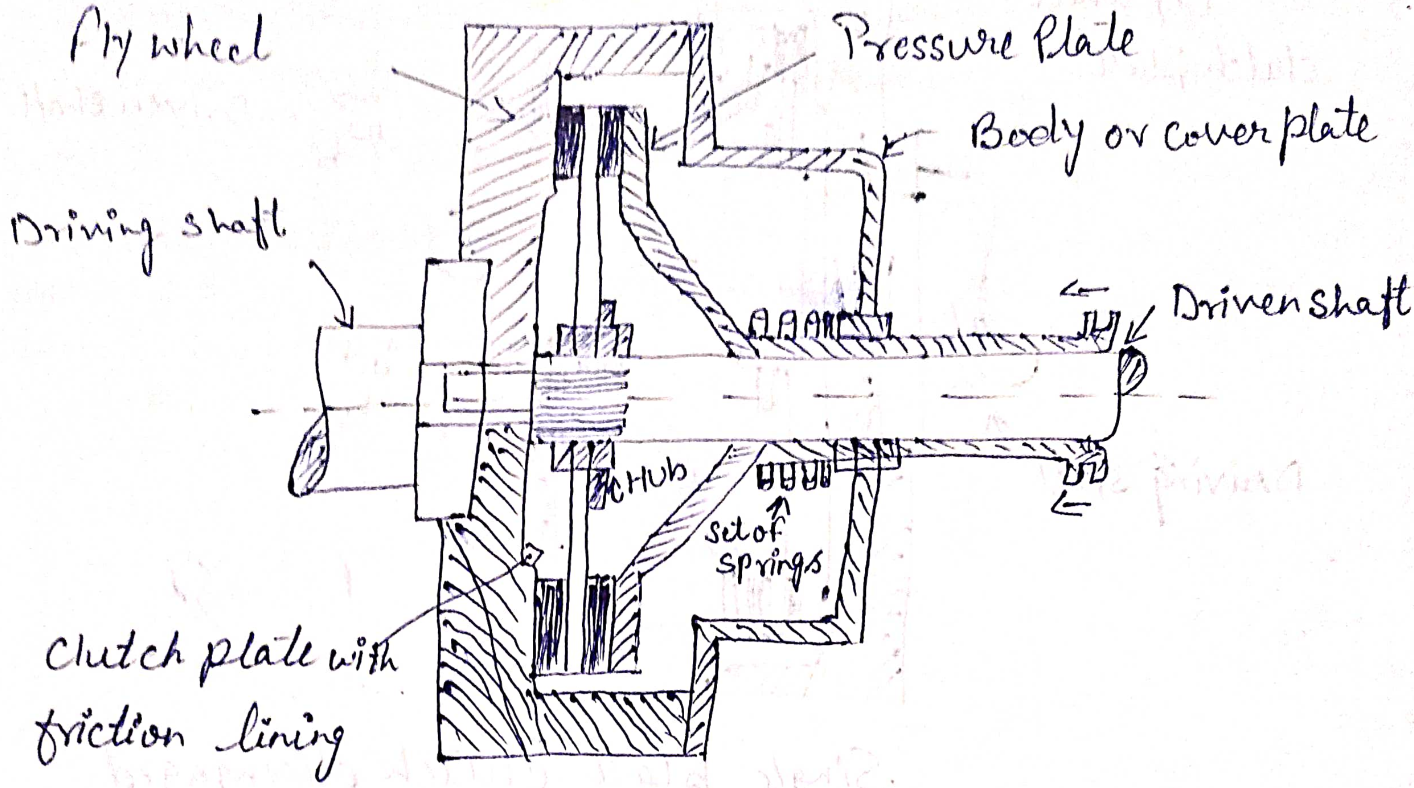


Single plate clutch engaged

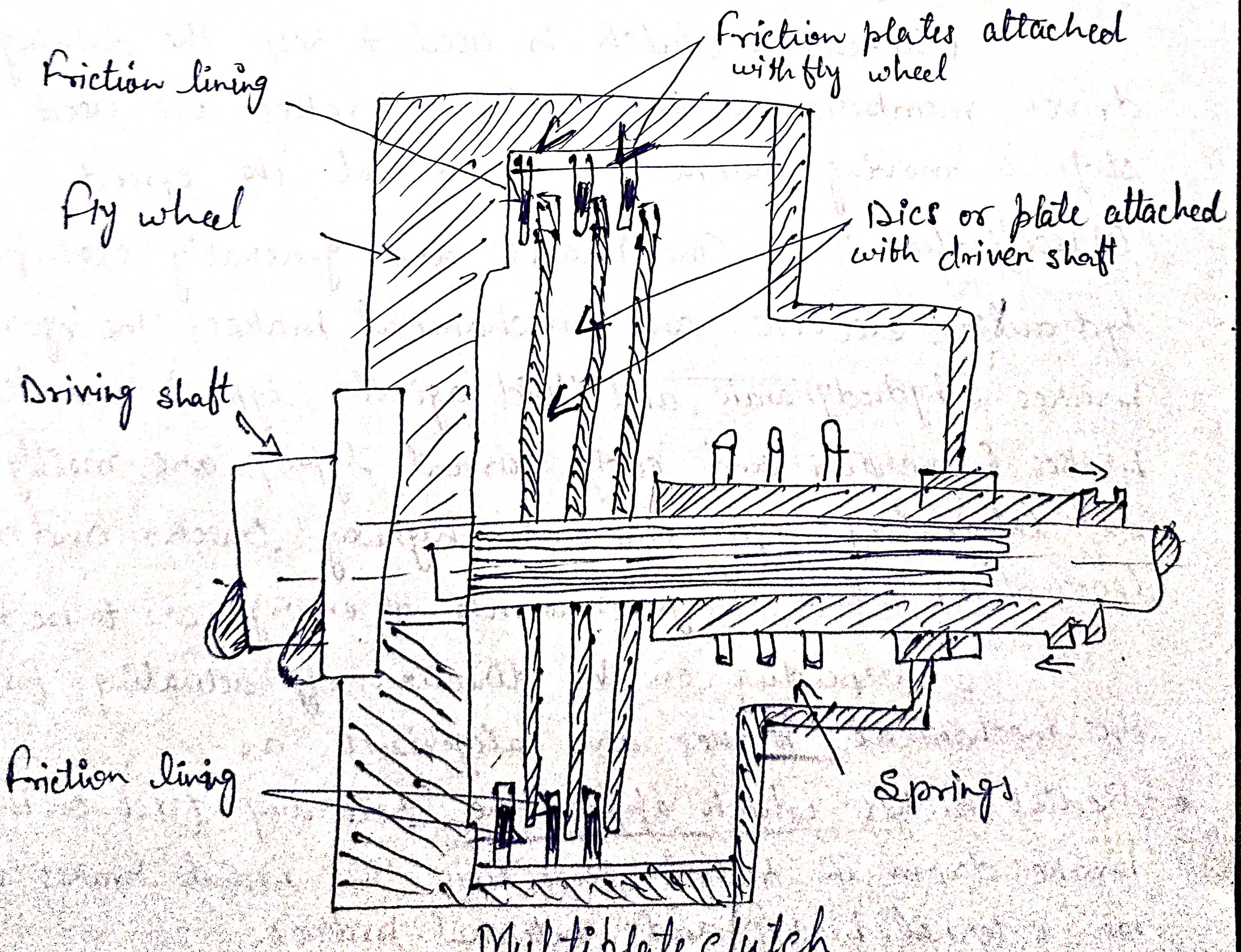
Multiplate Clutch

When more torque is to be transmitted such as in heavy transport vehicles and racing cars, use is made of multiple clutch in which the number of friction surfaces is increased. The unit essentially consists of

- Friction plates which have friction lining on both sides. However the plate adjacent to the flywheel has friction lining only on the side away from the flywheel. These friction plates are attached at the top and to the flywheel and are also free to move axially. These plates rotate with the flywheel and hence with driving shaft.

Discs or plates which are supported on splines of the driven shafts. These plates are located in between the friction plates and can slide axially.

The position of the friction plates and disc plates in disengaged position. when the foot is taken off from the clutch pedal, the set of springs press the disc into contact with the friction plates. There is tight gripping between the flywheel, the friction plates and the discs, and the whole assembly rotates as one unit. Hence the power is transmitted from the flywheel (driving shaft) to the driven shaft upon which are mounted the dics.



Multiplate clutch

(6) BRAKES

A brake is a device that brings a moving body to rest or holds the body in a state of rest against the action of external forces. Essentially, when the brakes is applied, it offers fricitional resistance to an element of the moving machine. The brake then absorbs the kinetic energe of motion. Consequently the motion of the machine is either retarded or stopped. The kinetic energy absorbed by the brakes gets converted into heat that is dissipated either to the surroundings or to the water that is circulated through passages in the brake drum. The heat is dissipation is necessary to avoid excessive heating of the brake lining.

Whereas a clutch is used to keep the driving and driven members moving together, brakes are used to stop a moving member or to control its speed.

Classification: The brakes are generally classified as hydraulic, electric and mechanical brakes. The hydraulic brakes (hydrodynamic and fluid agitator type) and electric brakes (generator and eddy current type) are mostly used in laboratory dynamometers. highway trucks and electric locomotives where large amounts of energy are to be absorbed.

Depending on the direction of actuating force, the mechanical brakes are categorized as-

- Redial brakes which apply the retarding force on the brake drum in redial direction. The redial brakes may be external brakes and internal brakes.

Further, depending on the shape of friction element, these brakes are subdivided into block or shoe brakes and band brakes.

- Axial brakes where in the force acting on the brake drum is in axial direction. Further, these brakes may be of the type disc brakes and cone brakes.

The classification of the brakes has been diagrammatically shown below.

Brake
- Friction brakes
  - Disc brakes
  - Drum brakes
    - Single block or shoe brake
    - Band brake
    - Band and block brake
    - Internal expanding brake
- Fluid brakes
  - Hydraulic brakes
  - Air brakes
- Electric brakes

The different types of friction brakes have been briefly discussed in the following paragraphs.

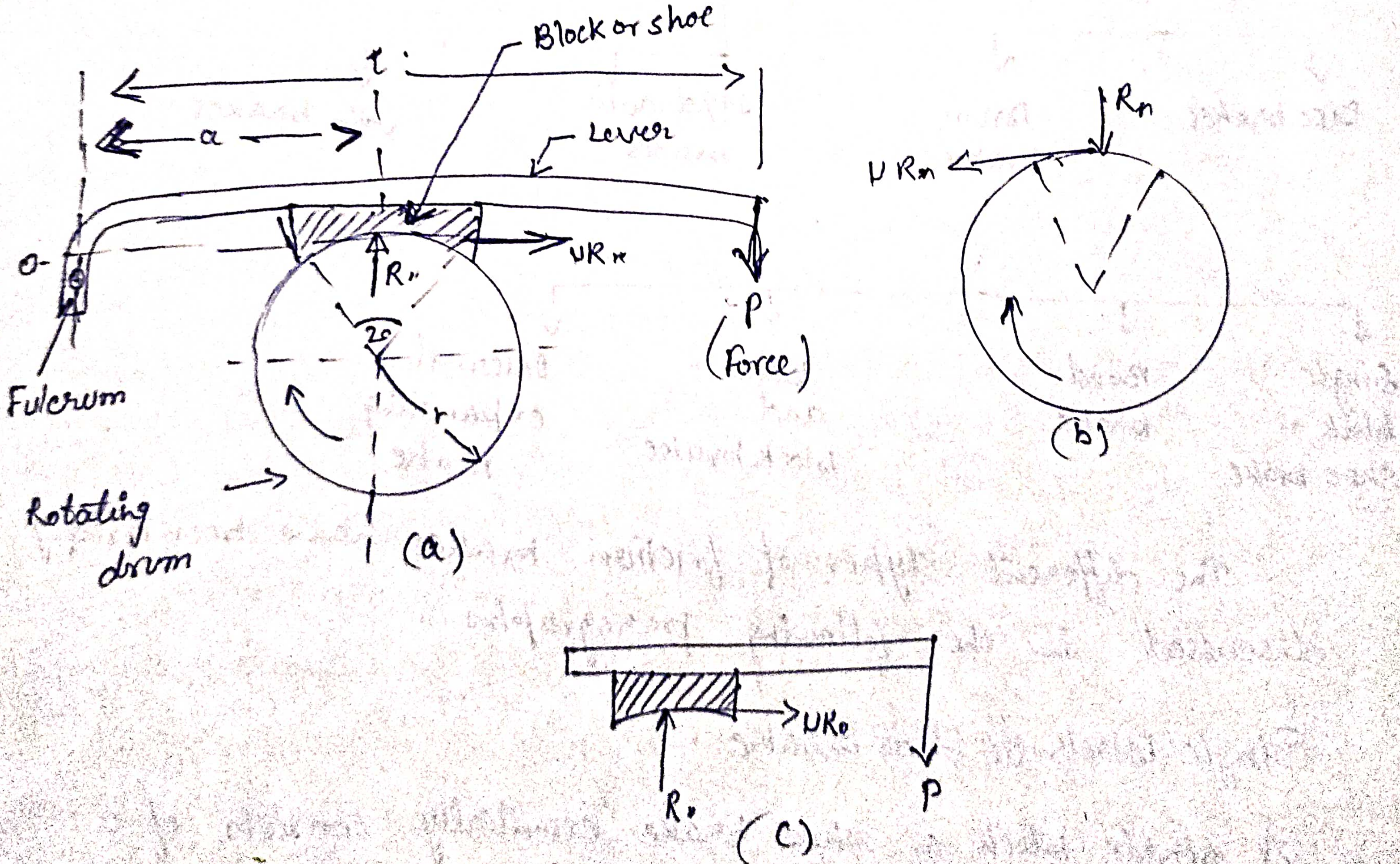
Single Block or Shoe Brake –

A single block or shoe brake essentially consists of a block or shoe which is pressed against the rotating drum. The block is rigidly fixed to a lever which has one end

(8)

pivoted to a fixed fulcrum and the other end free.
The block is made of a material that is softer than that of the drum. This aspect helps to easily replace the block as and when it wears out. Wood and rubber blocks are used with light and slow moving vehicles. For heavy and flat vehicles, the block is generally made of cast steel.

When force is applied at free end of the lever the block gets pressed against the rotating drum. The block exterts a redial force or the drum, this force passes through the centre of drum. The friction between the block and drum sets up a braking force and that retards / stops the motion of drum.



Single block or Shoe brake

(9.)

The figure shows the arrangement of shoe brake where the drum/wheel has a clockwise rotation and the line of action of frictional force passes through fulcrum of the lever. Let

P = force applied at the end of the lever
R_n = normal force pressing the block
μ = coefficient of friction
r = radius of wheel, and
F_t = frictional force acting at contact surface of the block.

The frictional force on the drum will be acting anti-clockwise i.e in a direction opposite to that of its motion. The frictional force on the block will be opposite to the direction of the frictional force on the drum. Hence the frictional force on the block will be in the clockwise direction, i.e., in the same direction in which the drum is rotating.

If the angle 2θ made by contact surface of the block at the ~~time~~ centre of the drum is less than 60°, it can be assumed that the normal reaction between the block and drum is uniform. Then

frictional force on the drum $F_t = \mu R_n$

Braking torque T_b = frictional force × radius

$= \mu R_n r$

Calculations for the braking torque can be made if the normal reaction R_n on the block is known. For that we consider equilibrium between the following set of forces acting on the block:

(i) normal reaction, R_n

(ii) frictional force, μR_n and

(iii) applied force, P

Taking moments of these forces about the fulcrum point O, we can write

$$\sum M_O = P \times l - R_n \times a$$
$$= 0 \text{ for equilibrium}$$

(clock wise moment +ve)

The frictional force passes through the fulcrum and hence its moment is zero.

$$\therefore \quad R_n = \frac{Pl}{a}$$

when this value of R_n is substituted in expression we get

$$\text{Braking torque } T_b = \mu \left(\frac{Pl}{a}\right) r = \frac{\mu P l r}{a}$$

The braking torque will be same even when the wheel rotates anti clockwise.

When the angle of contact is greater than 60°, the block or shoe is pivoted to the lever and the braking torque is given by

$$T_b = \mu' R_n \times r = \mu' \left(\frac{Pl}{a}\right) r$$

where μ' is the equivalent cofficient of friction defined as

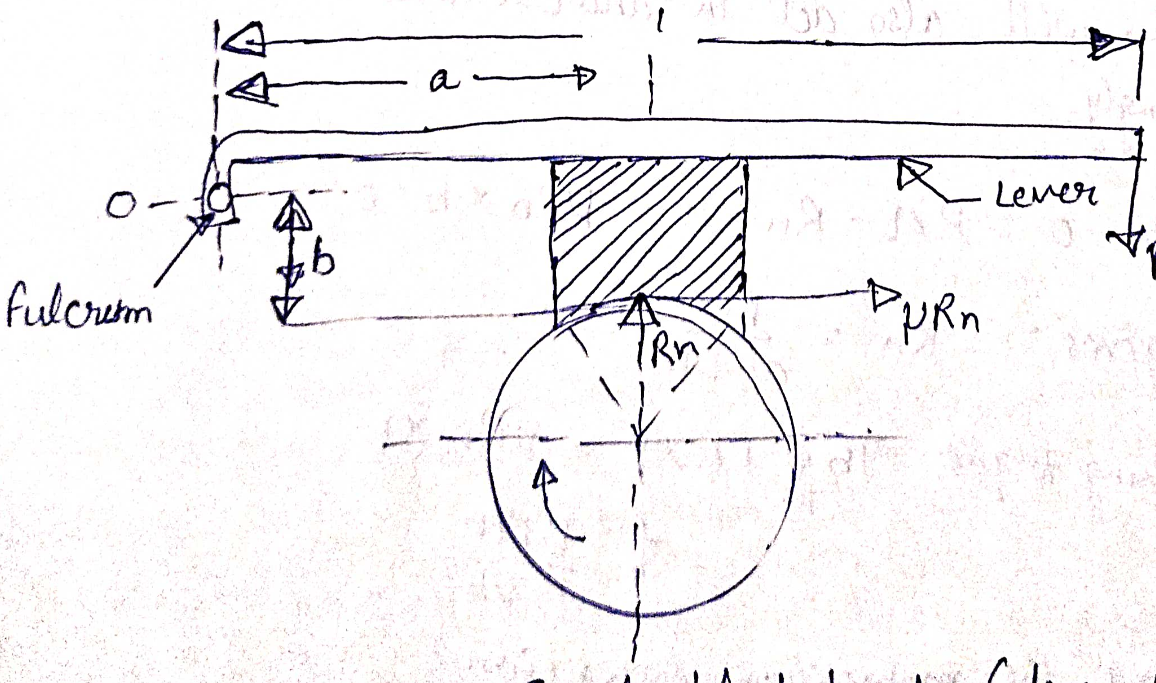
$$\mu' = \frac{4\mu \sin\theta}{2\theta + \sin 2\theta} \quad ; \quad \mu \text{ is actual coefficient of friction}$$

It is not necessary that the line of action of the frictional force should pass through the fulcrum point. The line of action of the friction force may be at a definite distance below or above the fulcrum point.

Case 1: Brake drum rotates clockwise and the line of action of frictional force is at a distance b below the fulcrum point.

The forces acting on the block are: R_n, $F_t = \mu R_n$, and P. Considering equilibrium and taking moments about the fulcrum point O, we have

$$\Sigma M_O = 0 : \; P \times l - R_n \times a - \mu R_n \times b = 0$$



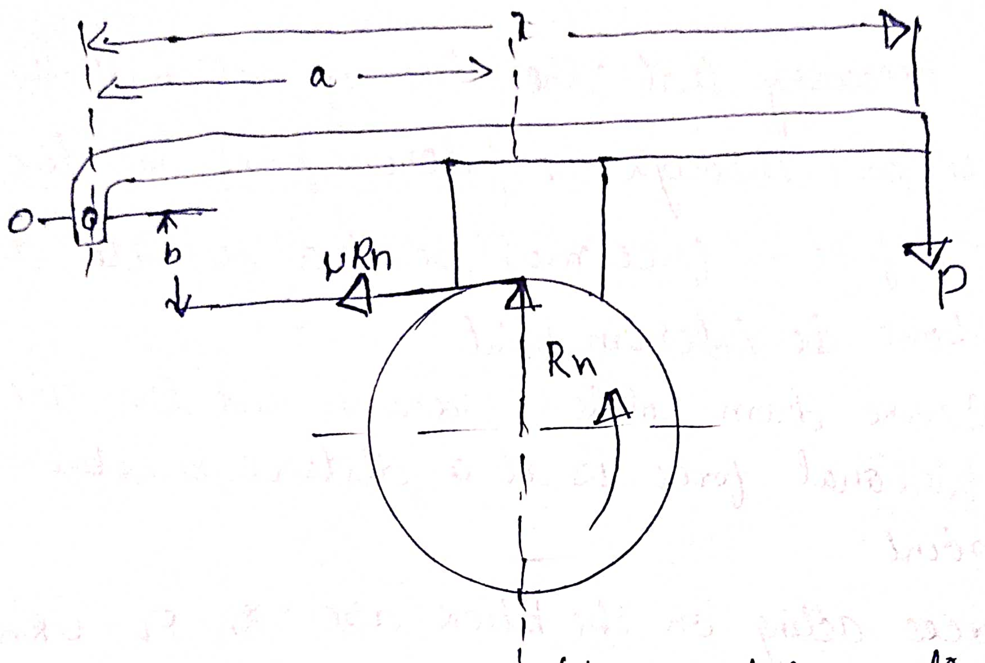
Single block brake (drum rotates clockwise)

That gives,

$$R_n = \frac{Pl}{a + \mu b}$$

$\therefore$ Braking torque $T_b = F_t \times r = \mu R_n \times r$

$$= \frac{\mu P l r}{a + \mu b}$$



Single block brake (drum rotates anti clockwise)

If the drum is rotating anti clockwise, then the frictional force μR_n will also act in anti clockwise direction. Accordingly

$$\Sigma M_O = 0 : P \times l - R_n \times a + \mu R_n \times b = 0$$

That gives : $R_n = \frac{Pl}{a - \mu b}$

$\therefore$ Braking torque $T_b = F_t \times r = \mu R_n \times r$

$$= \frac{\mu P l r}{a - \mu b}$$

Rewritinging the momentum equation

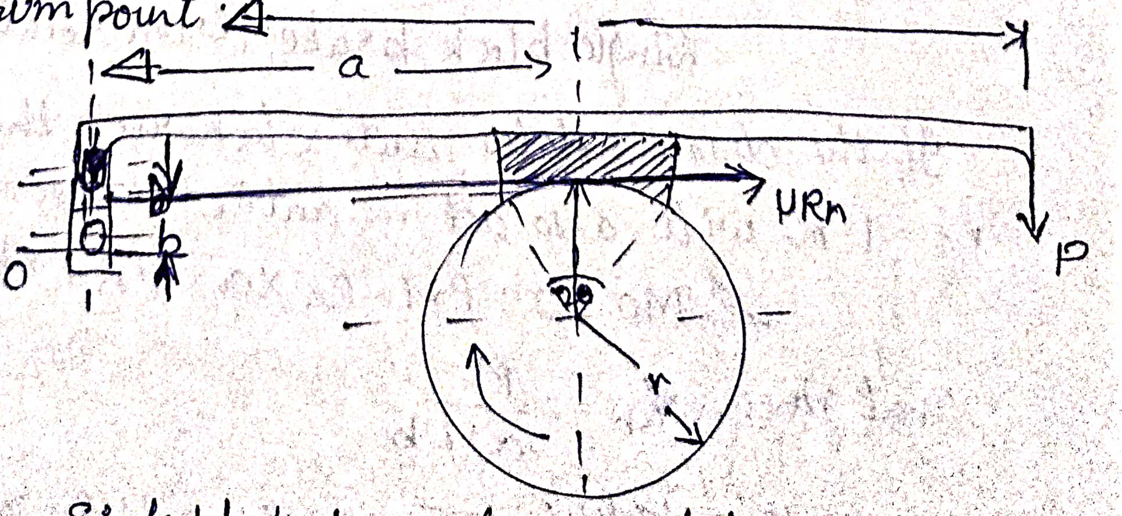
$$R_n \times a = P \times l + \mu R_n \times b$$

It is noticed that moment of frictional force ($\mu R_n \times b$) adds to the moment of force (Pl) and as such the frictional force helps to apply the brake. Such brakes are reffered to as self-energizing brakes. When the frictional force is great enough to apply the brake with no external force, then the brake is called self locking brake.
The expression indicates that if $a \leq \mu b$, then P will be negative or equal to zero. This implies that no external force is needed to apply and hence the brake is self-locking. Accordingly the condition for the brake to be self locking is

$$a \leq \mu b$$

For effective operation, the brake should be self-energizing and not self-locking. In order to avoid self-locking and prevent the brake from grabbing a is kept greater than μb.

Case 2-: Brake drum rotates clockwise and the line of action of frictional force is at a distance b above the fulcrum point.



Single block brake (drum rotates clockwise)

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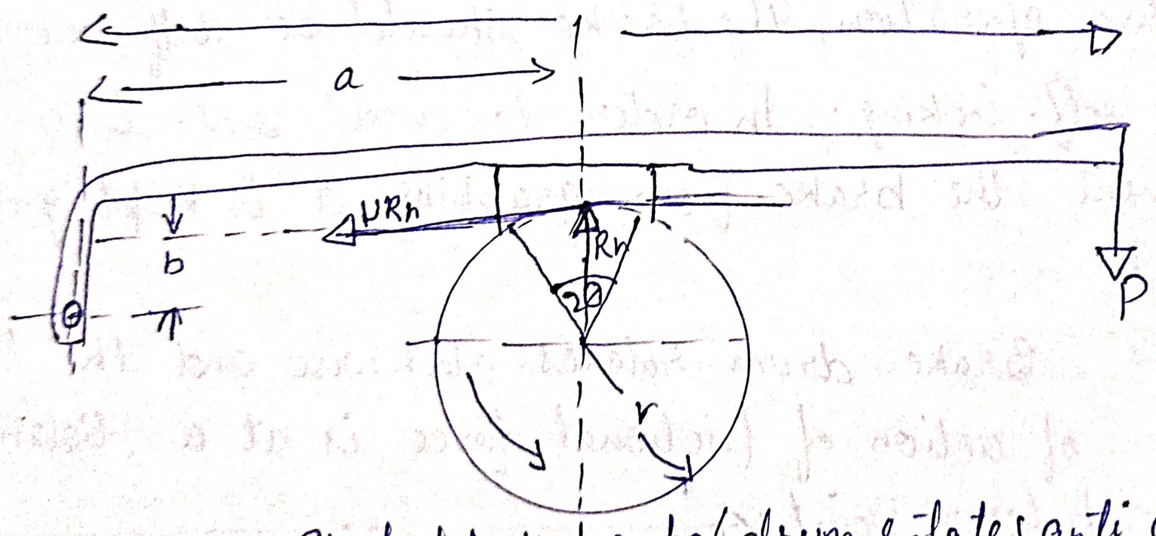
The forces acting on the block are : R_n, $F_t = \mu R_n$, and P.
Considering equilibrium and taking moments about the fulcrum point, O, we have

$$\Sigma M_O = 0 : P \times l - R_n \times a + \mu R_n b = 0$$

That gives $R_n = \frac{Pl}{a - \mu b}$

$\therefore$ Braking torque $T_b = F_t \times r = \mu R_n \times r = \frac{\mu P l r}{a - \mu b}$

This arrangement too has the tendency to provide the self-energy action. To avoid self-locking and to prevent the brake from grabbing, a is kept greater than μb.



Single block brake (drum rotates anti clockwise)

If the drum rotates anti clockwise, the the frictional force $F_t = \mu R_n$ will also act in anti clockwise direction. Accordingly,

$$\Sigma M_O = 0 : P \times l - R_n \times a - \mu R_n \times b = 0$$

That gives $R_n = \frac{Pl}{a + \mu b}$

$\therefore$ Braking torque $T_b = F_t \times r = \mu R_n \times r = \frac{\mu P l r}{a + \mu b}$

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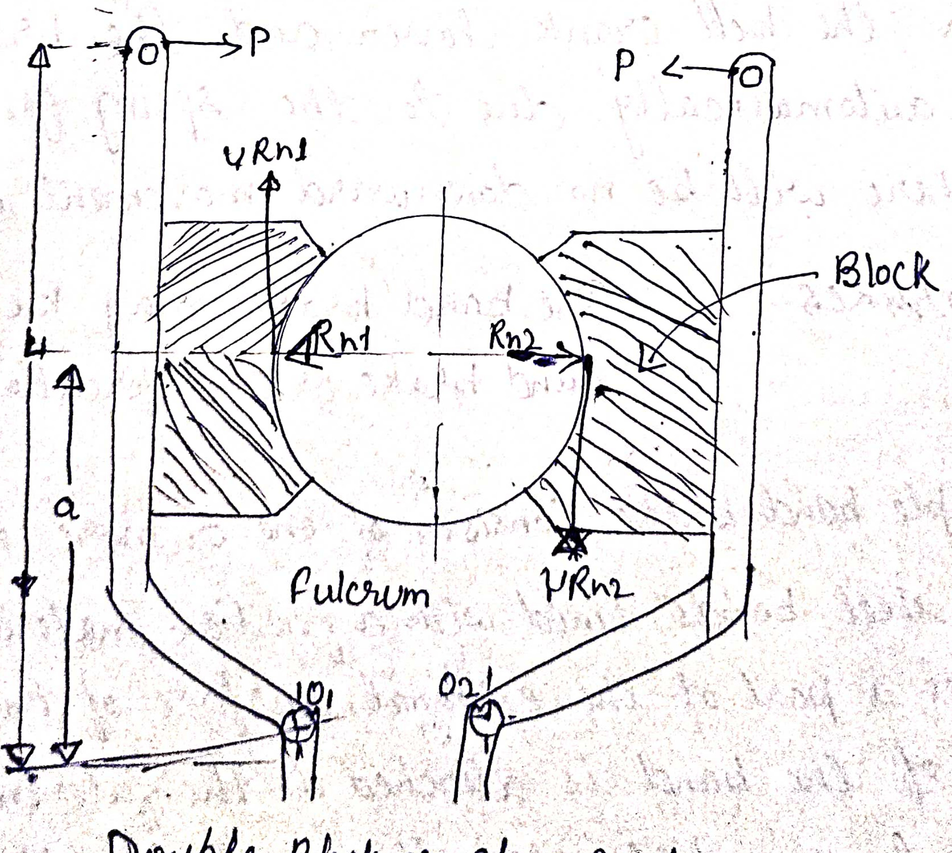
Double Block or Shoe Brake

When pressure is applied by pressing the single block (shoe) against the rotating drum, there is side thrust in the shaft bearings because of additional load due to the normal force. This produces bending of the shaft. To counterbalance the side thrust two blocks are used opposite to each other. The brake is set by a spring which pulls the upper ends of the brake arms together. When force is applied to the bell crank lever, the spring is compressed and the brake is released.



Double Block or Shoe Brake

In the double block brake, the braking torque becomes two times, and it is given by

$$T_b = (F_{t1} + F_{t2})r = (\mu R_{n1} + \mu R_{n2})r$$

The value of normal reaction R_{n1} is obtained by taking moments of forces R_{n1}, μR_{n1} and P about fulcrum O_1. Likewise, the value of R_{n2} is worked out by taking the moments of forces R_{n2}, μR_{n2} and P about fulcrum O_2.

This type of brake is often used in electric cranes and the force P is produced by an electromgnet or solenoid. When the current is swithed off, there is no force on the bell crank lever and the brake is engaged automatically due to the spring force. Apparently then, there will be no downward movement of the load.

Band Brakes- The band brake may be a simple band brake or a differential band brake.

The simple band brake consists of one or more ropes, belts or flexible steel bands lined with a friction material. The unit embraces a part of the external surface of the brake drum. One end of the band is attached to the fulcrum (or fixed pin) of the lever, while the other end is attached to the lever at a point that lies at a known distance from the fulcrum pin.