Machine DESIGN II

Lecture 2

Brakes

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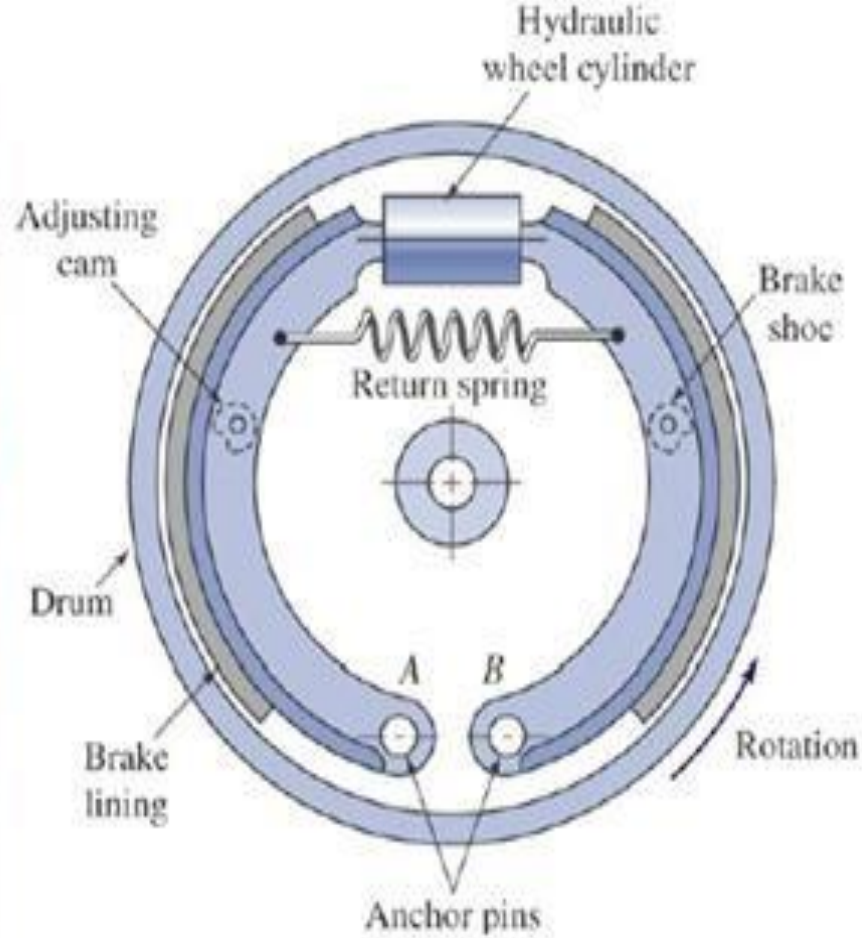
Brakes are machine elements that absorb either kinetic or potential energy in the process of slowing down or stopping a moving part.

Brake capacity depends upon :

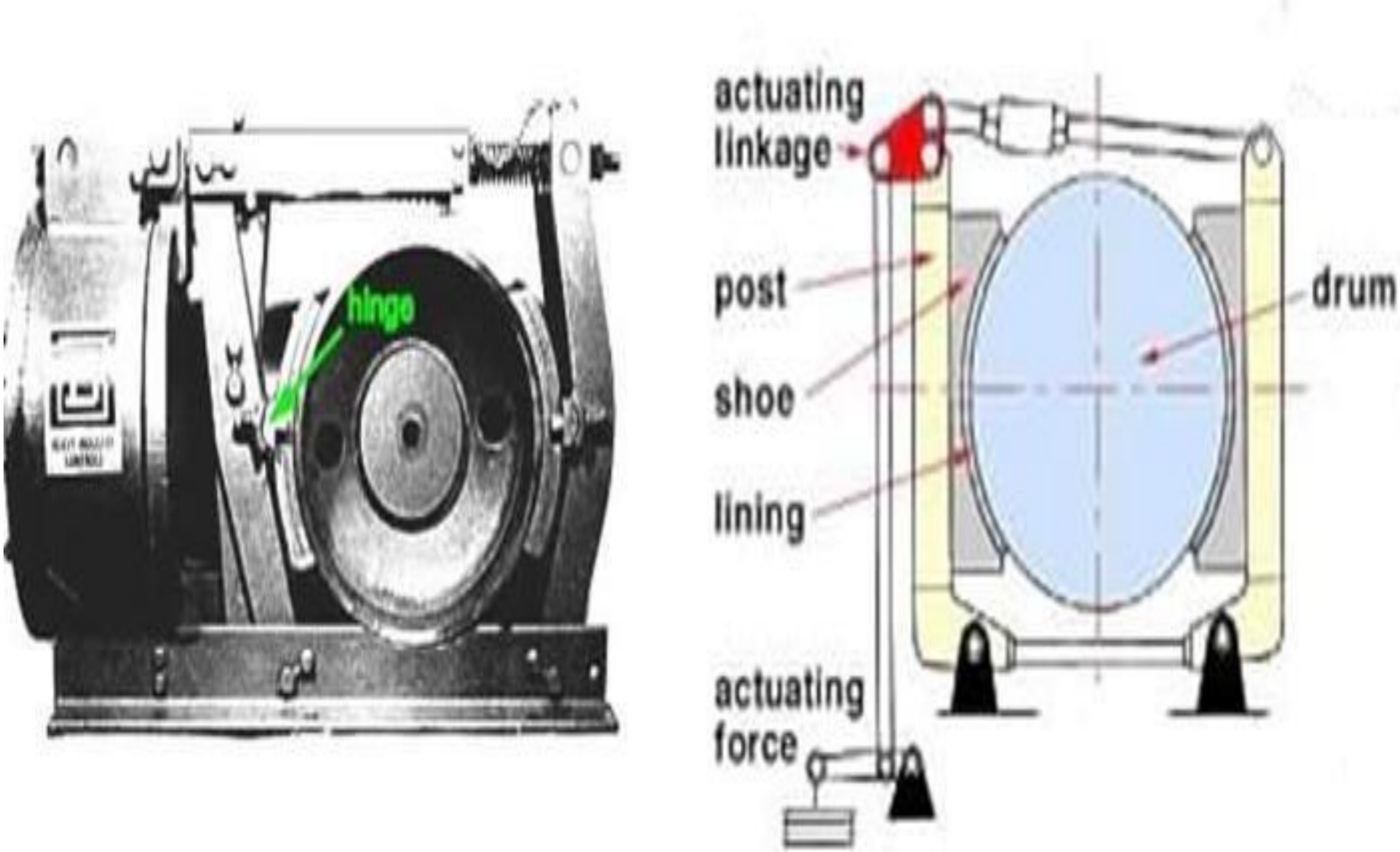
1. the unit pressure between the braking surfaces.
2. The coefficient of friction.
3. The ability of the brake to dissipate heat equivalent to energy being absorbed.

The mechanical brakes are primarily of three types:

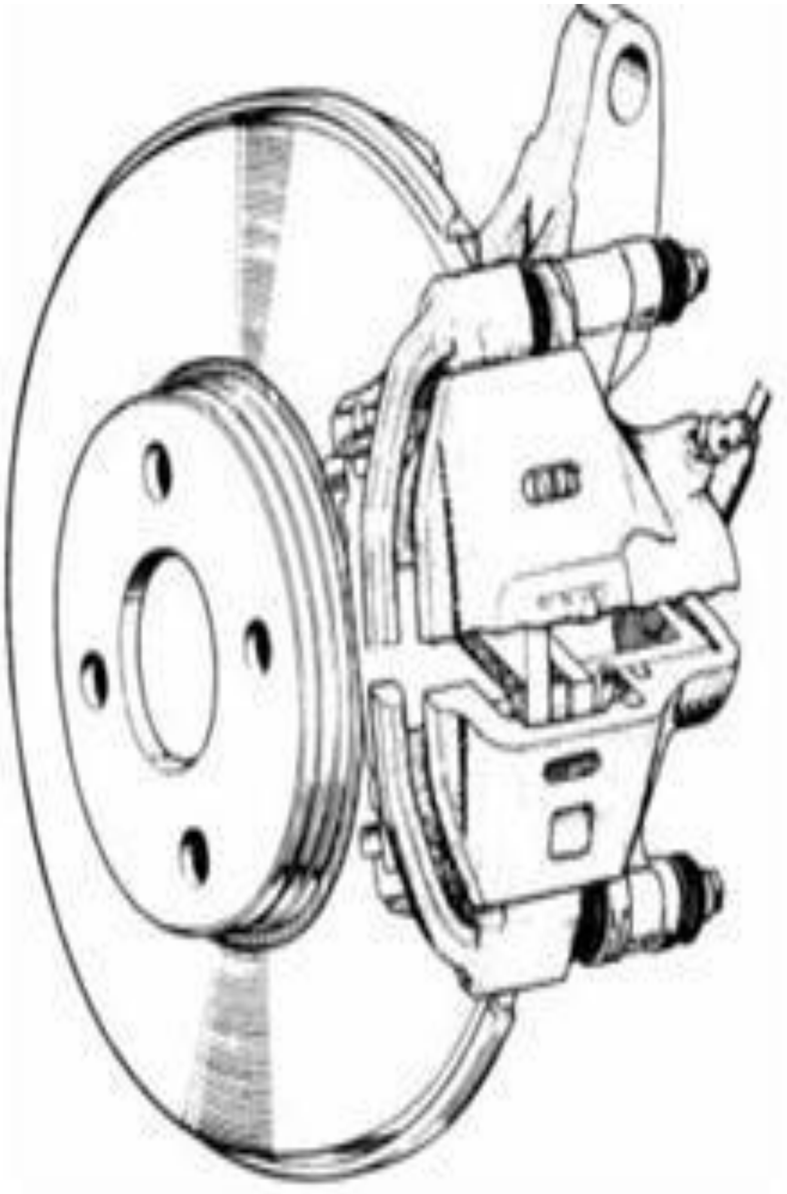
- Drum brake .
    - Internal expanding shoes brake.
    - External contracting shoes brake.
- Disc brake.
- Band brake .

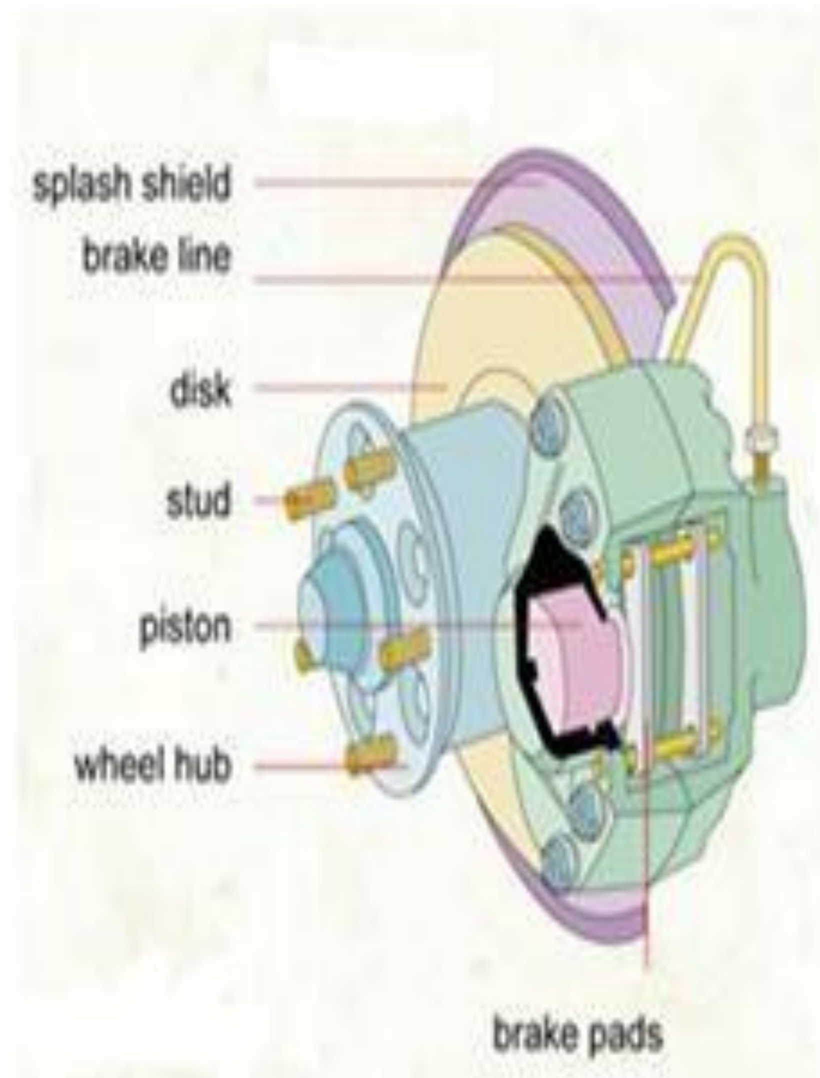


Internal shoe brake

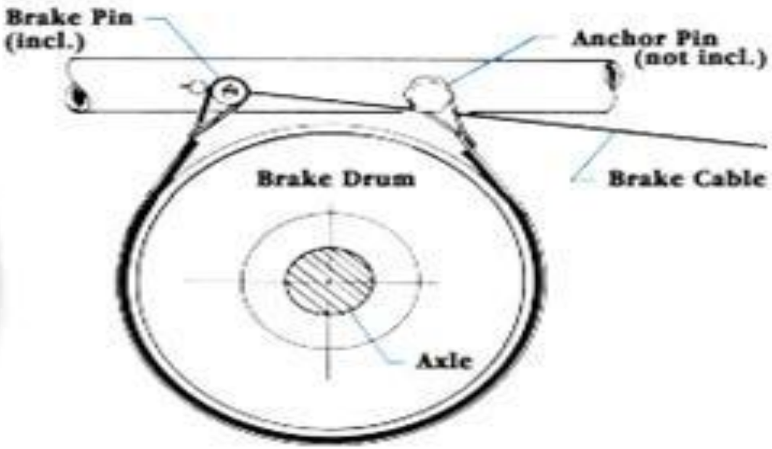


External shoe brake




splash shield
brake line
disk
stud
piston
wheel hub
brake pads

Disc Brake


Brake Pin
(incl.)
Anchor Pin
(not incl.)
Brake Drum
Brake Cable
Axle

band Brakes

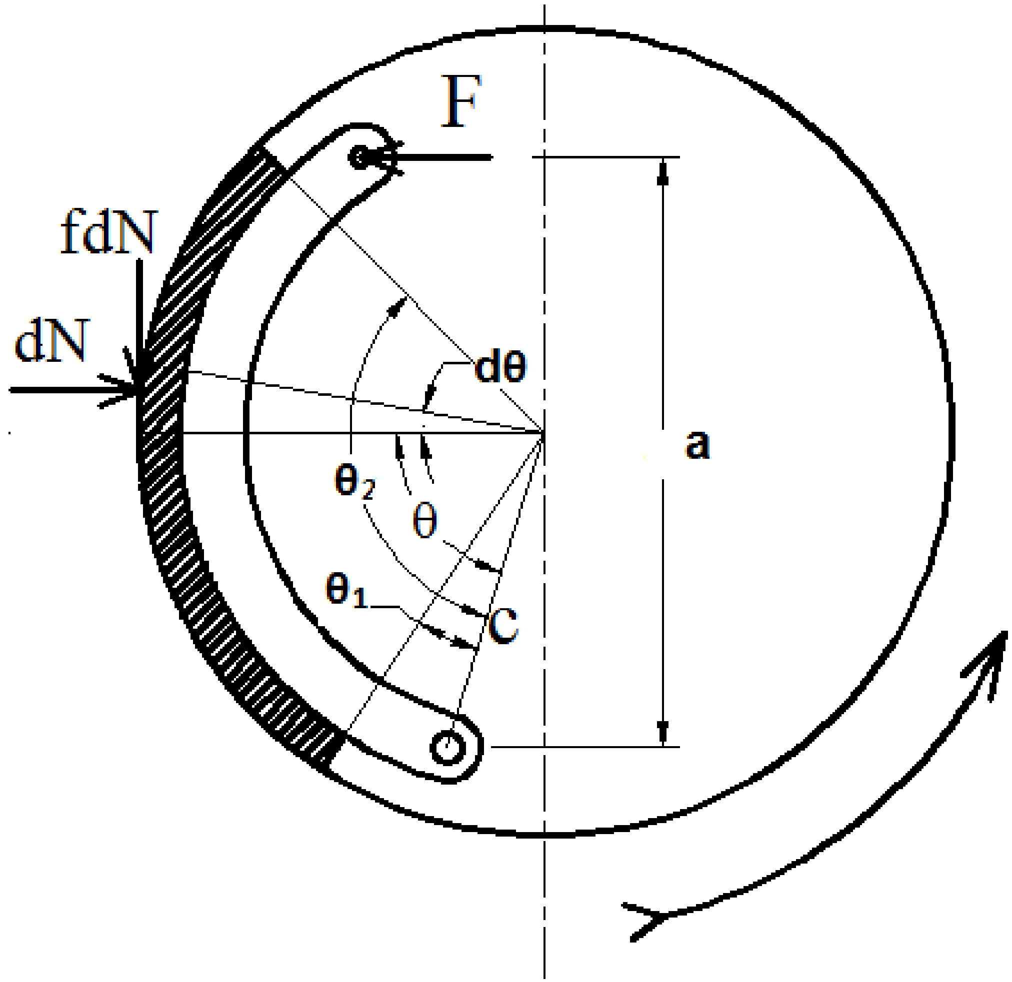
Brake lining is a heat-resistant material used in brake pad; it is high coefficient of dynamic friction. It was made from asbestos, but due to health risks, it has now replaced by ceramic materials or a mix of alternative fibers (mineral, cellulose, aramid, chopped glass, steel, and copper). Table (1) lists properties of typical brake linings.

	Woven Lining	Molded Lining	Rigid Block
Compressive strength, kpsi	10–15	10–18	10–15
Compressive strength, MPa	70–100	70–125	70–100
Tensile strength, kpsi	2.5–3	4–5	3–4
Tensile strength, MPa	17–21	27–35	21–27
Max. temperature, °F	400–500	500	750
Max. temperature, °C	200–260	260	400
Max. speed, ft/min	7500	5000	7500
Max. speed, m/s	38	25	38
Max. pressure, psi	50–100	100	150
Max. pressure, kPa	340–690	690	1000
Frictional coefficient, mean	0.45	0.47	0.40–45

INTERNAL EXPANDING SHOE BRAKE:

The internal shoe drum brake is widely used for braking systems in automotive applications

Single internal Shoe Brakes:



The normal pressure between the friction lining and brake drum at any point due to force F is Proportional to the vertical distance from the pivot.

Consider an elemental area on the friction lining located at angle θ, the element normal force due to the braking force F is:

$$\mathbf{dN} = \boldsymbol{p} * \mathbf{area} = \mathbf{pbrd\theta}$$

where,

p = the normal pressure

b = the width of the friction lining parallel to the drum axis

r = the internal radius of the drum.

$$\mathbf{p} \propto \mathbf{r}\, \boldsymbol{sin\, \theta}$$

Since the distance r is constant, the normal pressure at any point is just proportional to $\sin\theta$. Call this constant of proportionality as K

Thus; $p = K \sin\theta$

Assume that:

$$p = p_{max.} \quad \text{when} \quad \theta = \theta_{max.}$$

$$\text{and} \quad \theta_{max.} = 90^{\circ} \quad \text{when } \theta_{max.} \geq 90^{\circ}$$

$$\theta_{max.} = \theta_2 \quad \text{when } \theta_{max.} \leq 90^{\circ}$$

Then:

$$p_{max.} = K \sin\theta_{max.}$$

$$\therefore p = p_{max.}\left(\frac{\sin\theta}{\sin\theta_{max}}\right)$$

$$\therefore dN = p_{max.}br\left(\frac{\sin\theta}{\sin\theta_{max}}\right)d\theta$$

The moment of the normal forces M_N about the pivot is:

$$M_N = \int dN(c\sin\theta) = \left(\frac{p_{max.}brc}{\sin\theta_{max}}\right)\int_{\theta_1}^{\theta_2} \sin^2\theta \, d\theta$$

$$\therefore \mathbf{M_N} = \left(\frac{\mathbf{p_{max.}brc}}{\mathbf{4\sin\theta_{max}}}\right)\{\mathbf{2(\theta_2 - \theta_1) - (\sin 2\theta_2 - \sin 2\theta_1)}\}$$

The moment (M_f) of the frictional force(fN) about the hinge pin at A is:

$$M_f = \int fdN(r - c\cos\theta) = \left(\frac{fp_{max.}br}{\sin\theta_{max}}\right)\int_{\theta_1}^{\theta_2} \sin\theta\,(r - c\cos\theta)\,d\theta$$

$$\therefore \mathbf{M_f} = \left(\frac{\mathbf{fp_{max.}br}}{\mathbf{4\sin\theta_{max}}}\right)\{\mathbf{4r}(\mathbf{\cos\theta_2} - \mathbf{\cos\theta_1}) - \mathbf{c}(\mathbf{\cos2\theta_2} - \mathbf{\cos2\theta_1})\}$$

The torque applied to the drum by the brake shoe is the sum of the frictional force (fN) times the radius of the drum:

$$T = \int fdN * r = \left(\frac{fp_{max.}br^2}{\sin\theta_{max}}\right)\int_{\theta_1}^{\theta_2} \sin\theta\,d\theta$$

$$\therefore \mathbf{T} = \left(\frac{\mathbf{fp_{max.}br^2}}{\mathbf{\sin\theta_{max}}}\right)\{\mathbf{\cos\theta_1} - \mathbf{\cos\theta_2}\}$$

The actuating force F is determined by the summation of the moments of normal and frictional forces about the hinge pin and equating it to zero;

For anticlockwise rotation of the brake wheel, as shown in Fig.,

$$F * a = M_N - M_f$$

$$\therefore \mathbf{F} = \frac{\mathbf{M_N} - \mathbf{M_f}}{\mathbf{a}}$$

For clockwise rotation of the brake wheel,

$$F * a = M_N + M_f$$

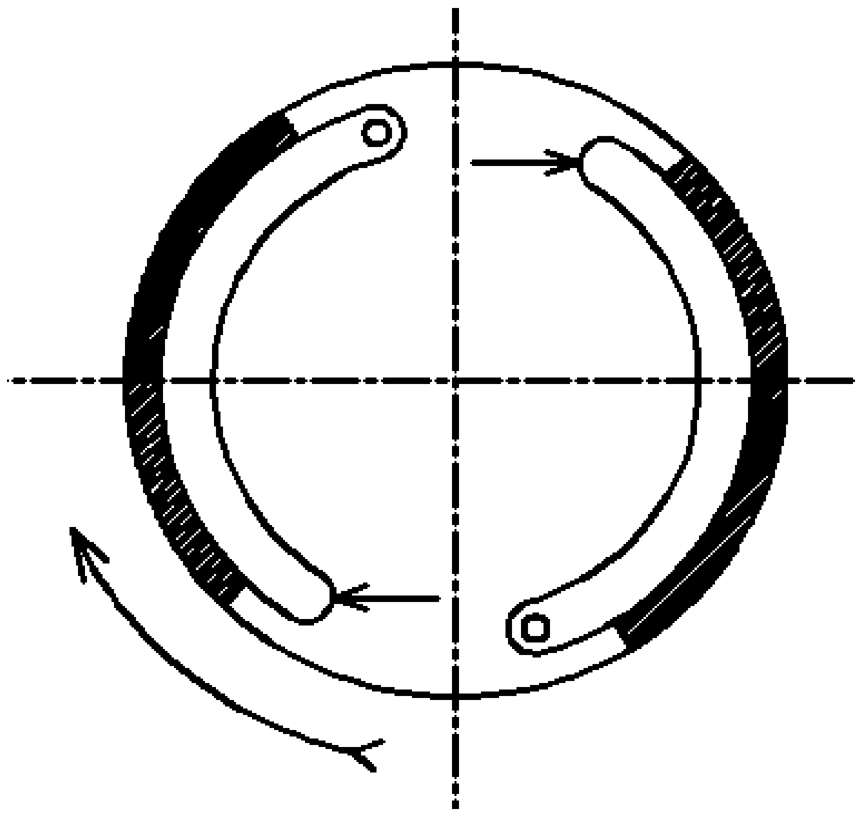
$$\therefore \mathbf{F} = \frac{\mathbf{M_N} + \mathbf{M_f}}{\mathbf{a}}$$

It may be noted that for anticlockwise rotating brake, M_f is in the direction of the moment of actuating force $(F * c)$, the brake is called **self-energized**. i.e. the friction is helping the actuating force to bake.

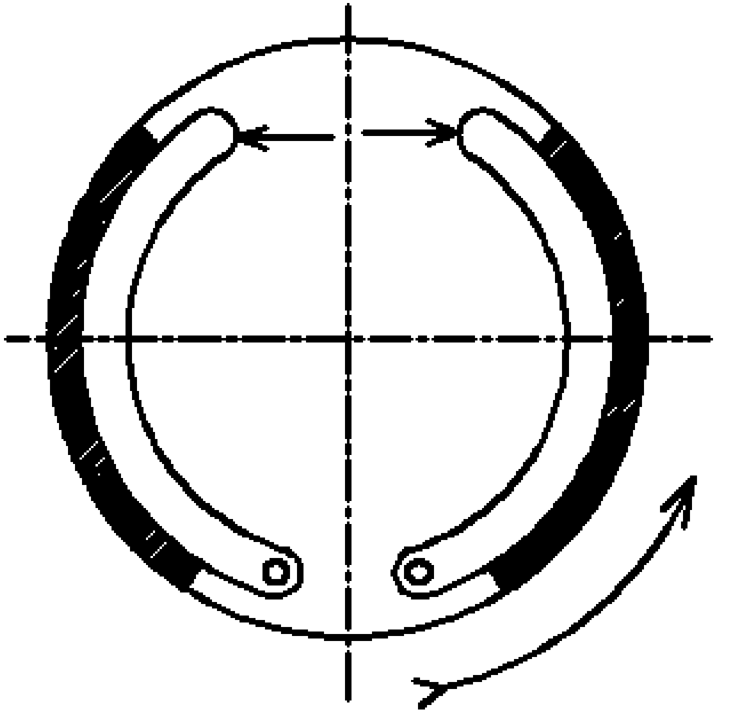
For this type of brake, if the value of M_f is larger than M_N, it is called **self-locking**, i.e. there is no need to apply the actuating force to brake.

If the brake is self locking for one direction, it is never self locking for the opposite direction. This makes the self locking brakes useful for 'back stop's of the rotors.

Double internal Shoe Brakes:



Both shoes are self energized



One shoe is self energized and the other is not self energized.

Equations :

$$M_N = \left(\frac{p_{max.} brc}{4 \sin \theta_{max}}\right)\{2(\theta_2 - \theta_1) - (\sin 2\theta_2 - \sin 2\theta_1)\} \quad (1)$$

$$M_f = \left(\frac{f p_{max.} br}{4 \sin \theta_{max}}\right)\{4r(\cos\theta_2 - \cos\theta_1) - c(\cos 2\theta_2 - \cos 2\theta_1)\} \quad (2)$$

$$T = \left(\frac{f p_{max.} br^2}{\sin \theta_{max}}\right)\{\cos\theta_1 - \cos\theta_2\} \quad (3)$$

- For self-Energized,

$$F = \frac{M_N - M_f}{a} \quad (4)$$

- For Non self-Energized.,

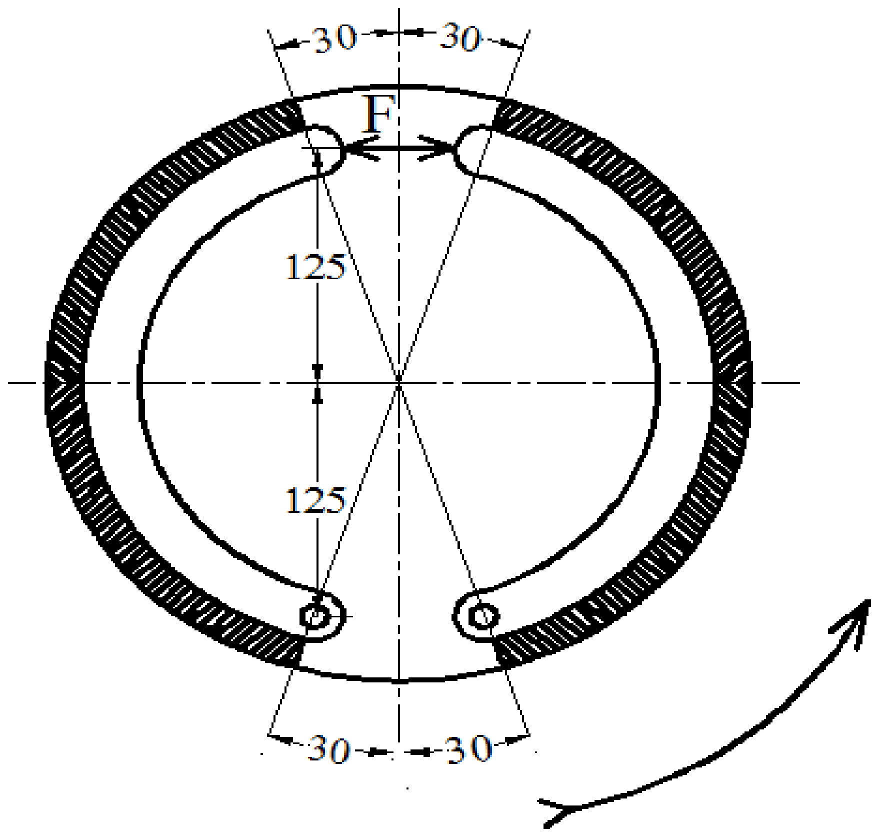
$$F = \frac{M_N + M_f}{a} \quad (5)$$

Example :

The brake shown in figure is 350 mm in diameter and is actuated by a mechanism that exerts the same force F on each shoe. The shoes are identical and have a face width of 45 mm. The lining is a molded asbestos having a coefficient of friction of 0.35 and a pressure limitation of 0.85 MPa. Estimate the maximum:

(a) Actuating force F.

(b) Braking capacity.



Solution:

The left-hand shoe is self-energizing, and so the force F is found on the basis that the maximum pressure will occur on this shoe.

Here,

$$\theta_1 = 0^\circ\ ,\quad \theta_2 = 120^\circ \qquad \therefore \theta_{max.} = 90^\circ$$

$$a = 250\ mm\quad ,\quad r = 175\ mm\ ,\quad b = 45\ mm$$

$$c = \frac{125}{\sin 60} = 144\ mm$$

the moment of the normal forces is

$$M_N = \left(\frac{p_{max.} brc}{4\sin\theta_{max}}\right)\{2(\theta_2 - \theta_1) - (\sin 2\theta_2 - \sin 2\theta_1)\}$$

$$M_N = \left(\frac{175 * 45 * 144}{4\sin 90}\right)\left\{2 * \frac{\pi}{180}(\theta_{120}) - (\sin 240)\right\} p_{max.}$$

$$M_N = 1.435 * 10^6\ p_{max.}\quad N.mm$$

The moment of the frictional forces is obtained from

$$M_f = \left(\frac{f p_{max.} b r}{4\sin\theta_{max}}\right)\{4r(\cos\theta_2 - \cos\theta_1) - c(\cos 2\theta_2 - \cos 2\theta_1)\}$$

$$M_f = \left(\frac{0.35 * 45 * 175}{4\sin 90}\right)\{4 * 175(\cos 120 - \cos 0) - 144(\cos 240 - \cos 0)\} \quad p_{max.}$$

$$M_f = 0.5741 * 10^6 \ p_{max.} \ \mathrm{N.mm}$$

The torque applied by the left-hand shoe is

$$T = \left(\frac{\mathrm{fp_{max.}br^2}}{\sin \theta_{\mathrm{max}}}\right)\{\cos\theta_1 - \cos\theta_2\}$$

$$T = \left(\frac{0.35 * 45 * 175^2}{\sin 90}\right)\{\cos 0 - \cos 120\}\ \mathrm{p_{max.}}$$

$$T = 723.52 * 10^3\ \mathrm{p_{max.}\ N.mm}$$

The moment of the frictional forces is obtained from

$$M_f = \left(\frac{fp_{max.}br}{4\sin\theta_{max}}\right)\{4r(\cos\theta_2 - \cos\theta_1) - c(\cos2\theta_2 - \cos2\theta_1)\}$$

$$M_f = \left(\frac{0.35 * 45 * 175}{4\sin 90}\right)\{4 * 175(\cos120 - \cos0) - 144(\cos240 - \cos0)\} \quad p_{max.}$$

$$M_f = 0.5741 * 10^6 \; p_{max.} \; N.mm$$

the actuating force is

$$F = \frac{M_N - M_f}{a} = \left(\frac{1.22 - .488}{250}\right)10^6$$

$$F = 2.93 \text{ kN}$$

Since, the right-hand shoe is not self-energized. The operating contact pressures $\left(p^{R}_{max.}\right)$ is less than the maximum pressure in the self energized one;

$$p^{R}_{max.} < p_{max.}$$

For the Left hand Brake

$p^{L}_{max} = 0.85$ MPa

From Eq. (4), the actuating force is

$$F = \frac{M_N - M_f}{a} = \left(\frac{1.435 - 0.5741}{250}\right) 10^6 \times p^{L}_{max}$$

$$F = 2.93 \text{ kN}$$

For the Right hand Brake

p_{max}^{R} is unknown

From Eq. (4), the actuating force is

$$\mathrm{F} = \frac{\mathrm{M_N} + \ \mathrm{M_f}}{\mathrm{a}} = \left(\frac{1.435 + 0.5741}{250}\right) 10^6 \ \times p_{max}^{R} = 2.93 * 10^3$$

$p_{max}^{R} = 0.364$ MPa

The torque applied by the left-hand and right-hand shoes is

$$T = \mathrm{T}_L + \mathrm{T}_R$$

$$T = 723.52 \times 10^3\ (p_{max}^L + p_{max}^R)$$

$$= 723.52 \times 10^3\ (0.85 + 0.364)$$

$$T = (615 + 263) \times 10^3 = 878 \times 10^3\ \mathrm{N.mm} = 878\ \mathrm{N.m}$$

$$\mathrm{T} = 878\ \mathrm{Joul}$$