Chapter-2A:Brakes and Dynamometers

Topics of Discussion

Brakes and Dynamometers- Different types of brakes, Shoe brak External and Internal shoe brakes, Block brakes, Band brakes, Band a Block brakes, Braking torques, Different types of absorption a transmission type dynamometers.

Brakes

- A ***brake is a device by means of which artificial*** frictional resistance is applied to a moving machine member, in order to retard or stop the motion of a machine.
- In the process of performing this function, the brake absorbs either kinetic energy of the moving member or potential energy given up by objects being lowered by hoists, elevators etc.
- The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in the surrounding air (or water which is circulated through the passages in the brake drum) so that excessive heating of the brake lining does not take place.

Requirement of Brakes

- The capacity of a brake depends upon the following factors :

  1.The unit pressure between the braking surfaces,

  2.The coefficient of friction between the braking surfaces,

  3.The peripheral velocity of the brake drum,

  4.The projected area of the friction surfaces, and

  5.The ability of the brake to dissipate heat equivalent to the energy being absorbed.

Materials for Brake Lining

1. It should have high co-efficient of friction with minimum fading. In other words, the coefficient of friction should remain constant with change in temperature.
2. It should have low wear rate.
3. It should have high heat resistance.
4. It should have high heat dissipation capacity.
5. It should have adequate mechanical strength.

.It should not be affected by moisture and oil.

Properties of materials for brake lining.

Table 19.1. Properties of materials for brake lining.

Material for braking lining	*Coefficient of friction* (μ)			*Allowable pressure* (*p*)
	Dry	*Greasy*	*Lubricated*	*N/mm*^{2}
Cast iron on cast iron	0.15 – 0.2	0.06 – 0.10	0.05 – 0.10	1.0 – 1.75
Bronze on cast iron	–	0.05 – 0.10	0.05 – 0.10	0.56 – 0.84
Steel on cast iron	0.20 – 0.30	0.07 – 0.12	0.06 – 0.10	0.84 – 1.40
Wood on cast iron	0.20 – 0.35	0.08 – 0.12	–	0.40 – 0.62
Fibre on metal	–	0.10 – 0.20	–	0.07 – 0.28
Cork on metal	0.35	0.25 – 0.30	0.22 – 0.25	0.05 – 0.10
Leather on metal	0.30 – 0.5	0.15 – 0.20	0.12 – 0.15	0.07 – 0.28
Wire asbestos on metal	0.35 – 0.5	0.25 – 0.30	0.20 – 0.25	0.20 – 0.55
Asbestos blocks on metal	0.40 – 0.48	0.25 – 0.30	–	0.28 – 1.1
Asbestos on metal (Short action)	–	–	0.20 – 0.25	1.4 – 2.1
Metal on cast iron (Short action)	–	–	0.05 – 0.10	1.4 – 2.1

Types of Brakes

- The brakes, according to the means used for transforming the energy by the braking elements, are classified as :

1.Hydraulicbrakes*e.g.pumpsor*
H***ydro dynamic brake*** and fluid agitator,

2.Electricbrakes*e.g.generatorsandeddy*
C***urrent*** brakes, and

3.Mechanical brakes.

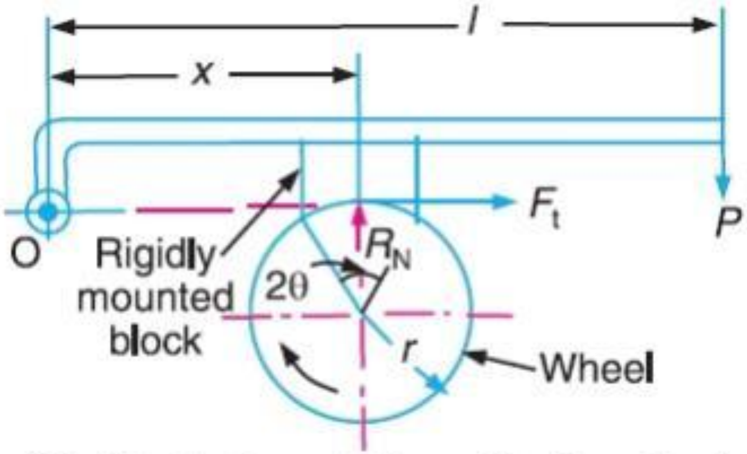
Radial Brakes and Axial Brakes

(a)Radial brakes .In these brakes, the force acting on the brake drum is in radial direction. The radial brakes may be sub-divided into ***external Brakes and internal brakes.***

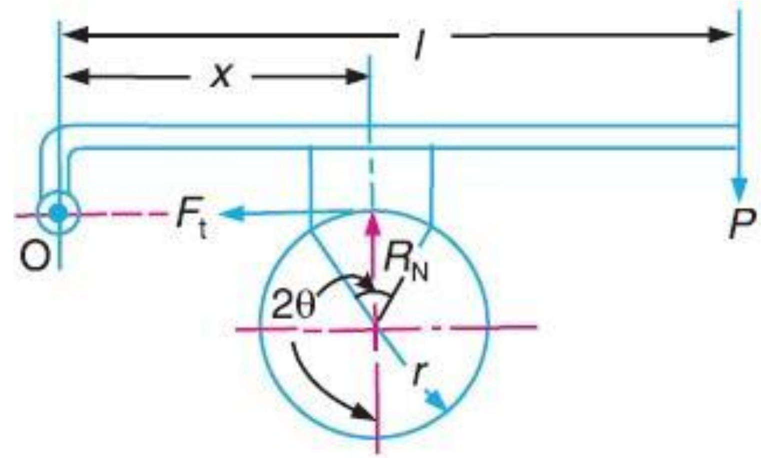
According to the shape of the friction elements, these brakes may be ***block or shoe brakes and Band brakes.***

(***b)Axial brakes. In these brakes, the force acting on the brake drum is in axial direction. The*** axial brakes may be disc brakes and cone brakes. The analysis of these brakes is similar to clutches.

Single Block or Shoe Brake



(a) Clockwise rotation of brake wheel



(b) Anticlockwise rotation of brake wheel

$$F_t = \mu . R_N \qquad \text{...}(i)$$

$$T_B = F_t . r = \mu . R_N . r \qquad \text{...}(ii)$$

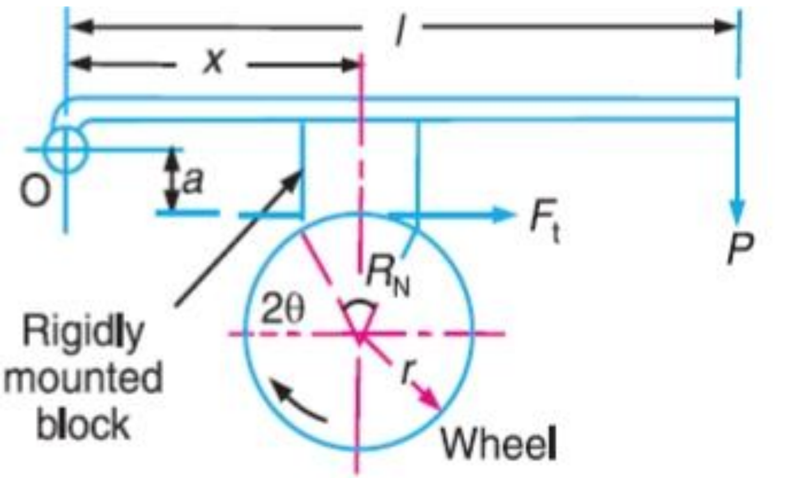
$$R_N \times x = P \times l \quad \text{or} \quad R_N = \frac{P \times l}{x}$$

Braking torque,

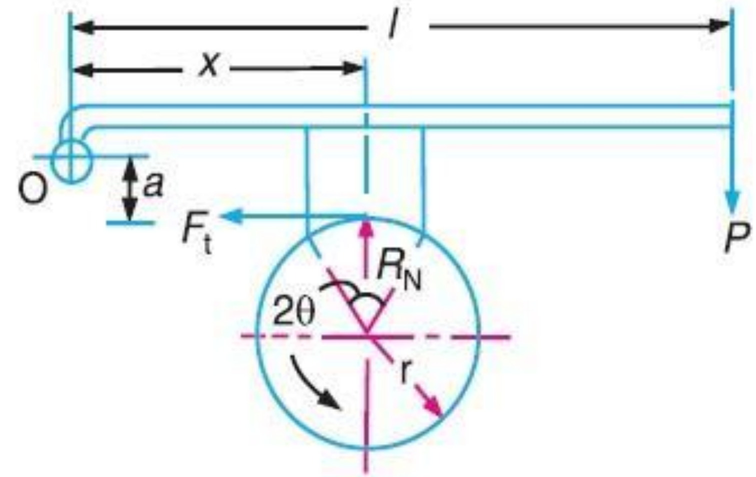
$$T_B = \mu . R_N . r = \mu \times \frac{P . l}{x} \times r = \frac{\mu . P . l . r}{x}$$

$$T_B = \mu . R_N . r = \frac{\mu . P . l . r}{x}$$

Friction Force below pivoting



(*a*) Clockwise rotation of brake wheel.



(*b*) Anticlockwise rotation of brake wheel.

$$R_N \times x + F_t \times a = P.l \quad \text{or} \quad R_N \times x + \mu R_N \times a = P.l \quad \text{or} \quad R_N = \frac{P.l}{x + \mu.a}$$

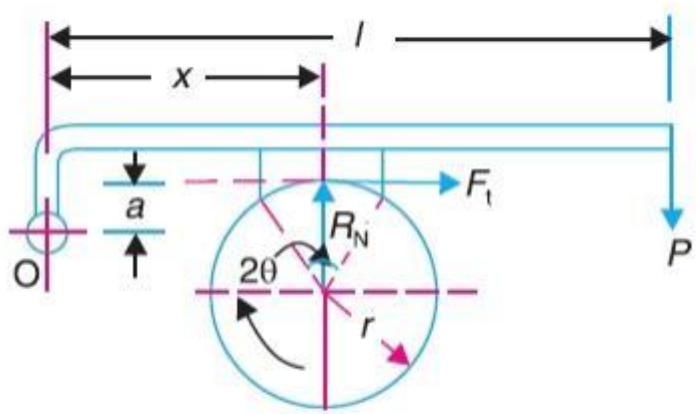
$$\boxed{T_B = \mu R_N . r = \frac{\mu.p.l.r}{x + \mu.a}}$$

$$R_N.x = P.l + F_t.a = P.l + \mu.R_N.a$$

$$R_N\,(x - \mu.a) = P.l \quad \text{or} \quad R_N = \frac{P.l}{x - \mu.a}$$

$$\boxed{T_B = \mu.R_N.r = \frac{\mu.P.l.r}{x - \mu.a}}$$

Friction Force above pivoting

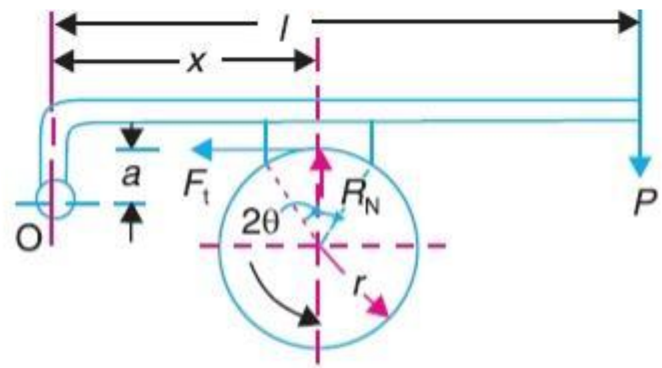


(*a*) Clockwise rotation of brake wheel.

$$R_N.x = P.l + F_t\,.\,a = P.l + \mu.R_N.a$$

$$R_N\,(x - \mu.a) = P.l \qquad \text{or} \qquad R_N = \frac{P.l}{x - \mu.a}$$

$$\boxed{T_B = \mu.R_N.r = \frac{\mu.P.l.r}{x - \mu.a}}$$



(*b*) Anticlockwise rotation of brake wheel.

$$R_N \times x + F_t \times a = P.l$$

$$R_N \times x + \mu.R_N \times a = P.l$$

$$R_N = \frac{P.l}{x + \mu.a}$$

$$\boxed{T_B = \mu.R_N.r = \frac{\mu.P.l.r}{x + \mu.a}}$$

Self energizing brakes

$$R_N \times x = P.l + \mu.R_N.a$$

- We see that the moment of frictional force ($\mu.R_N.a$) *adds to the moment* of force (*P.l*). *In other words,* the frictional force helps to apply the brake.

Self Locking brakes

- When the frictional force is great enough to apply the brake with no external force, then the brake is said to

$x \le \mu.a$, then P will be negative or equal to zero.

The self locking brake is used only in back-stop applications.

The brake should be self energizing and not the self locking.

In order to avoid self locking and to prevent the brake from grabbing, x is kept greater than $\mu \, . \, a$.

If A_b is the projected bearing area of the block or shoe, then the bearing pressure on the shoe,

$$p_b = R_N / A_b$$

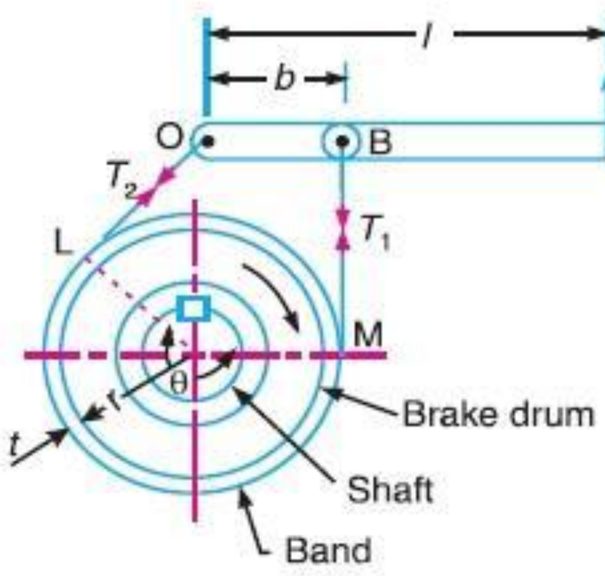
We know that A_b = Width of shoe × Projected length of shoe = $w(2r \sin\theta)$

5. When a single block or shoe brake is applied to a rolling wheel, an additional load is thrown on the shaft bearings due to heavy normal force (R_N) and produces bending of the shaft.

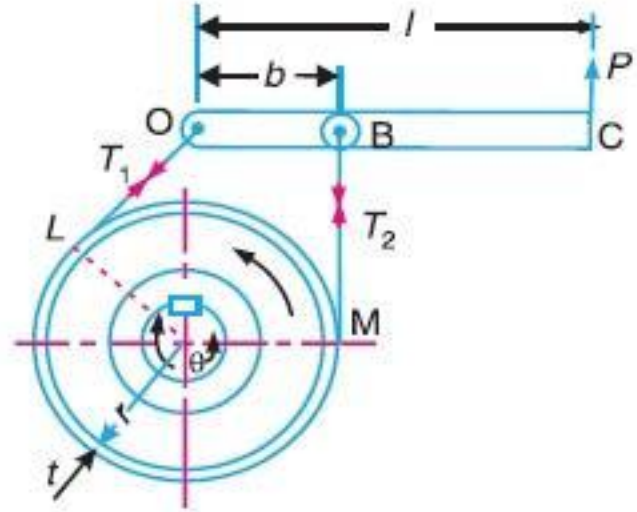
Simple Band Brake

- A band brake consists of a flexible band of leather, one or more ropes, or a steel lined with friction material, which embraces a part of the circumference of the drum. A band brake, as shown in Fig, is called a ***simple band brake in which one end of the band is attached to a fixed pin or*** fulcrum of the lever while the other end is attached to the lever at a distance *b from the fulcrum.*

Simple Band Brake



(a) Clockwise rotation of drum.



(b) Anticlockwise rotation of drum.

We know that limiting ratio of the tensions is given by the relation,

$$\frac{T_1}{T_2} = e^{\mu\theta} \quad \text{or} \quad 2.3\log\left(\frac{T_1}{T_2}\right) = \mu.\theta$$

and braking force on the drum $= T_1 - T_2$

$\therefore$ Braking torque on the drum,

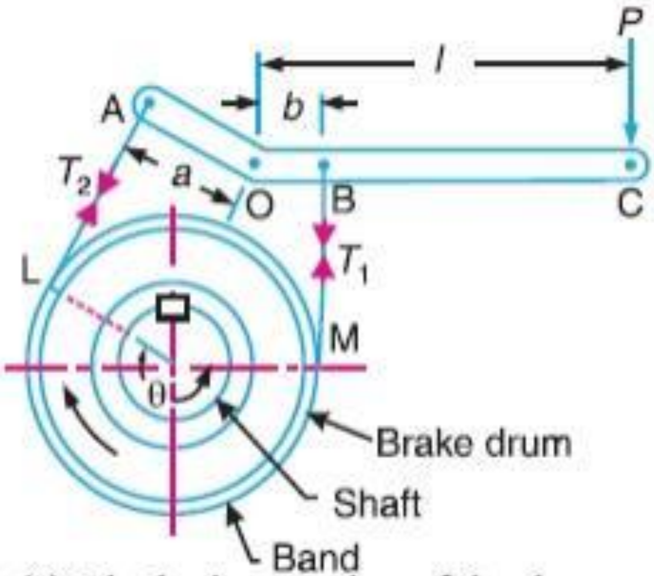
$$T_B = (T_1 - T_2)\,r \qquad \text{. . . (Neglecting thickness of band)}$$

$$= (T_1 - T_2)\,r_e \qquad \text{. . . (Considering thickness of band)}$$

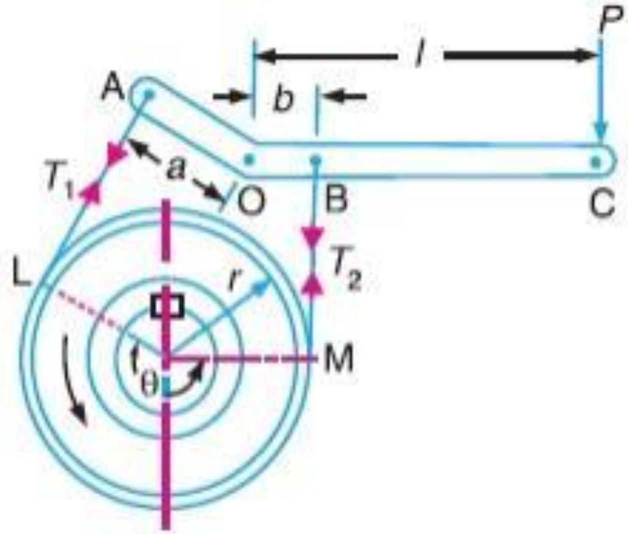
$$P.l = T_1.b \qquad \text{. . . (For clockwise rotation of the drum)}$$

$$P.l = T_2.b \qquad \text{. . . (For anticlockwise rotation of the drum)}$$

Differential Band Brake



(a) Clockwise rotation of the drum.



(a) Anticlockwise rotation of the drum.

$$P.l + T_1.b = T_2.a$$

.... (For clockwise rotation of the drum)

or $$P.l = T_2.a - T_1.b \quad \text{... } (i)$$

and $$P.l + T_2.b = T_1.a$$

... (For anticlockwise rotation of the drum)

or $$P.l = T_1.a - T_2.b \quad \text{... } (ii)$$

Self locking conditions

Thus for differential band brake and for clockwise rotation of the drum, the condition for self locking is

$$T_2.a \leq T_1.b \qquad \text{or} \qquad T_2 / T_1 \leq b / a$$

and for anticlockwise rotation of the drum, the condition for self locking is

$$T_1.a \leq T_2.b \qquad \text{or} \qquad T_1 / T_2 \leq b / a$$

Notes : 1. The condition for self locking may also be written as follows :

For clockwise rotation of the drum,

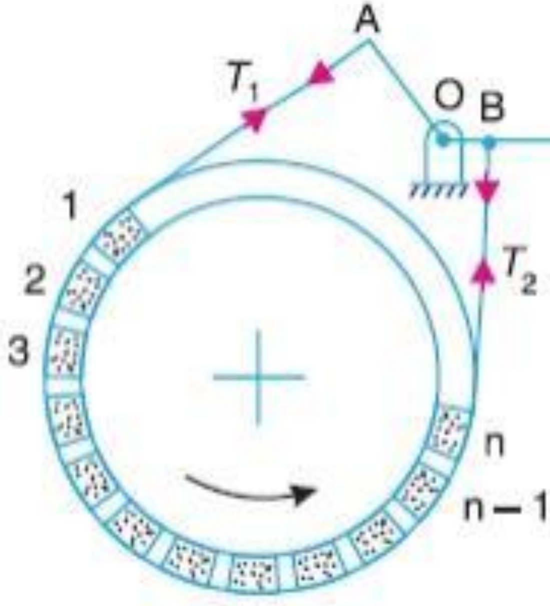
$$T_1.b \geq T_2.a \qquad \text{or} \qquad T_1 / T_2 \geq a / b$$

and for anticlockwise rotation of the drum,

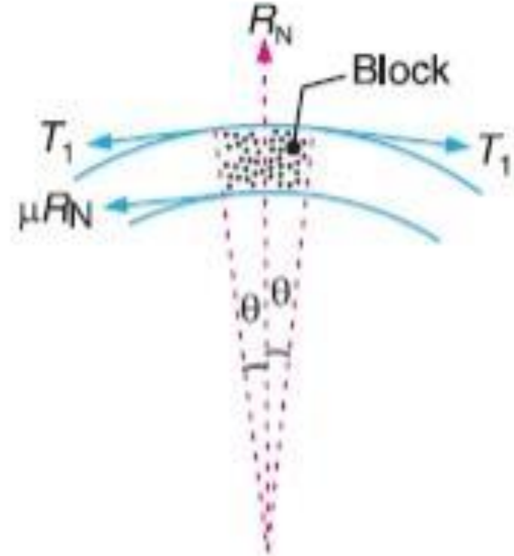
$$T_2.b \geq T_1.a \qquad \text{or} \qquad T_1 / T_2 \geq a / b$$

2. When in Fig. 19.14 (*a*) and (*b*), the length *OB* is greater than *OA*, then the force *P* must act in the upward direction in order to apply the brake. The tensions in the band, *i.e.* T_1 and T_2 will remain unchanged.

Band and Block Brake



(a)



(b)

Consider one of the blocks (say first block) as shown in Fig. 19.20 (*b*). This is in equilibrium under the action of the following forces :

1. Tension in the tight side (T_1),
2. Tension in the slack side (T_1') or tension in the band between the first and second block,
3. Normal reaction of the drum on the block (R_N), and
4. The force of friction ($\mu.R_N$).

Resolving the forces radially, we have

$$(T_1 + T_1')\sin\theta = R_N \quad \text{... (i)}$$

Resolving the forces tangentially, we have

$$(T_1 + T_1')\cos\theta = \mu.R_N \quad \text{... (ii)}$$

Dividing equation (*ii*) by (*i*), we have

$$\frac{(T_1 - T_1')\cos\theta}{(T_1 + T_1')\sin\theta} = \frac{\mu.R_N}{R_N}$$

or
$$(T_1 - T_1') = \mu\tan\theta(T_1 + T_1')$$

$\therefore$
$$\frac{T_1}{T_1'} = \frac{1+\mu\tan\theta}{1-\mu\tan\theta}$$

Similarly, it can be proved for each of the blocks that

$$\frac{T_1'}{T_2'} = \frac{T_2'}{T_3'} = \frac{T_3'}{T_4'} = \dots\dots \frac{T_{n-1}}{T_2} = \frac{1+\mu\tan\theta}{1-\mu\tan\theta}$$

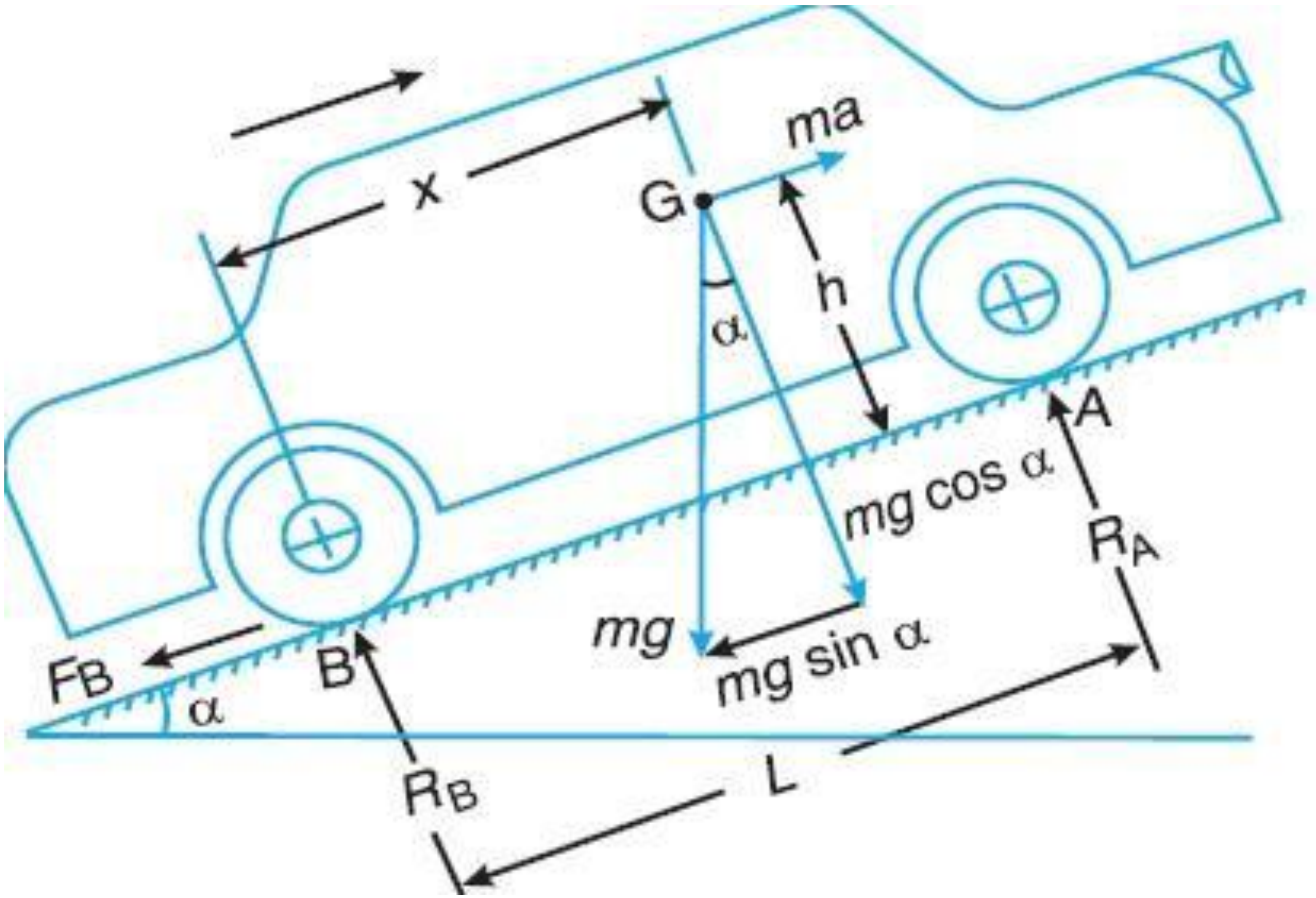
$\therefore$
$$\frac{T_1}{T_2} = \frac{T_1}{T_1'} \times \frac{T_1'}{T_2'} \times \frac{T_2'}{T_3'} \times \dots\dots \times \frac{T_{n-1}}{T_2} = \left(\frac{1+\mu\tan\theta}{1-\mu\tan\theta}\right)^n \quad \text{... (iii)}$$

Braking torque on the drum of effective radius r_e,

$$T_B = (T_1 - T_2)\,r_e$$
$$= (T_1 - T_2)\,r \quad \text{... [Neglecting thickness of band]}$$

Note : For the first block, the tension in the tight side is T_1 and in the slack side is T_1' and for the second block, the tension in the tight side is T_1' and in the slack side is T_2'. Similarly for the third block, the tension in the tight side is T_2' and in the slack side is T_3' and so on. For the last block, the tension in the tight side is T_{n-1} and in the slack side is T_2.

Brakes are applied to rear wheels only



1. *When the brakes are applied to the rear wheels only*

It is a common way of braking the vehicle in which the braking force acts at the rear wheels only.

Let F_B = Total braking force (in newtons) acting at the rear wheels due to the application of the brakes. Its maximum value is $\mu.R_B$.

The various forces acting on the vehicle are shown in Fig. 19.27. For the equilibrium of the vehicle, the forces acting on the vehicle must be in equilibrium.

Resolving the forces parallel to the plane,

$$F_B + m.g.\sin\alpha = m.a \quad \text{. . . (i)}$$

Resolving the forces perpendicular to the plane,

$$R_A + R_B = m.g\cos\alpha \quad \text{. . . (ii)}$$

Taking moments about G, the centre of gravity of the vehicle,

$$F_B \times h + R_B \times x = R_A (L - x) \quad \text{. . . (iii)}$$

Substituting the value of $F_B = \mu.R_B$, and $R_A = m.g\cos\alpha - R_B$ [from equation (*ii*)] in the above expression, we have

$$\mu.R_B \times h + R_B \times x = (m.g\cos\alpha - R_B)(L - x)$$

$$R_B (L + \mu.h) = m.g\cos\alpha\,(L - x)$$

$$\therefore \qquad R_B = \frac{m.g\cos\alpha(L-x)}{L+\mu.h}$$

and

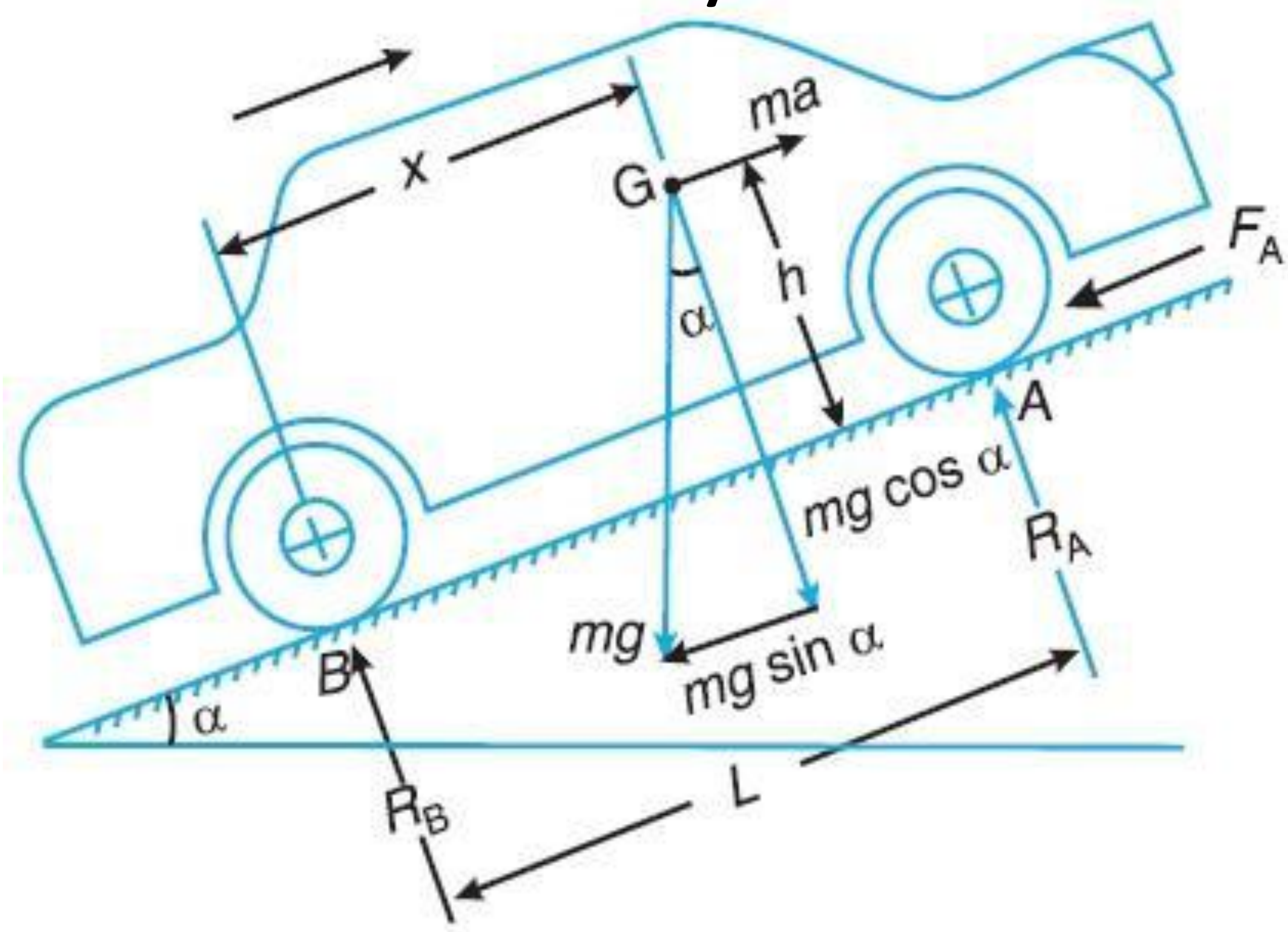
$$R_A = m.g\cos\alpha - R_B = m.g\cos\alpha - \frac{m.g\cos\alpha(L-x)}{L+\mu.h}$$

$$= \frac{m.g\cos\alpha(x+\mu.h)}{L+\mu.h}$$

We know from equation (*i*),

$$a = \frac{F_B + m.g\sin\alpha}{m} = \frac{F_B}{m} + g\sin\alpha = \frac{\mu.R_B}{\text{m}} + g\sin\alpha \quad = \frac{\mu.g\cos\alpha(L-x)}{L+\mu.h} + g\sin\alpha$$

Brakes are applied to front wheels only

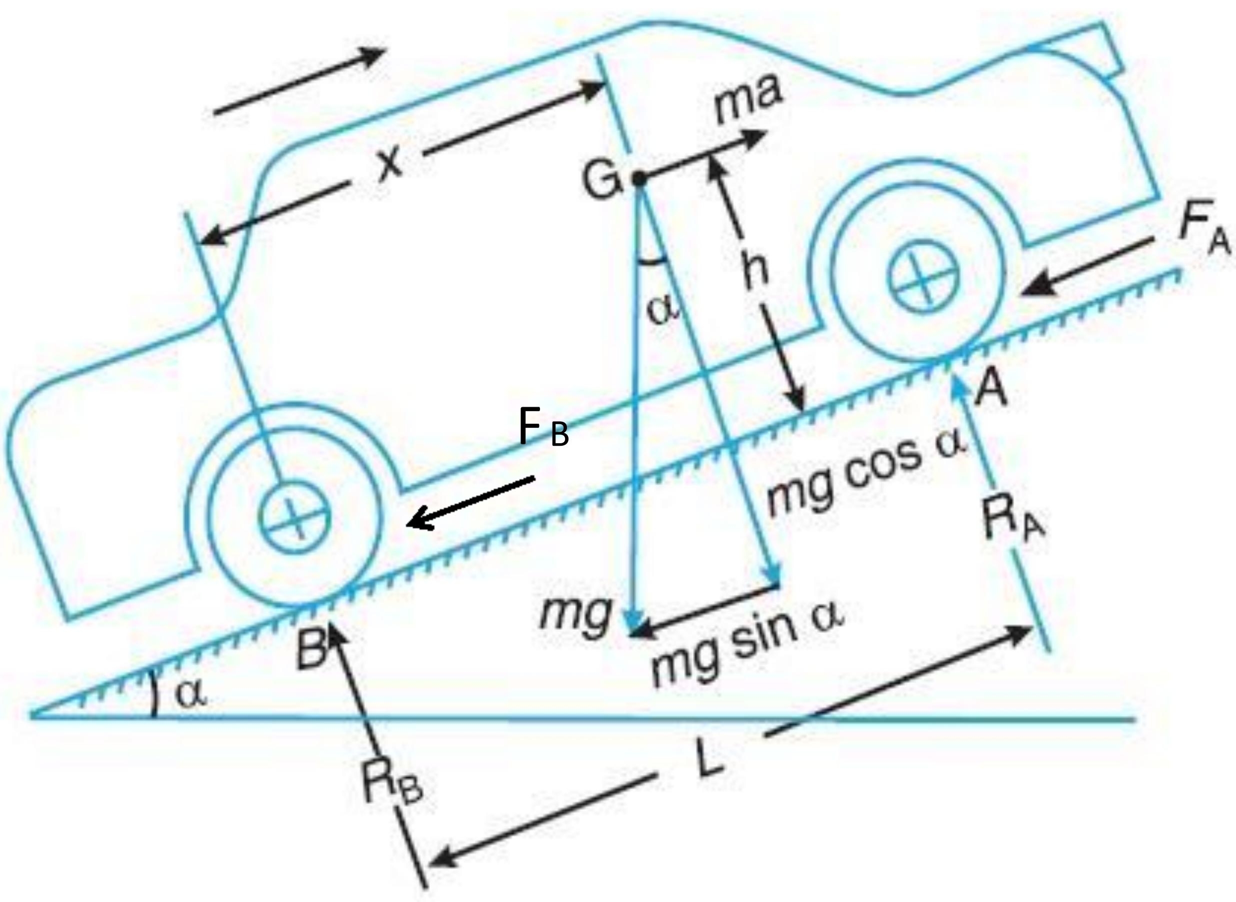


$$a = \frac{F_{\mathrm{A}} + m.g\sin\alpha}{m} = \frac{\mu.R_{\mathrm{A}} + m.g\sin\alpha}{m}$$

$$= \frac{\mu.m.g\cos\alpha \times x}{(L - \mu.h)m} + \frac{m.g\sin\alpha}{m}$$

$$= \frac{\mu.g\cos\alpha \times x}{L - \mu.h} + g\sin\alpha$$

Brakes are applied to ALL wheels



Resolving the forces parallel to the plane,

$$F_A + F_B + m.g \sin\alpha = m.a \qquad \ldots (i)$$

Resolving the forces perpendicular to the plane,

$$R_A + R_B = m.g \cos\alpha \qquad \ldots (ii)$$

Taking moments about G, the centre of gravity of the vehicle,

$$(F_A + F_B)h + R_B \times x = R_A (L - x) \qquad \ldots (iii)$$

$$\mu(R_A + R_B)h + (m.g \cos\alpha - R_A)x = R_A (L - x)$$

$$\mu(R_A + m.g \cos\alpha - R_A)h + (m.g \cos\alpha - R_A)x = R_A (L - x)$$

$$\mu.m.g \cos\alpha \times h + m.g \cos\alpha \times x = R_A \times L$$

$$\therefore \quad R_A = \frac{m.g \cos\alpha(\mu.h + x)}{L}$$

$$R_B = m.g \cos\alpha - R_A = m.g \cos\alpha - \frac{mg \cos\alpha(\mu.h + x)}{L}$$

$$= m.g \cos\alpha\left[1 - \frac{\mu.h + x}{L}\right] = m.g \cos\alpha\left(\frac{L - \mu.h - x}{L}\right)$$

equation (*i*),

$$\mu.R_A + \mu R_B + m.g \sin\alpha = m.a$$

$$\mu(R_A + R_B) + m.g \sin\alpha = m.a$$

$$\mu.m.g.\cos\alpha + m.g \sin\alpha = m.a$$

$$a = g(\mu.\cos\alpha + \sin\alpha)$$

Dynamometer

- A dynamometer is a brake but in addition it has a device to measure the frictional resistance.
- Knowing the frictional resistance, we may obtain the torque transmitted and hence the power of the engine.

Types of Dynamometers

- Following are the two types of dynamometers, used for measuring the brake power of an engine.

1. **Absorption dynamometers, and**
2. **Transmission dynamometers**

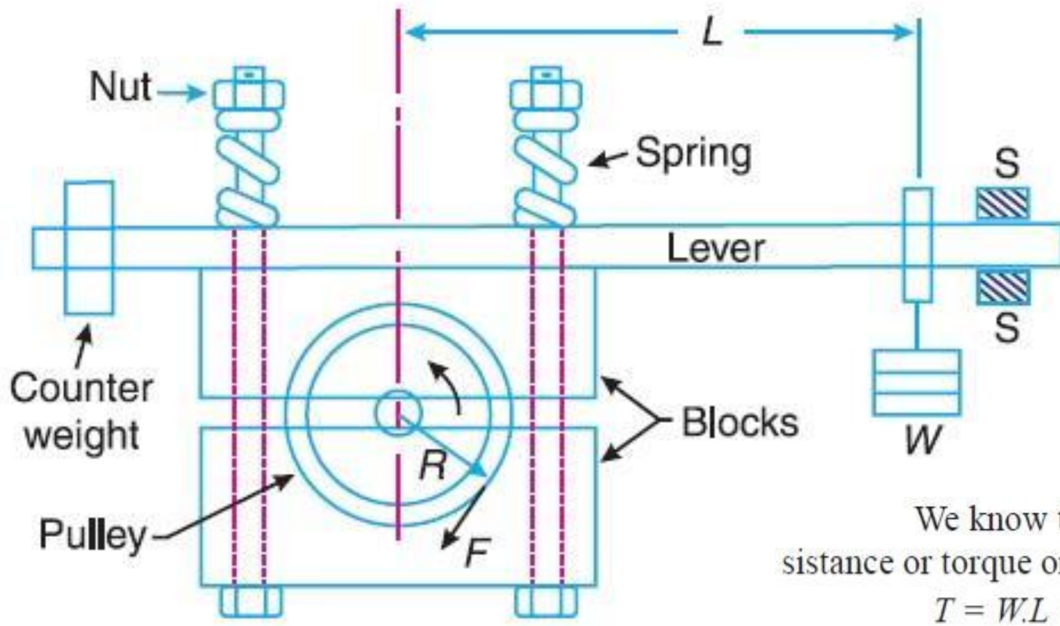
Absorption dynamometers & Transmission dynamometers

- In the *absorption* ***dynamometers, the*** entire energy or power produced by the engine is absorbed by the friction resistances of the brake and is transformed into heat, during the process of measurement.
- But in the ***transmission dynamometers, the energy*** is not wasted in friction but is used for doing work.
- The energy or power produced by the engine is transmitted through the dynamometer to some other machines where the power developed is suitably measured.

Classification of Absorption Dynamometers

1. **Prony brake dynamometer, and**
2. **Rope brake dynamometer.**

Prony Brake Dynamometer



We know that the moment of the frictional resistance or torque on the shaft,

$T = W.L = F.R$ N-m

Work done in one revolution

= Torque × Angle turned in radians

$= T \times 2\pi$ N-m

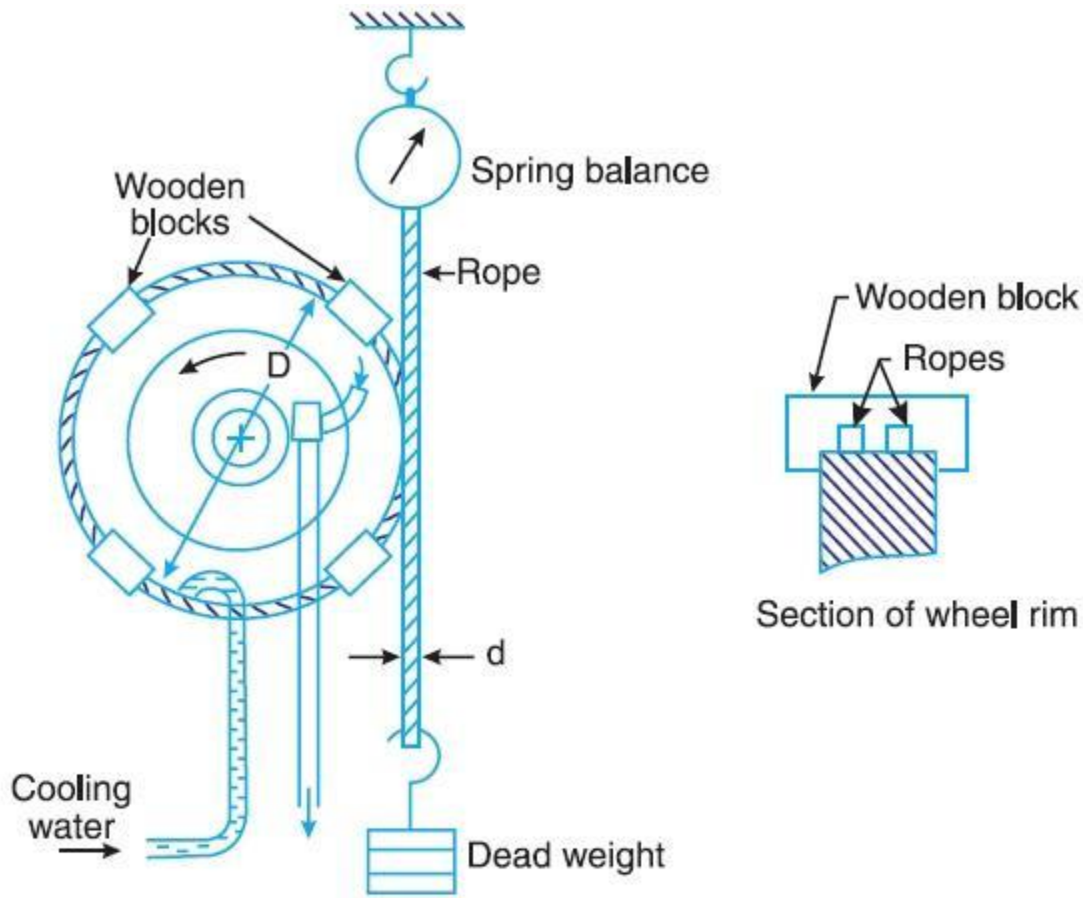
∴ Work done per minute

$= T \times 2\pi N$ N-m

We know that brake power of the engine,

$$B.P. = \frac{\text{Work done per min.}}{60} = \frac{T \times 2\pi N}{60} = \frac{W.L \times 2\pi N}{60} \text{ watts}$$

Rope Brake Dynamometer



Let W = Dead load in newtons,

S = Spring balance reading in newtons,

D = Diameter of the wheel in metres,

d = diameter of rope in metres, and

N = Speed of the engine shaft in r.p.m.

∴ Net load on the brake

$$= (W - S) \text{ N}$$

We know that distance moved in one revolution

$$= \pi(D + d) \text{ m}$$

∴ Work done per revolution

$$= (W - S)\,\pi\,(D + d) \text{ N-m}$$

and work done per minute

$$= (W - S)\,\pi\,(D + d)\,N \text{ N-m}$$

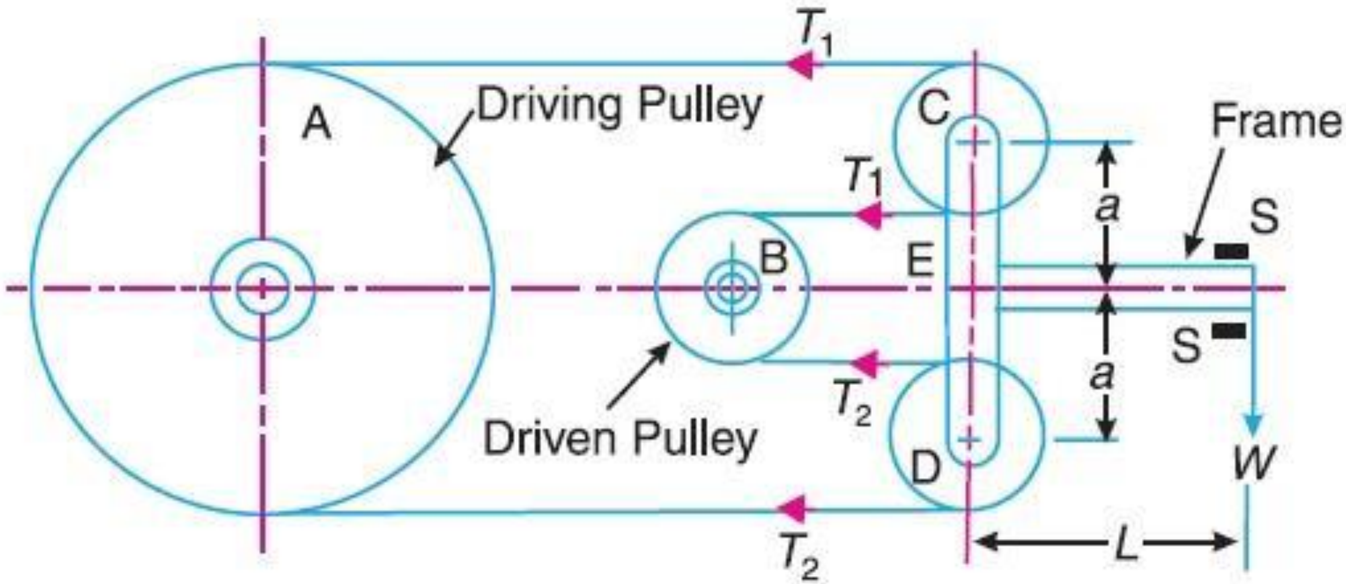
∴ Brake power of the engine,

$$\text{B.P} = \frac{\text{Work done per min}}{60} = \frac{(W - S)\,\pi\,(D + d)N}{60} \text{ watts}$$

If the diameter of the rope (d) is neglected, then brake power of the engine,

$$\text{B.P.} = \frac{(W - S)\,\pi D\,N}{60} \text{ watts}$$

Belt Transmission Dynamometer



Now taking moments about the pivot E, neglecting friction,

$$2T_1 \times a = 2T_2 \times a + W.L \quad \text{or} \quad T_1 - T_2 = \frac{W.L}{2a}$$

Let D = diameter of the pulley A in metres, and
N = Speed of the engine shaft in r.p.m.

$\therefore$ Work done in one revolution = $(T_1 - T_2)\,\pi\, D$ N-m

and workdone per minute = $(T_1 - T_2)\,\pi\, DN$ N-m

$\therefore$ Brake power of the engine, $\text{B.P.} = \dfrac{(T_1 - T_2)\,\pi\, DN}{60}$ watts

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