Kinematics of Machines
(NME-502)

Unit – V
Friction Drives

Characteristics of Dry Friction

Friction

- Force that resists the movement of two contacting surfaces that slide relative to one another
- Acts tangent to the surfaces at points of contact with other body
- Opposing possible or existing motion of the body relative to points of contact
- Two types of friction – Fluid and Coulomb Friction

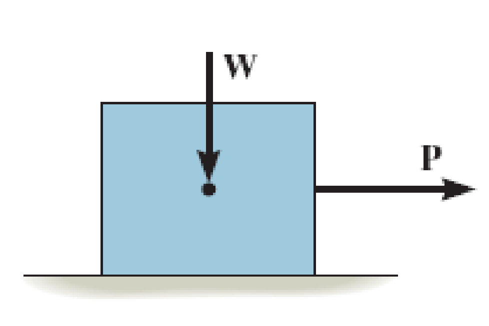
Characteristics of Dry Friction

- **Fluid friction** exist when the contacting surface are separated by a film of fluid (gas or liquid)
- Depends on velocity of the fluid and its ability to resist shear force
- **Coulomb friction** occurs between contacting surfaces of bodies in the absence of a lubricating fluid

Characteristics of Dry Friction

Theory of Dry Friction

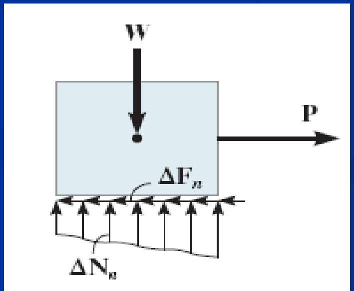
- Consider the effects caused by pulling horizontally on a block of uniform weight **W** which is resting on a rough horizontal surface
- Consider the surfaces of contact to be nonrigid or deformable and other parts of the block to be rigid



Characteristics of Dry Friction

Theory of Dry Friction

- Normal force $\Delta \mathbf{N}_n$ and frictional force $\Delta \mathbf{F}_n$ act along the contact surface



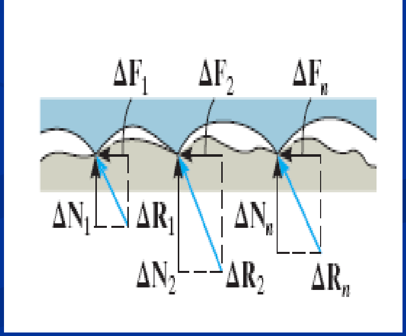
- For equilibrium, normal forces act upward to balance the block's weight **W**, frictional forces act to the left to prevent force **P** from moving the block to the right

Characteristics of Dry Friction

Theory of Dry Friction

- Many microscopic irregularities exist between the two surfaces of floor and the block

- Reactive forces $\Delta\mathbf{R}_n$ developed at each of the protuberances
- Each reactive force consist of both a frictional component $\Delta\mathbf{F}_n$ and normal component $\Delta\mathbf{N}_n$

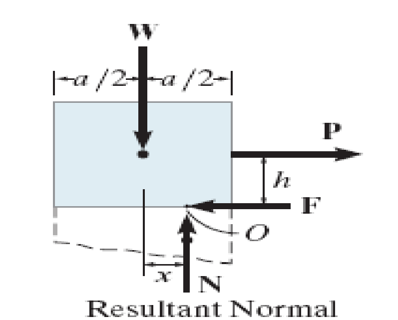


Characteristics of Dry Friction

Theory of Dry Friction

Equilibrium

- Effect of normal and frictional loadings are indicated by their resultant **N** and **F**
- Distribution of $\Delta \mathbf{F}_n$ indicates that **F** is tangent to the contacting surface, opposite to the direction of **P**
- Normal force **N** is determined from the distribution of $\Delta \mathbf{N}_n$



Resultant Normal and Frictional Forces

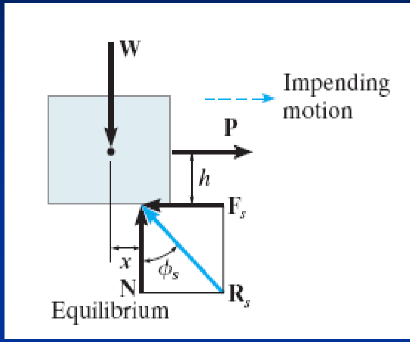
Characteristics of Dry Friction

Theory of Dry Friction

Equilibrium

- **N** is directed upward to balance **W**
- **N** acts a distance x to the right of the line of action of **W**
- This location coincides with the centroid or the geometric center of the loading diagram in order to balance the "tipping effect" caused by **P**

8.1 Characteristics of Dry Friction



Theory of Dry Friction

Impending Motion

- As P is slowly increased, F correspondingly increase until it attains a certain maximum value F, called the limiting static frictional force
- Limiting static frictional force F_s is directly proportional to the resultant normal force N

$F_s = \mu_s N$

8.1 Characteristics of Dry Friction

Theory of Dry Friction

Impending Motion

- Constant of proportionality μ_s is known as the coefficient of static friction
- Angle Φ_s that $\mathbf{R}_s$ makes with $\mathbf{N}$ is called the angle of static friction

$$\phi_s = \tan^{-1}\left(\frac{F_s}{N}\right) = \tan^{-1}\left(\frac{\mu_s N}{N}\right) = \tan^{-1}\mu_s$$

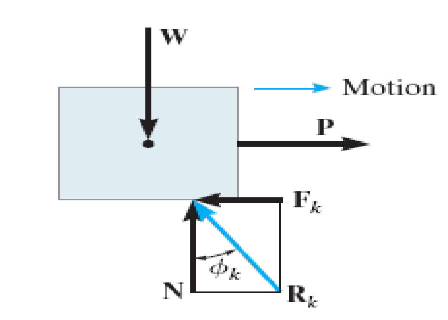
8.1 Characteristics of Dry Friction

Theory of Dry Friction

Typical Values of μ_s

Contact Materials	Coefficient of Static Friction μ_s
Metal on ice	0.03 – 0.05
Wood on wood	0.30 – 0.70
Leather on wood	0.20 – 0.50
Leather on metal	0.30 – 0.60
Aluminum on aluminum	1.10 – 1.70

Characteristics of Dry Friction



Theory of Dry Friction

<u>Motion</u>

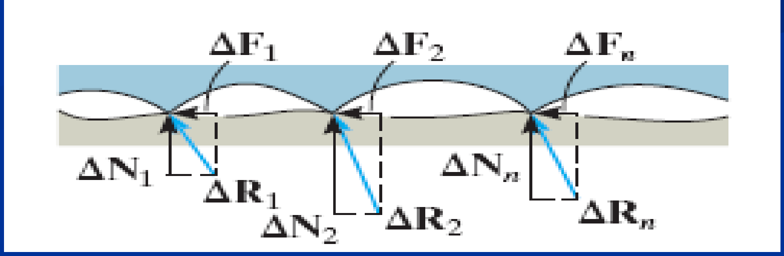
- When **P** is greater than F_s, the frictional force is slightly smaller value than F_s, called kinetic frictional force
- The block will not be held in equilibrium ($P > F_s$) but slide with increasing speed

Characteristics of Dry Friction

Theory of Dry Friction

Motion

- The drop from F_s (static) to F_k (kinetic) can by explained by examining the contacting surfaces
- When $P > F_s$, P has the capacity to shear off the peaks at the contact surfaces



Characteristics of Dry Friction

Theory of Dry Friction

- Resultant frictional force $\mathbf{F}_k$ is directly proportional to the magnitude of the resultant normal force $\mathbf{N}$

  $F_k = \mu_k N$

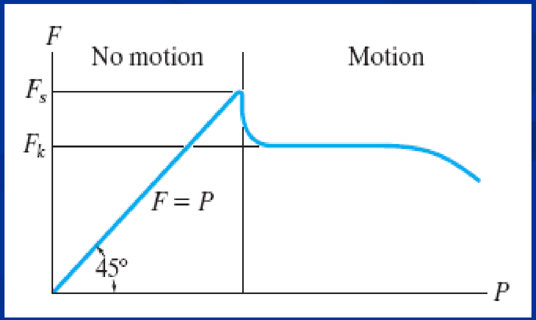
- Constant of proportionality μ_k is coefficient of kinetic friction
- μ_k are typically 25% smaller than μ_s
- Resultant $\mathbf{R}_k$ has a line of action defined by Φ_k, angle of kinetic friction

$$\phi_k = \tan^{-1}\left(\frac{F_k}{N}\right) = \tan^{-1}\left(\frac{\mu_k N}{N}\right) = \tan^{-1}\mu_k$$

Characteristics of Dry Friction

Theory of Dry Friction

- *F* is a *static frictional force* if equilibrium is maintained
- *F* is a *limiting static frictional force* when it reaches a maximum value needed to maintain equilibrium
- *F* is termed a *kinetic frictional force* when sliding occurs at the contacting surface



Characteristics of Dry Friction

Characteristics of Dry Friction

- The frictional force acts tangent to the contacting surfaces
- The max static frictional force F_s is independent of the area of contact
- The max static frictional force is greater than kinetic frictional force
- When slipping, the max static frictional force is proportional to the normal force and kinetic frictional force is proportional to the normal force

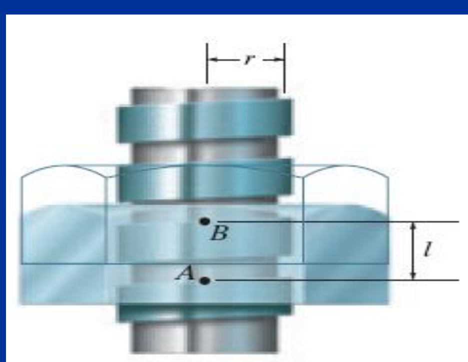
Frictional Forces on Screws

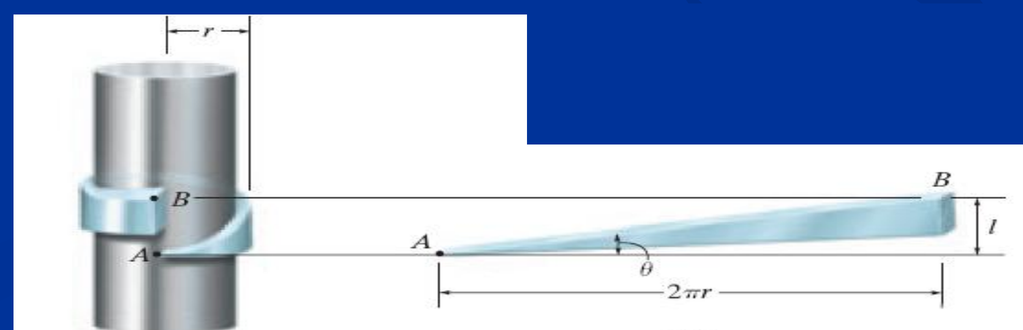
- Screws used as fasteners
- Sometimes used to transmit power or motion from one part of the machine to another
- A square-ended screw is commonly used for the latter purpose, especially when large forces are applied along its axis
- A screw is thought as an inclined plane or wedge wrapped around a cylinder

Frictional Forces on Screws

- A nut initially at A on the screw will move up to B when rotated 360° around the screw
- This rotation is equivalent to translating the nut up an inclined plane of height l and length $2\pi r$, where r is the mean radius of the head
- Applying the force equations of equilibrium, we have

$$M = rW\tan(\phi_s + \theta)$$



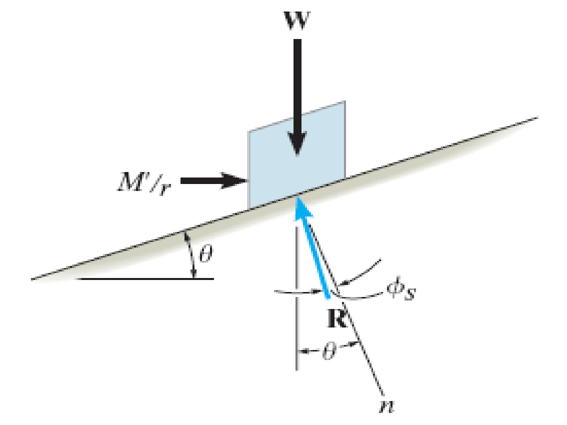


Frictional Forces on Screws

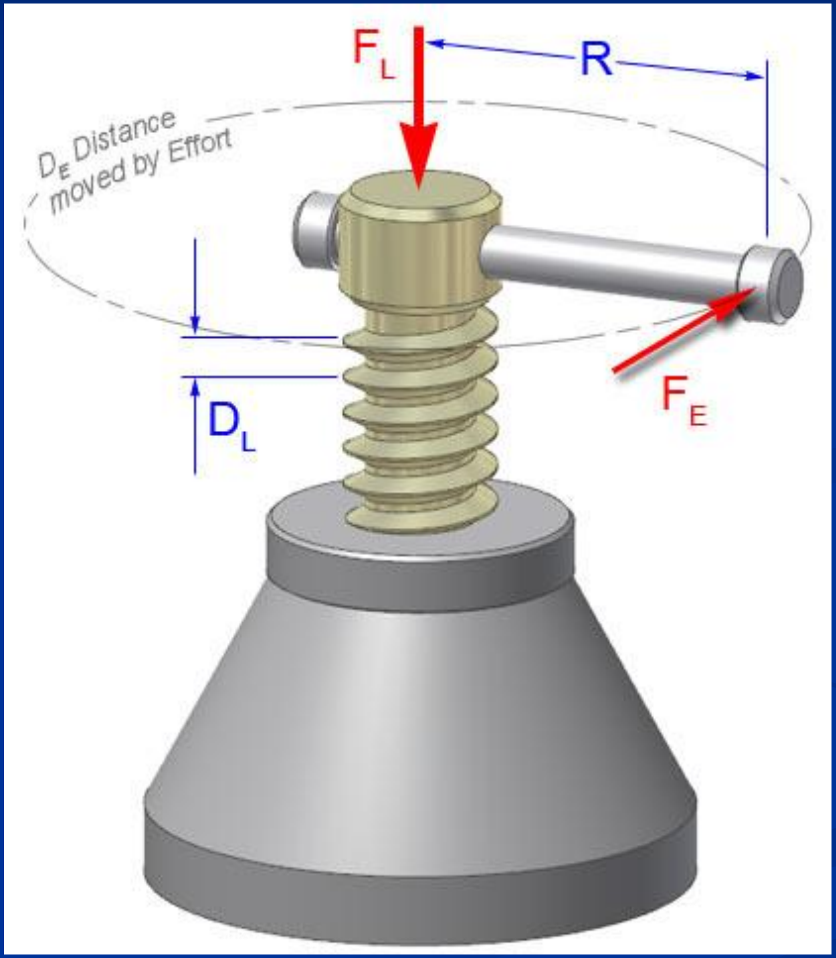
Downward Screw Motion

- If the surface of the screw is very slippery, the screw may rotate downward if the magnitude of the moment is reduced to say $M' < M$
- This causes the effect of $\mathbf{M'}$ to become $\mathbf{S'}$

$$M' = Wr \tan(\theta - \Phi)$$

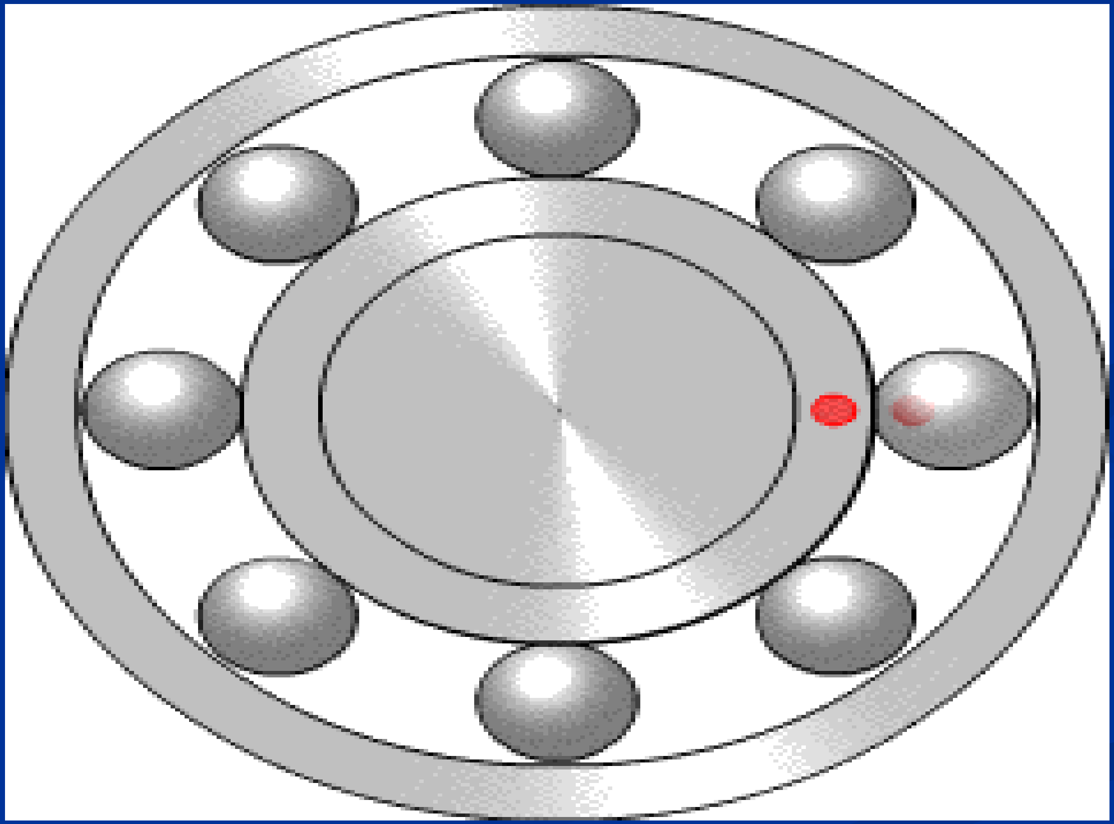


Downward screw motion ($\theta > \phi_s$)



F L
R
D E Distance moved by Effort
D L
F E

Bearing

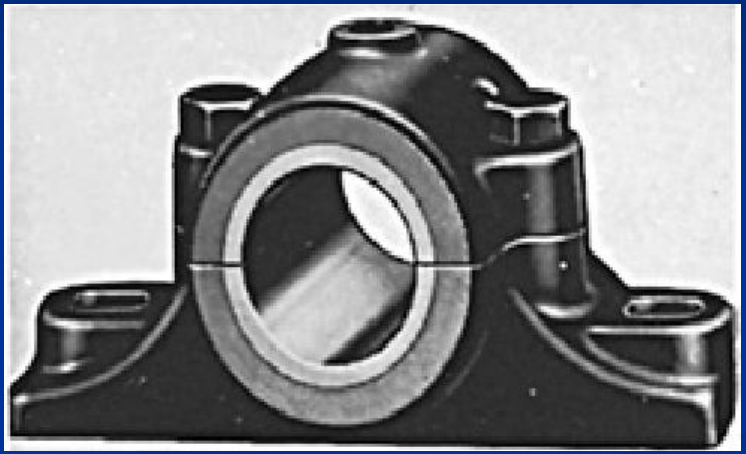


FUNCTION OF A BEARING

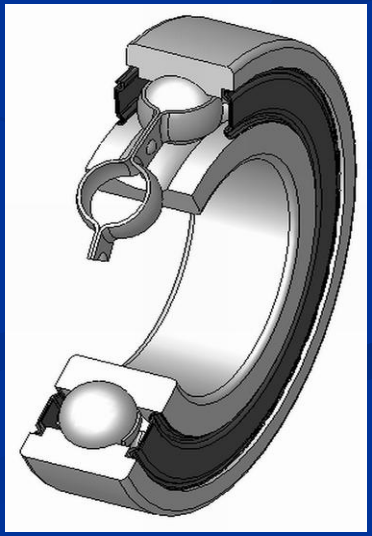
- The main function of a rotating shaft is to transmit power from one end of the line to the other.
  - It needs a good support to ensure stability and frictionless rotation. The support for the shaft is known as **"bearing"**.
- The shaft has a "**running fit**" in a bearing. All bearing are provided some lubrication arrangement to reduced friction between shaft and bearing.

Bearings are classified under two main categories:

- **Plain or slider bearing** : -
  - In which the rotating shaft has a sliding contact with the bearing which is held stationary . Due to large contact area friction between mating parts is high requiring greater lubrication.



- **Rolling or anti-friction bearing** : -
  - Due to less contact area rolling friction is much lesser than the sliding friction , hence these bearings are also known as **antifriction bearing**.



Advantages and disadvantages of the plain bearing

- Plain bearing are cheap to produce and have noiseless operation. They can be easily machined, occupy small radial space and have vibration damping properties. Also they can cope with tapped foreign matter.
- **Disadvantages** are they require large supply of lubricating oil, they are suitable only for relative low temperature and speed; and starting resistance is much greater than running resistance due to slow build up of lubricant film around the bearing surface.

“Belt and Rope Drives”

Introduction:

The belts or ropes are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds. The amount of power transmitted depends upon the following factors:

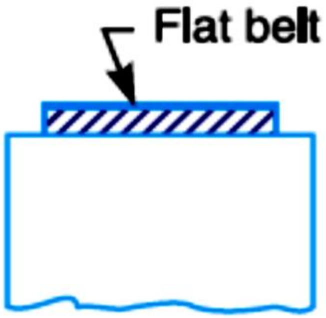
1. **The velocity of the belt.**
2. **The tension under which the belt is placed on the pulleys.**
3. **The arc of contact between the belt and the smaller pulley.**

Types of Belts:

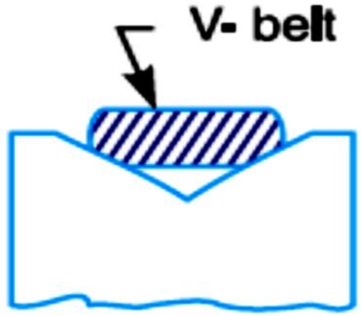
<u>1. *Flat belt* :</u> The flat belt is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another when the two pulleys are not more than 8 meters apart.

<u>2. *V-belt* :</u> The V-belt is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another, when the two pulleys are very near to each other.

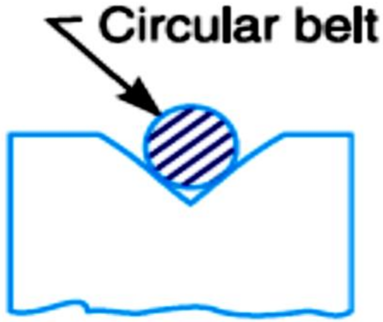
<u>3. *Circular belt or rope* :</u> The circular belt or rope is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are more than 8 meters apart.



(*a*) Flat belt.

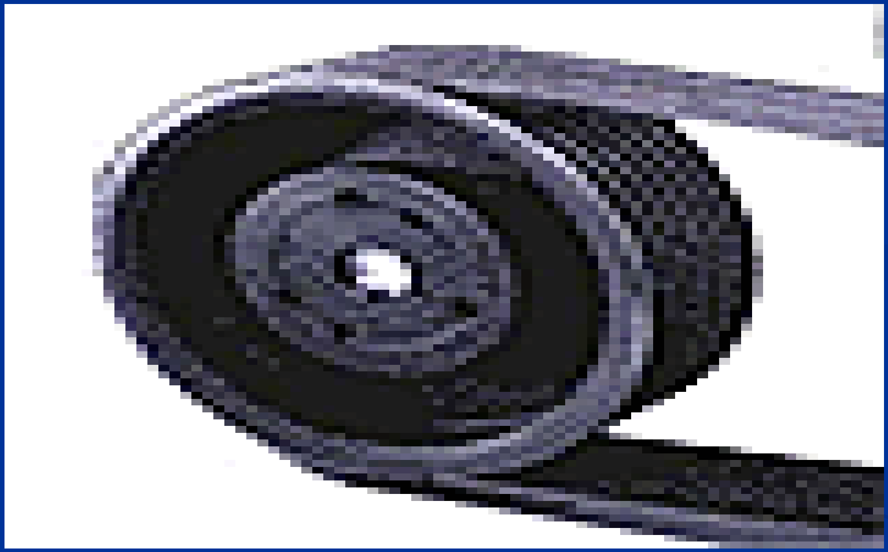


(*b*) V-belt.

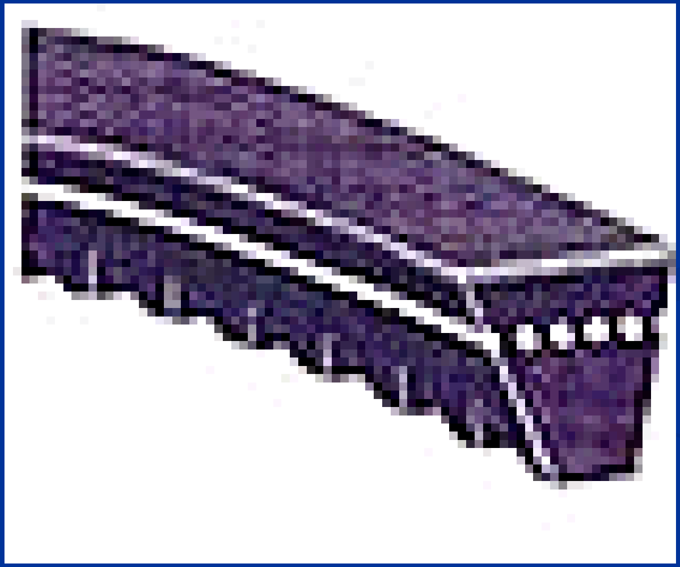


(*c*) Circular belt.

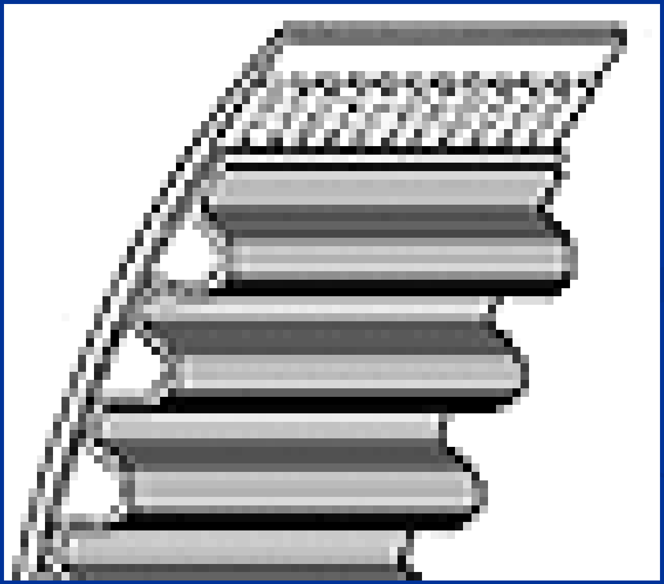
FLAT BELT



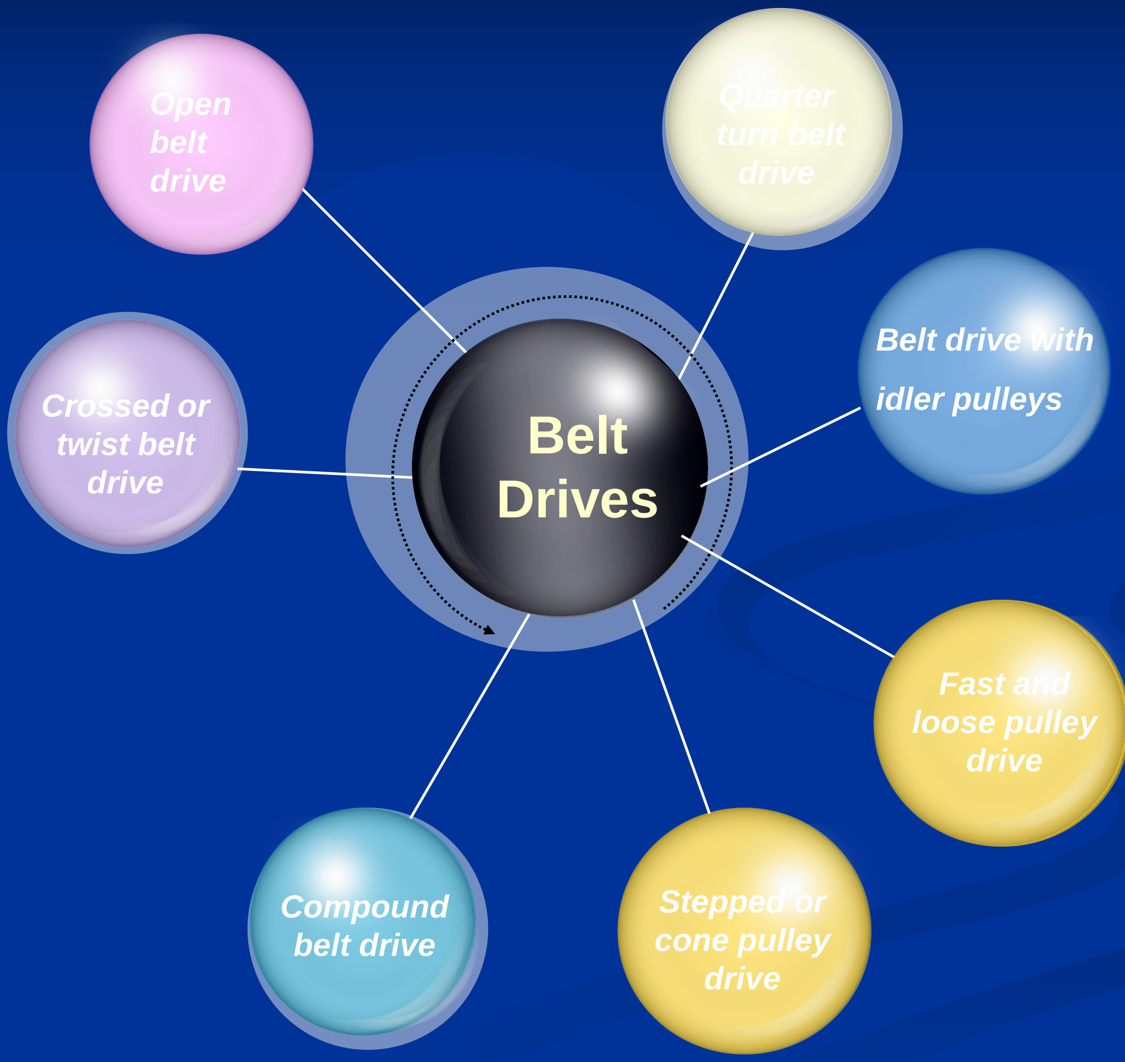
VEE BELT



TIMING BELT



Types of Flat Belt Drives:



Velocity Ratio of Belt Drive:

It is the **ratio between the velocities of the driver and the follower or driven.**

It may be expressed, mathematically, as discussed below:

Let $d1$ = Diameter of the driver,

$d2$ = Diameter of the follower,

$N1$= Speed of the driver in r.p.m., and

$N2$ = Speed of the follower in r.p.m.

Length of the belt that passes over the driver, in one minute= $\pi\, d1.N1$

Similarly, length of the belt that passes over the follower,

in one minute = $\pi\, d2 \,.\, N2$

Since the length of belt that passes over the driver in one minute is equal to the length of belt that passes over the follower in one minute,

therefore $\pi\, d1 \,.\, N1 = \pi\, d2 \,.\, N2$

$\therefore$ Velocity ratio, $\dfrac{N2}{N1} = \dfrac{d1}{d2}$

Velocity Ratio of a Compound Belt Drive:

Sometimes the power is transmitted from one shaft to another, through a number of pulleys.

Let *d*1 = Diameter of the pulley 1,

*N*1 = Speed of the pulley 1 in r.p.m.,

*d*2, *d*3, *d*4, and *N*2, *N*3, *N*4= Corresponding values for pulleys 2, 3 and 4. We know that velocity ratio of pulleys 1 and 2, $\frac{N2}{N1} = \frac{d1}{d2}$

Similarly, velocity ratio of pulleys 3 and 4, $\frac{N4}{N3} = \frac{d3}{d4}$

Multiplying the above equations $\frac{N2}{N1} \times \frac{N4}{N3} = \frac{d1}{d2} \times \frac{d3}{d4}$

Since N2=N3, therefore; $\frac{N4}{N1} = \frac{d1}{d2} \times \frac{d3}{d4}$

$$\frac{\text{Speed of last driven}}{\text{Speed of first driven}} = \frac{\text{Product of diameters of drivers}}{\text{Product of diameters of drivens}}$$

Slip of Belt:

Let s_1 % = Slip between the driver and the belt, and

s_2 % = Slip between the belt and the follower.

∴ Velocity of the belt passing over the driver per second

$$v = \frac{\pi d_1 . N_1}{60} - \frac{\pi d_1 . N_1}{60} \times \frac{s_1}{100} = \frac{\pi d_1 . N_1}{60}\left(1 - \frac{s_1}{100}\right) \qquad \ldots\ldots\ldots\ldots\ldots(i)$$

and velocity of the belt passing over the follower per second,

$$\frac{\pi d_2 . N_2}{60} = v - v \times \frac{s_2}{100} = v\left(1 - \frac{s_2}{100}\right)$$

Substituting the value of v from equation *(i)*,

$$\frac{\pi d_2 N_2}{60} = \frac{\pi d_1 N_1}{60}\left(1 - \frac{s_1}{100}\right)\left(1 - \frac{s_2}{100}\right)$$

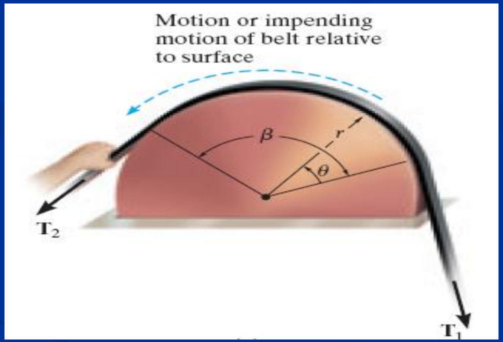
$$\frac{N_2}{N_1} = \frac{d_1}{d_2}\left(1 - \frac{s_1}{100} - \frac{s_2}{100}\right) \qquad \ldots\left(\text{Neglecting } \frac{s_1 \times s_2}{100 \times 100}\right)$$

$$= \frac{d_1}{d_2}\left(1 - \frac{s_1 + s_2}{100}\right) = \frac{d_1}{d_2}\left(1 - \frac{s}{100}\right)$$

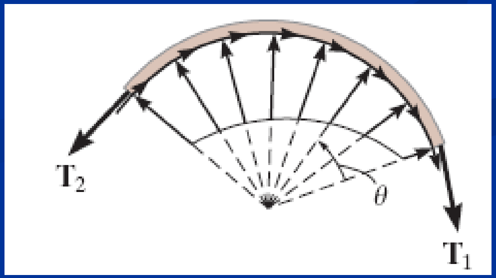
... (where $s = s_1 + s_2$, *i.e.* total percentage of slip)

8.5 Frictional Forces on Flat Belts

- It is necessary to determine the frictional forces developed between the contacting surfaces
- Consider the flat belt which passes over a fixed curved surface



- Obviously $T_2 > T_1$
- Consider FBD of the belt segment in contact with the surface
- **N** and **F** vary both in magnitude and direction

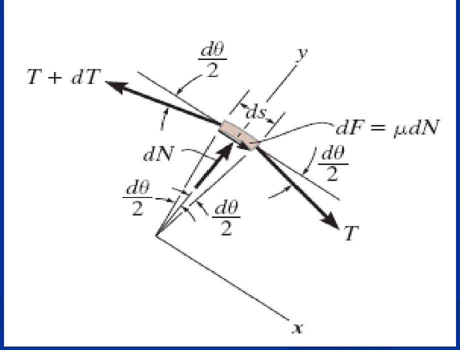


Frictional Forces on Flat Belts

- Consider FBD of an element having a length ds
- Assuming either impending motion or motion of the belt, the magnitude of the frictional force

$$dF = \mu\, dN$$

- Applying equilibrium equations



$$\sum F_x = 0;$$

$$T\cos\left(\frac{d\theta}{2}\right) + \mu dN - (T + dT)\cos\left(\frac{d\theta}{2}\right) = 0$$

$$\sum F_y = 0;$$

$$dN - (T + dT)\sin\left(\frac{d\theta}{2}\right) - T\sin\left(\frac{d\theta}{2}\right) = 0$$

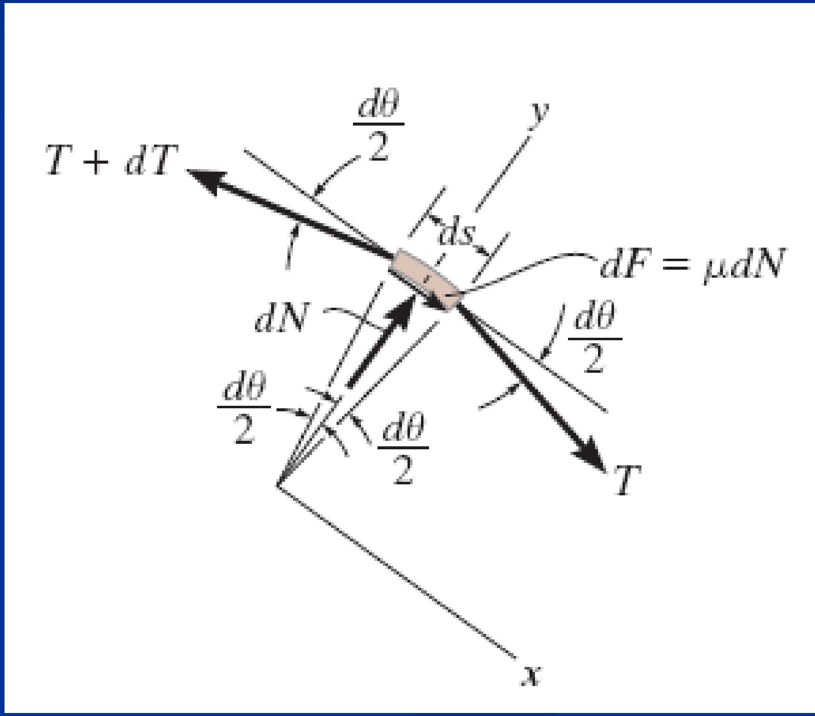
Frictional Forces on Flat Belts

- We have

$$\mu dN = dT$$

$$dN = T d\theta$$

$$\frac{dT}{T} = \mu d\theta$$



$$T = T_1, \theta = 0, T = T_2, \theta = \beta$$

$$\int_{T_1}^{T_2} \frac{dT}{T} = \mu \int_0^{\beta} d\theta$$

$$In \frac{T_2}{T_1} = \mu\beta$$

$$T_2 = T_1 e^{\mu\beta}$$

Example: ***An engine, running at 150 r.p.m., drives a line shaft by means of a belt. The engine pulley is 750 mm diameter and the pulley on the line shaft being 450 mm. A 900 mm diameter pulley on the line shaft drives a 150 mm diameter pulley keyed to a dynamo shaft. Find the speed of the dynamo shaft, when:***

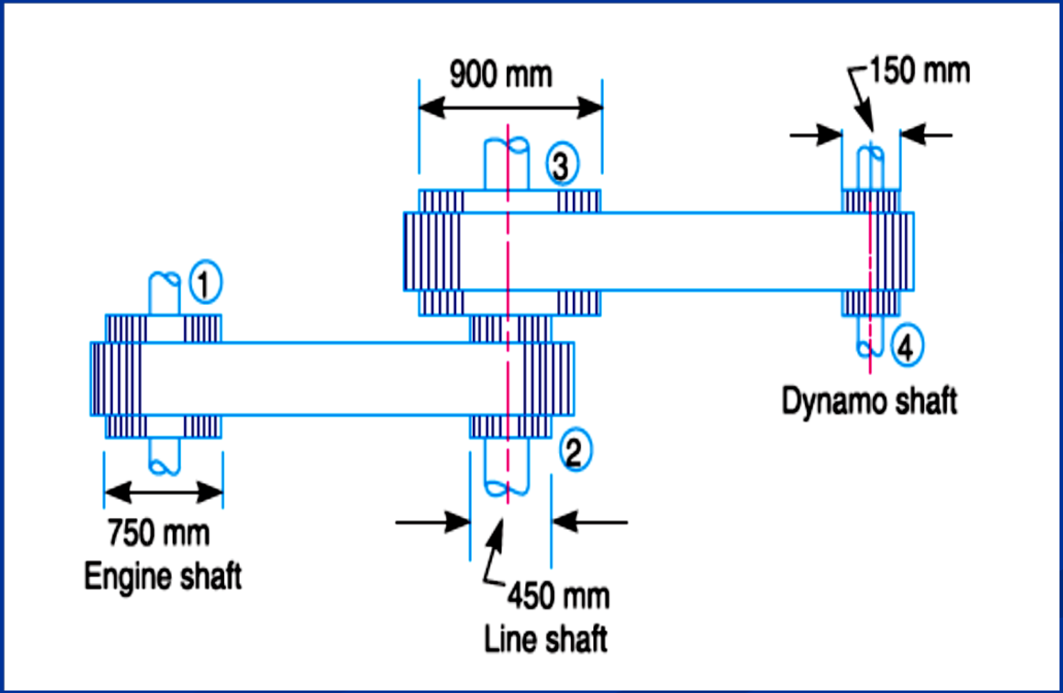
1. There is no slip, and

2. There is a slip of 2% at each drive.

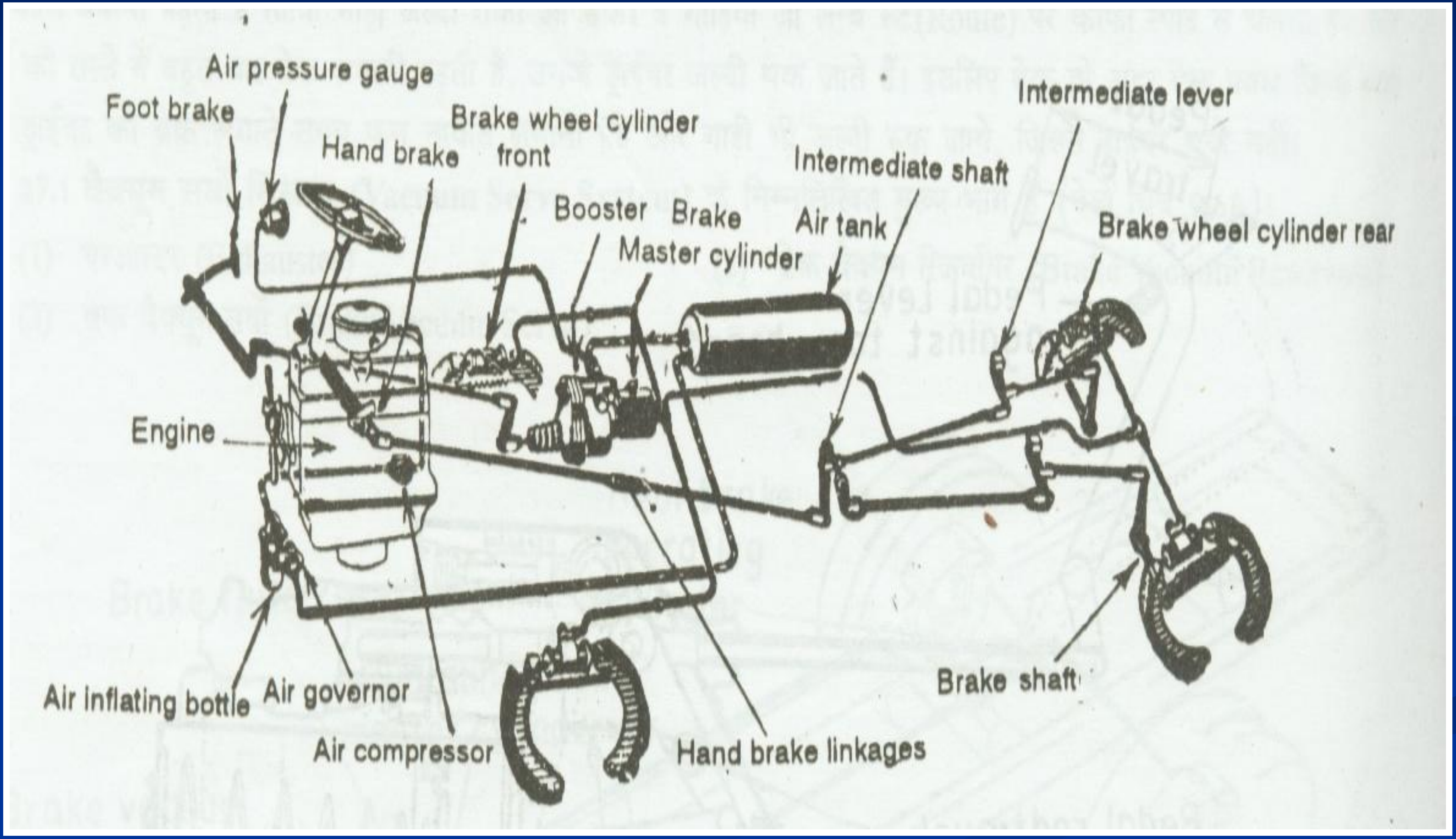
Solution:

Given: N_1 = 150 r.p.m.; d_1 = 750 mm ; d_2 = 450 mm ; d_3 = 900 mm ; d_4 = 150 mm

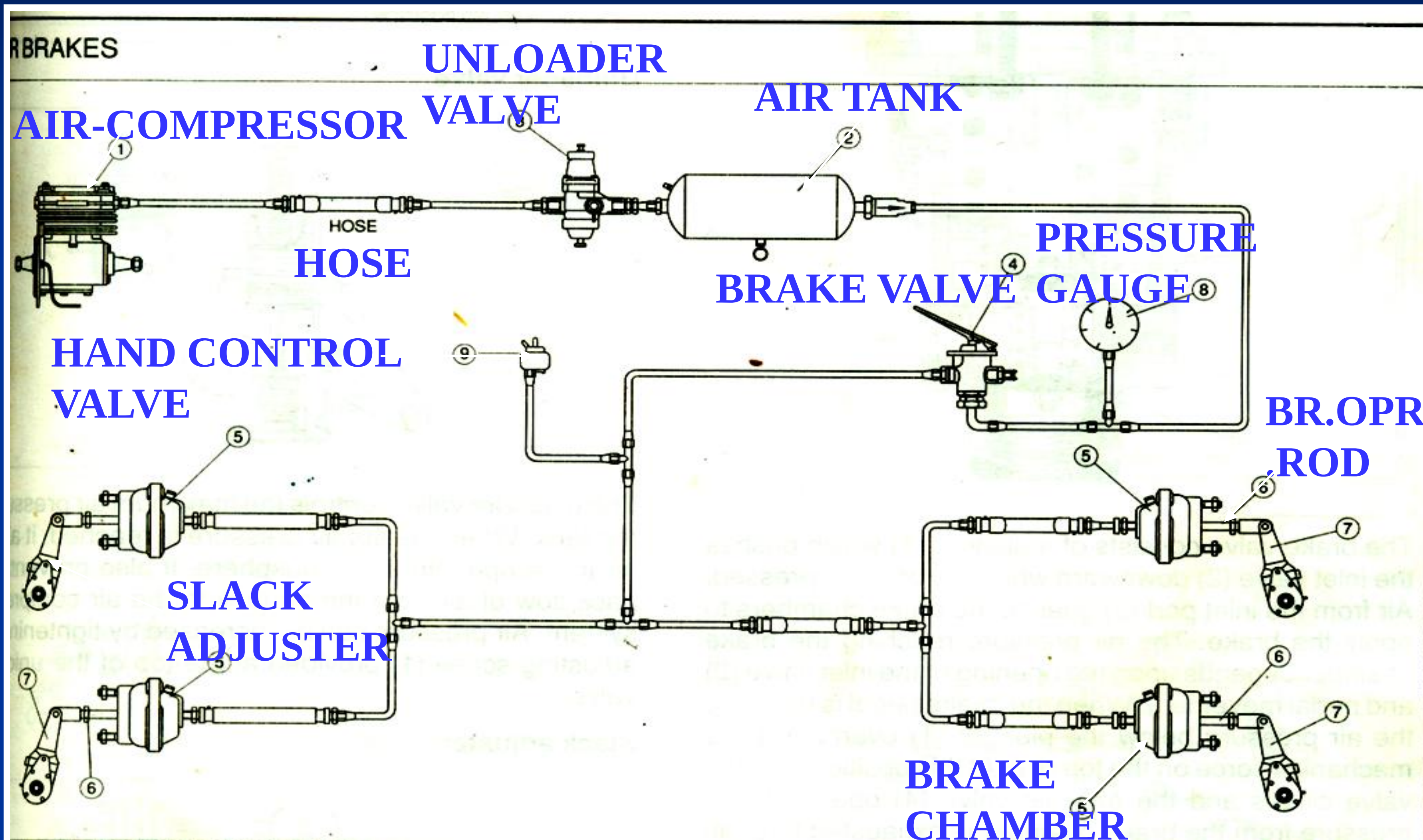
Let N_4 = Speed of the dynamo shaft.



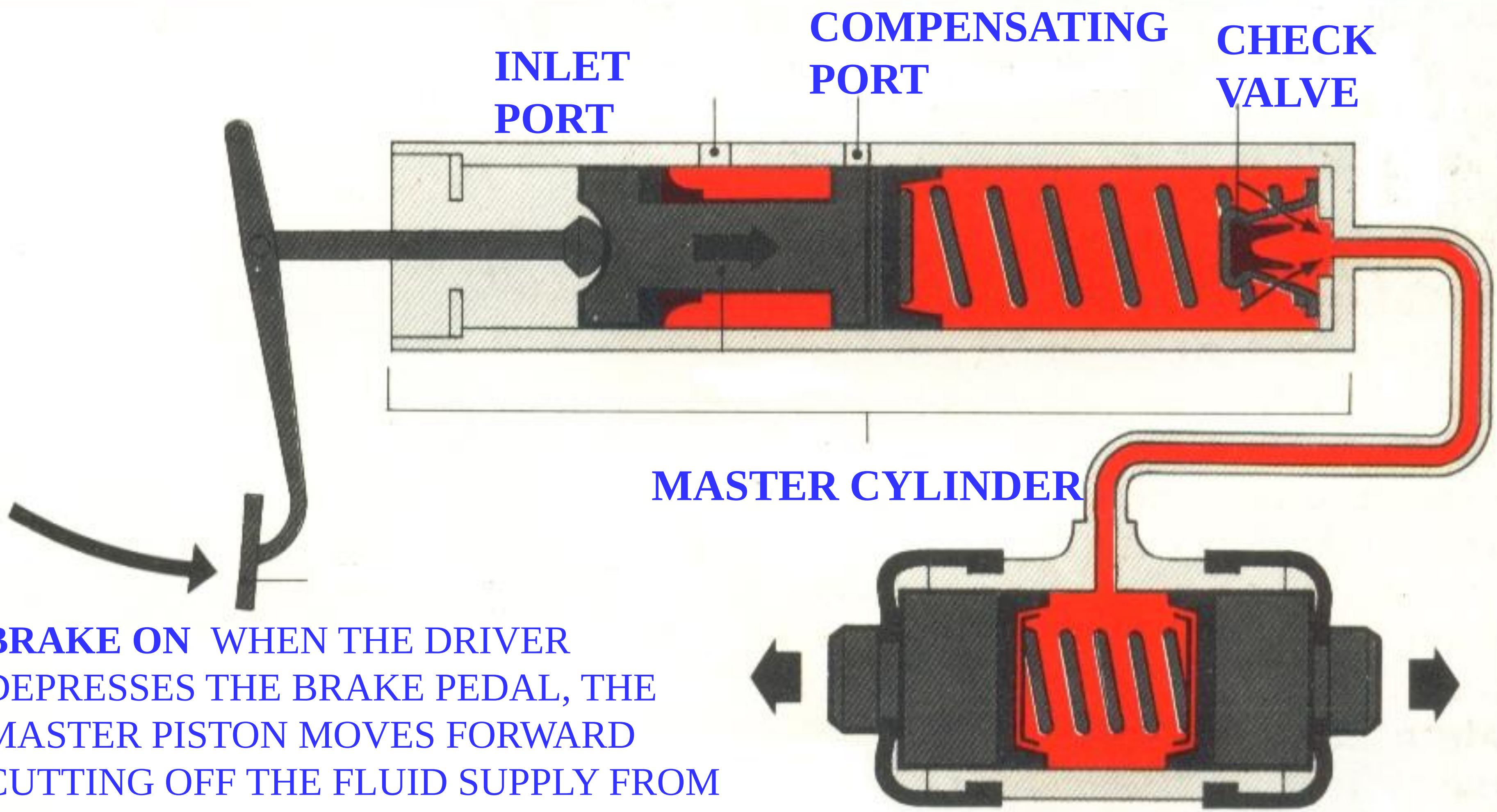
AIR PRESSURE ASSISTED BRAKES



AIR PRESSURE BRAKES

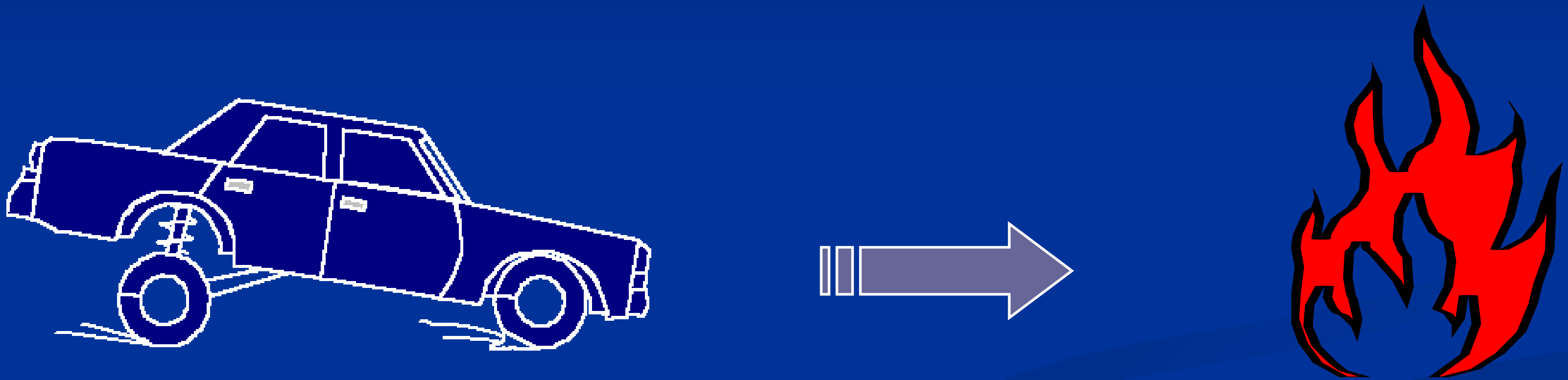


WORKING OF HYDRAULIC BRAKE



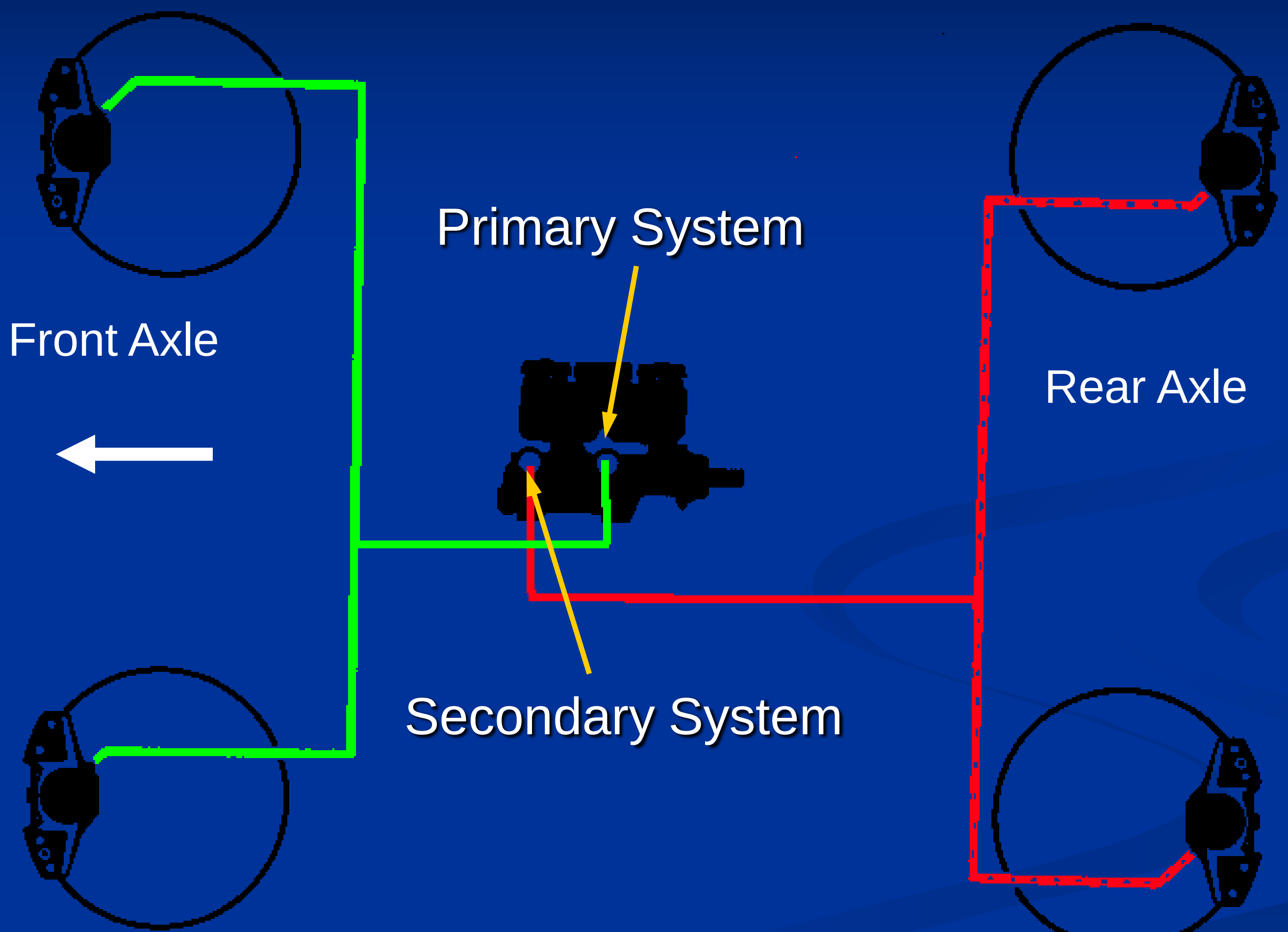
BRAKE ON WHEN THE DRIVER DEPRESSES THE BRAKE PEDAL, THE MASTER PISTON MOVES FORWARD CUTTING OFF THE FLUID SUPPLY FROM THE RESERVOIR . HYDRAULIC PRESSURE MOVES THE PISTONS OF THE WHEEL CYLENDER

Energy Conversion



The brake system converts the kinetic energy of vehicle motion into *heat*

Front/rear Hydraulic Split



QUIZ

1. A friction force always acts _____ to the contact surface.

A) Normal B) At 45°

C) Parallel D) At the angle of static friction

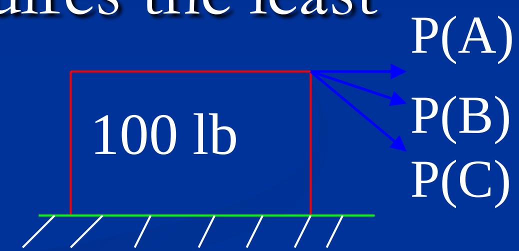
2. If a block is stationary, then the friction force acting on it is ________ .

A) $\leq \mu_s N$ B) $= \mu_s N$

C) $\geq \mu_s N$ D) $= \mu_k N$

QUIZ

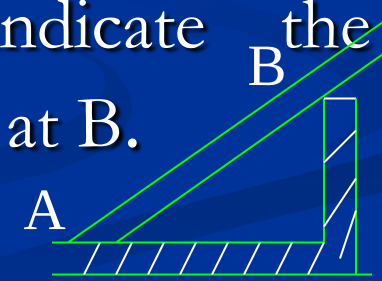
3. A 100 lb box with a wide base is pulled by a force P and μs = 0.4. Which force orientation requires the least force to begin sliding?



A) P(A) B) P(B)

C) P(C) D) Not determined

4. A ladder is positioned as shown. Please indicate the direction of the friction force on the ladder at B.



A) ↑ B) ↓

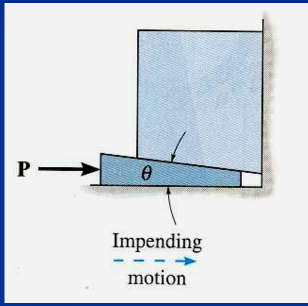
C) D)

QUIZ

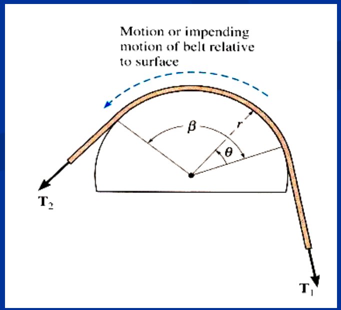
5. A wedge allows a ______ force P to lift a _________ weight W.

A) (large, large) B) (small, small)

C) (small, large) D) (large, small)



6. Considering friction forces and the indicated motion of the belt, how are belt tensions T_1 and T_2 related?



A) $T_1 > T_2$ B) $T_1 = T_2$

C) $T_1 < T_2$ D) $T_1 = T_2 e^{\mu}$

QUIZ

7. When determining the force P needed to lift the block of weight W, it is easier to draw a FBD of ______ first.

A) The wedge B) The block

C) The horizontal ground D) The vertical wall

8. In the analysis of frictional forces on a flat belt, $T_2 = T_1 e \mu \beta$. In this equation, β equals ______ .

A) Angle of contact in deg B) Angle of contact in rad

C) Coefficient of static friction D) Coefficient of kinetic friction

Just a couple more things…

Pedal Travel