ME101: Engineering Mechanics (3 1 0 8)

2019-2020 (II Semester)

LECTURE: 11

SCREW JACK

- Basic use- Raise Heavy weights by small distances.
- Screws are used for fastening and for transmitting power or motion
- Square-threaded screws are frequently used in jacks, presses, and other mechanisms.
- Different Types of Threads which can be used are- Square, V-Shape, Buttress, ACME, Whitworth, etc.
- For Screw Jacks, square threads are found to be most efficient.

Screw

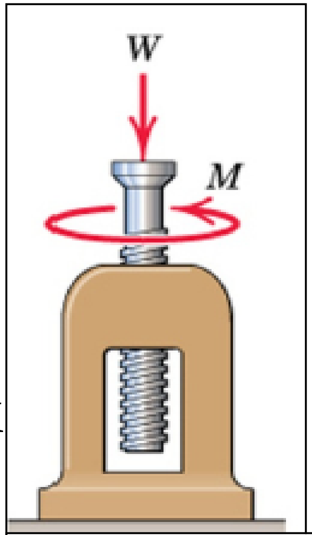
❖ **Square Threaded Screws**

✓ Used for fastening and for transmitting power or motion

✓ Square threads are more efficient.

✓ Friction developed in the threads largely determines the action of the screw.

❖ **FBD of the Screw**: R exerted by the thread of the jack frame on a small portion of the screw thread is shown,



✓ Lead = L = advancement per revolution.

✓ L = Pitch – for single threaded screw.

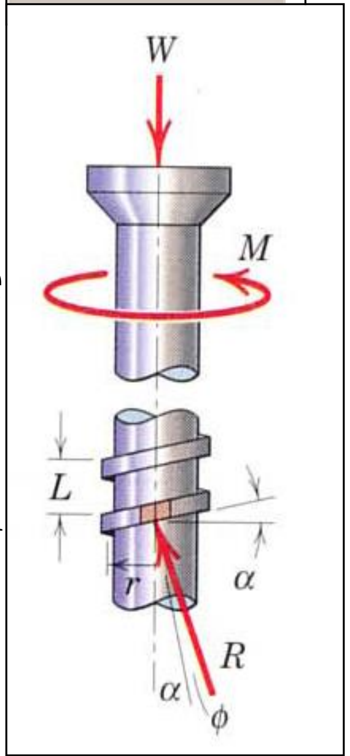
✓ L = 2xPitch – for double threaded screw (twice advancement per revolution).

✓ Pitch = axial distance between adjacent threads on a helix or screw,

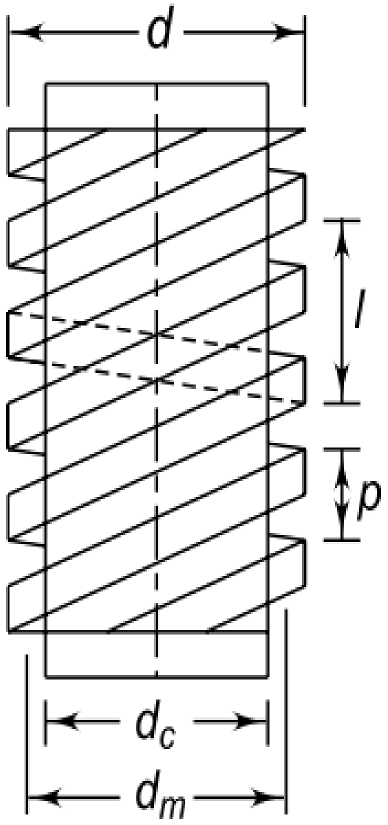
Mean Radius = $\boldsymbol{r}$;

Helix angle α can be determined by unwrapping the thread of the screw for one complete turn

$$\alpha = \tan^{-1}(L/2\pi r)$$

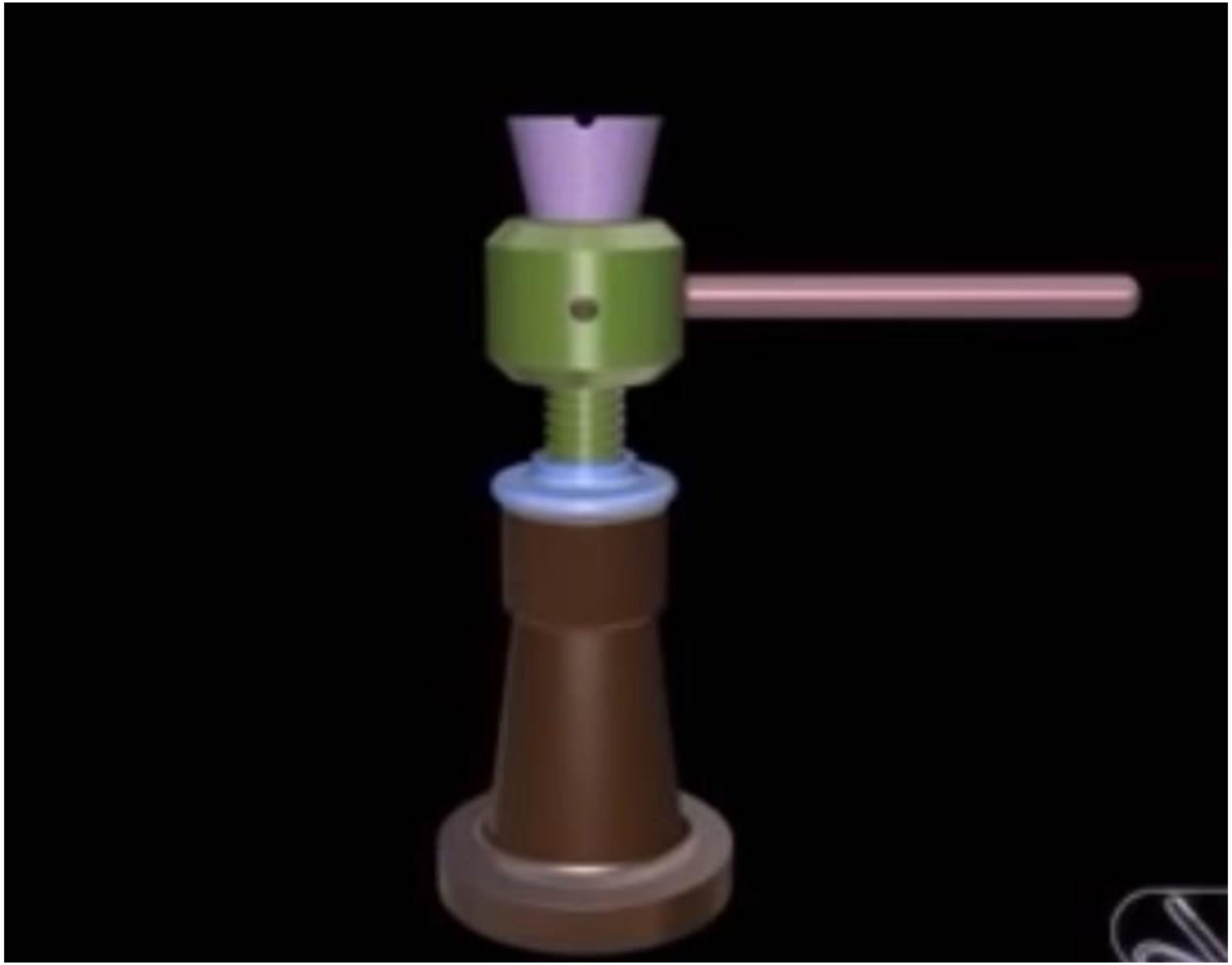


Thread Terminologies

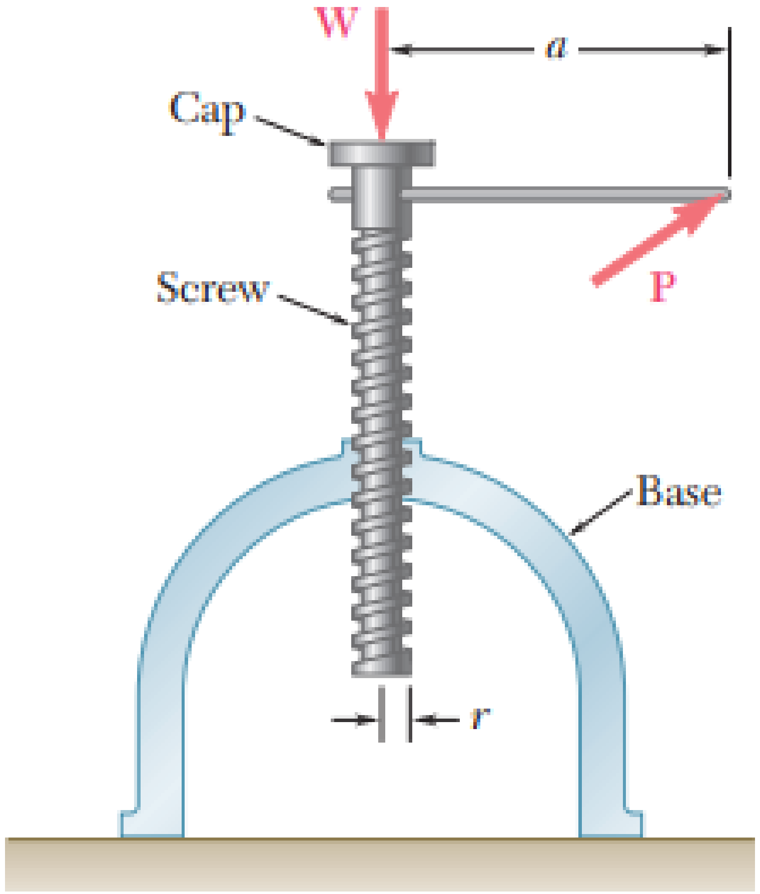


- ***(i) Pitch*** The pitch is defined as the distance measured parallel to the axis of the screw from a point on one thread to the corresponding point on the adjacent thread.
- ***(ii) Nominal Diameter*** Nominal diameter is the largest diameter of the screw. It is also called *major diameter*.
- ***(iii) Core Diameter*** The core diameter is the smallest diameter of the screw thread. It is also called *minor diameter*

Demonstration of Raising of Cup by Screw Jack



Schematic of Screw Jack



- Screw Carries Load “W” which is supported by the Base
- Contact between screw and base takes place along a portion of their threads
- Applying a force **P** on the handle, the screw can be made to turn and to raise the load **W**.

Analysis of Screw Jack

- Lifting of Weight “W” in Screw Jack can be compared with a Weight “W” being lifted on an angular incline.

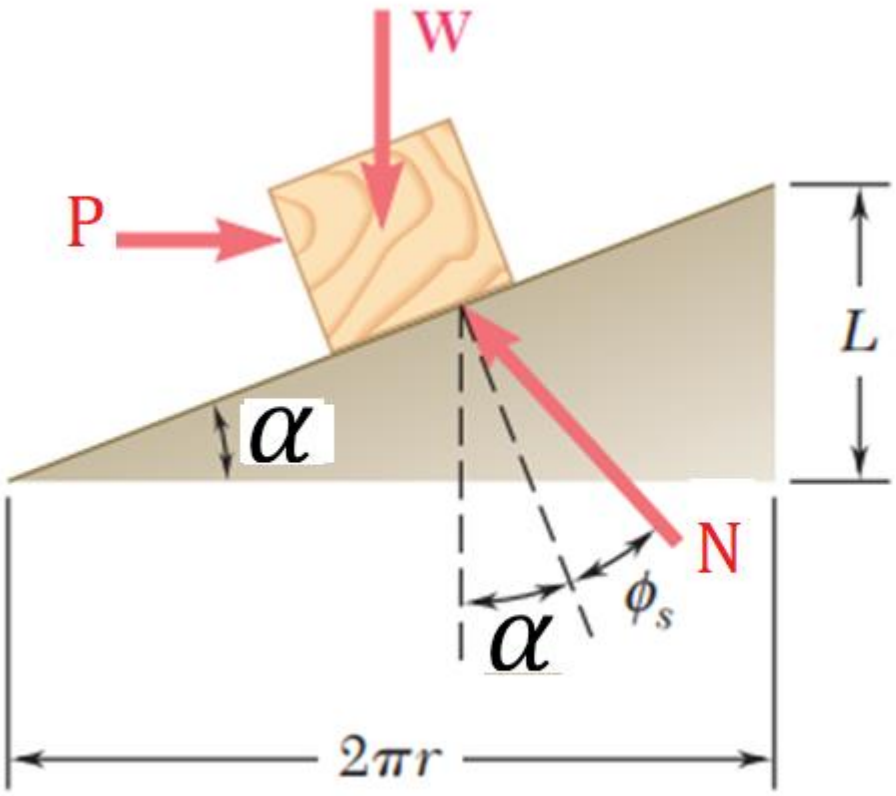
- Lead of a screw is the Lift of Weight because of one complete revolution of Screw.

- Lead – 1) Single Start thread= pitch

  2) Multi start thread = n*pitch

Analysis of Screw Jack….(contd)

- Unwrapping of thread involved in one rotation of screw



(a) Impending motion upward

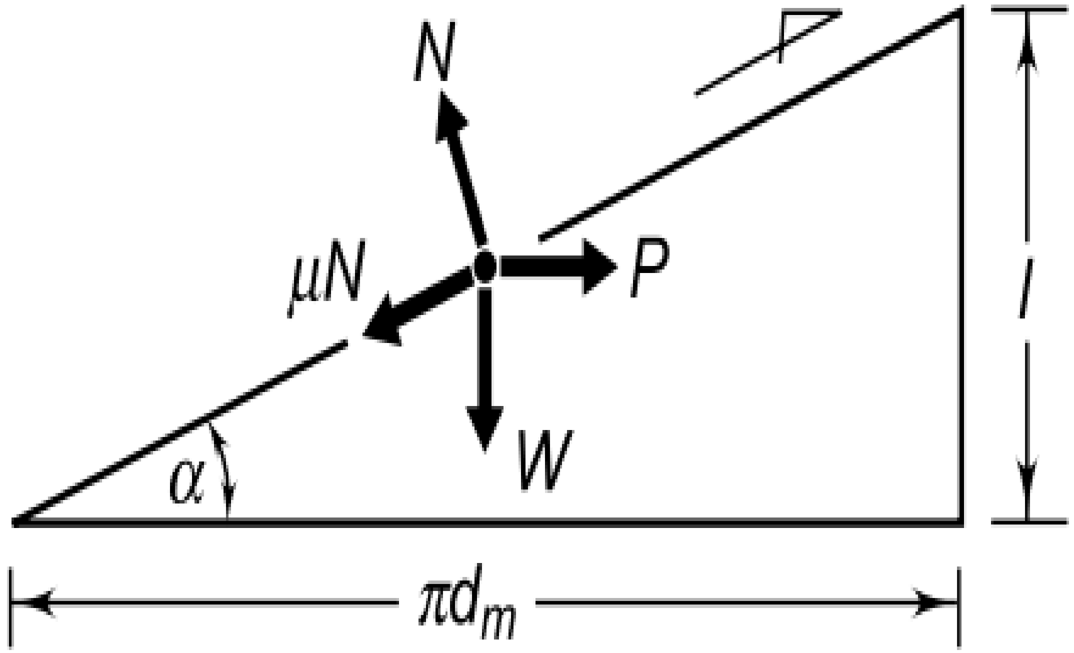
- Right angle triangle is obtained as shown.
- Height of right angled triangle = LEAD of screw
- Base of Triangle = $2*\pi*r$

  r – mean radius of thread

$$\tan\alpha = \frac{L}{2\pi r}$$

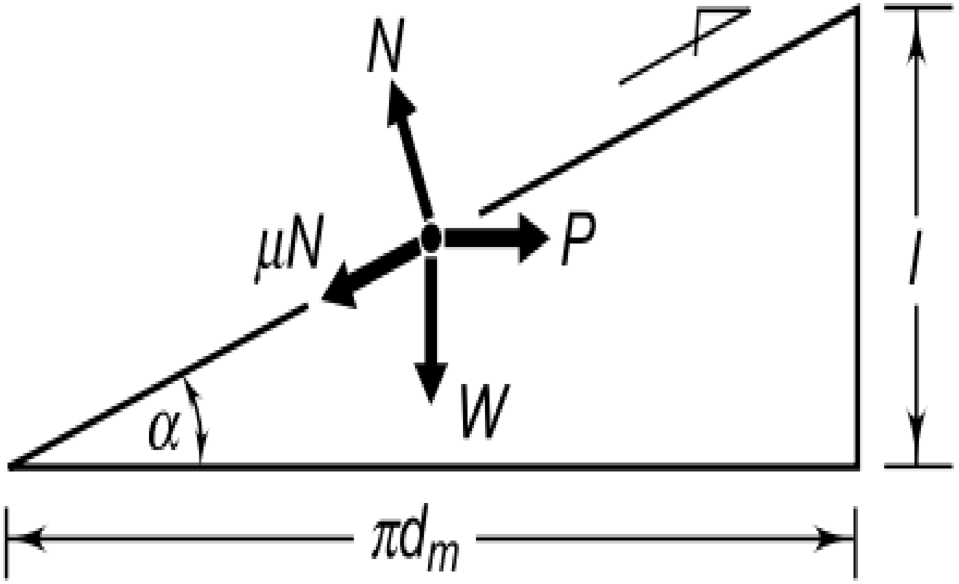
Where "α" is called as ***Lead Angle***

Analysis for Lifting Load



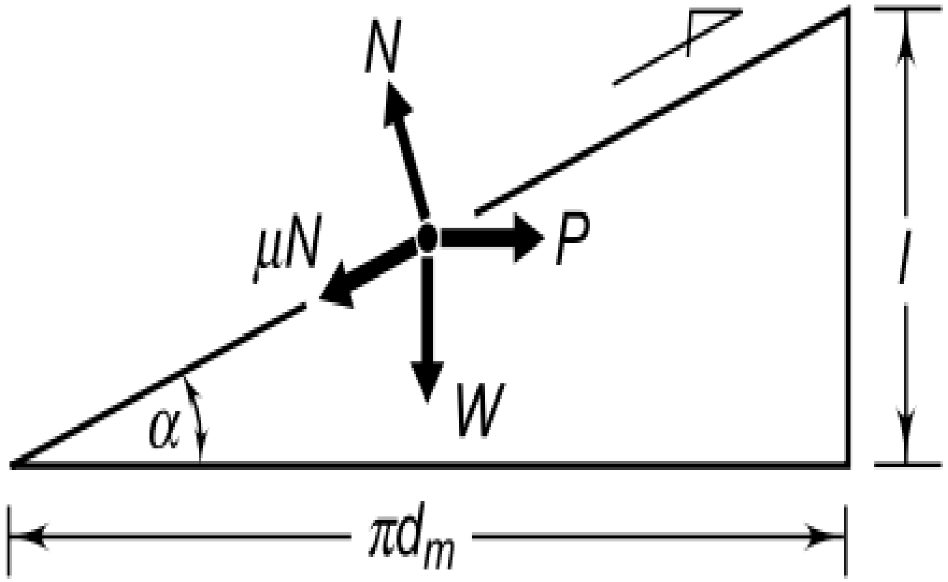
- ***(i) Load W*** It always acts in a vertically downward direction.
- ***(ii) Normal Reaction N*** It acts perpendicular (normal) to the inclined plane.
- ***(iii) Frictional Force μN*** Frictional force acts opposite to the motion. Since the load is moving up the inclined plane, frictional force acts along the inclined plane in the downward direction

Analysis of Lifting Load



- ***(iv) Effort P:*** Effort *P* acts perpendicular to the load *W*. It may act towards the right or towards the left. It should act towards the right to overcome the friction and raise the load.

Analysis of Lifting Load



- Horizontal Force Balance

$$\boldsymbol{P = \mu N cos\alpha + N sin\alpha}$$

- Vertical force balance

$$\boldsymbol{W = N cos\alpha - \mu N sin\alpha}$$

- Solving above equations,

$$\boldsymbol{P = \frac{W(\mu + tan\ \alpha)}{(1 - \mu\ tan\ \alpha)}}$$

Analysis of Lifting Load

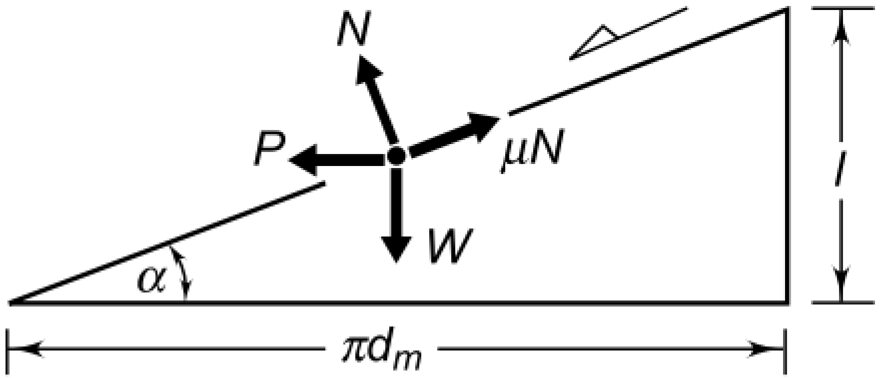
- Substituting, $\boldsymbol{\mu = \tan\phi}$ in above equation, it can be simplified as given below :

$$\boldsymbol{P = W\tan(\phi + \alpha)}$$

- Torque required to raise the load

$$\boldsymbol{M_t = \frac{Pd_m}{2} = \frac{Wd_m\tan(\phi + \alpha)}{2}}$$

Analysis of Lowering Load



- Horizontal Force Balance

$$\boldsymbol{P = \mu N\cos\alpha - N\sin\alpha}$$

- Vertical force balance

$$\boldsymbol{W = N\cos\alpha + \mu N\sin\alpha}$$

- Solving above equations,

$$\boldsymbol{P = \frac{W(\mu - \tan\alpha)}{(1 + \mu\tan\alpha)}}$$

Analysis of Lowering Load

- Substituting, $\boldsymbol{\mu} = \mathbf{tan}\boldsymbol{\phi}$ in above equation, it can be simplified as given below :

$$\boldsymbol{P = W\mathbf{tan}(\phi - \alpha)}$$

- Torque required to lower the load

$$\boldsymbol{M_t = \frac{Pd_m}{2} = \frac{Wd_m\mathbf{tan}(\phi - \alpha)}{2}}$$

Self Locking Screw

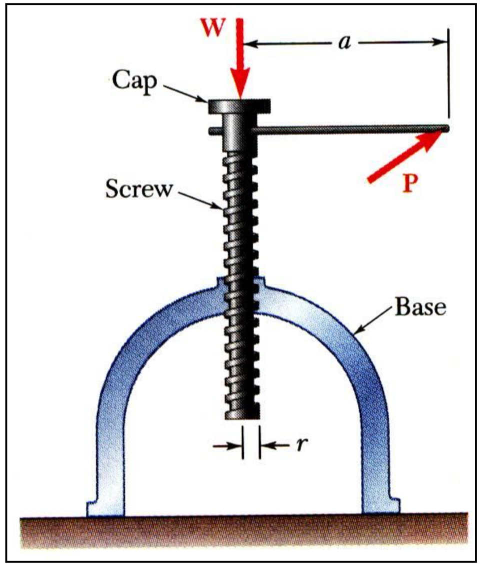
- Torque required to lower the load

$$M_t = \frac{Pd_m}{2} = \frac{Wd_m \tan(\phi - \alpha)}{2}$$

- If $\phi < \alpha$, value of torque required to lower load in negative. This implies that, zero effort will be required to lower the load and it will lower automatically. This is undesirable. It is called as "Overhauling"

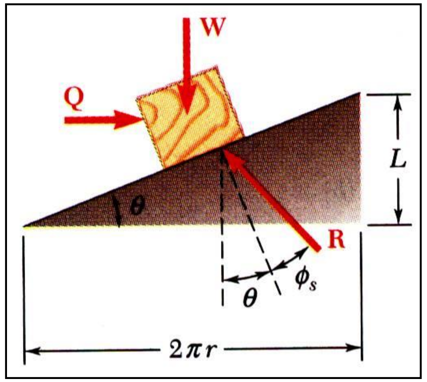
- If $\phi \geq \alpha$, a net positive torque is required to lower load, and it will not lower automatically. This is called **SELF LOCKING**

Square-Threaded Screws

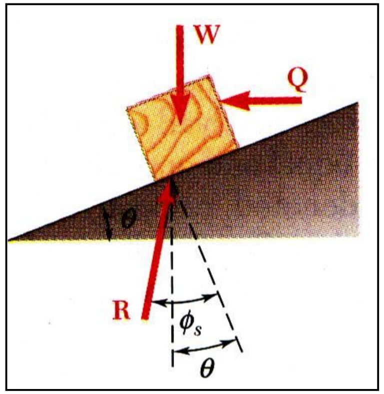


- **Square-threaded screws** frequently used in jacks, presses, etc. Analysis similar to block on inclined plane. Recall friction force does not depend on area of contact.
- Thread of base has been "unwrapped" and shown as straight line. Slope is 2p*r* horizontally and lead *L* vertically.
- Moment of force *Q* is equal to moment of force *P*.

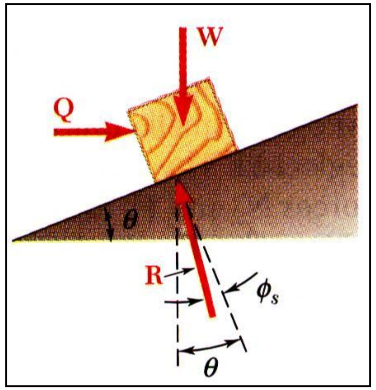
$$Q = Pa/r$$



- Impending motion upwards. Solve for *Q*.

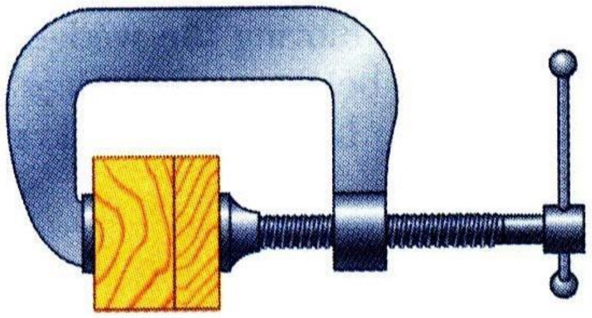


- $\phi_s > \theta$, Self-locking, solve for *Q* to lower load.



- $\phi_s > \theta$, Non-locking, solve for *Q* to hold load.

Sample Problem



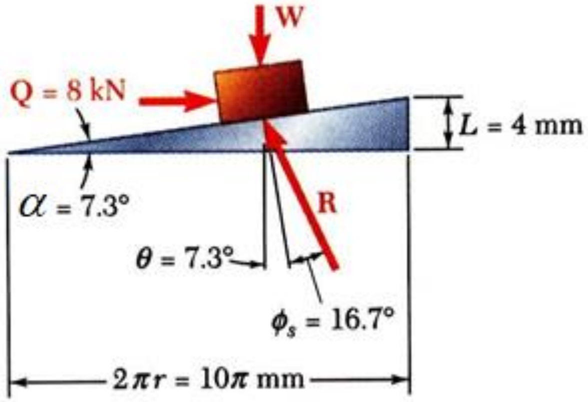
A clamp is used to hold two pieces of wood together as shown. The clamp has a double square thread of mean diameter equal to 10 mm with a pitch of 2 mm. The coefficient of friction between threads is $\mu_s = 0.30$.

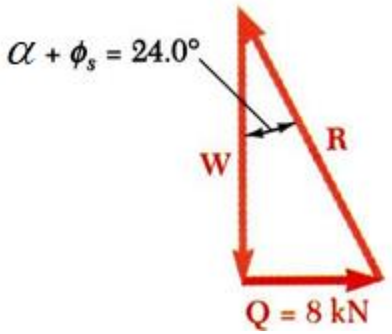
If a maximum torque of 40 N*m is applied in tightening the clamp, determine (a) the force exerted on the pieces of wood, and (b) the torque required to loosen the clamp.

<u>SOLUTION</u>

- Calculate lead angle and pitch angle.
- Using block and plane analogy with impending motion up the plane, calculate the clamping force with a force triangle.
- With impending motion down the plane, calculate the force and torque required to loosen the clamp.

Sample Problem





SOLUTION

- Calculate lead angle and pitch angle. For the double threaded screw, the lead L is equal to twice the pitch.

$$\tan\alpha = \frac{L}{2\pi r} = \frac{2(2\text{ mm})}{10\pi\text{ mm}} = 0.1273 \qquad \alpha = 7.3°$$

$$\tan\phi_s = \mu_s = 0.30 \qquad \phi_s = 16.7°$$

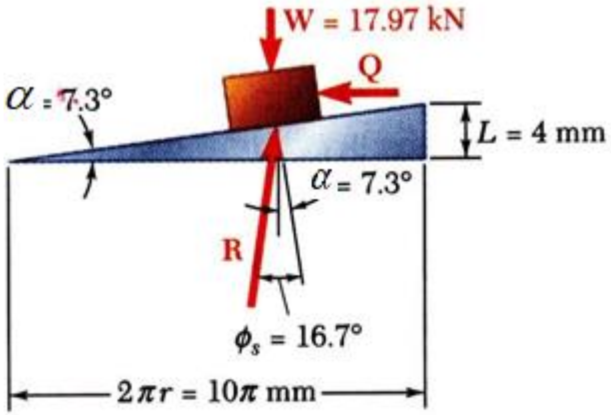
- Using block and plane analogy with impending motion up the plane, calculate clamping force with force triangle.

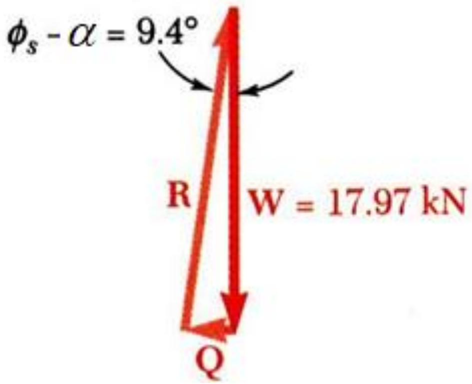
$$Qr = 40\text{ N}\cdot\text{m} \qquad Q = \frac{40\text{ N}\cdot\text{m}}{5\text{ mm}} = 8\text{ kN}$$

$$\tan(\alpha + \phi_s) = \frac{Q}{W} \qquad W = \frac{8\text{ kN}}{\tan 24°}$$

$$\boxed{W = 17.97\text{ kN}}$$

Sample Problem





- With impending motion down the plane, calculate the force and torque required to loosen the clamp.

$$\tan(\phi_s - \alpha) = \frac{Q}{W} \qquad Q = (17.97\,\mathrm{kN})\tan 9.4^\circ$$

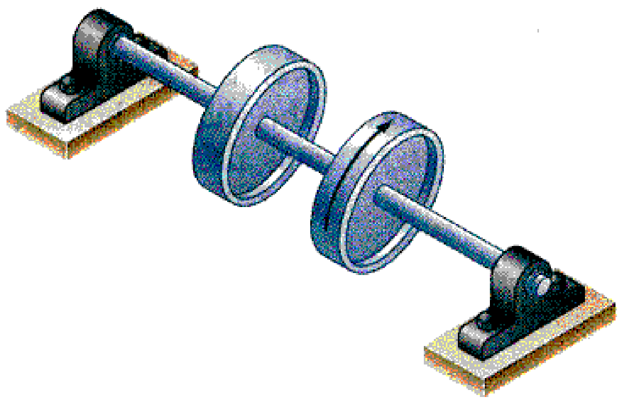
$$Q = 2.975\,\mathrm{kN}$$

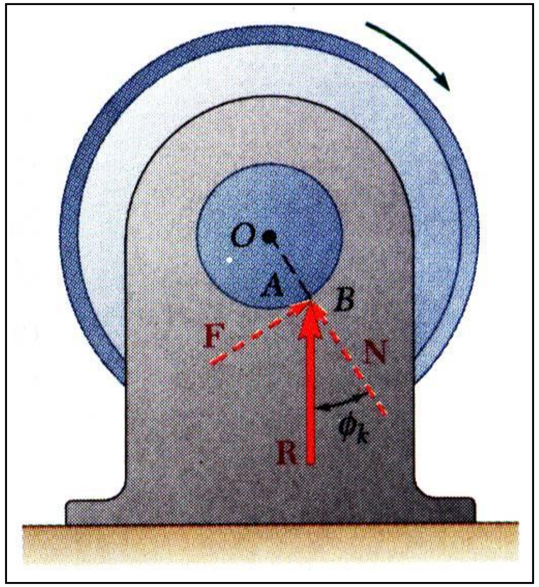
$$Torque = Qr = (2.975\,\mathrm{kN})(5\mathrm{mm})$$

$$= \left(2.975\times10^{3}\,\mathrm{N}\right)\left(5\times10^{-3}\,\mathrm{m}\right)$$

$$\boxed{Torque = 14.87\,\mathrm{N\cdot m}}$$

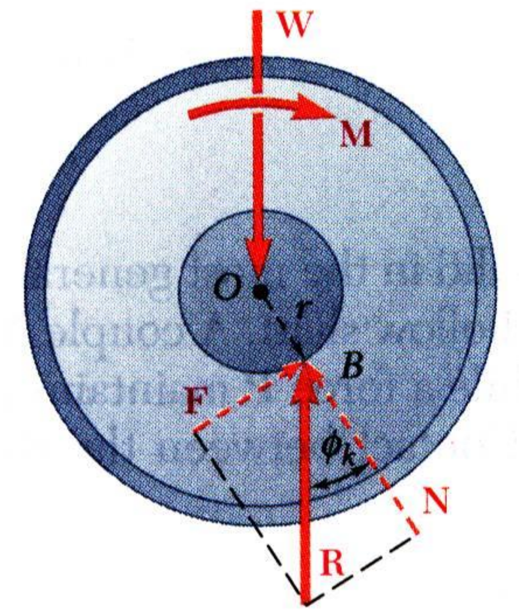
Journal Bearings & Axle Friction

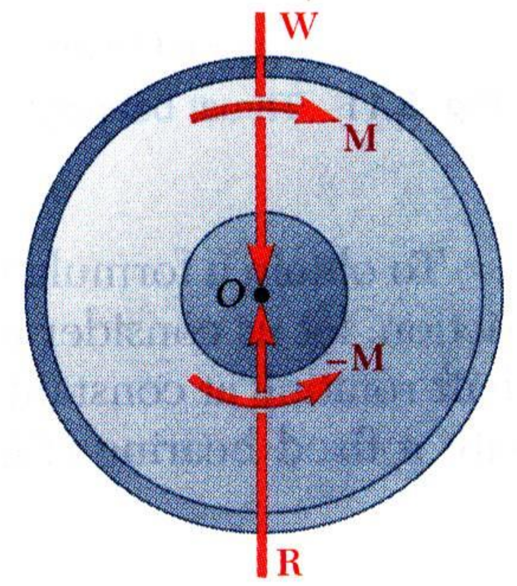


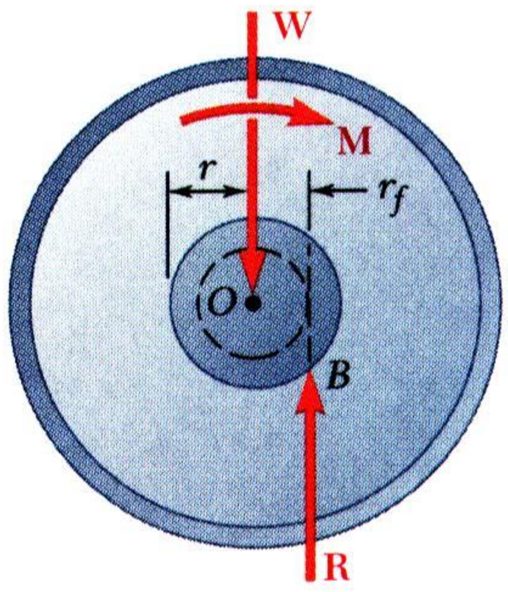


- ✓ **Journal bearings** provide lateral support to rotating shafts. Thrust bearings provide **axial support.**
- ✓ Frictional resistance of fully lubricated bearings depends on clearances, speed and lubricant viscosity. Partially lubricated axles and bearings can be assumed to be in direct contact along a straight line.
- ✓ Forces acting on bearing are weight *W* of wheels and shaft, couple *M* to maintain motion, and reaction *R* of the bearing.
- ✓ Reaction is vertical and equal in magnitude to W.
- ✓ Reaction line of action does not pass through shaft center *O*; *R* is located to the right of *O*, resulting in a moment that is balanced by *M*.
- ✓ Physically, contact point is displaced as axle "climbs" in bearing.

Journal Bearings & Axle Friction *(contd.)*







- Angle between *R* and normal to bearing surface is the angle of kinetic friction φ_k.

$$M = Rr\sin\phi_k$$
$$\approx Rr\mu_k$$

- May treat bearing reaction as force-couple system.

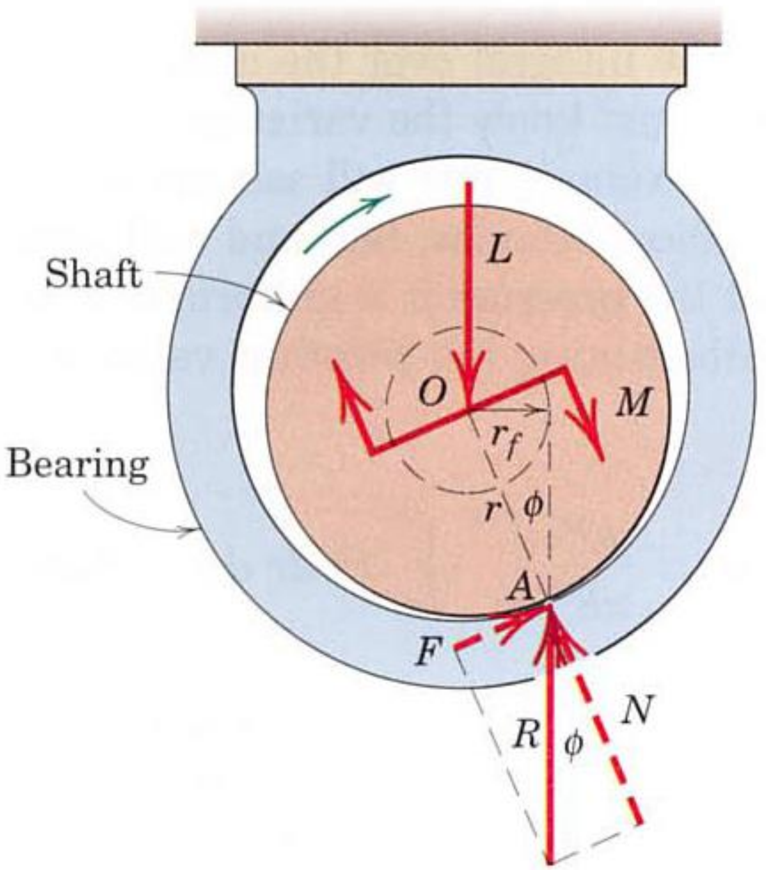
- For graphical solution, *R* must be tangent to *circle of friction*.

$$r_f = r\sin\phi_k$$
$$\approx r\mu_k$$

Moment acting on Journal Bearing

$$M = Lr_f = Lr \sin \phi$$

Angle of kinetic friction - φ



For a small coefficient of friction, the angle ϕ is small, and the sine and tangent may be interchanged with only small error. Since $\mu = \tan \phi$, a good approximation to the torque is

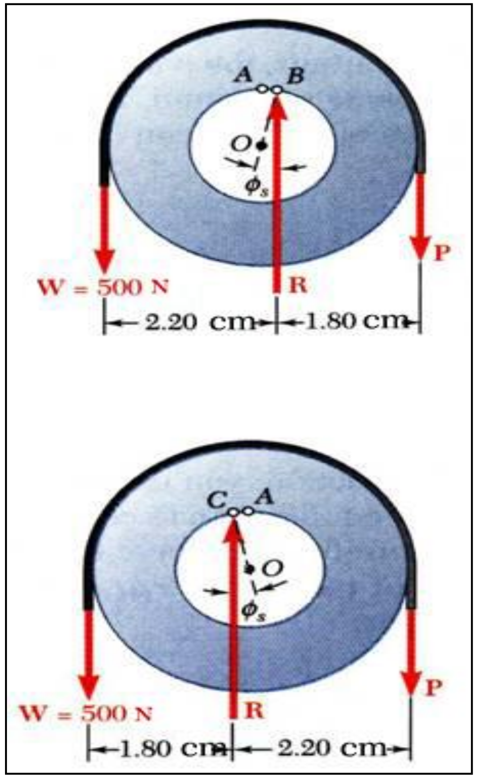
$$M = \mu Lr$$

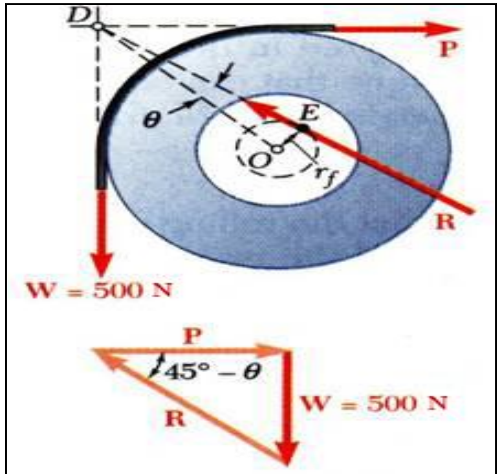
Problem on Journal Bearing

A pulley of diameter 4 cm can rotate about a fixed shaft of diameter 2 cm. The coefficient of static friction between the pulley and shaft is 0.20.

Determine:

- the smallest vertical force *P* required to start raising a 500 N load,
- the smallest vertical force *P* required to hold the load, and
- the smallest horizontal force P required to start raising the same load.

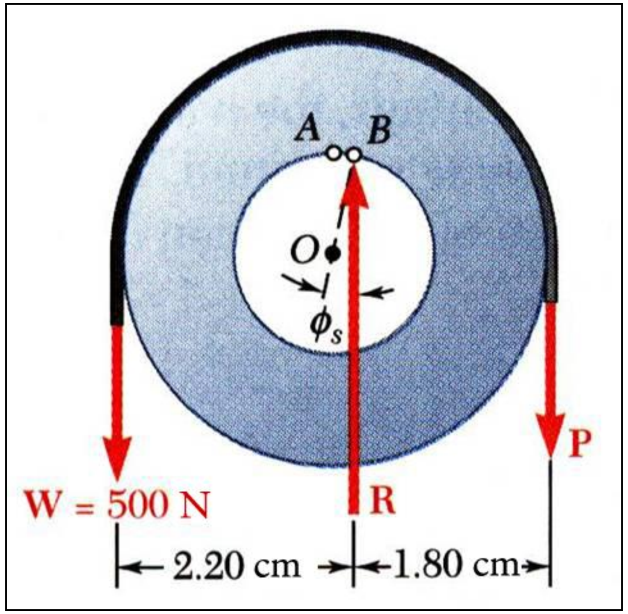




Solution:

- ✓ With the load on the left and force *P* on the right, impending motion is clockwise to raise load. Sum moments about displaced contact point *B* to find *P*.
- ✓ Impending motion is counter-clockwise as load is held stationary with smallest force *P*. Sum moments about *C* to find *P*.
- ✓ With the load on the left and force *P* acting horizontally to the right, impending motion is clockwise to raise load. Utilize a force triangle to find *P*.

Problem on Belt Friction *(contd.)*



SOLUTION:

- With the load on the left and force P on the right, impending motion is clockwise to raise load. Sum moments about displaced contact point B to find P.

- The perpendicular distance from center O of pulley to line of action of R is

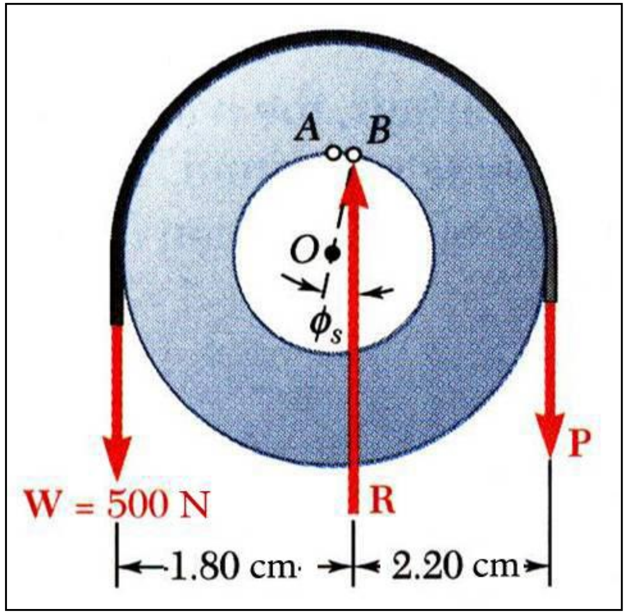
$$r_f = r\sin\varphi_s \approx r\mu_s \qquad r_f \approx (1\,\text{cm})0.20 = 0.20\,\text{cm}$$

- Summing moments about B,

$$\sum M_B = 0: \qquad (2.20\,\text{cm})(500\,\text{N}) - (1.80\,\text{cm})P = 0$$

$$\boxed{P = 611\,\text{N}}$$

Problem on Journal Bearing *(contd.)*



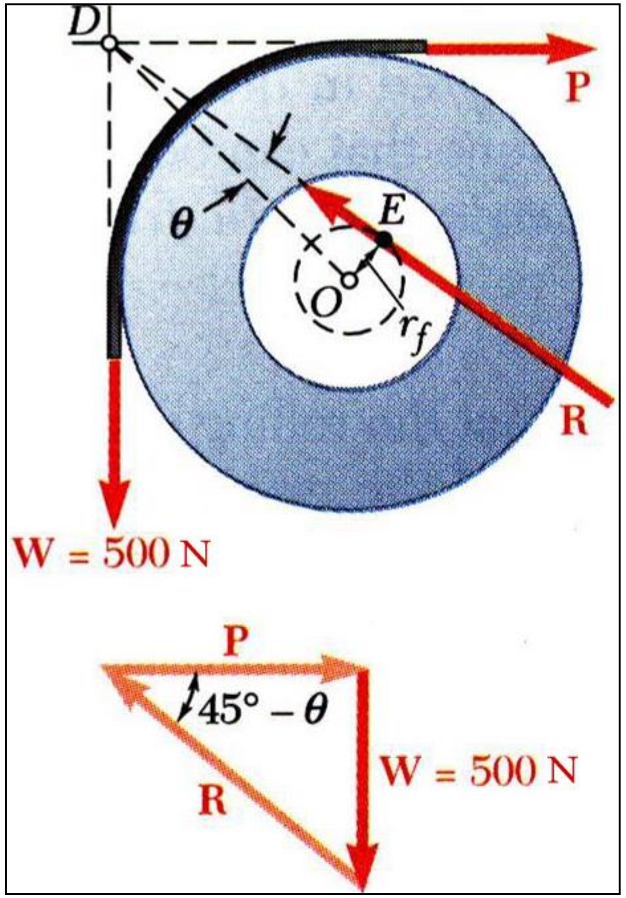
- Impending motion is counter-clockwise as load is held stationary with smallest force *P*. Sum moments about *C* to find *P*.

- The perpendicular distance from center *O* of pulley to line of action of *R* is again 0.20 cm. Summing moments about C,

$$\sum M_C = 0: \qquad (1.80\,\text{cm})(500\,\text{N}) - (2.20\,\text{cm})P = 0$$

$$\boxed{P = 409\,\text{N}}$$

Problem on Journal Bearing(*contd.)*



- With the load on the left and force P acting horizontally to the right, impending motion is clockwise to raise load. Utilize a force triangle to find P.
- Since W, P, and R are not parallel, they must be concurrent. Line of action of R must pass through intersection of W and P and be tangent to circle of friction which has radius $r_f = 0.20$ cm.

$$\sin\theta = \frac{OE}{OD} = \frac{0.20\,\text{cm}}{(2\,\text{cm})\sqrt{2}} = 0.0707$$

$$\theta = 4.1°$$

$$P = W\cot(45° - \theta) = (500\,\text{N})\cot 40.9°$$

- From the force triangle,

$$\boxed{P = 577\ \text{N}}$$

Thrust Bearing & Disk friction

- Friction between circular surfaces under distributed normal pressure occurs in pivot bearings, clutch plates and disk brakes. To examine these applications,

p is the normal pressure at any location

frictional force acting on an elemental area

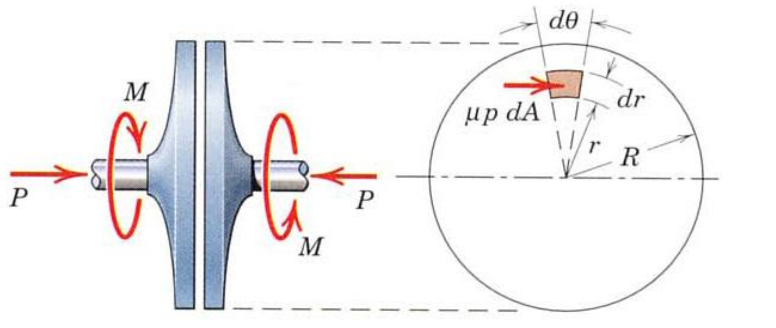


Figure 6/9

- Moment of the elemental friction,

$$M = \int \mu p r\, dA$$

- If p is uniform over the entire surface

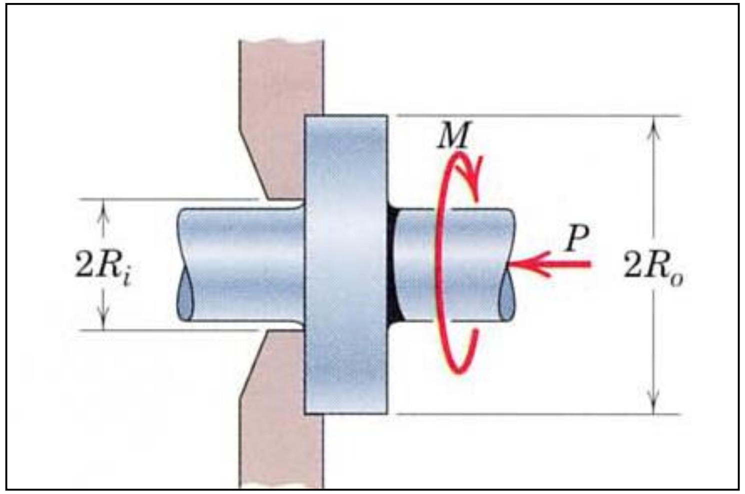
$$\pi R^2 p = P.$$

$$M = \frac{\mu P}{\pi R^2} \int_0^{2\pi} \int_0^R r^2\, dr\, d\theta = \tfrac{2}{3}\mu P R$$

Moment in Collar
(following Uniform Wear Theory)

If the friction disks are rings, as in the collar bearing shown in Fig

$$M = \frac{2}{3}\mu P \frac{R_o^3 - R_i^3}{R_o^2 - R_i^2}$$



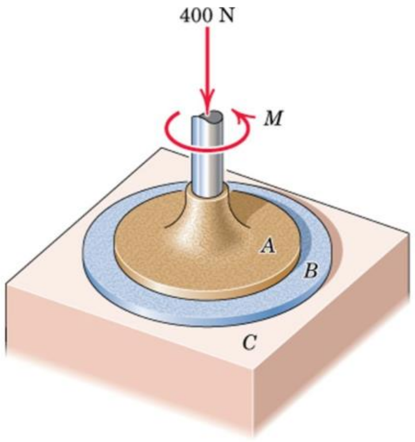
Problem on Disk Friction

Circular disk A (225 mm dia.) is placed on top of disk B (300 mm dia.) and is subjected to a compressive force of 400 N. Pressure under each disk is constant over its surface. Coefficient of friction between A and B = 0.4.

Determine:

(a) the couple M which will cause A to slip on B.

(b) Min coefficient of friction μ between B and supporting surface C which will prevent B from rotating shown in **Fig(e)**?



Solution:

✓ Impending slip between A and B:

$\mu=0.4$, $P=400$ N, R=225/2 mm

$M = 2/3 \times 0.4 \times 400 \times 0.225/2$ $M = 12$ Nm

(b) Impending slip between B and C :

Slip between A and B $M = 12$ Nm

$\mu=?$ $P=400$ N, R=300/2 mm

$12 = 2/3 \times \mu \times 400 \times 0.300/2$ $\mu = 0.3$

Fig(e)