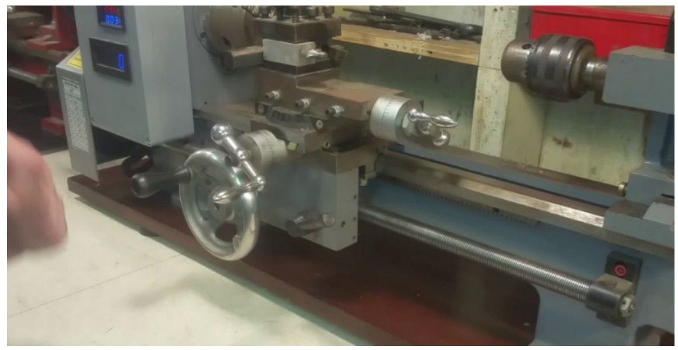
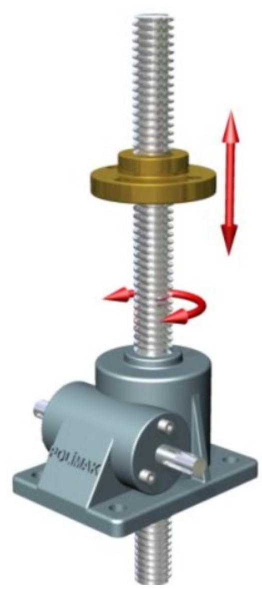
MENG 3050-Power Transmission Components

Lesson 04

POWER SCREWS

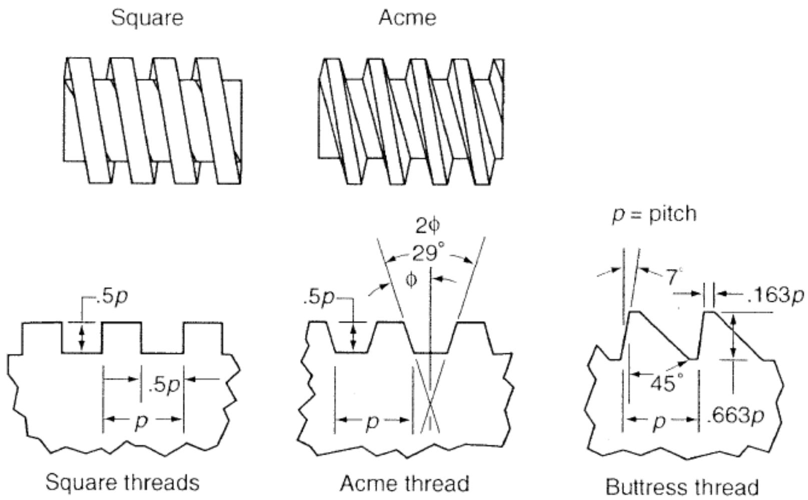
- The power screws (also known as translation screws) are used to convert rotary motion into translatory motion.
- For example, the lead screw of lathe,
- In case of screw jack, a small force applied in the horizontal plane is used to raise or lower a large load.
- Power screws are also used in vices, testing machines, presses, etc.





- In most of the power screws, the nut has axial motion, while the screw rotates in its bearings.

Types of Screw Threads used for Power Screws:



Square thread.:

- A square thread is adapted for the transmission of power in either direction.
- This thread results in maximum efficiency and minimum radial pressure on the nut.
- It is difficult to cut with taps and dies. usually cut on a lathe,
- It can't be easily compensated for wear.
- The standard dimensions for square threads according to IS : 4694 – 1968

Acme or trapezoidal thread.

- Is a modification of square thread. The slight slope given to its sides lowers the efficiency than square thread and it also introduce some radial pressure on the nut,
- Wear may be taken up by means of an adjustable split nut.
- An acme thread may be cut by means of dies and hence it is more easily manufactured than square thread.

Buttress thread:

- is used when large forces act along the screw axis in one direction only.
- This thread combines the higher efficiency of square thread and the ease of cutting and the adaptability to a split nut of acme thread.
- It is stronger than other threads because of greater thickness at the base of the thread.
- The buttress thread has limited use for power transmission. It is employed as the thread for light jack screws and vices.

Torque and Ball Screw:

- Ball screws are unique adaption of lead screw concept in which the principles of ball bearing are adapted to a lead screw
- Resulting in significantly lower friction than conventional lead screw.

Friction Angle:

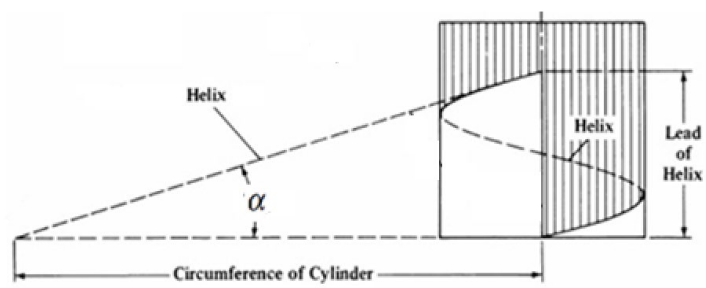
The angle between the helix of the thread and a line perpendicular to the axis of rotation, is called angle of Friction.

When μ= tan φ, At this angle, φ , part will just start to move.

Helix Angle:

The helix angle is the angle between the helix of the thread and a line parallel to the axis of rotation. This could be any angle designer/ fabricator decides to use.

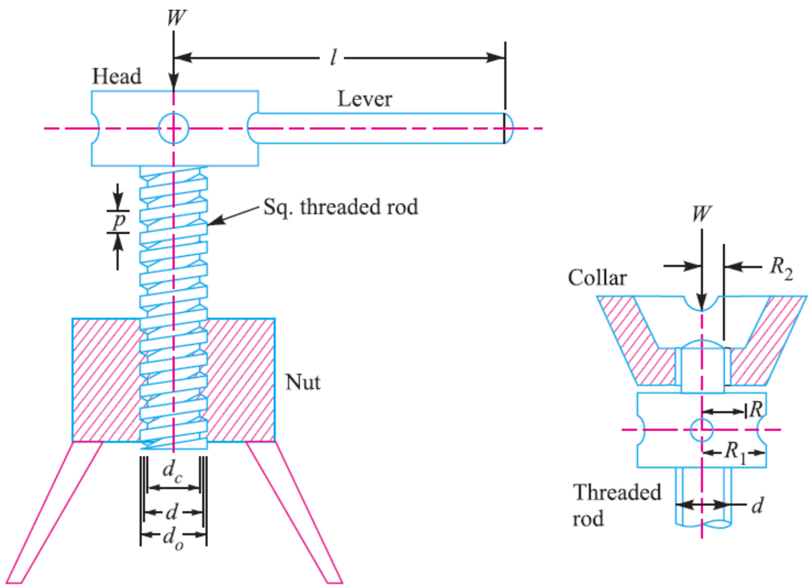
- When ϕ is greater than or equal to α, a positive torque is required to lower the load.
- Screw will be self-locking if the co-efficient of friction is equal to or greater than the tangent of the helix angle, the screw is said to be self-locking.



ϕ could be =, < or > from α

Torque Required to Raise Load by Square Threaded Screws

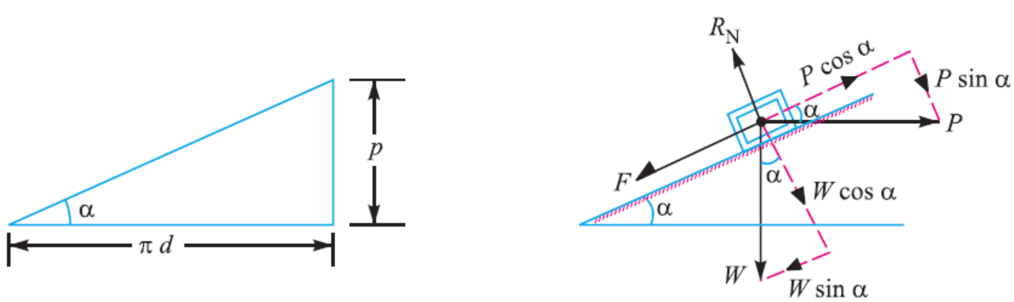
- The load to be raised or lowered is placed on the head of the square threaded rod which is rotated by the application of an effort at the end of lever for lifting or lowering the load.



(*a*) Screw jack.

(*b*) Thrust collar.

- If one complete turn of a screw thread be unwound, it will form an inclined plane as shown.



(*a*) Development of a screw.

(*b*) Forces acting on the screw.

Where:

p = Pitch of the screw,
d = Mean diameter of the screw,
α = Helix angle,
P = Effort applied at the circumference of the screw to lift the load,
W = Load to be lifted, and
μ= = Coefficient of friction, between the screw and nut = tan φ, where φ is the friction angle.
From the geometry:

$$\tan \alpha = p / \pi d$$

Forces along the plane:

$$P \cos \alpha = W \sin \alpha + F = W \sin \alpha + \mu . R_N$$

Forces Perpendicular to the plane:

$$R_N = P \sin \alpha + W \cos \alpha$$

$$\begin{aligned} P \cos \alpha &= W \sin \alpha + \mu\,(P \sin \alpha + W \cos \alpha) \\ &= W \sin \alpha + \mu\, P \sin \alpha + \mu W \cos \alpha \\ P \cos \alpha - \mu\, P \sin \alpha &= W \sin \alpha + \mu W \cos \alpha \\ P\,(\cos \alpha - \mu \sin \alpha) &= W\,(\sin \alpha + \mu \cos \alpha) \\ \therefore \qquad P &= W \times \frac{(\sin \alpha + \mu \cos \alpha)}{(\cos \alpha - \mu \sin \alpha)} \end{aligned}$$

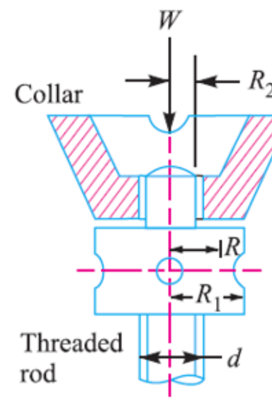
Substituting the value of $\mu = \tan \varphi$ in the above equation, we get

$$\begin{aligned} P &= W \times \frac{\sin \alpha \cos \phi + \sin \phi \cos \alpha}{\cos \alpha \cos \phi - \sin \alpha \sin \phi} \\ &= W \times \frac{\sin (\alpha + \phi)}{\cos (\alpha + \phi)} = W \tan (\alpha + \phi) \end{aligned}$$

Hence the torque to overcome friction between screw and nut:

$$T_1 = P \times \frac{d}{2} = W \tan (\alpha + \phi) \frac{d}{2}$$

When the axial load is taken up by a thrust collar as shown, so that the load does not rotate with the screw, then the torque required to overcome friction at the collar, (T2) ;



$$= \mu_1 \times W \left(\frac{R_1 + R_2}{2} \right) = \mu_1 \; W R \qquad \text{....(Assuming uniform wear conditions)}$$

where R_1 and R_2 = Outside and inside radii of collar,

R = Mean radius of collar $= \frac{R_1 + R_2}{2}$, and

μ_1 = Coefficient of friction for the collar.

Total torque required to overcome friction (i.e. to rotate the screw),

$$T = T1 + T2$$

If an effort P1 is applied at the end of a lever of arm length *l*, then the total torque required to overcome friction must be equal to the torque applied at the end of lever, i.e.

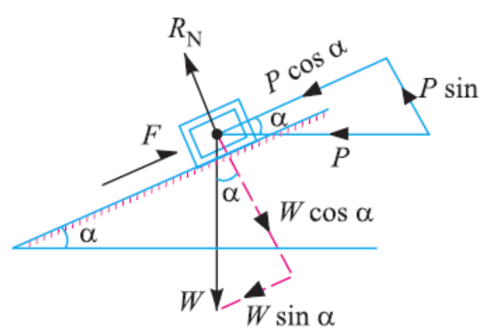
$$T = P \times \frac{d}{2} = P_1 \times l$$

By following same procedure, Torque Required to *Lower* Load for a Squair thread.

$$P = W \times \frac{(\sin\phi \cos\alpha - \cos\phi \sin\alpha)}{(\cos\phi \cos\alpha + \sin\phi \sin\alpha)}$$

$$= W \times \frac{\sin(\phi - \alpha)}{\cos(\phi - \alpha)} = W \tan(\phi - \alpha)$$

$$T_1 = P \times \frac{d}{2} = W \tan(\phi - \alpha) \frac{d}{2}$$



Efficiency of Square Threaded Screws

- The efficiency of square threaded screws is defined as the ratio between the effort required to move the load, neglecting friction to the actual effort (i.e. the effort required to move the load taking friction into account).

$P = W \tan(\alpha + \varphi)$
W = Load to be lifted,
α = Helix angle,
φ = Angle of friction, and
μ= Coefficient of friction between the screw and nut = $\tan\varphi$.

- If there would have been no friction between the screw and the nut, then φ will be equal to zero. The value of effort P_0 necessary to raise the load, will then be given by the equation,

$P_0 = W \tan\alpha$, Substituting $\varphi = 0$ in equation

$$\therefore \text{Efficiency,} \quad \eta = \frac{\text{Ideal effort}}{\text{Actual effort}} = \frac{P_0}{P} = \frac{W \tan\alpha}{W \tan(\alpha + \phi)} = \frac{\tan\alpha}{\tan(\alpha + \phi)}$$

Coefficient of Friction

- The coefficient of friction depends upon various factors like
  - Material of screw and nut,
  - Workmanship in cutting screw,
  - Quality of lubrication,
  - Unit bearing pressure and the rubbing speeds.

- The value of coefficient of friction does not vary much with different combinations of material, load or rubbing speed, except under starting conditions.
- The coefficient of friction, with good lubrication and average workmanship, may be assumed between 0.10 and 0.15.
- The various values for coefficient of friction for steel screw and cast iron or bronze nut, under different conditions are shown in the following table.

S.No.	Condition	Average coefficient of friction	
		Starting	Running
1.	High grade materials and workmanship and best running conditions.	0.14	0.10
2.	Average quality of materials and workmanship and average running conditions.	0.18	0.13
3.	Poor workmanship or very slow and in frequent motion with indifferent lubrication or newly machined surface.	0.21	0.15

S.No.	Materials	Average coefficient of friction	
		Starting	Running
1.	Soft steel on cast iron	0.17	0.12
2.	Hardened steel on cast iron	0.15	0.09
3.	Soft steel on bronze	0.10	0.08
4.	Hardened steel on bronze	0.08	0.06

Example:

A vertical screw with single start square threads of 50 mm mean diameter and 12.5 mm pitch is raised against a load of 10 kN by means of a hand wheel, the boss of which is threaded to act as a nut. The axial load is taken up by a thrust collar which supports the wheel boss and has a mean diameter of 60 mm. The coefficient of friction is 0.15 for the screw and 0.18 for the collar. If the tangential force applied by each hand to the wheel is 100 N, find suitable diameter of the hand wheel.

Solution

We know that $\tan \alpha = \dfrac{p}{\pi d} = \dfrac{12.5}{\pi \times 50} = 0.08$

and the tangential force required at the circumference of the screw,

$$P = W \tan(\alpha + \phi) = W \left(\frac{\tan \alpha + \tan \phi}{1 - \tan \alpha \tan \phi} \right)$$

$$= 10 \times 10^3 \left[\frac{0.08 + 0.15}{1 - 0.08 \times 0.15} \right] = 2328 \text{ N}$$

We also know that the total torque required to turn the hand wheel,

$$T = P \times \frac{d}{2} + \mu_1 W R = 2328 \times \frac{50}{2} + 0.18 \times 10 \times 10^3 \times 30 \text{ N-mm}$$

$$= 58\,200 + 54\,000 = 112\,200 \text{ N-mm} \quad \text{...}(i)$$

Let D_1 = Diameter of the hand wheel in mm.

We know that the torque applied to the handwheel,

$$T = 2 P_1 \times \frac{D_1}{2} = 2 \times 100 \times \frac{D_1}{2} = 100 D_1 \text{ N-mm} \quad \text{...}(ii)$$

Equating equations (*i*) and (*ii*),

$$D_1 = 112\,200 / 100 = 1122 \text{ mm} = 1.122 \text{ m}$$ **Ans.**

Example:

An electric motor driven power screw moves a nut in a horizontal plane against a force of 75 kN at a speed of 300 mm / min. The screw has a single square thread of 6 mm pitch on a major diameter of 40 mm. The coefficient of friction at screw threads is 0.1. Estimate power of the motor.

Solution

Given: W = 75 kN = 75 × 10^3 N; v = 300 mm/min ; p = 6 mm ; d_o = 40 mm, $\mu = \tan \varphi = 0.1$

We know that mean diameter of the screw,

$$d = d_o - p/2 = 40 - 6/2 = 37 \text{ mm}$$

and

$$\tan \alpha = \frac{p}{\pi\, d} = \frac{6}{\pi \times 37} = 0.0516$$

We know that tangential force required at the circumference of the screw,

$$P = W \tan(\alpha + \phi) = W\left[\frac{\tan \alpha + \tan \phi}{1 - \tan \alpha \tan \phi}\right]$$

$$= 75 \times 10^3 \left[\frac{0.0516 + 0.1}{1 - 0.0516 \times 0.1}\right] = 11.43 \times 10^3 \text{ N}$$

and torque required to operate the screw,

$$T = P \times \frac{d}{2} = 11.43 \times 10^3 \times \frac{37}{2} = 211.45 \times 10^3 \text{ N-mm} = 211.45 \text{ N-m}$$

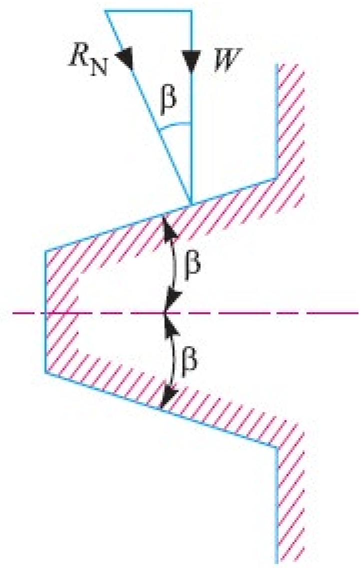
Since the screw moves in a nut at a speed of 300 mm / min and the pitch of the screw is 6 mm, therefore speed of the screw in revolutions per minute (r.p.m.),

$$N = \frac{\text{Speed in mm/min.}}{\text{Pitch in mm}} = \frac{300}{6} = 50 \text{ r.p.m.}$$

and angular speed, $\omega = 2\pi N / 60 = 2\pi \times 50 / 60 = 5.24$ rad /s

$\therefore$ Power of the motor $= T.\omega = 211.45 \times 5.24 = 1108$ W = 1.108 kW **Ans.**

Acme or Trapezoidal Threads



in case of Acme or trapezoidal thread, the normal re-action between the screw and nut is increased because the axial component of this normal reaction must be equal to the axial load (W).

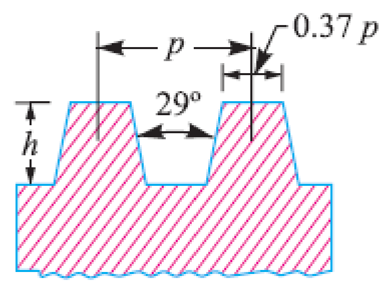
Consider an Acme or trapezoidal thread as shown
Let 2β = Angle of the Acme thread, and
β = Semi-angle of the thread.

Note: Acme threads, 2 β = 29°, and for trapezoidal threads, 2 β = 30°.

$$\therefore \qquad R_N = \frac{W}{\cos\beta}$$

and frictional force, $F = \mu . R_N = \mu \times \frac{W}{\cos\beta} = \mu_1 . W$

where $\mu / \cos\beta = \mu_1$, known as ***virtual coefficient of friction.***



$h = 0.5\,p + 0.25$ mm

Note1:

When coefficient of friction,

$$\mu_1 = \frac{\mu}{\cos\beta}$$

is considered, then the Acme thread is equivalent to a square

Note 2 :

All equations of square threaded screw also hold good for Acme threads. In case of Acme threads, μ_1 (i.e. tan φ_1) may be substituted in place of μ (i.e. tan φ). Thus, for Acme threads,

$P = W \tan(\alpha + \varphi_1)$
Where: φ_1 = Virtual friction angle, and $\tan\varphi_1 = \mu_1$

Example

The lead screw of a lathe has Acme threads of 50 mm outside diameter and 8 mm pitch. The screw must exert an axial pressure of 2500 N in order to drive the tool carriage. The thrust is carried on a collar 110 mm outside diameter and 55 mm inside diameter and the lead screw rotates at 30 r.p.m. Determine (a) the power required to drive the screw;. Assume a coefficient of friction of 0.15 for the screw and 0.12 for the collar.

Solution:

Given: $d_o = 50$ mm ; $p = 8$ mm ; $W = 2500$ N ; $D_1 = 110$ mm or $R_1 = 55$ mm ; D2 = 55 mm or $R_2 = 27.5$ mm ; N = 30 r.p.m. ; $\mu = \tan \varphi = 0.15$; μ2 = 0.12

Power required to drive the screw

We know that mean diameter of the screw,

$$d = d_o - p/2 = 50 - 8/2 = 46 \text{ mm}$$

$$\therefore \qquad \tan\alpha = \frac{p}{\pi d} = \frac{8}{\pi \times 46} = 0.055$$

Since the angle for Acme threads is $2\beta = 29°$ or $\beta = 14.5°$, therefore virtual coefficient of friction,

$$\mu_1 = \tan\phi_1 = \frac{\mu}{\cos\beta} = \frac{0.15}{\cos 14.5°} = \frac{0.15}{0.9681} = 0.155$$

We know that the force required to overcome friction at the screw,

$$P = W\tan(\alpha + \phi_1) = W\left[\frac{\tan\alpha + \tan\phi_1}{1 - \tan\alpha\tan\phi_1}\right]$$

$$= 2500\left[\frac{0.055 + 0.155}{1 - 0.055 \times 0.155}\right] = 530 \text{ N}$$

and torque required to overcome friction at the screw.

$$T_1 = P \times d/2 = 530 \times 46/2 = 12\ 190 \text{ N-mm}$$

We know that mean radius of collar,

$$R = \frac{R_1 + R_2}{2} = \frac{55 + 27.5}{2} = 41.25 \text{ mm}$$

Assuming uniform wear, the torque required to overcome friction at collars,

$$T_2 = \mu_2 W R = 0.12 \times 2500 \times 41.25 = 12\ 375 \text{ N-mm}$$

∴ Total torque required to overcome friction,

$$T = T_1 + T_2 = 12\ 190 + 12\ 375 = 24\ 565 \text{ N-mm} = 24.565 \text{ N-m}$$

We know that power required to drive the screw

$$= T.\omega = \frac{T \times 2\pi N}{60} = \frac{24.565 \times 2\pi \times 30}{60} = 77 \text{ W} = 0.077 \text{ kW} \qquad \textbf{Ans.}$$

$$\ldots (\because\ \omega = 2\pi N/60)$$