Power Screws and Bolted Connections

ME4020 - Applied Machine Design

Mechanical Engineering

Tennessee Technological University

Power Screws

Power Screws

- Overview and Applications
- Threads for Power Transmission
- Force and Torque Analysis
- Friction and Efficiency
- Design Considerations

Overview and Applications

A power screw is a machine component that converts rotational motion into linear motion. This is neccesary in variety of applications.

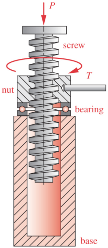
Leadscrews are used to raise and lower the front door of the Boeing 747-8F Freighter aircraft

images: wikimedia, wikipedia

Overview and Applications

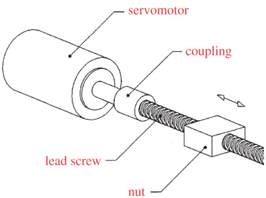
Common Applications:

- automotive jack and jack post
- machining tool positioning
- automatic doors and gates
- aircraft control surfaces
- automation/production machines



Overview and Applications

Machining Tool Positioning - 3 Axis Mill



Overview and Applications

Linear Actuator - General Purpose Machine Component

wikipedia: animation

Overview and Applications

Advantages:

- large mechanical advantage possible
- capable of lifting or moving large loads
- suitable for precision motion control
- self locking or back-drivable

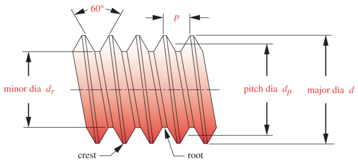
Disadvantages:

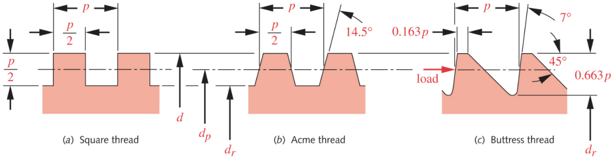
- Low Efficiency due to high friction
- High wear possible

Threads for Power Transmission

The standard thread form is not strong enough for high load applications. Many power screw applications use a square, acme, or other type of thread for power transmission.

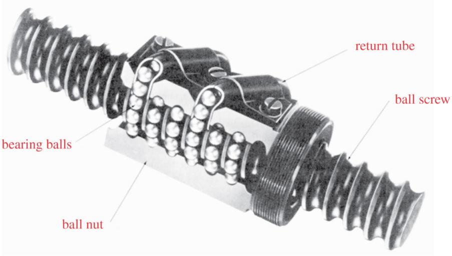
UN and ISO Standard Thread Form





Threads for Power Transmission

Lubrication is required for smooth operation and to avoid excessive wear. Ball Screws are used to reduce friction. This adds mechanical complexity, but can increase machine life.

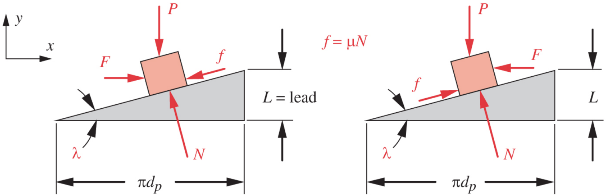


Courtesy of Thompson Industries Inc., Wood Dale, I L

Threads for Power Transmission

Force and Torque Analysis

Consider unwinding a single rotation of a square thread. The nut and power screw can be modeled as a block in contact with an inclined plane as shown in the image.



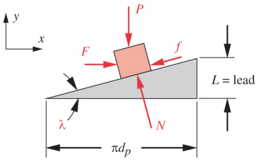
(a) Lifting the load up the plane (b) Lowering the load down the plane

The **lead angle** λ can be easily found through trigonometry:

$$tan(\lambda) = \frac{L}{\pi d_p}$$

Force and Torque Analysis

Write a static force balance for the lifting case.



(a) Lifting the load up the plane

$$\Sigma F_x = 0 = F - f cos\lambda - N sin\lambda = F - \mu N cos\lambda - N sin\lambda$$

$$F = N(\mu cos\lambda - sin\lambda)$$

$$\Sigma F_y = 0 = N cos\lambda - f sin\lambda - P = N cos\lambda - \mu N sin\lambda - P$$

$$N = \frac{P}{cos\lambda - \mu sin\lambda}$$

Force and Torque Analysis

Combine the results of the previous equations to get an expression relating the forces on the nut. The relationship is dependent on the friction coeffient and lead angle of the screw.

$$F = P\left(\frac{\mu cos\lambda + sin\lambda}{cos\lambda - \mu sin\lambda}\right)$$

The screw torque required to lift the load can be found as the force in the x direction F times the half pitch diameter.

$$T_{s_u} = F\frac{d_p}{2} = \frac{Pd_p}{2}\left(\frac{\mu cos\lambda + sin\lambda}{cos\lambda - \mu sin\lambda}\right) = \frac{Pd_p}{2}\left(\frac{\mu\pi d_p + L}{\pi d_p - \mu L}\right)$$

The torque required to turn the collar must also be modeled with d_c as the mean diameter and μ_c as the thrust bearing coefficient

$$T_c = \mu_c P\frac{d_c}{2}$$

Force and Torque Analysis

The total torque required to lift the load with a square thread is given as follows:

$$T_u = T_{s_u} + T_c = \frac{Pd_p}{2}\left(\frac{\mu\pi d_p + L}{\pi d_p - \mu L}\right) + \mu_c P \frac{d_c}{2}$$

The torque required to lower the load can be found through a similar analysis.

$$T_d = T_{s_u} + T_c = \frac{Pd_p}{2}\left(\frac{\mu\pi d_p - L}{\pi d_p + \mu L}\right) + \mu_c P \frac{d_c}{2}$$

Force and Torque Analysis

The results for a ACME thread are shown below which include the influence of the angle alpha.
The total torque required to lift the load with a ACME thread is given as follows:

$$T_u = T_{s_u} + T_c = \frac{Pd_p}{2}\left(\frac{\mu\pi d_p + Lcos\alpha}{\pi d_p cos\alpha - \mu L}\right) + \mu_c P \frac{d_c}{2}$$

The torque required to lower the load can be found through a similar analysis.

$$T_d = T_{s_u} + T_c = \frac{Pd_p}{2}\left(\frac{\mu\pi d_p - Lcos\alpha}{\pi d_p cos\alpha + \mu L}\right) + \mu_c P \frac{d_c}{2}$$

If $\alpha = 0$ these will reduce to the equations derived for the square thread.

Force and Torque Analysis

Given the friction coeffients, A force balance can also be used to predict whether the system can be back-driven or not. A power screw which cannot be rotated by any amount of axial load is called *self-locking*, which is a useful characteristic in many applications. Power screws that are not self-locking require constant motor input and or a break to hold the system in place.

A screw will **self-lock** if:

$$\mu \geq \frac{L}{\pi d_p} cos\lambda \qquad OR \qquad \mu \geq tan\lambda cos\alpha$$

for a square thread this becomes:

$$\mu \geq \frac{L}{\pi d_p} \qquad OR \qquad \mu \geq tan\lambda$$

Friction and Efficiency

The efficiency of the system is defined as the ratio of *work out* to *work in*. The work done on the power screw is the torque times the angular displacement in radians. For a single rotation this is given as:

$$W_{in} = 2\pi T$$

The work delivered through one revolution is the load force time the lead.

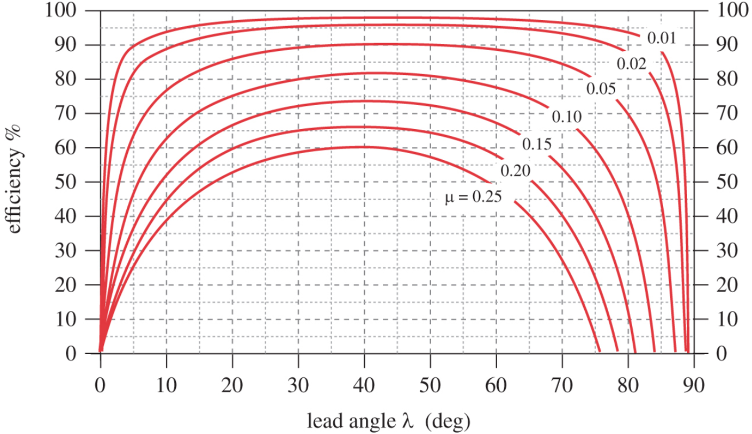
$$W_{out} = PL$$

The efficiency of the system is:

$$e = \frac{w_{out}}{W_{in}} = \frac{PL}{2\pi T} = \frac{1 - \mu tan\lambda}{1 + \mu cot\lambda}$$

Friction and Efficiency

Efficiency of an ACME-Thread at different lead angles and coefficients of friction.



Design Considerations

References:

This lecture was adapted from Machine Design by Norton, 6th ed. Section 15.3

Images are from the above textbook and wikipedia/wikimedia.