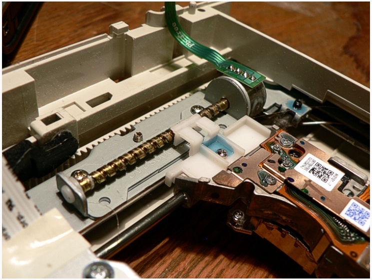
Power Screws

Sappinandana Akamphon

Department of Mechanical Engineering, TSE

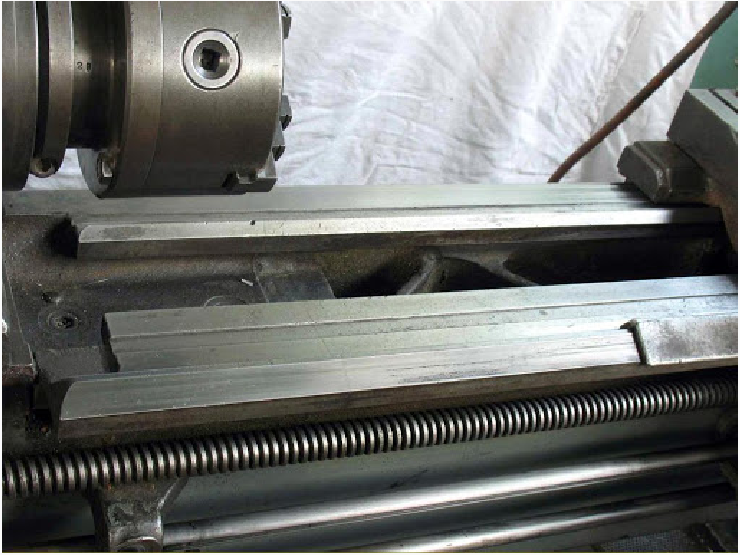
Outline

What is a Power Screw?



- Accurate screw used to push a nut with load along the screw
- Nut is kept from rotating, so it moves along the screw
- Transform rotation (torque) into linear motion (axial force)
- Similar to screw fasteners, but used for motion rather than clamping

What is a Power Screw Used for?



Outline

Lead Screws vs Ball Screws

Figure 1: Lead Screw

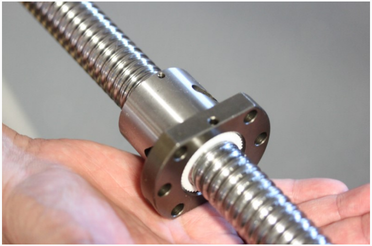
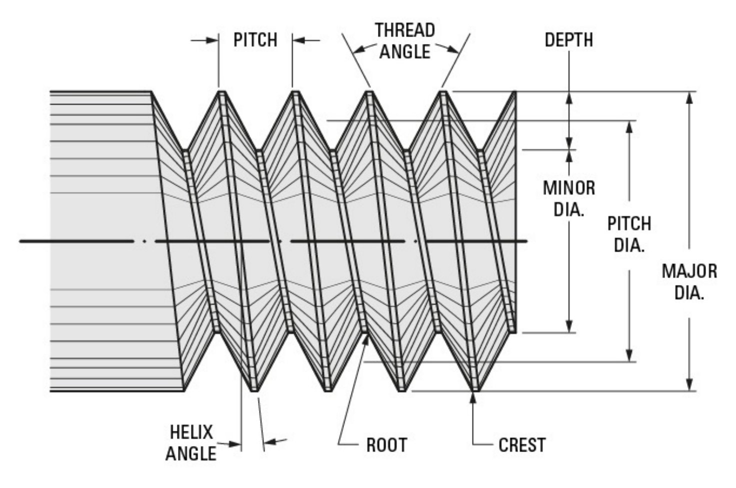


Figure 2: Ball Screw

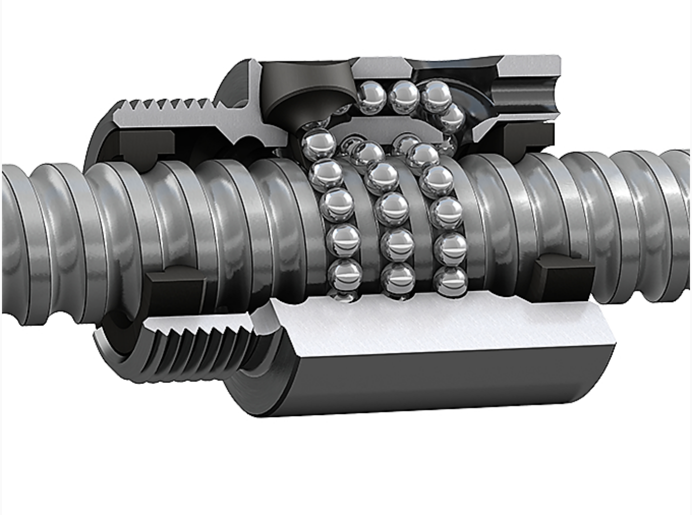
Lead Screws

Lead Screw Geometry

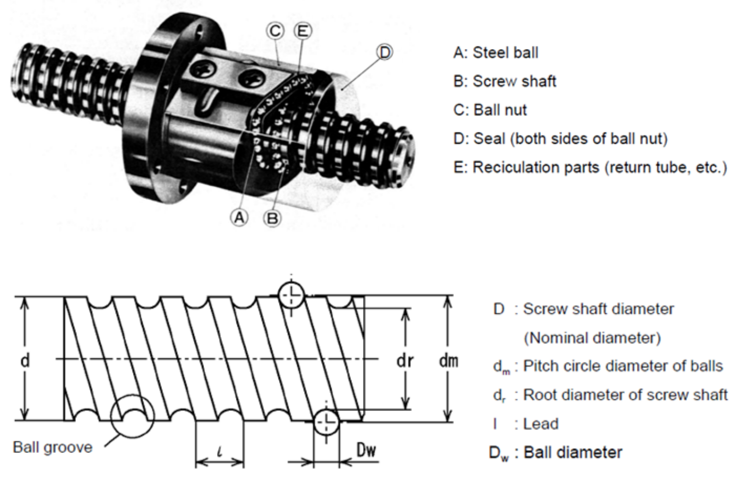


Ball Screws

- Bearing + Lead screw = Ball screw
- Ball screws: recirculating ball bearing, expensive, up to 95% efficiency



Ball Screw Geometry



Thread Profiles

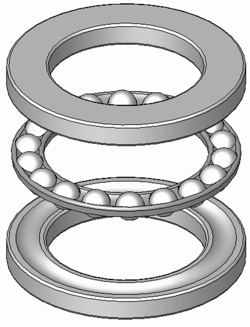
Thread Form	Figure	Uses
Unified		General use.
Metric		General use.
Square		Ideal thread for power transmission.
ACME		Stronger than the square thread.
Buttress		Designed to handle heavy forces in one direction (e.g. truck jack).

Lead vs Ball Screws

Lead	Ball
Inexpensive + Less complex	More efficient
Self-locking	Lower temperature
More quiet	Lubrication required

Outline

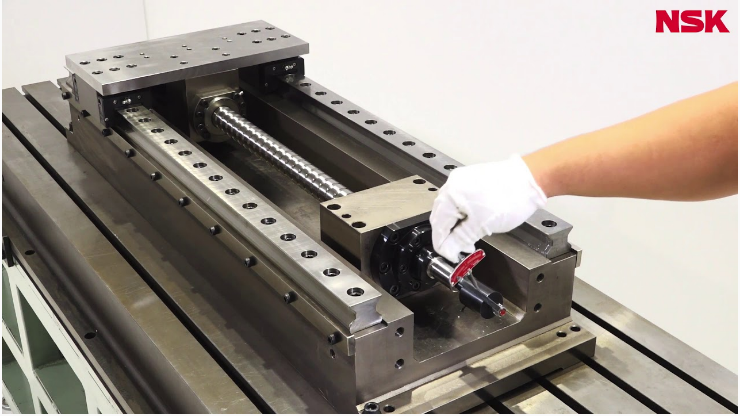
Mounting



- Power screws should be mounted with bearings that can take thrust (axial) loads

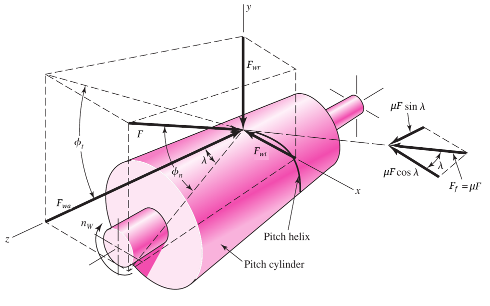
Mounting II

- For heavy loads, linear bearings may be needed

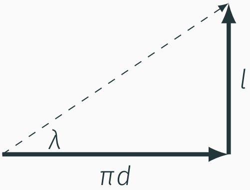


Outline

Forces on Power Screws



$$F_t = F\cos\phi_n \sin\lambda + \mu F\cos\lambda$$
$$F_r = F\sin\phi_n$$
$$F_a = F\cos\phi_n\cos\lambda - \mu F\sin\lambda$$



$$\tan\lambda = \frac{v_{nut}}{v_{shaft}} = \frac{l}{\pi d}$$

λ lead angle

l screw lead (pitch)

d screw diameter

Power Screw Efficiency

- Input and output power

$$H_{in} = F_t v_{shaft} = T_{shaft} \omega_{shaft}$$
$$H_{out} = F_a v_{nut}$$

$$\eta = \frac{F_a v_{nut}}{F_t v_{shaft}} = \frac{F_{nut} v_{nut}}{T_{shaft} \omega_{shaft}}$$
$$\eta_{raise} = \frac{\cos\phi_n \cos\lambda - \mu \sin\lambda}{\cos\phi_n \sin\lambda + \mu \cos\lambda} \tan\lambda$$
$$= \frac{\cos\phi_n - \mu \tan\lambda}{\cos\phi_n + \mu \cot\lambda}$$
$$\eta_{lower} = \frac{\cos\phi_n + \mu \tan\lambda}{\cos\phi_n - \mu \cot\lambda}$$

Required Torque

$$
\begin{aligned}
T_{raise} &= \frac{F_{nut} v_{nut}}{\omega_{shaft}} \frac{\cos\phi_n + \mu \cot\lambda}{\cos\phi_n - \mu \tan\lambda} \\
&= \frac{F_{nut} v_{nut}}{v_{shaft}/(d/2)} \frac{\cos\phi_n + \mu \cot\lambda}{\cos\phi_n - \mu \tan\lambda} \\
&= \frac{F_{nut} d \tan\lambda}{2} \frac{\cos\phi_n + \mu \cot\lambda}{\cos\phi_n - \mu \tan\lambda} \\
T_{lower} &= \frac{F_{nut} d \tan\lambda}{2} \frac{\cos\phi_n - \mu \cot\lambda}{\cos\phi_n + \mu \tan\lambda}
\end{aligned}
$$

- set $F_{nut} = F$ to determine required torque

Required Torque II

- Power screw sizes are usually given in lead l, (major) diameter, effective (median) diameter d, root (minor) diameter

$$
\begin{aligned}
\tan\lambda &= \frac{l}{\pi d} \\
T_{raise} &= \frac{F_{nut} d \tan\lambda}{2} \frac{\cos\phi_n + \mu\cot\lambda}{\cos\phi_n - \mu\tan\lambda} \\
&= \frac{F_{nut} d}{2} \frac{l}{\pi d} \frac{\cos\phi_n + \mu\frac{\pi d}{l}}{\cos\phi_n - \mu\frac{l}{\pi d}} \\
&= \frac{F_{nut} d}{2} \frac{l\cos\phi_n + \mu\pi d}{\pi d\cos\phi_n - \mu l} \\
T_{lower} &= \frac{F_{nut} d}{2} \frac{l\cos\phi_n - \mu\pi d}{\pi d\cos\phi_n + \mu l}
\end{aligned}
$$

Self-Locking

- Similar to worm gears

$$
\begin{aligned}
F_t &= F\cos\phi_n \sin\lambda - \mu F\cos\lambda \leqslant 0 \\
\mu &\geqslant \cos\phi_n \tan\lambda
\end{aligned}
$$

- Possible in lead screws ($\mu > 0$), NOT in ball screws ($\mu \approx 0$).
- This makes lead screws desirable in vertical application: self-locking prevents weight drop

Buckling

- Buckling is a common failure in shafts
- Put shafts in TENSION whenever possible
- Power screws can easily generate forces that will buckle them
- Heavy loads should be PULLED, not PUSHED

Shaft Whirling

- Shafts (or screws) that spins too fast can excite shaft bending (whirling or whip) → bearing failure

$$\omega_{\text{max}} \leqslant 0.8\omega_1$$

Buckling and Whirling Formula

$$\omega_1 = k^2 \sqrt{\frac{EI}{A\rho L^4}}$$

$$P_{cr} = \frac{cEI}{L^4}$$

End conditions	k	c
cantilevered	1.88	2.47
simply supported	3.14	9.87
fixed-simple	3.93	20.2
fixed-fixed	4.73	39.5

Example: Power Screw Design

We need to drive a 50-kg mass vertically. The selected lead screw has $\mu = 0.1$, $\phi_n = 0^{\circ}$, $l = 2$ mm, $d = 10$ mm, $E = 210$ GPa. Determine the required torque to drive this mass

Solution

Required torque is (typically) T_{raise}, as it is usually larger.

$$\begin{aligned} T_{raise} &= \frac{F_{nut} d}{2} \frac{l \cos\phi_n + \mu \pi d}{\pi d \cos\phi_n - \mu l} \\ &= \frac{500(0.01)}{2} \frac{0.002(1) + 0.1\pi(0.01)}{\pi(0.01)(1) - 0.1(0.002)} \\ &= 0.412 \text{ N-m} \end{aligned}$$