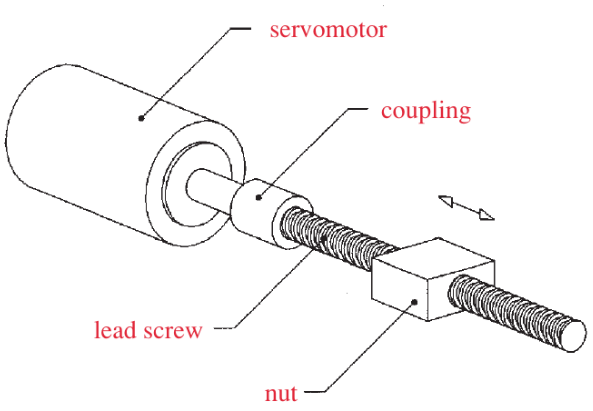
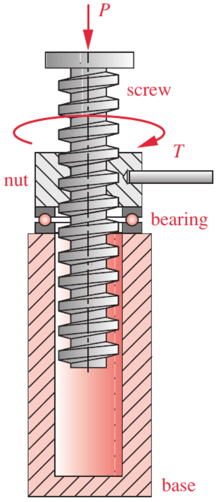
Power or Lead Screws

Helical-thread screw is the basis of:

power or lead screws which change angular motion to linear motion to transmit power or to develop large forces (presses, jacks, etc.), and

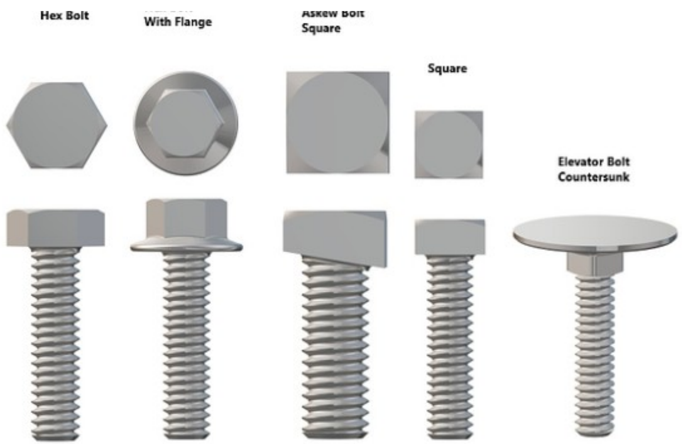
threaded fasteners, an important element in nonpermanent joints





Power-Screw Jack

Screw Press



Types of Fasteners

https://www.design-engineering.com/what-is-a-lead-screw-1004040732/

https://www.mtixtl.com/EQ-YLJ-SP.aspx

https://forum.digikey.com/t/types-of-threaded-fasteners-screws-and-bolts/7954

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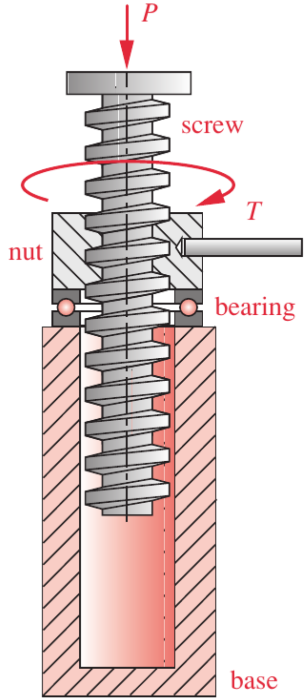
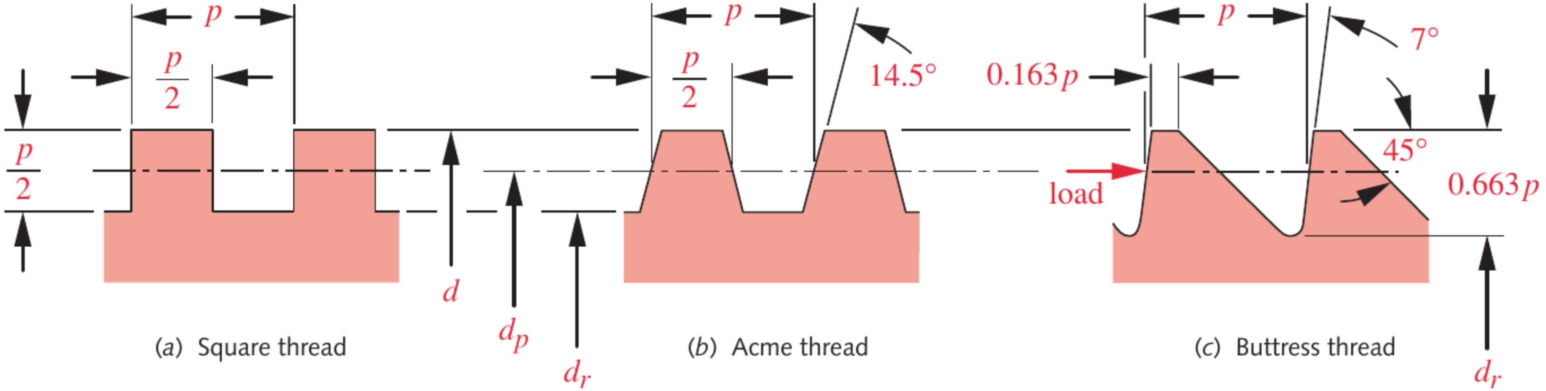
Power or Lead Screws

Power screws, also called lead screws, are used to convert rotation to linear motion.

They are capable of very large mechanical advantages and so can lift or move large loads.

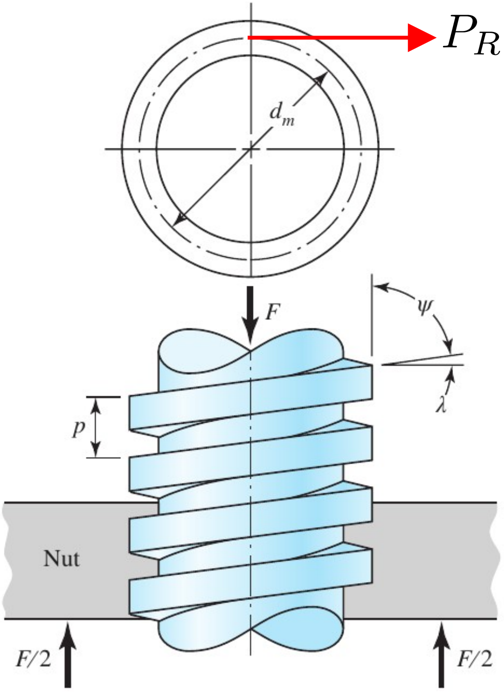




Typical Threads used in Power Screws: Square, Acme, and Buttress Threads

Force and Torque Analysis: Square Threads

A square-threaded power screw with single thread having a mean diameter d_m, a pitch p and a lead angle is loaded by the axial compressive force F. Want to find an expression for the torque required to raise this load, and another expression for the torque required to lower the load



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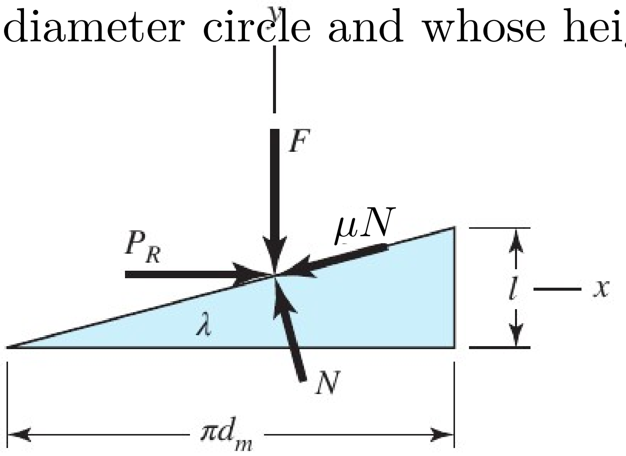
- Imagine that a single thread of the screw is unrolled or developed for exactly a single turn.
- Then one edge of the thread will form the hypotenuse of a right triangle whose base is the circumference of the mean thread diameter circle and whose height is the lead.



P_R – horizontal load

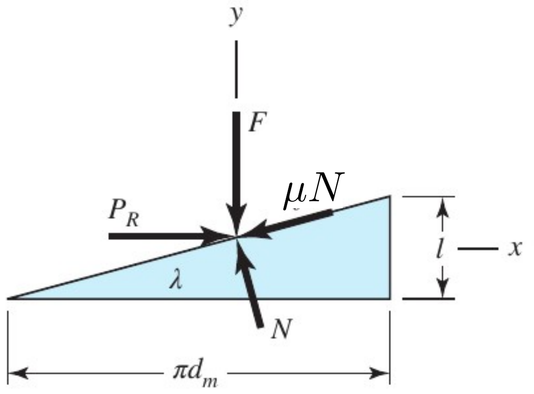
F – axial force

N – normal force

- coefficient of friction between nut and screw

$$\tan \lambda = \frac{l}{\pi d_m} \qquad \mu = 0.15 \pm 0.05$$

Force and Torque Analysis: Square Threads



Load Raising Case

$$\sum F_x = 0, \text{ or } P_R - \mu N \cos\lambda - N \sin\lambda = 0$$

$$P_R = N(\mu \cos\lambda + \sin\lambda)$$

$$\sum F_y = 0, \text{ or } -F - \mu N \sin\lambda + N \cos\lambda = 0$$

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

$$T_R = P_R \frac{d_m}{2} = \frac{F d_m}{2}\left(\frac{\mu \cos\lambda + \sin\lambda}{\cos\lambda - \mu \sin\lambda}\right) = \frac{F d_m}{2}\left(\frac{\mu \pi d_m + l}{\pi d_m - \mu l}\right)$$

The required torque depends on the load, coefficient of friction and the geometry of the screw

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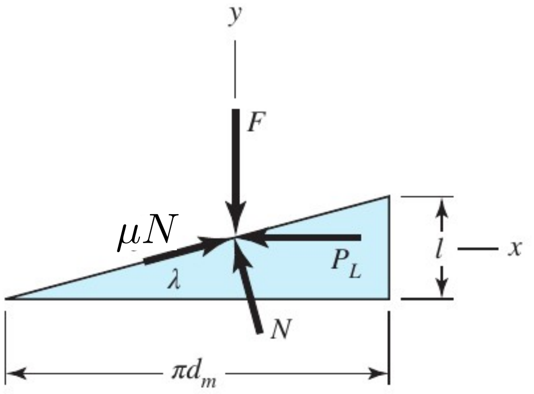
Force and Torque Analysis: Square Threads



Load Lowering Case

$$\sum F_x = 0, \text{ or } -P_L + \mu N\cos\lambda - N\sin\lambda = 0$$

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

$$\sum F_y = 0, \text{ or } -F + \mu N\sin\lambda + N\cos\lambda = 0$$

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

$$T_L = P_L\frac{d_m}{2} = \frac{Fd_m}{2}\left(\frac{\mu\cos\lambda - \sin\lambda}{\cos\lambda + \mu\sin\lambda}\right) = \frac{Fd_m}{2}\left(\frac{\mu\pi d_m - l}{\pi d_m + \mu l}\right)$$

If $\mu < \dfrac{l}{\pi d_m} = \tan\lambda$ then the load will lower itself without the application of any torque

Condition for self-locking (positive torque required to lower the load)

$$\mu > \frac{l}{\pi d_m} = \tan\lambda$$

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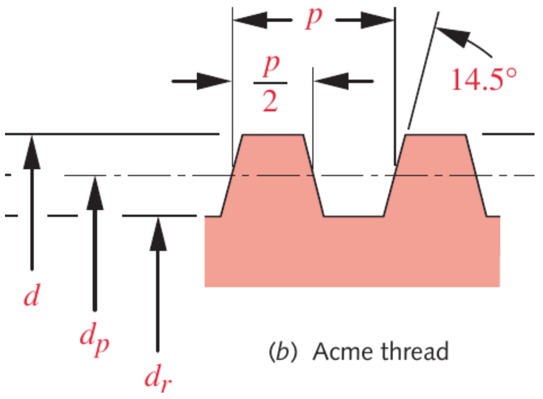
Force and Torque Analysis: ACME Threads

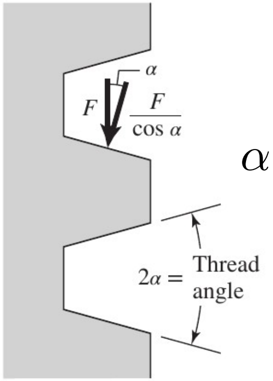


Torque required to raise the load

$$T_R = \frac{Fd_m}{2}\left(\frac{\mu\pi d_m + l\cos\alpha}{\pi d_m \cos\alpha - \mu l}\right)$$

Torque required to lower the load

$$T_L = \frac{Fd_m}{2}\left(\frac{\mu\pi d_m - l\cos\alpha}{\pi d_m \cos\alpha + \mu l}\right)$$



$\alpha = 14.5^o$

Change in the Normal Force due to α

Condition for self-locking

$$\mu > \tan\lambda\cos\alpha$$

- ACME thread is not as efficient as the square thread because of the additional friction
- It is preferred because it is easier to machine

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Efficiency of Power Screws

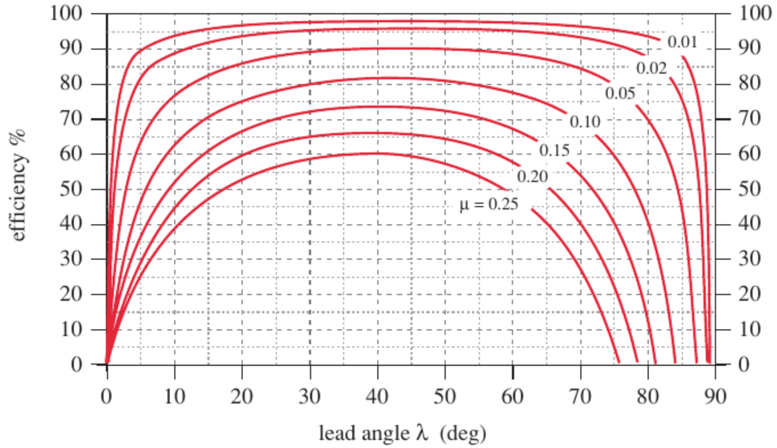
The efficiency of the screw is defined as $e = \dfrac{W_{out}}{W_{in}} = \dfrac{FL}{2\pi T}$

Square Thread

The efficiency while raising the load is given by $e = \dfrac{FL}{2\pi T_R} = \dfrac{1 - \mu \tan\lambda}{1 + \mu \cot\lambda}$

ACME Thread

The efficiency while raising the load is given by $e = \dfrac{FL}{2\pi T_R} = \dfrac{\cos\alpha - \mu \tan\lambda}{\cos\alpha + \mu \cot\lambda}$



Efficiency of ACME Thread Power Screw

Typical lead angle

$2^o \leq \lambda \leq 5^o$

Efficiency is quite low

$18\% \leq e \leq 36\%$ ($\mu = 0.15$)

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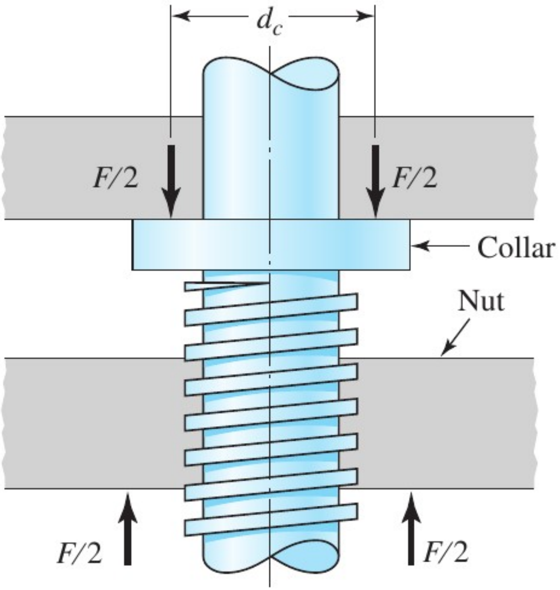
Thrust Collars and Power Requirement

When the screw is loaded axially, a thrust or collar bearing must be employed between the rotating and stationary members in order to carry the axial component.



- Friction torque due to thrust collar

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

- Total Torque required to raise the load

$$T_{Rt} = T_R + T_c$$

- Total Torque required to lower the load

$$T_{Lt} = T_L + T_c$$

- Power required to drive the lead screw at a constant angular velocity

$$P = T_{total}\omega$$

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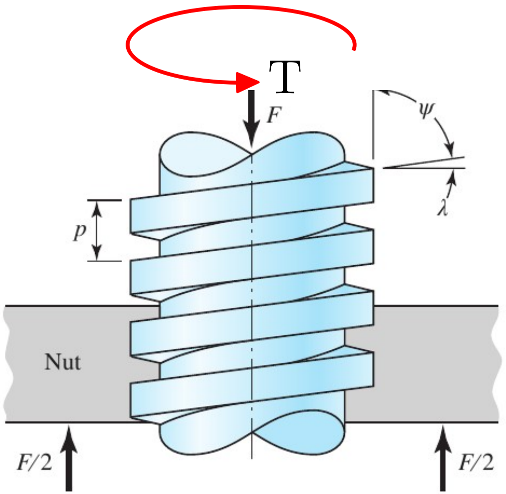
Design of Screw and Nut

- Screws are typically made up of plain carbon steel and nut is made up of bronze
- The body of the screw is subject to a torsion T and axial force F



	Boundary conditions	c	k
1.	P-P	1.00	1.00
2.	P-C	2.05	0.70
3.	C-F	0.25	2.00
4.	C-C	4.00	0.50

P-Pinned, C-Clamped, F-Free

- Maximum nominal shear stress in the screw body

$$\tau = \frac{16T}{\pi d_r^3}$$

- Compressive axial stress in the screw body

$$\sigma = -\frac{4F}{\pi d_r^2}$$

- For a lead screw of length L, the critical buckling load is estimated using the Euler formula (assuming the lead screw is slender)

$$P_{cr} = c\pi^2 \frac{EI}{L^2} \text{ or } P_{cr} = \pi^2 \frac{EI}{(kL)^2}, \quad I = \frac{\pi d_r^4}{64}$$

- Critical Speed – refer to catalogues

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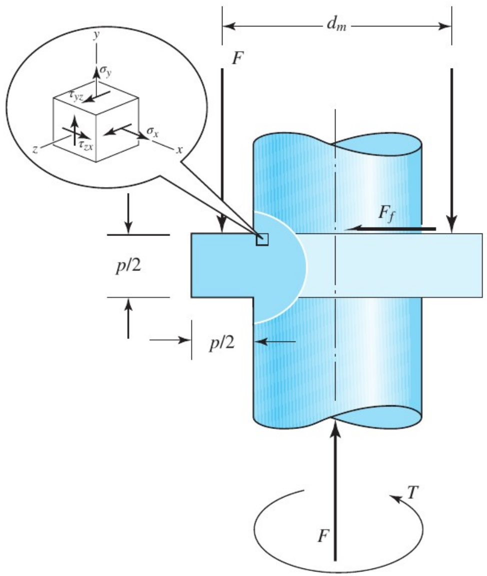
Design of Screw and Nut - Thread Stresses



- Bearing stress due to the force F acting on the surface of the thread

$$\sigma_B = \sigma_{yy} = -\frac{F}{(\pi d_m p/2)n_t} = \frac{2F}{\pi d_m p n_t} \quad n_t - \text{number of engaged threads}$$

- Bending stress at the root of the thread

$$\sigma_{xx} = \frac{M}{Z} = \frac{(Fp/4)}{(\pi d_r n_t)(p/2)^2/6} = \frac{6F}{\pi d_r n_t p}$$

- Shear stress τ_{xz} at the root of the thread

$$\tau_{xz} = \frac{T}{A_r r_r} = \frac{T}{\pi d_r n_t p/2 r_r} = \frac{4T}{\pi d_r^2 n_t p}$$

- Shear stress τ_{yz} at the root of the thread

$$\tau_{yz} = \frac{16T}{\pi d_r^3}$$

Using these stress components, the equivalent stress (von Mises stress) at the root of the thread can be obtained.

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The stresses at the root of the thread of the nut can be estimated similarly

Design of Screw and Nut - Thread Stresses

- The equations derived earlier assume all engaged threads are equally sharing the load (non conservative assumption)

- A power screw lifting a load is in compression and its thread pitch is shortened by elastic deformation. Its engaging nut is in tension and its thread pitch is lengthened.

- **The engaged threads do not share the load equally**.

- Some experiments show that the first engaged thread carries 0.38 of the load, the second 0.25, the third 0.18, and the seventh is free of load.

- In estimating thread stresses by the equations derived earlier, substituting $0.38F$ for F and setting n_t to 1 gives the largest level of stresses in the thread-nut combination.

Useful Information

Table 8–4 Screw Bearing Pressure p_b

Screw Material	Nut Material	Safe p_b, MPa	Notes
Steel	Bronze	17.2–24.1	Low speed
Steel	Bronze	11.0–17.2	≤50 mm/s
	Cast iron	6.9–17.2	≤40 mm/s
Steel	Bronze	5.5–9.7	100–200 mm/s
	Cast iron	4.1–6.9	100–200 mm/s
Steel	Bronze	1.0–1.7	≥250 mm/s

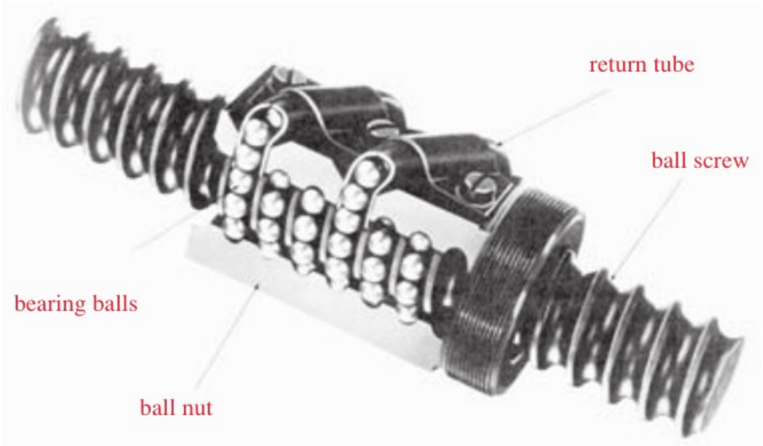
Table 8–6 Thrust-Collar Friction Coefficients

Combination	Running	Starting
Soft steel on cast iron	0.12	0.17
Hard steel on cast iron	0.09	0.15
Soft steel on bronze	0.08	0.10
Hard steel on bronze	0.06	0.08

Table 8–5 Coefficients of Friction f for Threaded Pairs

	Nut Material			
Screw Material	**Steel**	**Bronze**	**Brass**	**Cast Iron**
Steel, dry	0.15–0.25	0.15–0.23	0.15–0.19	0.15–0.25
Steel, machine oil	0.11–0.17	0.10–0.16	0.10–0.15	0.11–0.17
Bronze	0.08–0.12	0.04–0.06	—	0.06–0.09

Ball Screws



- The efficiency of lead screws is poor
- Ball Screw is an adaptation of the lead screw wherein the friction between the screw and the nut is minimized by using bearing balls
- Load path: Screw thread to bearing balls to the nut to the driven device
- Efficiency is as high as 90%

Working of a ball screw
https://www.youtube.com/watch?v=kl6qNn9-nkk

Design Considerations

- Axial load exerted by the screw
- Rotational speed (critical speed)
- Supporting end conditions of the screw (critical speed, buckling)
- Length of the screw
- Expected life – this calculation is similar to the rolling bearing calculation

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END