18. Power Screws and Ball Screws

Objectives

- Recognize and understand advantages and disadvantages of different types of power screws.
- Determine the power necessary for driving power screws at different speeds and torques.
- Understand principles of operation of ball screws and how they differ from friction-type power screws.
- Understand and calculate torque and efficiencies of power screws and ball screws.
- Understand and envision how power screws and ball screws can be used in different designs.

MACHINE DESIGN TIMOT

Power screw

A screw and nut to transmit power or motion

The axial movement of the nut is used to drive a load

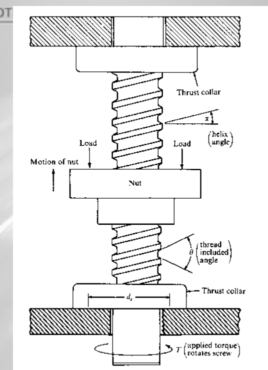
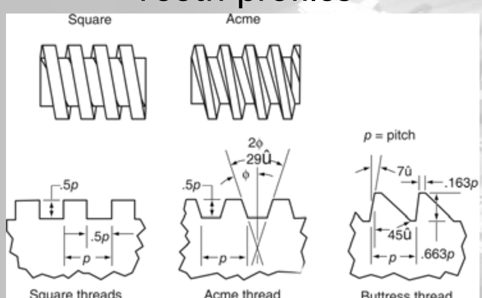


FIGURE 11.31 Power screw

MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Tooth profiles



MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Tooth profiles

- Square thread
  - Most efficient for transferring torque to linear motion
- Acme thread
  - Easier to make
  - Good when well lubricated
  - Efficiency slightly lower than square
- Buttress thread
  - More efficient than Acme
  - Closer to square than Acme
  - Used when force is transmitted in only direction

MACHINE DESIGN

TABLE 18.1

STANDARDS FOR SQUARE THREADS, ACME THREADS, AND BALL SCREWS

	Square Threads		Acme Threads		Ball Screws
Size, Inches	Threads per Inch	Minor Diameter	Threads per Inch	Minor Diameter	Threads per Inch
1/4	10	.163	16	.188	
5/16			14	.241	
3/8	8	.266	12	.292	8
7/16			12	.354	
1/2	6 1/2	.366	10	.400	5
5/8	5 1/2	.466	8	.500	
3/4	5	.575	6	.583	2
7/8	4 1/2	.681	6	.708	
1	4	.781	5	.800	
1 1/8			5	.925	
1 1/4	3 1/2	1.000	5	1.050	
1 3/8			4	1.125	
1 1/2	3	1.208	4	1.250	2
1 3/4	2 1/2	1.400	4	1.500	
2	2 1/4	1.612	4	1.750	2
2 1/4	2 1/4	1.862	3	1.917	
2 1/2	2	2.063	3	2.167	1
2 3/4	2	2.313	3	2.417	
3	1 3/4	2.500	2	2.500	1 1/2
3 1/2	1 5/8	2.962	2	3.000	
4	1 1/2	3.418	2	3.500	
4 1/2			2	4.000	
5			2	4.500	

MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Torque, power and Efficiency

- Lead screw can be considered as an inclined plane

$$\tan \lambda = \frac{L}{\pi D_p}$$

- λ= angle of incline
- L = lead
- D_p = pitch diameter

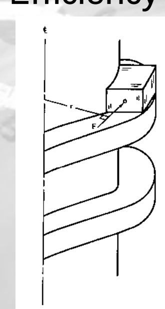
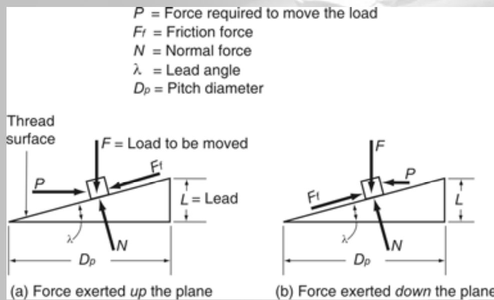


FIGURE 11.34 Power screw concept

Fig. 18.2 Force required to push a box up or down an incline



MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Torque, power and Efficiency

- Pitch diameter = Mean diameter
- Torque (T_{up}) needed to move a load up or horizontally against a force is

$$T_{up} = \frac{F D_p}{2}\left(\frac{L + \pi f D_p}{\pi D_p - f L}\right) \qquad \text{Eq 18.2}$$

- f = coefficient of friction
- L = lead
- D_p = pitch diameter

MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Torque, power and Efficiency

- Torque (T_{down}) needed to lower a load is

$$T_{down} = \frac{F D_p}{2}\left(\frac{\pi f D_p - L}{\pi D_p + f L}\right) \qquad \text{Eq 18.3}$$

- f = coefficient of friction
- L = lead
- D_p = pitch diameter

MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Example Problem 18-1: Torque, Power, and Efficiency in Power Screws

- Elevator-type lift is being designed to raise a load of up to 5000 pounds between floors.
- Two square-thread lead screws, 1½ inches in diameter, are used for this application.
- Determine torque required to raise lift if moving part of elevator weighs 800 pounds and coefficient of friction is assumed to be .15.
  - From Table 18-1, the 1½-inch-square thread has three threads per inch:

$$D_m = \frac{1.5 + 1.208}{2} = 1.354 \text{ in}$$

  - Determining the torque up:

$$T_{up} = \frac{F D_p}{2}\left(\frac{L + \pi f D_p}{\pi D_p - f L}\right) \qquad (18\text{-}2)$$

$$T_{up} = \left(\frac{5800 \text{ lb}}{2}\right)\left(\frac{1.354 \text{ in}}{2}\right)\left(\frac{1/3 \text{ in} + \pi\ .15\,(1.354 \text{ in})}{\pi\,(1.354 \text{ in}) - .15\,(1/3 \text{ in})}\right)$$

$$T_{up} = 454 \text{ in-lb} \quad \text{(for each lead screw)}$$

MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Efficiency of a power screw

- Efficiency, e is given by

$$e = \frac{\tan\lambda\,(1 - f\,\tan\lambda)}{\tan\lambda + f} \qquad \text{Eq 18.8}$$

- Self locking is when $f > \tan\lambda$ Eq 18.6

MACHINE DESIGN TIMOTHY H. WENTZELL, P.E.

Example Problem 18-2: Efficiency of a Power Screw

- For elevator described in previous example problem, find efficiency and power required if each lead screw is driven at 175 rpm.
  - The lead angle is:

$$\tan\lambda = \frac{L}{\pi D_p} \qquad (18\text{-}1)$$

$$\tan\lambda = \frac{1/3 \text{ in}}{\pi\, 1.354 \text{ in}}$$

$$\lambda = 4.5°$$

  - The efficiency would be:

$$e = \frac{\tan\lambda\,(1 - f\tan\lambda)}{\tan\lambda + f} \qquad (18\text{-}8)$$

$$e = \frac{\tan 4.5°\,(1 - .15\tan 4.5°)}{\tan 4.5 + .15}$$

$$e = 34\%$$

Example Problem 18-2: Efficiency of a Power Screw
(cont'd.)

– Power would then be:

$$P = \frac{T\,n}{63{,}000} \qquad (2\text{-}6)$$

$$P = \frac{454\ (175)}{63{,}000}$$

$$P = 1.26\ hp \quad \text{(per lead screw)}$$

or

$$P = 2.52\ hp \quad \text{(total)}$$

– Verifying that this is self-locking:

$$f > \tan\lambda$$

$$f > \tan 4.5°$$

$$.15 > .079$$

- Yes, it is self-locking.

Acme Threads

- Torque up is $T_{up} = \frac{F\,D_p}{2}\left(\frac{\cos\varphi\,\tan\lambda + f}{\cos\varphi - f\,\tan\lambda}\right)$
- φ = face angle 14 ½ °
- Torque down is

$$T_{down} = \frac{F\,D_p}{2}\left(\frac{f - \cos\varphi\,\tan\lambda}{\cos\varphi + f\,\tan\lambda}\right)$$

Example Problem 18-3: Acme Threads

- For elevator in Example Problem 18-1, find torque and power if a 1½-inch diameter acme thread was substituted:

$$D_p = D_m = \frac{1.5 + 1.25}{2} = 1.375 \qquad \text{(from Table 18-1)}$$

$$\tan\lambda = \frac{L}{\pi\,D_p} \qquad (18\text{-}1)$$

$$\tan\lambda = \frac{1/4}{\pi\,1.375}$$

$$\lambda = 3.3°$$

$$T_{up} = \frac{F\,D_p}{2}\left(\frac{(\cos\varphi\,\tan\lambda + f)}{(\cos\varphi - f\,\tan\lambda)}\right) \qquad (18\text{-}9)$$

$$T_{up} = \left(\frac{5800\ lb}{2}\right)\left(\frac{1.375\ in}{2}\right)\left(\frac{[\cos 14.5°\ \tan 3.3° + .15]}{[\cos 14.5° - .15\ (\tan 3.3°)]}\right)$$

$$T_{up} = 428\ in\text{-}lb$$

- This result is lower than that of Example Problem 18-1 because lead is lower, not because an acme thread is more efficient.

Example Problem 18-3: Acme Threads (cont'd.)

- Find the power.
- For obtaining the same rate, drive speed would need to be changed by ratio of leads.

$$n = 175 \cdot \frac{4}{3} = 233\ rpm$$

$$P = \frac{T\,n}{63{,}000} \qquad (2\text{-}6)$$

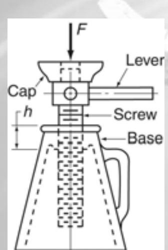
$$P = \frac{428\ in\text{-}lb\ \ 233\ rpm}{63{,}000}$$

$$P = 1.59\ hp \quad \text{(per lead screw)}$$

- This value reflects the lower efficiency of an acme versus a square thread.

Problem 18-7

- For the bottle jack shown, using a 1½-inch square thread, f = .15, and F = 7500 pounds, determine the torque required to raise this load.



Problem 18-7 (cont'd.)

– For 1½-inch square thread:

3 threads/inch   Minor diameter of 1.208   (Table 18-1)

$$D_m = D_p = \frac{1.5 + 1.208}{2}$$

$$D_m = 1.354 \text{ inch}$$

$$\lambda = \tan^{-1}\left(\frac{L}{\pi\ D_p}\right) \qquad (18\text{-}1)$$

$$\lambda = \tan^{-1}\left(\frac{.333}{\pi\ 1.354}\right)$$

$$\lambda = 4.5°$$

$$T_{up} = \frac{F\,D_p}{2}\left(\frac{L + \pi\ f\,D_p}{\pi\ D_p - f\,L}\right) \qquad (18\text{-}2)$$

$$T_{up} = \frac{7500\ (1.354)}{2}\left(\frac{.333 + \pi\ (.15)\ (1.354)}{\pi\ (1.354) - .15\ (.333)}\right)$$

$$T_{up} = 1170 \text{ in-lb}$$

Conclusions

- Design of power screw is established.