

## Power Screws

Lecture 27

Engineering 473  
Machine Design



## Power Screws

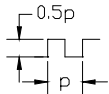
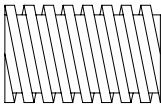
Power screws are designed to convert rotary motion to linear motion and to exert the necessary force required to move a machine element along a desired path.



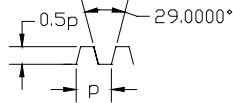
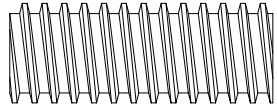
## Types of Power Screws

Power Screws are classified by their threads.

### Square Thread



### ACME Thread



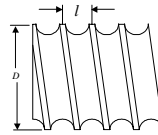
## Types of Power Screws

(Continued)

### Ball Screws

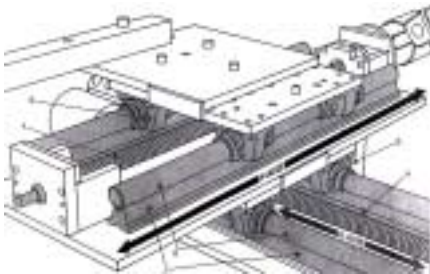


Recirculating Ball Screws are generally preloaded to give zero backlash.



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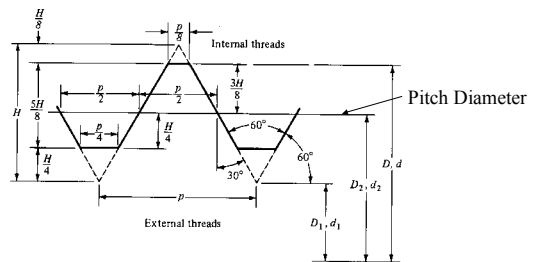
## Recirculating Ball Screws (Example)



A - Ball Screw  
B - Linear Bearings    Microcomputer Controlled X-Y Table

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## Thread Pitch Diameter



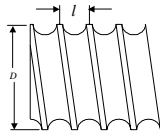
## Lead and Threads/In

The **lead** or **pitch** of a thread is the distance that a nut will travel if turned one complete revolution.

The number of threads per inch can be related to the lead or pitch through the formula.

$$n = \frac{1}{l}$$

$n$   $\equiv$  threads per inch  
 $l$   $\equiv$  distance per thread



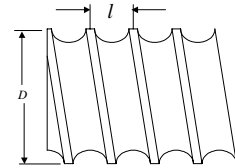
## Rotational to Linear Motion Conversion

**Lead or Pitch**— distance the nut moves parallel to the screw axis when the screw is given one revolution.

$V_f$   $\equiv$  Feed Velocity

$$n = \frac{V_f}{l}$$

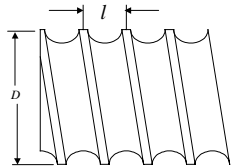
$$\Rightarrow \frac{\left[ \frac{\text{in}}{\text{min}} \right]}{\left[ \frac{\text{in}}{\text{rev}} \right]} = \left[ \frac{\text{rev}}{\text{min}} \right]$$



## Positioning Resolution

$$u = l \cdot \theta \cdot \left( \frac{1}{360} \right)$$

$u$   $\equiv$  axial displacement [in]  
 $l$   $\equiv$  ball screw lead [in/rev]  
 $\theta$   $\equiv$  rotation angle [degrees]  
 $\left( \frac{1}{360} \right)$   $\equiv$  converts revolution to degrees  $\left[ \frac{\text{rev}}{\text{degrees}} \right]$



## Positioning Resolution Example

$l = 0.125$  in  
 $\theta = 15$  degrees

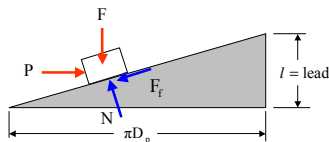
**Example**  
 A ball screw has a lead of 0.125 in/rev. What is the distance that the nut will travel if the screw is turned 15 degrees?

$$u = l \cdot \theta \cdot \left( \frac{1}{360} \right)$$

$$u = (0.125 \text{ in}) \cdot (15 \text{ degrees}) \cdot \left( \frac{\text{rev}}{360 \text{ degrees}} \right)$$

$$= 0.0052 \text{ in}$$

## Torque Required to Move a Load

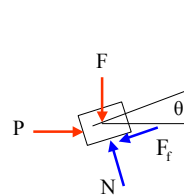


$P$   $\equiv$  Force needed to move load  
 $T$   $\equiv$  Torque needed to move load up  
 $F$   $\equiv$  Load to be moved  
 $D_p$   $\equiv$  Pitch diameter  
 $\mu$   $\equiv$  Coefficient of friction  
 $N$   $\equiv$  Normal Force  
 $F_r$   $\equiv$  Friction Force

**Torque Equation**

$$T = \frac{PD_p}{2}$$

## Torque Required to Move a Load



$$\tan \theta = \frac{l}{\pi D_p}$$

$$\sum F_h = P - F_r \cos \theta - N \sin \theta = 0$$

$$\sum F_v = -F - F_r \sin \theta + N \cos \theta = 0$$

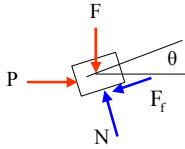
$$F_r = \mu N$$

$$P - \mu N \cos \theta - N \sin \theta = 0$$

$$-F - \mu N \sin \theta + N \cos \theta = 0$$

### Torque Required to Move a Load

(Continued)  $\tan \theta = \frac{l}{\pi D_p}$



Note that the force can be a weight or an inertial load,  $F = m\ddot{x}$

$$P - \mu N \cos \theta - N \sin \theta = 0$$

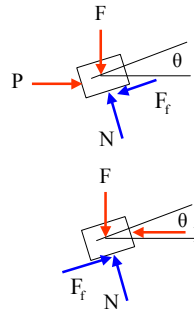
$$-F - \mu N \sin \theta + N \cos \theta = 0$$

$$N = \frac{F}{\cos \theta (1 - \mu l / \pi D_p)}$$

$$P = F \left( \frac{l + \mu \pi D_p}{\pi D_p - \mu l} \right)$$

$$T = \frac{FD_p}{2} \left( \frac{l + \mu \pi D_p}{\pi D_p - \mu l} \right)$$

### Torque Required to Move a Load



#### Torque to "Raise" Load

$$T_u = \frac{FD_p}{2} \left( \frac{l + \mu \pi D_p}{\pi D_p - \mu l} \right)$$

#### Torque to "Lower" Load

$$T_d = \frac{FD_p}{2} \left( \frac{\mu \pi D_p - l}{\pi D_p + \mu l} \right)$$

### Alternate Form of Equations

#### Torque to "Raise" Load

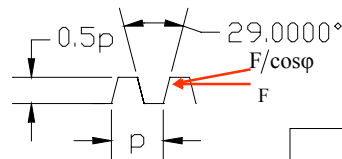
$$T_u = \frac{FD_p}{2} \left( \frac{\tan \theta + \mu}{1 - \mu \cdot \tan \theta} \right)$$

#### Torque to "Lower" Load

$$T_d = \frac{FD_p}{2} \left( \frac{\mu - \tan \theta}{1 + \mu \cdot \tan \theta} \right)$$

$$\tan \theta = \frac{l}{\pi D_p}$$

### Adjustment for ACME Thread



$$T_u = \frac{FD_p}{2} \left[ \frac{\cos \phi \cdot \tan \theta + \mu}{\cos \phi - \mu \tan \theta} \right]$$

$$T_d = \frac{FD_p}{2} \left[ \frac{\mu - \cos \phi \cdot \tan \theta}{\cos \phi + \mu \tan \theta} \right]$$

### Efficiency of a Power Screw

$$\text{Efficiency} = \frac{\text{Torque required with zero friction}}{\text{Torque required with friction}}$$

$$T_u = \frac{FD_p}{2} \left( \frac{l + \mu \pi D_p}{\pi D_p - \mu l} \right) = \frac{Fl}{2\pi}$$

$$e = \frac{Fl}{2\pi \cdot T_u}$$

### Power Required to Drive a Power Screw

$$P = \frac{T_n}{63,000}$$

$P \equiv$  Horsepower

$n \equiv$  rpm

$T \equiv$  Torque [in - lb]

Either  $T_u$  or  $T_d$  is used depending on whether the load is being raised or lowered.

## Life of a Ball Screw

$$\frac{L_2}{L_1} = \left( \frac{P_1}{P_2} \right)^3$$

$$L_2 = \left( \frac{\text{Rated Load}}{P_2} \right)^3 \times \text{million inches}$$

➤ The life of a ball screw can be related to the load ratio using the same equation used for ball bearings.

➤ Manufacturers usually report the rated load that a given screw can exert for 1 million inches of cumulative travel.

## Ball Screw Life Example

$$L_2 = \left( \frac{\text{Rated Load}}{P_2} \right)^3 \times \text{million inches}$$

$P_2 = 2 \times \text{rated load}$ ,  $L_2 = 0.125$  million inches of travel

$P_2 = 1/2 \times \text{rated load}$ ,  $L_2 = 8$  million inches of travel

## Tensile Stress Area

The average axial stress in a power screw is computed using a "tensile stress area".

$$\sigma_{\text{ave}} = \frac{F}{A_t}$$

$$A_t = \frac{\pi}{4} \left[ \frac{D_r + D_p}{2} \right]^2$$

$F \equiv$  Load to be moved

$D_r \equiv$  Root Diameter

$D_p \equiv$  Pitch Diameter

$A_t \equiv$  Tensile Stress Area

$\sigma_{\text{ave}} \equiv$  Average axial stress

Tests of threaded rods have shown that an unthreaded rod having a diameter equal to the mean of the pitch diameter and the minor diameter will have the same tensile strength as the threaded rod.

## Standards

Acme Threads – ANSI B1.5, 1973

Buttress Threads – ANSI B1.9-1973

## Preferred ACME Screw Thread Sizes

TABLE 17-1 Preferred Acme screw threads

Nominal major diameter (in)	Threads per in, n	Pitch, p = 1/n (in)	Minimum minor diameter (in)	Minimum pitch diameter (in)	Tensile stress area (in <sup>2</sup> ) <sup>a</sup>	Shear stress area (in <sup>2</sup> ) <sup>a</sup>
.144	16	0.0625	0.1618	0.2043	0.02632	0.3355
.5/16	14	0.0714	0.2149	0.2614	0.04438	0.4344
.3/8	12	0.0833	0.2632	0.3161	0.06589	0.5276
7/16	12	0.0833	0.3253	0.3783	0.09720	0.6396
1/2	10	0.1000	0.3594	0.4306	0.12255	0.7278
.5/8	8	0.1250	0.4470	0.5403	0.15935	0.9180
3/4	6	0.1667	0.5371	0.6424	0.2732	1.084
.7/8	6	0.1667	0.6615	0.7663	0.4003	1.313
1	5	0.2000	0.7509	0.8726	0.5175	1.693
1 1/8	5	0.2000	0.8753	0.9967	0.6884	1.722
1 1/2	5	0.2000	0.9998	1.1210	0.8851	1.952
1 3/4	4	0.2500	1.0719	1.2388	1.039	2.110
2	4	0.2500	1.1965	1.3429	1.266	2.341
2 1/4	4	0.2500	1.4456	1.5916	1.811	2.803
3	4	0.2500	1.6948	1.8402	2.454	3.262
3 1/2	3	0.3333	1.8572	2.0450	2.982	3.610
4	3	0.3333	2.1065	2.2939	3.802	4.075
4 1/2	3	0.3333	2.3558	2.5427	4.711	4.538
5	3	0.5000	2.4326	2.7044	5.181	4.757
5 1/2	2	0.5000	2.9314	3.2026	7.388	5.700
6	2	0.5000	3.4302	3.7008	9.985	6.640
6 1/2	2	0.5000	3.9291	4.1991	12.972	7.577
7	2	0.5000	4.4281	4.6973	16.351	8.511

<sup>a</sup>Per inch of length of engagement

## Assignment

**Problem 1** – A single-threaded 25-mm power screw is 25 mm in diameter with a pitch of 5 mm. A vertical load on the screw reaches a maximum of 6 kN. The coefficients of friction are 0.05 for the collar and 0.08 for the threads. The frictional diameter of the collar is 40 mm. Find the overall efficiency and the torque to "raise" the load.

