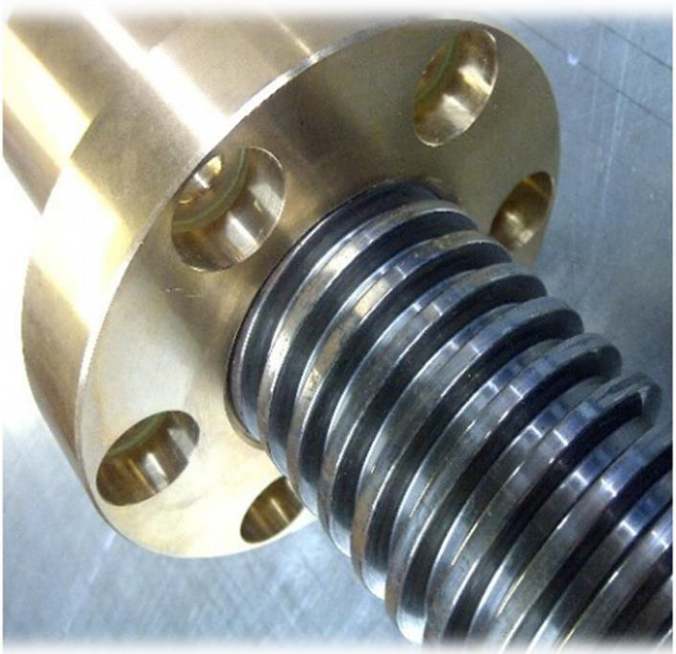
University of Technology
Mechanical Engineering Department

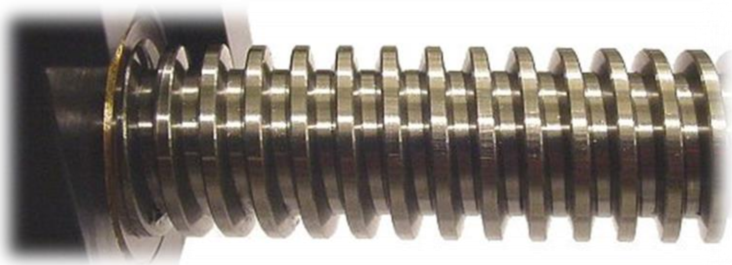
Machine Design I

Third Class for All Branches

LECTURES TWENTY FIVE & TWENTY SIX

LINEAR MOTION ELEMENTS

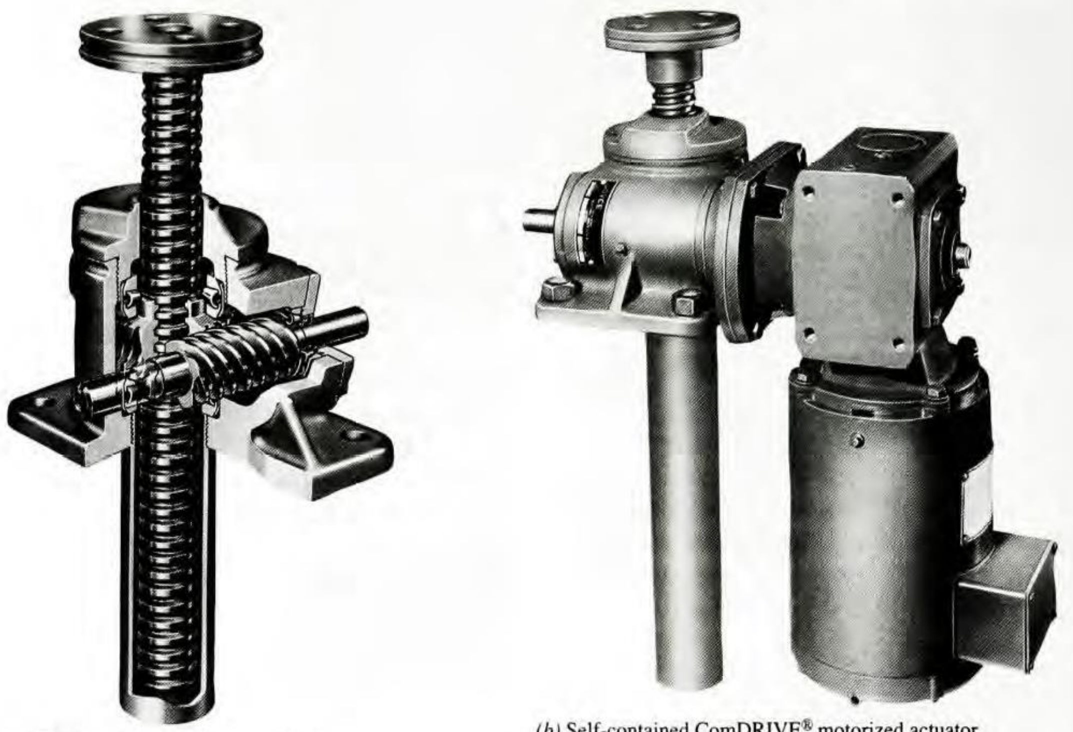




Reference: "Machine Elements in Mechanical Design" 4th Edition, by: Robert L. Mott.

- Many kinds of mechanical devices produce linear motion for machines such as automation equipment, packaging systems and machine tools.
- Power screws, jacks and ball screws are designed to convert rotary motion to linear motion or to convert linear motion to rotary motion to exert the necessary force to move a machine element a long a desired path. They use the principle of screw thread and it's mating nut.
- The linear motion also can be achieved by using the pressure vessels.
- Some examples of components and systems that facilitate linear motion are: Power screws, Ball screws, Jacks, Fluid power cylinders, Linear actuators, linear slides, Screw vice, Lead screw, Screw drills,……..

  Form Fig. 17-1 as an example.

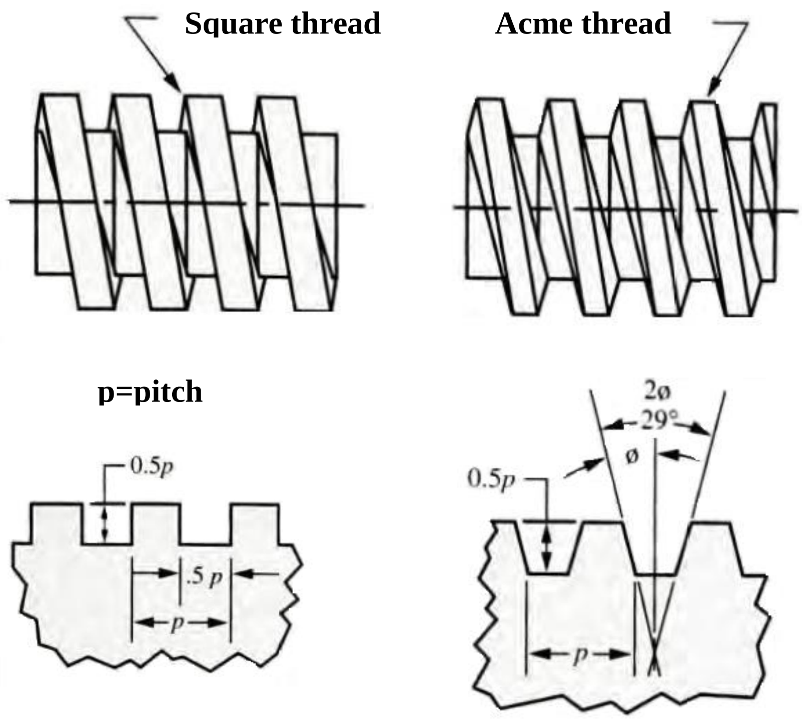


(a) Cutaway of a machine screw jack

(b) Self-contained ComDRIVE® motorized actuator

FIGURE 17–1 Examples of linear motion machine elements (Joyce/Dayton Corporation, Dayton, OH)

Forms of power screw threads: (see Fig. 17-2 P.697)

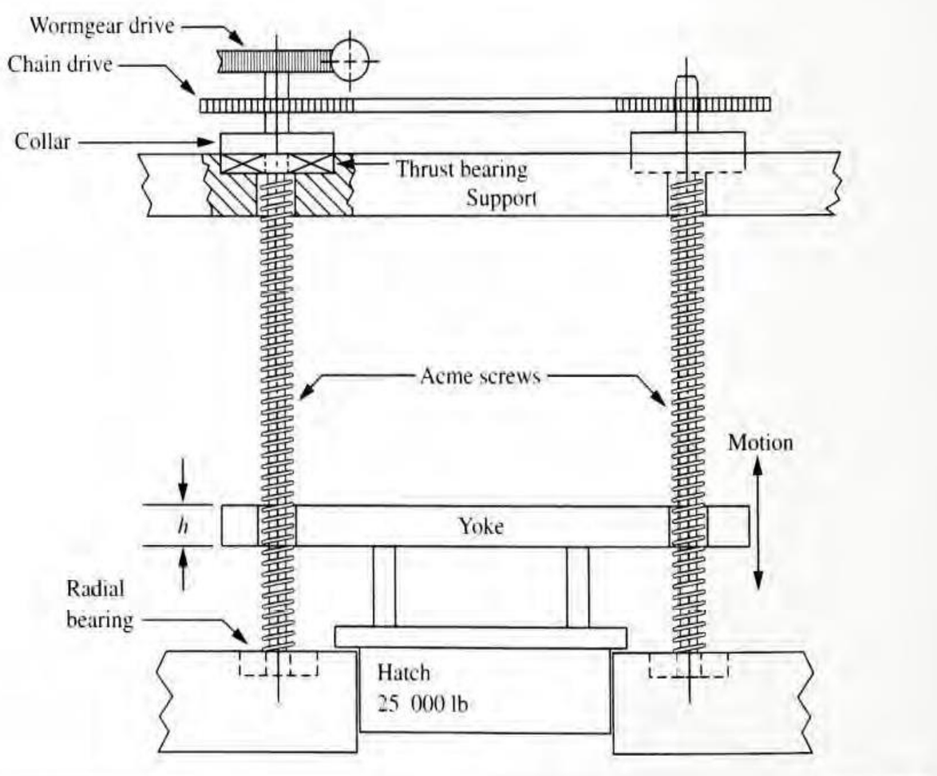


(a) Square thread (b) Acme thread

FIGURE 17-2 Forms of power screw threads

See Fig. 17-4 P.698 to see an example for using an ACME (Trapezoidal thread) screw-driven system for rasing a hatch.

FIGURE 17–4 An Acme screw-driven system for raising a hatch



Requirements:

(a) Study the design carefully.

(b) Draw complete construction for the system showing all details for trapezoidal screw, nut, bearings, chain, worm gears, supports…

2. See section 17-1 (objective of this chapter)   p.698.

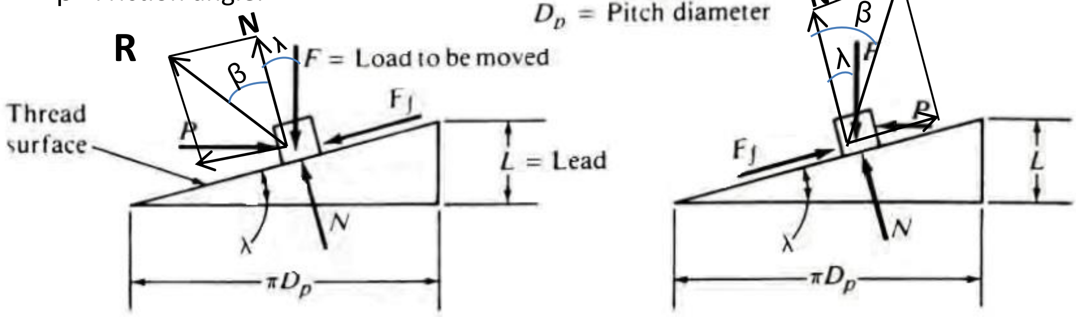
17-2 Power Screw p.699:

D_r= Minor or Root dia.

D= Nominal major dia.

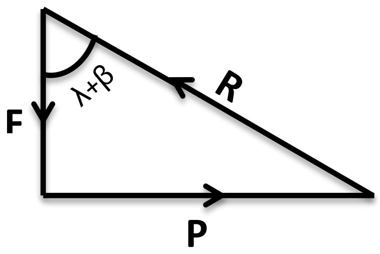
β= Friction angle.

P = Force required to move the load
F_f = Friction force
N = Normal force
λ = Lead angle
D_p = Pitch diameter



(a) Force exerted *up* the plane (b) Force exerted *down* the plane

(a) Force exerted up the plane



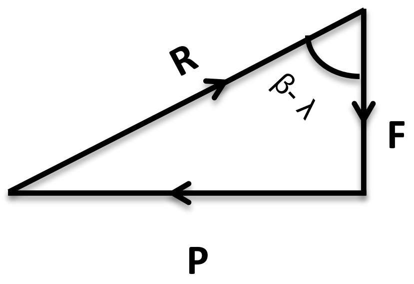
$$\tan(\lambda+\beta)=\frac{P}{F} \ \&\ T_u = P*\frac{D_P}{2}$$

$$\therefore T_u = F*\frac{D_P}{2}*\tan(\lambda+\beta) \ \&\ f=\tan\beta$$

$$T_u = F*\frac{D_P}{2}*\frac{\tan\lambda+f}{1-f\tan\lambda} \ \&\ \tan\lambda=\frac{L}{\pi D_P}$$

$$\therefore\ T_u=\frac{FD_p}{2}\left[\frac{L+\pi f D_P}{\pi D_P - fL}\right] \ldots.(17-2)$$

(b) Force exerted down the plane



$$\tan(\beta-\lambda)=\frac{P}{F} \ \&\ T_d = P*\frac{D_P}{2}$$

$$\therefore T_d = F * \frac{D_P}{2} * \tan(\beta - \lambda) \ \& \ f = \tan\beta$$

$$\therefore T_d = F * \frac{D_P}{2} * \frac{f - \tan\lambda}{1 + f\tan\lambda}$$

$$\therefore T_d = \frac{FD_p}{2}\left[\frac{\pi f D_P - L}{\pi D_P + fL}\right] \dots .(17-4)$$

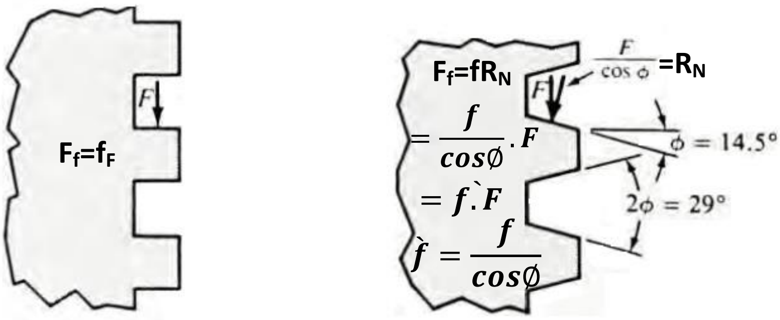
Note:

1- The condition that must be met for self-locking is:

$$f > \tan\lambda \quad .... (17\text{-}5)$$

2- The above equations for square thread, but the adjustment for Acme threads is.

FIGURE 17–6 Force on an Acme thread



(a) Force normal to a square thread

(b) Force normal to an Acme thread

So from fig. above

$$T_u = F * \frac{D_P}{2} * \frac{\tan\lambda + \grave{f}}{1 - \grave{f}\tan\lambda}$$

$$T_u = F * \frac{D_P}{2} * \frac{\cos\emptyset\tan\lambda + f}{\cos\emptyset - f\tan\lambda} \dots \dots .(17-10)$$

$$T_u = F * \frac{D_P}{2} * \frac{f - \cos\emptyset\tan\lambda}{\cos\emptyset + f\tan\lambda} \dots \dots .(17-11)$$

3- Lead =L = pitch for single start.

= 2*pitch for double start.

= 3*pitch for triple start.

4- f =0.1 - 0.15 for running coefficient of friction.

f =0.14 - 0.21 for staring coefficient of friction.

5- Use table 17-1 P.699 for standard proportion of preferred Acme screw thread.

TABLE 17–1 Preferred Acme screw threads

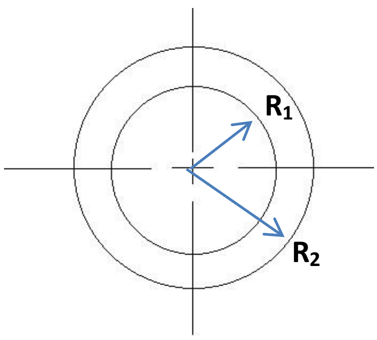
Nominal major diameter, D (in)	Threads per in. n	Pitch, $p = 1/n$ (in)	Minimum minor diameter, D_r (in)	Minimum pitch diameter, D_p (in)	Tensile stress area, A_t (in^2)	Shear stress area, A_s (in^2)[a]
1/4	16	0.0625	0.1618	0.2043	0.026 32	0.3355
5/16	14	0.0714	0.2140	0.2614	0.044 38	0.4344
3/8	12	0.0833	0.2632	0.3161	0.065 89	0.5276
7/16	12	0.0833	0.3253	0.3783	0.097 20	0.6396
1/2	10	0.1000	0.3594	0.4306	0.1225	0.7278
5/8	8	0.1250	0.4570	0.5408	0.1955	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	1.493
$1\frac{1}{8}$	5	0.2000	0.8753	0.9967	0.6881	1.722
$1\frac{1}{4}$	5	0.2000	0.9998	1.1210	0.8831	1.952
$1\frac{3}{8}$	4	0.2500	1.0719	1.2188	1.030	2.110
$1\frac{1}{2}$	4	0.2500	1.1965	1.3429	1.266	2.341
$1\frac{3}{4}$	4	0.2500	1.4456	1.5916	1.811	2.803
2	4	0.2500	1.6948	1.8402	2.454	3.262
$2\frac{1}{4}$	3	0.3333	1.8572	2.0450	2.982	3.610
$2\frac{1}{2}$	3	0.3333	2.1065	2.2939	3.802	4.075
$2\frac{3}{4}$	3	0.3333	2.3558	2.5427	4.711	4.538
3	2	0.5000	2.4326	2.7044	5.181	4.757
$3\frac{1}{2}$	2	0.5000	2.9314	3.2026	7.388	5.700
4	2	0.5000	3.4302	3.7008	9.985	6.640
$4\frac{1}{2}$	2	0.5000	3.9291	4.1991	12.972	7.577
5	2	0.5000	4.4281	4.6973	16.351	8.511

[a]Per inch of length of engagement.

6- Use T_c = Torque to overcome collar friction:

$$T_c = f_1.F.R_m$$

$$R_m = \frac{R_1+R_2}{2}$$



$$total\ torque = T_{tot} = T_u + T_c$$

7- f_1= coefficient of friction when thrust collar are used =0.06-0.12 for running coefficient of friction.

=0.08-0.17 for staring coefficient of friction.

8- **Efficiency of a power screw:**

$$\mathbf{e = \ Efficiency \ = \frac{Torque\ without\ friction}{Torque\ with\ friction} = \frac{\grave{T}}{T_{tot}} = \frac{FL/2\pi}{T_{tot}}}$$

Example Problem 17-1:

Two Acme-threaded power screws are to be used to raise a heavy access hatch, as sketched in Figure 17-4. The total weight of the hatch is 111.2 kN, divided equally between the two screws. Select a satisfactory screw from table 17-1 on the basis of tensile strength, limiting the tensile stress to 68.95 MPa. Then determine the required thickness of the yoke that acts as the nut on the screw to limit the shear stress in the threads to 34.475 MPa. For the screw thus designed, compute the lead angle, the torque required to raise the load, the efficiency of the screw, and the torque required to lower the load. Use a coefficient of friction of 0.15.

Solution:

The load to be lifted places each screw in direct tension. Therefore, the required tensile stress area is:

$$\boldsymbol{A_t = \frac{F}{\sigma_d} = \frac{55.6\ KN}{68.95 * 10^6 N/m^2} = 806.5\ mm^2}$$

From Table 17-1, a 38.1 mm-diameter Acme thread screw with four threads per 25.4 mm would provide a tensile stress area of 816.8 mm^2

For this screw, each inch of length of a nut would provide 1510.4 mm^2 of shear stress area in the threads. The required shear area is then

$$\boldsymbol{A_s = \frac{F}{\tau_d} = \frac{55.6\ KN}{34.475 * 10^6 N/m^2} = 1613\ mm^2}$$

Then the required length of the yoke would be

$$h = 1613\ mm^2 \left(\frac{25.4\ mm}{1510.4\ mm^2}\right) = 27.18\ \ mm$$

For convenience, let's specify $h = 31.75\ mm$

The lead angle is (remember that $L = p = 1/n$ = 1/4 = 6.35 mm)

$$\lambda = tan^{-1}\left(\frac{L}{\pi D_p}\right) = tan^{-1}\left(\frac{6.35}{\pi(34.11)}\right) = 3.39^{\circ}$$

The torque required to raise the load can be computed from equation (17-10):

$$T_u = \frac{FD_p}{2}\left(\frac{(cos\ \phi\ tan\ \lambda + f)}{(cos\ \phi - f tan\ \lambda)}\right)$$

Using: cos ϕ = cos (14.5°) = 0.968, and tan λ = tan (3.39°) = 0.0592, we have

$$T_u = \frac{(55.6\ kN)(34.11\ mm)}{2}\left(\frac{(0.968)(0.0592) + (0.15)}{(0.968) - (0.15)(0.0592)}\right) = 204.4\ N.m$$

The efficiency can be computed from Equation (17-7):

$$e = Efficiency\ = \frac{FL}{2\pi T_u} = \frac{(55.6\ KN)(6.35\ mm)}{2(\pi)(204.4\ N.m)} = 0.275\ or\ 27.5\ \%$$

The torque required to lower the load can be computed from Equation (17-11):

$$T_d = F * \frac{D_P}{2} * \frac{f - cos\ \emptyset\ tan\lambda}{cos\ \emptyset + f\ tan\lambda} \dots \dots (17 - 11)$$

$$T_d = (55.6\ kN) * \frac{(34.11\ mm)}{2} * \frac{(0.15) - (0.968)(0.0592)}{(0.968) - (0.15)(0.0592)} = 89.95\ N.m$$

Example Problem 17-2:

It is desired to raise the hatch in Figure 17-4 a total of (381 mm) in no more than (12.0 s). Compute the required rotational speed for the screws and the power required.

Solution:

The screw selected in the solution for Example Problem 17-1 was a (38.1) mm Acme-threaded. Screw with four threads per 25.4 mm. Thus, the load would be moved (6.35 mm) with each revolution. The linear speed required is:

$$\mathbf{V} = \frac{\mathbf{381\ mm}}{\mathbf{12.0\ s}} = \mathbf{31.75}\ \boldsymbol{mm/s}$$

The required rotational speed would be

$$\boldsymbol{\omega} = \frac{\mathbf{31.75\ mm}}{\boldsymbol{s}} * \frac{\mathbf{1}\ \boldsymbol{rev}}{\mathbf{6.35}\ \boldsymbol{mm}} * \frac{\mathbf{2}\boldsymbol{\pi}}{\mathbf{1}\ \boldsymbol{rev}} = \mathbf{31.415}\ \boldsymbol{rad/sec}$$

Then the power required to drive each screw would be

$$\boldsymbol{P = T * \omega} = (\mathbf{204.4}\ \boldsymbol{N.m})\left(\mathbf{31.415}\frac{\boldsymbol{rad}}{\boldsymbol{s}}\right) = \mathbf{6421.41}\ \boldsymbol{W}$$