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Design of a Power Screw

R. Gopinath

Department of Mechanical Engineering, Bharath University,
Selaiyur, Chennai, Tamilnadu, India

Abstract: The power screw is used for lifting and lowering the mass slowly which is required in Any assembly shop of heavy industry. It mainly contains a set of worm and worm gears, a pinion and bevel gear, a screw and bronze nut and a motor to drive. These frames are fabricated out of steel channel of 100x50x6 size. A worm is fixed to a motor shaft through a coupling. The worm drives a worm gear when the motor is switched on. The worm gear and the bevel pinion are mounted on a shaft on either end. This shaft is supported by two ball bearings on the vertical frame. Hence when the worm gear rotated, the bevel gear pinion drives the bevel gear. This bevel gear is fitted with a bronze bush with internal square thread. This bevel gear with bronze bush is mounted on a flat support frame with a thrust bearing over the plate. The extended portion of the bush is locked at the bottom side of the support frame to arrest and make bevel gear to rotate at its position. A motor is provided with a bidirectional switch so that the motor can be operated on both directions for raising or lowering the load. Here in this arrangement, main base frame, vertical channel with bevel support, top support guide plate, screw, load base, guide pipe support etc are detachable since they are bolted together.

Key words:

INTRODUCTION

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. The power screw used for lifting and lowering the mass slowly as required in any assembly shop of heavy industry. It mainly contains a set of worm and worm gear, a pinion and bevel gear, a screw and bronze nut and a motor to drive. Power Screws are used for providing linear motion in a smooth uniform manner. They are linear actuators that transform rotary motion into linear motion. Power screws are generally based on Acme, Square and Buttress threads. Ball screws are a type of power screw. Efficiencies of between 30% and 70% are obtained with conventional power screws. The wear life of power screw and nut drive systems is difficult to predict theoretically. The number of variables involved in such a prediction is large; load, speed, screw material, nut material, surface finishes, lubrication, duty cycle, operating temperature and environmental factors such as the presence of abrasive contaminants, corrosives, vibration, etc. Understanding of how these factors interact is limited. Because of this, the only proper approach to evaluating the service life of power screws is too thoroughly life tests each application prior to final specification and production. However, even under laboratory conditions, results may vary quite markedly as rubbing friction and wear are notoriously capricious. Test life cycle variations of two or three to one are not uncommon.

Ball screws have efficiencies of above 90%.Power Screws are used for the following three reasons;

- To obtain high mechanical advantage in order to move large loads with minimum effort. e.g. Screw Jack.
- To generate large forces e.g. a compactor presses.
- To obtain precise axial movements e.g. a machine tool leads screw.

Power Screws: Power screws cover a wide variety of screw series and include Acmes, Hileads(r), Torqsplines(r) and other special series (not offered in this catalog but produced for OEM customers) such as Stub Acme,

Corresponding Author: R. Gopinath, Department of Mechanical Engineering,
Bharath University, Selaiyur, Chennai, Tamilnadu, India.

Trapezoidal ("metric Acme") and Buttress. Regardless of the thread series, an externally threaded screw mates with an internally threaded nut of the same thread form; when either member rotates, the other member translates. Contact between the screw and nut is sliding friction at the screw and nut interface surface. Efficiencies vary from 20% - 30% for standard Acmes to 25% - 40% for Hileads(r) and up to 75% for some Torqsplines(r). Efficiency of any power screw and nut juis dependent upon the coefficient of friction between the screw and nut materials, the lead angle and the pressure angle of the screw thread. Of these, the lead angle has the greatest effect, the coefficient of friction has a secondary effect and the pressure angle has a minimal effect. For the exact formula of efficiency as a function of these variables, see the Useful Formulas section. Efficiencies of power screws may vary with load. When the load increases, unit pressure increases and the coefficient of friction can drop. This is especially true for plastic nuts but has also been observed with bronze nuts. Power screws in the Acme screw series (single start screws) are self-locking. This means that they can sustain loads without the use of holding brakes. In vibrating environments, some locking means may be needed, but Acme screws rarely require brakes. This makes them simple and inexpensive for use in many different applications such as machine tools, clamping mechanisms, farm machinery, medical equipment, aerospace and other mechanisms of many industries. Power screws are typically made from carbon steel, alloy steel, or stainless steel and they are usually used with bronze, plastic, or steel mating nuts. Bronze and plastic nuts are popular for higher duty applications and they provide low coefficients of friction for minimizing drive torques. Steel nuts are used for only occasional adjustment and limited duty so as to avoid galling of like materials. For more information about using steel Acme nuts, see Roton Engineering Bulletin.

The power screw used for lifting and lowering the mass slowly as required in any assembly shop of heavy industry. It mainly contains a set of worm and worm gear, a pinion and bevel gear, a screw and bronze nut and a motor to drive. These frames are fabricated out of steel channel of 100x50x6 size.

A worm is fixed to a motor shaft through a coupling. The worm drives a worm gear when the motor switched on. The worm gear and the bevel pinion are mounted on a shaft on either end. This shaft is supported by two ball bearings on the vertical frame. Hence when the worm gear rotated, the bevel pinion drives the bevel gear. This bevel gear is fitted with a bronze bush with internal square thread. This bevel gar with bronze bush is mounted on a flat support frame with a thrust bearing over the plate. The extended portion of the bush is locked at the bottom side of the support frame to arrest and make bevel gear to rotate at its position.

A motor is provided with a bidirectional switch so that the motor can be operated on both directions for raising or lowering the load. Now, if he motor is switched on toward upward direction, the drive is transferred form worm to worm gear. Since the worm gear and bevel pinion are mounted on the same shaft, the pinion drives the bevel gear. When the bevel gear rotates at its position, the screw engaged with the bevel gear bush moves up.

The anti rotation of the screw is taken care off by the two guide rods fixed to the load base. These guide rods travel through the guide pipes rising from the bottom frame.

Here in this arrangement, main base frame, vertical channel with bevel support, top support guide plate, screw, load base, guide pipe support etc are detachable since they are bolted together.

Wear Life of Power Screw: The wear life of power screw and nut drive systems is difficult to predict theoretically. The number of variables involved in such a prediction is large; load, speed, screw material, nut material, surface finishes, lubrication, duty cycle, operating temperature and environmental factors such as the presence of abrasive contaminants, corrosives, vibration, etc. and our understanding of how these factors interact is limited. Because of this, the only proper approach to evaluating the service life of power screws is too thoroughly life tests each application prior to final specification and production. However, even under laboratory conditions, results may vary quite markedly as rubbing friction and wear are notoriously capricious. Test life cycle variations of two or three to one are not uncommon. A general understanding of the wear mechanism, some simple design and operating guidelines and recommendations for life testing will help you get the best performance from your screw and nut drive system.

Wear Mechanism the study of wear is a field called tribology. There is much research on the subject, but little definitive work that can help determine the wear rate of two surfaces in any specific application.

The wear mechanism itself is simple to understand. Two rubbing surfaces contact only at their highest microscopic aspersions. When the contact stress is high enough and under relative motion, these aspersions shear off and become debris. Lower aspersions then come into

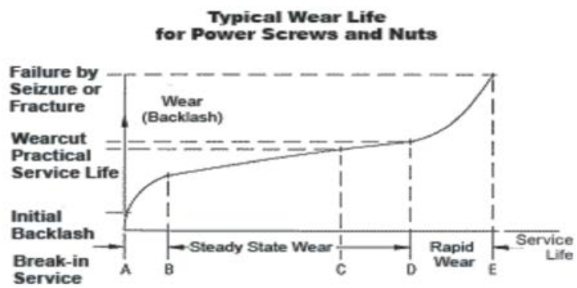

Figure 1 Wear life of power screw

contact and the contact area increases until the unit pressure and the underlying materials shear strengths are in balance. At this point break-in wear has occurred and the surfaces appear and can be represented by the curved line between A and B in Fig.1. After break-in a steady state, continuous wear pattern begins, as represented by the straight line between points B and D in fig.1. Unless the surfaces are completely separated with a lubricant film some wear will occur continually as the mating surfaces rub each other in normal service life.

Design of Power Screw: The following notes are provided for general guidance. In practice power screws are provided by specialist suppliers who provide technical literature which includes all the necessary data for selecting power screws from their range. The notes below are general in nature and cannot provide detailed information about precise strength levels because there are limitations on the understanding of the stress levels in screws. Calculations assume that loading is distributed along the whole length of the engaged screw. In practice this is not the case and the loading is actually mainly taken by the first two threads. These may yield a little to distribute to load along the thread. The stress levels are also effected by thread finish, clearance, shape, lubrication etc etc. The following factors need to be considered in calculating the strength of a power screw

- Bearing Strength
- Bending Strength
- Shear Strength
- Direct tensile/compressive strength
- Direct tensile/compressive strength
- Column strength

Bearing Stress: The bearing stress results from the crushing force between the screw surface and the adjacent nut surface developed by lifting and supporting the load, W.

$\sigma_b = W / (\pi.\, d_m.\, h.n)$

Bending Stress: The maximum bending stress occurs at the root of the thread. It is calculated by assuming the thread is a simple cantilever beam built in at the root. The load is assumed to act at mid point on the thread. The maximumum stress is provided by the bending moment relationship,

$M/I = \sigma /(y) = e/R$. that is $\sigma = M.y/I$

The section under bending has a length = $\pi.d_m.n$
The width of the section at the thread root = b.
The Moment of Inertia at the root $I = \pi.d_m.n.b^3 /12$
The distance from the centroid the the most remote fibre ..y = b/2.
The Bending Moment M = W.h/2
The maximum bending stress is therefore..

$$\sigma_b = \frac{W.h}{2}\left(\frac{12}{\pi.d_m.n.b^3}\right)\frac{b}{2} = \frac{3W.h}{\pi.d_m.n.b^2}$$

Shear Stress: Both the nut and screw threads are subject to traverse shear stress resulting from the bending forces. For a rectangular section the maximums shear stress occurs at the neutral axis and equals

Screw, $\tau = 3.W /2.A = 3.W /(2.\pi.d_r.n.b)$
Nut, $\tau = 3.W /2.A = 3.W /(2.\pi.d_o.n.b)$

Tensile /Compressive Stresses: A loaded power screw is subject to a direct tensile or compressive load.. This is simply calculated as the load / tensile stress area. The tensile stress area is generally provided in screw tables and is generally larger than that calculated by the root dia. Using a stress area based on the root diameter may be used for conservative design studies. ($A = \pi d_o^2/4$)

The preferred stress area is actually based on the (pitch dia + root dia)/2

$\tau_{t\ or\ c} = W /A$

$A = (d_r + d_r) /2$

Combined Stresses: Based on maximum shear stress theory...

$$\tau_{max} = \sqrt{(\sigma/2)^2 + (\tau)^2}$$

The shear stress τ caused by torque on the screw,

$$\tau = \frac{T.(d_r/2)}{J} = \frac{T.(d_r/2)}{J\pi(d_r^4/32)} = \frac{16.T}{\pi\ d_r^3}$$

The value of the combined stress is therefore

$$\tau_{max} = \sqrt{\left(\frac{W}{2.A}\right)\left(\frac{16.T}{\pi\ d_r^3}\right)^2}$$

This equation always applies when the screw is in tension. When a screw is in compression and the length is greater than 8 time the root diameter then the buckling stress has to be considered.

Buckling Stress: When the screw is longer than 8 times the root diameter it must be considered a column. Long columns with are dealt with using the Euler equation. Columns with slenderness ratios of less than 100 are considered as short columns. The slenderness ratio is the length (between supports) / Least radius of gyration of the section.

For Machine tool design a variation on the Gordon-Rankine formula is used. This is called the Ritter equation..

$$\sigma_{co} = \frac{P}{A}\left[1 + \left(\frac{L}{k}\right)^2 \frac{L}{\pi^2 K.E}\right]$$

For a column the maximum stress at the concave side of the column σ_{co} should not exceed the design compressive strength of the screw material..

K = factor to allow the column end supports
One end fixed and one end free K= 0,25
Both ends pin-connected K= 1
One end pin-connected and one end fixed K= 2
Both ends fixed K= 4

The above equation applies only the screws with purely axial loads. When the load is eccentric from the screw centre line by distance. Then the following variation of the Ritter equation applies.

$$\sigma_{co} = \frac{P}{A}\left[1 + \left(\frac{L}{k}\right)^2 \frac{S}{\pi^2 K.E}\frac{y.e}{k^2}\right]$$

Design and Operational Considerations: Here are the most important keys to maximizing service life. Increasing the screw size and nut size will reduce thread contact pressure for the same working load. The higher the unit pressure and the higher the surface speed, the more rapid the wear will be. Increasing the screw lead will reduce the surface speed for the same linear speed. The better the lubrication, the longer the service life. Power screws and nut should be treated as any other wear surfaces. If grease fittings or other lubrication means are provided for other wear elements in the application, the designer will be well served by providing a like means to lubricate the power screw and nut.

Dirt, especially hard particle type dirt, can easily embed itself in the soft nut material. Once established the dirt will act as a file and readily abrade the mating screw surface. The soft nut material backs away during contact leaving the hard dirt particles to scrap away the mating screw material. Approximately 2/3 of the drive energy in an ACME screw and nut system goes into heat. When the mating surfaces heat up, they become much softer and are more easily worn away. Means to remove the heat such as limited duty cycles or heat sinks must be provided so that rapid wear of over heated materials can be avoided. Some applications and tests indicate that wear is proportional to load and speed, however, others show proportionality to load and speed to the 2nd - 4th power. The general relationship of more wear with higher loads and speeds is well accepted and has been demonstrated in laboratory and field tests.

Design Calculations

Design of Screw

screw material: C40 (unhardened) with σ_Y = 330 **N**/mm^2
$[\sigma_c] = \sigma_Y/$ Fs = 165 **N**/mm^2
$[\tau] = [\sigma_c]/2$ = 25 N/mm^2
Nut material : bronze, $[\tau]$ = 25 **N**/mm^2 (assumed)

Screw Minor Diameter:

$w = \pi d_c^2/4 * [\sigma_c]/ = 45000$ N
d_c = 18.6 mm
d_o = 28 mm
d = 25.5mm

Combined Compression and Torsional Load on the Screw:

T = w d/2 tan(ϕ+α) = 117774 **N**/mm^2
direct compression stress due to axial load
$\sigma_c = w/\pi d_c^2/4$ = 108.4 **N**/mm^2
maximum shear stress
τ_{max} = 73.27 **N**/mm^2 < $[\tau]$ = 82.5 N/mm^2

Design of Nu:t

assume $[P_b] = 10$ N/mm^2
n = 10 (assumed)
$P_b = w/ (\pi/4)(d_o^2-d_c^2)n = 22.5$ N/mm^2 > $[P_b] = 10$ N/mm^2
revise the screw diameters and check P_b
$P_b = w/ (\pi/4)(d_o^2-d_c^2)n = 8.53$ N/mm^2 < $[P_b]$

Check the Threads for Shear:

$\tau_{d\ screw} = W/n\ \pi\ d_c\ t = 8.98$ N/mm^2 < $[\tau]_{screw}$
$\tau_{d\ nut} = W/n\ \pi\ d_o t = 7.42$ N/mm^2 < $[\tau]_{nut} = 25$ N/mm

Stability Calculations:

$n_e = 2$
$wcr = Ac\ \sigma_Y [1- \sigma_Y/4\ n^e\ \pi^2\ E\ (I/K)^2\ ] = 359.5$ KN

Time Required to Raise the Load:

Vs = 8 m/min
Nn = 60.66 rpm
$V_{load} = 485.28$ mm/min
Time to raise the load = 46.98 sec

Motor Power:

$P = T\omega_N = 1220.6$ Nm/s
P = 1.22 Kw

Test Result:

Applied load = 45 KN
Time required to raise the load = 45.98 sec
Distance raised = 380 mm

Fabrication of a Power Screw: The power screw is used for lifting and lowering the mass slowly which is required in any assembly shop of heavy industry.

It mainly contains a set of worm and worm gear, a pinion and bevel gear, a screw and bronze nut and a motor to drive. These frames are fabricated out of steel channel of 100x50x6 size.

A worm is fixed to a motor shaft through a coupling. The worm drives a worm gear when the motor switched on. The worm gear and the bevel pinion are mounted on a shaft on either end. This shaft is supported by two ball bearings on the vertical frame.

Hence when the worm gear rotated, the bevel pinion drives the bevel gear. This bevel gear is fitted with a bronze bush with internal square thread. This bevel gar with bronze bush is mounted on a flat support frame with a thrust bearing over the plate. The extended portion of the bush is locked at the bottom side of the support frame to arrest and make bevel gear to rotate at its position.

The screw is engaged with the bush/nut. The up and down movement of the screw in guided by a guide bush fixed on the top flat portion of the main frame.

On the top of the screw, the load base is fixed. This load base is provided with two guide rods and they travel inside the guide pipe rising from the bottom main frame in to and fro motion.

The motor is provided with a bidirectional switch so that the motor can be operated on both directions for raising or lowering the load.

Now, if the motor is switched on towards upward direction, the drive is transferred form worm to worm gear. Since the worm gear and bevel pinion are mounted on the same shaft, the pinion drives the bevel gear. When the bevel gear rotates at its position, the screw engaged with the bevel gear bush moves up.

The anti rotation of the screw is taken care off by the two guide rods fixed to the load base. These guide rods travel through the guide pipes rising from the bottom frame.

Here in this arrangement, main base frame, vertical channel with bevel support, top support guide plate, screw, load base, guide pipe support etc are detachable since they are bolted together.

CONCLUSIONS

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. Thus, We have fabricated all the components as per the design. The result of its testing has been successful. Thus this machine is used for lifting heavy loads using mechanical advantage and we have tested our project by lifting 45 KN weight upto 380 mm successfully. Hence the power screw is used for lifting and lowering the mass slowly as required in any assembly shop of heavy industry.

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