MSD
MOTION SYSTEM DESIGN

Sizing and applying ROLLER SCREWS

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How it works

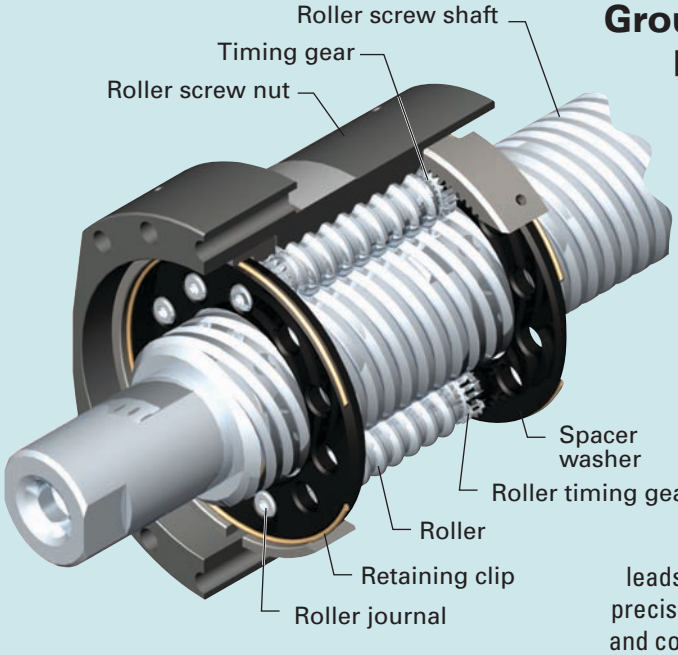
Roller screws convert rotary motion into linear motion just like acme and ballscrews. Comparably sized roller screws, however, have better efficiency than acme screws and can carry larger loads than ballscrews. In addition, they can cycle more often and turn significantly faster than either, suiting them to precise, continuous-duty applications.

Radiused flanks on the rollers deliver point contact like balls on a raceway, and only the radius is part of the profile. Therefore, a larger radius and additional contact points can be packed into the available space, thus lowering stress. In addition, the rolling contact between components has low friction, yielding high efficiency. Because the rolling members are fixed relative to each other and never touch adjacent rollers, roller screws can turn at speeds up to 5,000 rpm. And, compared to similarly sized ballscrews, roller screws can have a load capacity up to 15 times greater.

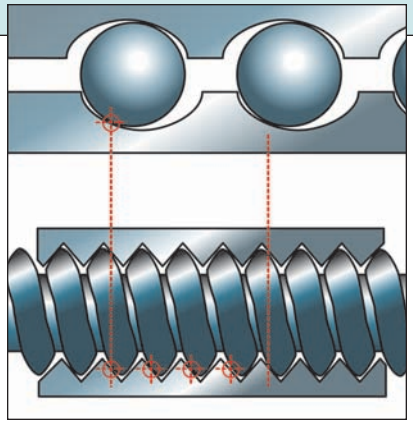
Nut options let users choose among backlash, load capacity, and cost trade-offs. The most common configuration is a **single nut**, ideal for maximum life with backlash less than 0.001 in. Another design is the **split nut**; although it virtually eliminates backlash, it also reduces the dynamic load rating by about 38%. In this design, the nut is split transversely and a precision-ground spacer is inserted between the front and back halves. The **double nut** is another alternative. As the name suggests, it uses two nuts preloaded against each other on one screw. There is no sacrifice of life for its decreased backlash, but the double nut costs more than standard single-nut arrangements.

Roller screws are sealed to varying degrees. Like other lead screws, roller screws must be well lubricated and able to tolerate contaminants such as nonlubricating fluids, metal chips, and abrasives. The first level of protection is adding wipers to the

Ground shaft planetary roller screw

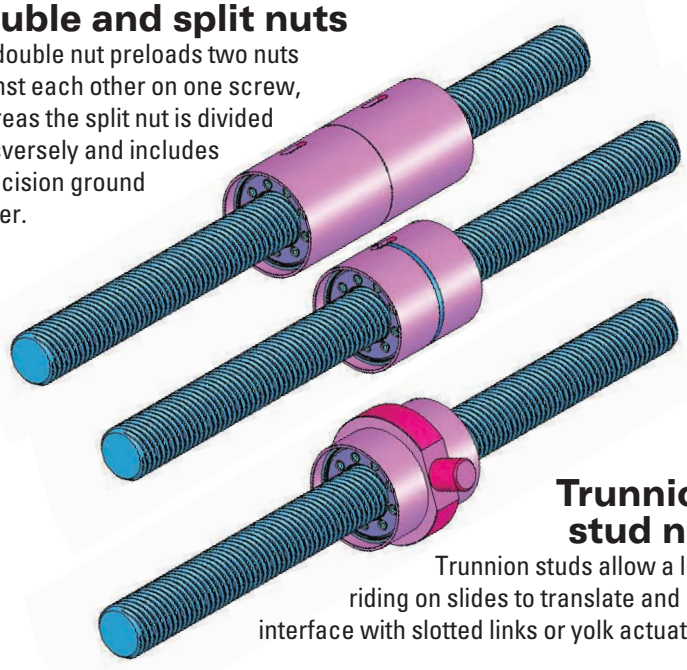


Roller screws' numerous contact points vs. ballscrews', lengthen their lives and increase load capacity and stiffness. They contain ground leadscrews for high-precision applications and come in tolerance classes G1, G3, G4, and G5.



Double and split nuts

The double nut preloads two nuts against each other on one screw, whereas the split nut is divided transversely and includes a precision ground spacer.



Trunnion stud nut

Trunnion studs allow a load riding on slides to translate and can interface with slotted links or yolk actuation.

front or back of the nut. Wipers scrape particulates from the threads as the screw cycles back and forth. This configuration requires maintenance of adequate lubrication to load-bearing parts of the nut. Another sealing option is force tubes, which enclose roller screws in a housing to keep lubricants in and foreign particles out. Force tubes can be made for IP67 ratings and mount in many arrangements.

General sizing procedures

Roller screws provide shock-load resistance and handle loads up to 779,000 lbf. To select the best diameter, lead, and sealing, some basic questions must be answered. What is the:

... budget?
... maximum required linear speed?
... maximum required load?
... maximum required stroke?

In addition, how will the components be protected from contaminants and what level of precision is needed?

Certain calculations must be performed when selecting roller screws. For instance, with the high-speed capacity of a roller screw, the shaft tends to set up natural frequency vibrations, which must be considered by calculating its *critical speed*. Screw diameter, length, loading direction, and bearing arrangement all affect critical speed. In particular, compressive axial loads reduce critical speeds, while tensile loads tend to increase them. A roller screw's rotational speed should always be below the critical speed, defined as:

$$n_{crit} = \frac{86.4x10^6 d_o f_s}{l^2}$$

Where:

n_{crit} = Critical rotational speed under zero axial load (rpm)
d_o = Screw diameter, in. (mm)
f_s = Support bearing factor
l = Screw's length, in. (mm)

Additionally, roller-screw nut speeds must not exceed their *mechanical speed limit*. This depends on screw diameter and lubrication method. Specifically, oil should not surpass $140{,}000/d_o$ and grease should not be more than $90{,}000/d_o$.

Another design factor is *buckling force*. Buckling occurs when the compressive load on a screw's shaft is too great for its diameter. Like critical speed, buckling force is based on screw length, diameter, and the type of bearing supporting the screw. When sizing roller screws, the application's maximum applied compressive load must be less than the buckling force, calculated as:

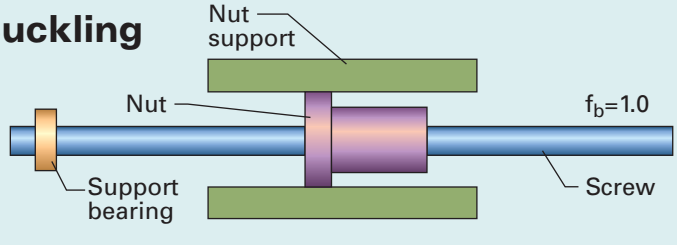
$$F_b = \frac{81.3 f_b d_o^4}{l^2}$$

Where:

F_b = Buckling force, kN
f_b = Buckling force bearing factor

When sizing a motor, engineers must also calculate the required *torque* and compare it against predetermined ratings of the motor and drive to control the roller screw's velocity and position. Load and acceleration torques must not exceed the proposed motor's torque rating. If an application requires a specific

Buckling



This schematic shows installation with a bearing on one end of the screw and supports to the nut, which prevent it from moving transversely.

motor, engineers should try a roller screw with a lower lead or a belt or gear reduction in between. Here are some helpful equations:

Under load: $\lambda = \frac{(SF)}{(2\ \pi\eta)}$

Where:

λ = Torque, lbf-in. (Nm)
F = Applied load, lbf (N)
S = Screw lead, in. (mm)
η = Motor efficiency (usually 71 to 90%)

Under acceleration: $\lambda = (I_l + I_m)\alpha$

Where:

I_l = Reflected inertia due to load, in.-lb-sec^2 (N-m-sec^2)
I_m = Inertia of proposed motor's armature; obtain from motor specs, lbf-in.-sec^2 (N-m-sec^2)
α = Acceleration of motor, rad/sec^2

or $I_l = \frac{(S/2\pi)^2 m}{g}$

Where:

m = Mass of applied load, lb (g)
g = Gravitational constant, 384 in./sec^2 (9.75 m/sec^2)

Another sizing parameter is the follower's (nut) *linear speed*, which relies on the shaft's rotational speed (S) and the roller screw's lead. This is found using $V = nS$

Where:

V = Linear velocity, in./sec (mm/sec)
n = Follower rotational speed, rev/sec

An important roller screw sizing parameter is diameter, which usually ranges from about 0.14 to 5.91 in.; leads are approximately 0.04 to 1.18 in. For split nuts, the dynamic load rating can be as little as 832 lbf or as great as 40,286 lbf; static load rating, on the other hand, is from 719 to 59,642 lbf. For single and double nuts, dynamic loads can be 1,304 to 234,251 lbf while static load ratings range from 1,461 to 794,670 lbf.

Common applications

Roller screw actuators can be used in place of hydraulics or pneumatics for high loads and fast cycles. Advantages include eliminating a complex system of valves, pumps, filters, and sensors; decreasing space; lengthening working lives; and reducing maintenance. The absence of high-pressure fluid also means that leaks do not exist and noise levels diminish significantly. Adding servo control to electromechanical actuators offers a stronger connection between the motion software and load, allowing for programmed positioning, velocity, and thrust.

Industries and applications utilizing planetary roller screws include:

- **Medical** — artificial hearts, patient positioning tables, and automated high-force syringes (for example, high-force syringes require a very slow, non-pulsing extension)
- **Machine tool** — presses, broaching, grinding, dressing, and cutting (broaching operations need high force at moderate speeds)
- **Military** — weapons positioning, door control, and artillery handling (military systems

EXAMPLE SIZING PROBLEM

SAMPLE CALCULATION	PROPOSED ROLLER SCREW
Application information	Diameter = 0.79 in. (20 mm)
Cubic mean load = 500 lbf (2,225 N)	Lead = 0.1969 in. (5 mm)
Max speed = 6 in./sec (152 mm/sec)	Dynamic load rating = 7,120 lb (31.7 kN)
Min time to max speed = 0.1 sec	Non-preloaded
Stroke length = 18 in. (457 mm)	Screw supported by two bearings on one side; none on the other
Required lifetime = 5 million in. (127 million mm)	Nut performs no guidance function

Lifetime: $L_{10} = (7{,}120/500)^3 \times 0.1969 = 568$ million in. of travel

Critical speed: The application's rotational speed must be less than the critical and mechanical speed limits. Rotational speed is determined from the linear speed equation:
$n = (152/5) \times 60 = 1{,}824$ rpm.
Using $f_s = 0.32$, the critical speed is:
$n_{crit} = 86.4\times10^6 \times 20 \times 0.32/(457^2) = 2{,}648$ rpm.
The mechanical speed limit with oil cooling is: 140,000/20 = 7,000 rpm.

Buckling force: The applied load, 500 lbf, must be below the force required to buckle the screw. In this case $f_b = 0.25$:

$$F_b = \frac{81.3 \times 0.25 \times (20^4)}{(457^2)} = 15.6 \text{ kN} = 3{,}500 \text{ lb}$$

Torque: Under load, the required torque is

$$l = \frac{(0.1969 \times 500)}{(2 \times 3.14 \times 0.75)} = 20.89 \text{ lbf-in.}$$

A motor whose continuous-torque rating is 30 lbf-in. may be appropriate. To determine if this accommodates the inertial load under acceleration (assume I_m for a servomotor is 0.00058 lbf-in.-sec^2; α = 1,884 rad/sec^2), one must use the reflected inertia equation:

$$I_l = \frac{(0.1969/2\pi)^2 \times 500}{384} = 0.0013 \text{ lbf-in.-sec}^2; \text{ then}$$

$\lambda = (0.00058+0.0013) \times 1{,}884 = 3.54$ lb-in.

These calculations show that the proposed roller screw — with the suggested motor — is acceptable under constant velocity and acceleration for the given conditions.

for optimal reliability and shock resistance)

• **Assembly** — riveting, fastening, joining, clamping, part positioning; and weld guns (for high speed and accurate positioning)

• **Food and beverage** — volumetric filling, palletizing, packaging, and sealing (for high speed and accurate positioning)

• **Plastics, glass, and textiles** — mold closing, toggle drives, eject axes, transfers, shifting (requiring accurate positioning and high force)

Installation and maintenance tips

Regular grease and oil lubrication increase roller-screw life. In particular, KP (DIN 51825) bearing greases with a consistency factor of 2 should be applied. Ultimately, screw size and operating conditions determine greasing intervals.

For higher duty cycles, oil lubrication may be needed. High-performance gear oil with EP additives should be used and must thoroughly lubricate the nut components. Lubrication rates depend on screw diameter, number of rollers, and amount of heat to be dissipated. In horizontal mounting, immersion lubrication requires that oil levels be deep enough for the bottom-most roller to fully submerge.

Failure modes

Correctly applied and maintained roller screws will normally fail from metal fatigue or abrasion of the thread flanks, caused by an applied load. Any other failure mode is considered to be premature and can be prevented by following basic guidelines.

As mentioned earlier, proper lubrication is critical: While rolling friction may not be as extreme as sliding friction, heat still builds up and must be dissipated, via lubricants. When the duty cycle increases heat conducting through the screw may prevent components from staying cool. Roller screws have been returned for repair where they've achieved temperatures high enough to temper steel. Such high temperatures lead to rapid (and eminent) catastrophic failure.

Protecting the roller screw from contaminants lengthens life. If metal chips, for example, get into the nut assembly, the roller screw can grind them into a "lapping compound." Even if they don't immediately cause failure, ground-up chips still damage lead screw components over time. Depending on the environment, shaft wipers, bellows, shrouding, or a complete enclosure may be added to guard against this.

Besides insufficient lubrication and foreign material, improper loading also leads to roller-screw failure. In general, lead screws do not tolerate side loading or applied moments. Therefore, high-accuracy slide rails can be used to carry these loads and ensure that loading on the nut is co-axial to the lead screw.

Like the dynamic load rating for bearings, a roller screw's *expected life* is based on the number of revolutions a system can make before failure. In lead screws, this value is converted to a total traveled linear distance. A dynamic load rating is a function of the load and number of traveled inches that 90% of screws meet or exceed before reaching metal fatigue. It should be noted that L_{10} estimates the travel life expected from planetary roller screws with a 90% probability and is not a guarantee of continued operation. Probability above 90% requires further de-rating.

Expected life is calculated as:

Single (non-preloaded) nut:

$L_{10} = (C/F)^3 \times S$

Where:

L_{10} = Travel life, millions of in. (mm)

C = Dynamic load rating, lbf (N)

F = Cubic mean applied load, lbf (N)

Preloaded (split) nut:

$$L_{10} = (L_{10(1)}^{-10/9} + L_{10(2)}^{-10/9})^{-9/10}$$

Where:

$L_{10(1)}$ = Expected life in the extend direction

$L_{10(2)}$ = Expected life in the retract direction

Cost-cutting tips

From the outset, roller screws might appear to be an ineffective cost solution. However, in the long run they cost about 1/7 that of ballscrews because they are not replaced as often. Questions to consider are: How much does downtime cost? How much space does a 4-in. ball screw and its support bearings and couplings use compared to a 1.18-in. roller screw? How can one measure unspent money? If the system being designed runs 15 times longer between repair cycles or is 40% the size, costs can be significantly reduced. **MSD**

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