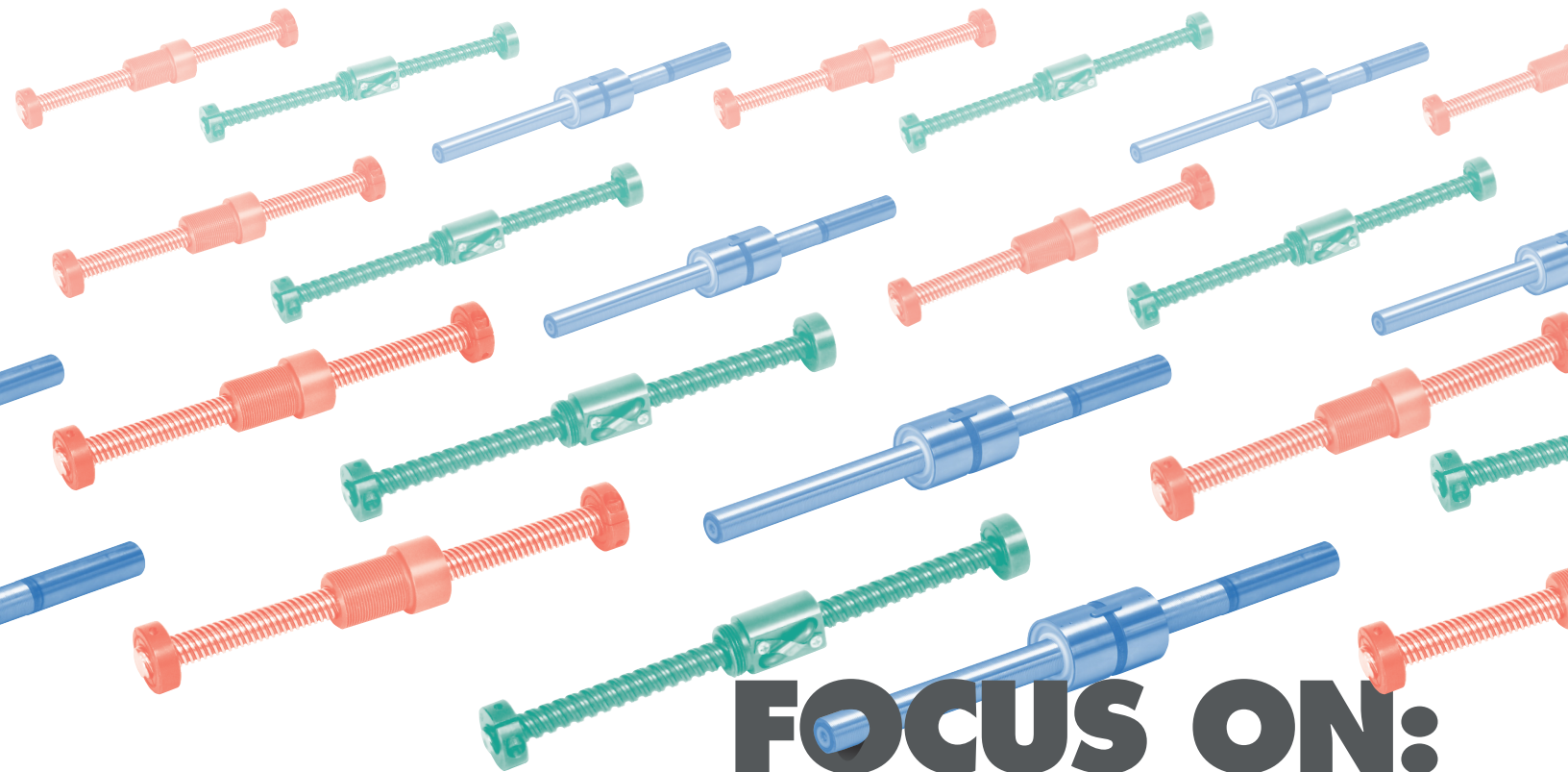


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FOCUS ON: BALL SCREWS

A compendium
of technical
articles from
Machine Design

FOCUS ON: BALL SCREWS



STEPHEN MRAZ
Senior Editor
Machine Design

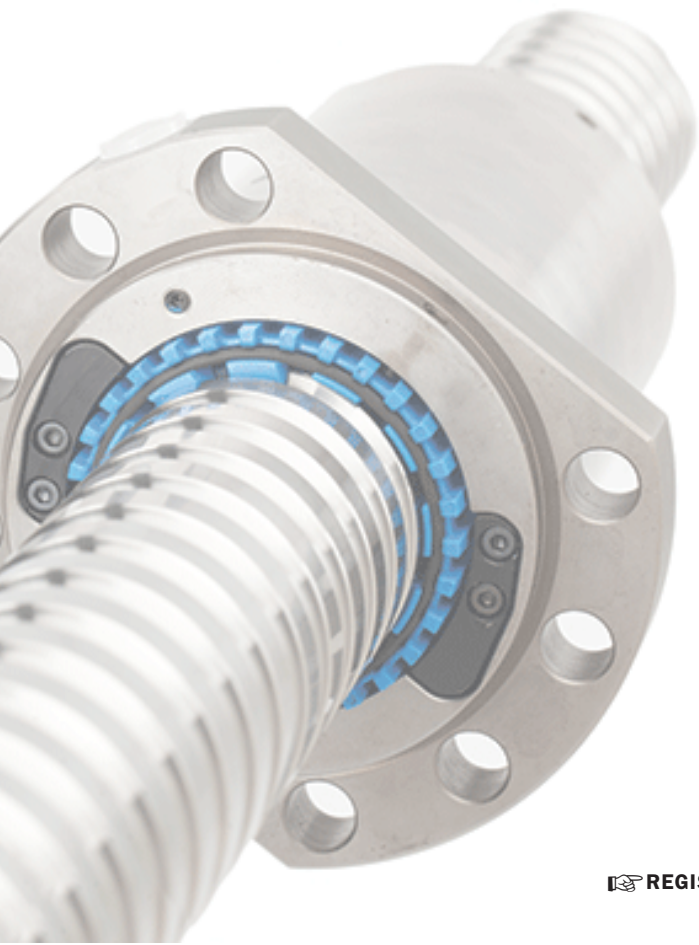
INTRODUCTION

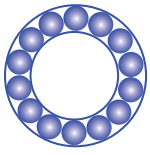
Machine Design is proud to announce a special 3-part e-book series on ball screws. When it comes to industrial motion control, ball screws offer several advantages over options like roller and acme screws. They also can be used as cost-saving alternatives to pneumatic and hydraulic actuators. Boasting efficiencies of at least 90%, ball screws provide an extremely economical method to convert rotary motion into precision linear motion. Ball screws also can move heavy loads at fast speeds with outstanding accuracy.

The series begins with a volume on “Ball Screw Basics,” which goes from the history of these components to design fundamentals. Part 2, “Advanced Ball Screws,” delves into some of the more advanced types that are available now and offers tips on selecting them and designing them into various applications. In “Delving Further into Ball Screws,” our final compendium, we look into topics such as whether ball screws really can be a good fit for miniature applications, extending the lifetime of these screws, and more.

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CHAPTER 1:

A SHORT
HISTORY ON

BALL SCREWS



First published Feb 10, 2016

Bruce Gretz, Steinmeyer | *Machine Design*

For centuries, the conventional lead screw (threaded shaft and nut) was the primary mechanism for converting rotary motion to linear motion. They were inexpensive to manufacture and reliable.

Ball screws date all the way back to the late 19th century, when some ingenious engineer placed ball bearings inside the nut threads to reduce friction. This eventually led to efficiencies of over 90% and the elimination of backlash.

In 1898, *The Practical Machinist* published what may have been the first publicly-documented ball screw. The Cleveland Machine Screw Co. is credited with the design. However, the performance of this device was probably quite limited. Ball bearings were just emerging around that time, so the most likely limitation was inconsistently sized balls, making recurring jams in the return tubes a problem. It was not until the post-war era that ball-bearing fabrication caught up, which partially took care of the problem. But return tubes were still a problem.

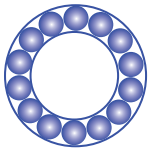
One of the first commercial ball screws was designed into the famous Saginaw steering gear. This gear was used on many vehicles as diverse as the Ford Fairlane (1956-78) and Chevrolet Corvette (1962-82). The Saginaw design used a ball screw to transform rotation of the steering wheel into perpendicular linear motion of a rack. It featured a tube return. Actually, two tubes were employed to recirculate the several dozen balls on separate circuits. No pre-loading was necessary due to the coarse positioning requirements. However, the tubes were still subject to jamming. To mitigate this problem, some designs used alternating balls, with every other one 0.001 in. larger than its neighbors.

BRUCE GRETZ is National Key Accounts Manager for Steinmeyer Inc.

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CHAPTER 2:

THE FUNDAMENTALS OF

BALL SCREWS

Proper ball-screw selection involves a number of design and application considerations.

First published July 30, 2015

Jonathan Kasberg, Nook Industries | *Machine Design*

Of all the screws used for industrial motion control, ball screws rise to the head of the class, offering several advantages over other options such as roller screws and acme screws. Featuring efficiencies of at least 90%, ball screws are one of the most economical ways of converting rotary motion into precision linear motion. They're able to move heavy loads at fast speeds with outstanding accuracy. Moreover, ball screws can be cost-effective alternatives to pneumatic and hydraulic actuators.

A ball screw consists of a threaded shaft and a nut, and either one can act as the traversing component. Ball screws work in a similar fashion to ball bearings, where hardened steel balls move

along an inclined-hardened inner and outer race.

To select the correct ball screw and nut for a specific application, engineers should consider design factors like loads, life expectancy, speed, length, and mountings. Application considerations include lubrication and environment. Here's a closer look.

Loads and Life

Several loading considerations impact ball-nut screws. For instance, static loads are generally straightforward and reach the maximum limit when screw and nut are loaded to their capacity without damage.

Dynamic loads are thrust loads that, when applied to the ball nut and rotating screw assembly, result in a specific minimum life. Dynamic-load ratings for metric screws indicate a load in Newtons that can be carried for 1 million revolutions. Inch/imperial screws, which factor in the lead of the screw, have dynamic-load ratings for 1 million inches of linear travel.

Due to their steel-on-steel design, bearing manufacturers have developed techniques to calculate the life expectancy of ball screws. However, contamination, lubrication, and improper mounting and installation techniques can also shorten a ball screw's lifetime. For manufacturers looking to extend the life of their screws, it's often beneficial to order a larger-size screw to handle a larger load.

Life expectancy, L , can be calculated from the following equations:

$$L = \left(\frac{C_a}{F_m \times f_w} \right)^3 \times 10^6$$

where L = life in revolutions; C_a = basic dynamic-load rating; F_m = equivalent axial



Ball screws are noted for efficiently moving high loads with outstanding accuracy. Here, they're used in solar arrays that track the sun.

load (N); and f_w = fatigue factor.

Calculate the equivalent axial load, F_m , using:

$$F_m = \sqrt[3]{\sum_{i=1}^n F_i^3 \times \frac{n_i}{n_m} \times \frac{q_i}{100}}$$

where F_i = each increment of axial load (N); q_i = percent of stroke at load F_i ; and n_i = rotational speed at load F_i (rpm). The final variable n_m = equivalent rotational speed (rpm) and is calculated using:

$$n_m = \sum_{i=1}^n \frac{q_i}{100} \times n_i$$

As an alternative to hand calculations, charts can help determine life expectancy.

For metric ball screws: http://www.nookindustries.com/LinearLibraryItem/Ballscrew_Life_Exp

For inch versions: http://www.nookindustries.com/LinearLibraryItem/Life_Expectancy_SRT_Rolled_Inch_Screws

Ball screws handle both compression and tensile loads. Compression loads tend to compress or squeeze the screw axially, which can make screws bow out. Tensile loads, on the other hand, often stretch the screw axially. While compression loads can be more problematic, tensile loads may cause a screw to elongate and crack.

It's also important to note that screws are only designed for thrust loads or straight-line axial thrust motion. Any type of over-turning or side load can reduce screw life by up to 90%.

Ball-Screw Basics

For any engineer working with ball screws, it helps to understand some key terminology.

Ball circle diameter is the diameter of the circle created by the center of the ball bearings when they contact both the screw and nut.

Root diameter is the minimum diameter of the screw measured at the bottommost point of the threads. Both ball-circle and root diameters are important when calculating application characteristics and sizing parameters for factors such as column loading and critical speed.

Pitch is the axial distance between two consecutive threads on

a screw.

Lead is the linear distance traveled by the nut or screw during one full rotation.

Starts are the number of independent threads on the screw shaft. Screws typically have one, two, or four starts, which resemble a helix that wraps around the shaft. The pitch multiplied by the number of starts equals the lead of the screw.

Lash is the result of axial movement between a nut and screw without rotation. While lash can disrupt the accuracy of the screw, it typically occurs without any serious issues. Normal screws come with a relative amount of lash, and screws which are only loaded in one direction won't be affected by lash. Lash can be controlled through preloading.

Mounting Considerations

Determining the screw's load direction as well as the type of mounting (end fixity) helps when selecting screws, as engineers must account for both critical speed and buckling (discussed later). The end fixity of bearings defines how a screw is supported at both ends. The degree of end fixity relates to the amount of restraint at the ends of a screw. End fixity breaks down into three basic types: free (no support); simple (supported at a single point); and fixed (rigidly restrained). End bearings give the screw stability and rigidity. Fixity also affects critical speed, column loading, and overall performance.

Multiple or spaced pairs of bearings are more rigid than simple supports. However, they aren't truly fixed because of their inherent compliance. A screw can be supported with different end-fixity combinations, such as:

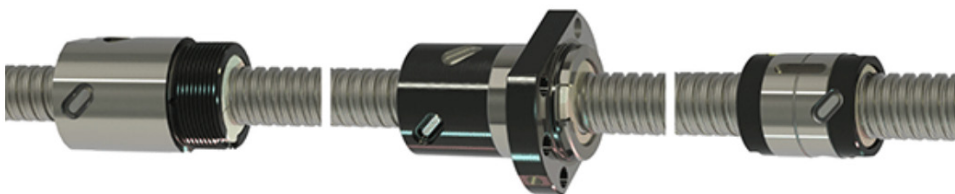
- One end supported with a double bearing, the other end free. This setup is not recommended, except for applications with short travels and slow speeds.
- One end with a double bearing, the other with a single bearing.
- Both ends with double bearings.
- Both ends supported with quad bearings. Note that in such cases, the screw is highly rigid and extra care should be taken to ensure compliance.

When using fixed bearing mounts on both ends, experts recommend reviewing the setup with the ball-screw manufacturer's application engineers to determine the mount-to-mount length tolerance of the final assembly.

Critical Speed

The speed that excites the natural frequency of the screw is referred to as the critical speed. The screw will resonate regardless of screw orientation or whether the nut rotates about the screw.

Critical speed varies with diameter, unsupported length, end fixity, and speed (rpm). Shaft straightness and assembly alignment can also play a role, so man-



Three widely used types of ball nuts are (left to right) cylindrical body with key, flanged, and v-thread. The flanged configuration is common to all ball nuts, and actuator companies and OEMs often use the cylindrical body with key style. V-threads are custom-made to be threaded into or attached to a flange.



Critical speed, the speed at which a screw resonates, varies with unsupported length, diameter, end fixity, and rotational speed.

Manufacturers recommend that maximum speed be limited to 80% of theoretical critical speed.

Calculate critical speed, n_{cr} , in rpm from:

$$n_{cr} = \frac{\lambda^2}{L^2} \sqrt{\frac{E \times I \times g}{\gamma \times A}} \left(\frac{60 \frac{\text{sec}}{\text{min}}}{2\pi \frac{\text{rad}}{\text{rev}}} \right)$$

where L = distance between supports (mm); E = modulus of longitudinal elasticity (2.05×10^6 N/mm²); I = minimum second area moment of inertia of screw shaft cross section (mm⁴), where $I = (\pi d_r^4)/64$; d_r = screw shaft root diameter (mm); g = acceleration of gravity (9.81×10^3 mm/sec²); γ = specific weight (7.71×10^{-5} N/mm³); and A = minimum cross-sectional area of the screw shaft (mm²), $A = \pi d_r^2/4$.

In addition, λ = a factor determined by the ball-screw support method, where:

- One end fixed and the other free, $\lambda = 0.59\pi$.
- Both ends simply supported, $\lambda = \pi$.
- One end fixed and the other simply supported, $\lambda = 1.25\pi$.
- Both ends fixed, $\lambda = 1.49\pi$.

Charts to help calculate critical speed can be found at:

Metric: www.nookindustries.com/LinearLibraryItem/Ballscrew_Life_Exp

Inch: www.nookindustries.com/LinearLibraryItem/Critical_Speed_Ball_Inch_Screws

Notes on Preloading

Preloading is the result of an internal force introduced between a ball nut and screw assembly that eliminates free axial and radial lash. There are three methods for preloading:

The **double-nut method** uses two ball nuts loaded in opposing directions by a spacer, so that they don't wiggle when stationary.

Lead shifting manufactures a shift or offset in the lead of the ball nut. For example, a lead might be shifted from 5.00 mm to 5.05 mm to shift the ball bearings in a different direction inside the ball nut. This is the preferred method when considering compactness, but it reduces load capacity.

Ball selection is a low-cost method that involves using pre-selected, oversized ball bearings to create four points of contact between the nut and screw. This permits heavier loads, but friction from the contact can reduce bearing life.

Column Loading

When a screw loaded in compression exceeds its limit of elastic stability, the screw will fail through bending or buckling. To calculate the column strength to verify a screw can carry the required load without buckling, solve for:

$$F_c = (C \times \pi^2 \times E \times I)/L^2$$

where F_c = permissible axial load to buckling (N); and C = a factor determined by the ball-screw support methods, where:

- One end fixed and the other free, $C = 0.25$.
- Both ends simply supported, $C = 1$.
- One end fixed and the other simply supported, $C = 2$.
- Both ends fixed, $C = 4$.

If the selected screw does not meet compression-load criteria, consider the following options:

- Change end fixity; for example, from simple to fixed.
- Design to use the screw in tension.
- Increase screw diameter.

Charts to help calculate column loading can be found at:

Metric: www.nookindustries.com/LinearLibraryItem/Column_Strength_SRT_XPR_and_SGT_Inch_Screws

Inch: www.nookindustries.com/LinearLibraryItem/Column_Strength_SRT_XPR_and_SGT_Inch_Screws

Application Considerations

Accuracy: Because manufacturers use different processes to make ball screws, engineers have several options for weighing accuracy versus cost.

Rolled screws are manufactured in a process that uses rotating dies to deform round metal bars and generate a helical thread pattern. This is a cost-effective manufacturing method, but typically produces screws with lower accuracy, compared to ground screws. Some manufacturers do, however, produce highly accurate screws through tightly controlled rolling processes.

Ground screws are made from a process by which a grinding wheel cuts screw threads into case-hardened material. As a result, lead accuracies are typically much tighter than in rolled screws. Ground screws are generally preferred over rolled versions in aerospace applications, because the seam formed close to the major diameter of the screw shaft is thought to have potential for crack propagation.

Backdriving: When loading ball screws, it's important to remember backdriving. Backdriving occurs when a motor-driven ball screw free-falls once the motor shuts off. To avoid this, install brakes on motors or use safety pins to lessen the risk and catch the load. Acme screws, which have lower efficiency, are less likely to experience backdriving.

Environment: Because ball screws often work in environments

exposed to dirt and debris, manufacturers should take precautions to keep out contaminants and prevent premature failure. Screws often are coated with a thin dense chrome, black oxide, or nickel-plated finish as a first line of defense.

Another option is to equip ball screws with bellows boots that cover the screw and exclude contamination. As the nut traverses, the boot expands and contracts like an accordion. Bellows boots come in various materials that suit everything from light-duty to the most extreme applications.

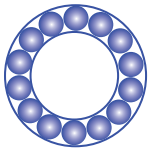
Wipers offer another form of protection. Nut wipers made of felt or plastic brush the nut free of dirt and other debris and keep contaminants from entering the ball nut.

Lubrication: The types of ball-screw applications vary widely, so there's no definitive recommendation for the type and amount of lubrication needed. However, factors such as frequency of use, temperature, and viscosity are essential considerations for lubrication options. While a light oil or grease suits most applications, avoid using lubricants containing molydisulfide or graphite. A good rule of thumb is to always apply enough lubrication to maintain a thin lubricant film between the nut and screw.

Jonathan Kasberg is Program Manager for Nook Industries, Cleveland, Ohio.

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CHAPTER 3: BALL SCREW SPEED BASICS

A look at the three important speeds when it comes to ball screws.

First published March 20, 2017

Bruce Gertz, Executive Vice President | Steinmeyer Inc.

Speed is an important characteristic in ball screws, as it is for most motion control devices. But ball screws have three kinds of speed associated with them. Here's a quick look at all three.



Maximum Speed

A second limitation, which determines the maximum speed, stems from inertial forces on the balls. It depends on the internal construction of the ball nut, in particular the ball return, and the ball size. In general, ball screws with small balls have somewhat lower speed limits than screws with larger balls. For Steinmeyer ball screws, speeds can range from 4,500 rpm for 3-mm balls to about 1050 rpm for 125-mm balls.

Critical speed

Critical speed is the lowest rotational speed at which the ball-screw shaft is in resonance. In applications with rotating shafts, it limits the screw's rpm. Variables that influence critical speed are shaft diameter, unsupported length, and the configuration of support bearings.

Similar to buckling, critical speed depends on how the support bearings are laid out. Fixed support bearings are assumed to resist angular deflection of the shaft, while simple support bearings do not. A bearing assembly consisting of two simple bearings with a spacer would however qualify as "fixed" bearing for these purposes.

For long screws, Steinmeyer, a worldwide leader in ball screws, recommends using the following equation. Make sure to select the proper factor for the bearing configuration used in the following equation:

$$n_k = k \cdot d_N \cdot \frac{1}{l_s^2} \cdot 10^7 [1/\text{min}]$$

where n_k is the critical speed (rpm), d_N is the nominal diameter (mm), l_s is the screw's unsupported length (mm), and k is the support-bearing factor.

DN Value

The concept of DN is a simplified way of determining the maximum rotational speed of a ball screw. DN is simply the multiplication of nominal diameter of the ball screw (in mm) times the maximum allowable speed (in rpm). Keep in mind that for very small and very large screws this will not return valid numbers.

DN, the driving speed values allow easy comparison between different ball screw designs. More sophisticated ball return systems have higher DN values and, conversely, lower DN values are associated with less sophisticated ball return methods. DN values provide direct correlation to ball velocity. It is calculated by:

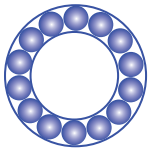
$$DN = n_{max} \cdot d_N$$

Where n_{max} is the maximum speed (rpm), d_N is the nominal diameter (mm), DN is the driving speed value.

Most ball screws available today have maximum DN values between 60,000 and 120,000, and in some cases even higher.

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CHAPTER 4:

HOW ROLLED AND
GROUND BALL SCREWS

STACK UP

Ground ball-screw accuracy always beats rolled ball screws, but lead deviation, production methods, and heat treatment also play significant roles in choosing one over the other.

First published July 8, 1999

George A. Jaffe, Executive Vice President Schneeberger Inc. Bedford, Mass.

Alexander F. Beck, A. Steinmeyer GmbH Albstadt, Germany

Is the following true or false? — “Rolled ball screws cost less than ground ball screws and work just as well.” The first part is true. Rolled ball screws certainly cost less, sometimes 50% less than ground ball screws. But when it comes to the second part, there is no comparison. Although some manufacturers claim they run just about the same, ground-ball-screw accuracy always surpasses that of rolled ball screws, even with equal lead errors. But this doesn’t mean it’s always best to choose ground ball screws. Each type has its own advantages that help engineers choose the one that best fits the application.

Accuracy is the most common parameter for comparing ball screws. Although many designers measure ball-screw accuracy by just how precisely the nut travels the length of the screw, other factors contribute as well. In fact, at least three values are necessary to specify lead accuracy.

Factor e_p represents average actual lead deviation over the full travel of the nut on the screw, thus e_{300} is the deviation per 300-mm interval. Designers should know whether the value is cumulative. For example, accuracy-grade 5 per DIN/ISO specification lists a maximum lead deviation of 23 $\mu\text{m}/300\text{ mm}$. However, a 900-mm-long screw has a maximum total deviation of 40 μm , not $(900/300) \times 23 = 69\text{ }\mu\text{m}$. When comparing ball screws with only specified “deviation per 300 mm” to ball screws governed by DIN/ISO or JIS accuracy grades, significant accuracy differences become obvious.

Factor $e_{2\pi}$ specifies lead variation in one revolution of the screw thread. This parameter has more impact on equal load distribu-

tion among the balls than on axial-nut travel (which may affect predicted life). Because applications requiring high-lead accuracy may also be more demanding with regard to other quality issues, the DIN/ISO standard links several properties to lead accuracy. For instance, parameters of DIN/ISO standards include screw straightness, bearing-journal concentricity, preload-torque consistency, and nut squareness. When the application calls for precise slide positioning, also consider stiffness and the assembly’s friction-torque consistency. For instance, although screws may be accurate in terms of lead error, when journals are eccentric the screws show poor torque consistency. This is often the case with rolled ball screws.

Many factors affecting performance go unnoticed when considering only lead accuracy, especially for rolled screws. Errors in manufacturing equipment, such as eccentric, worn, or wobbling rolling dies, often produce periodic lead errors. But a nut riding on several ball circles may mask periodic lead errors. Such errors, however, can distribute the load unevenly, reducing ballscrew stiffness and life.

A specific application is often the initial deciding factor for choosing rolled or ground ball screws. Rolled screws, for instance, are typically used in low-precision applications. Examples include some pick-and-place devices and actuators. Ground ball screws, on the other hand, drive precision machine tools, such as milling machines, lathes, profile grinders, and EDM machines. Ground ball screws are also recommended for precision X-Y tables, such as those used in semiconductor wafer-inspection equipment.

Rolled ball screws, however, are gaining widespread use in many applications that traditionally held ground screws. Rotary encoders on servosystems are one example. The encoders are mounted to drive motors and provide position feedback. Positioning accuracy varies with ballscrew lead error. Ground ball screws used

in these applications meet ISO5 standards requiring positioning accuracy within 0.025 mm per 300 mm. Recent improvements in rolling processes, however, let manufacturers make rolled screws with lead errors meeting ISO5 standards.

On the other hand, sometimes economical designs are used when they shouldn't, such as in linear encoders. Using rolled instead of ground screws in linear scales, for instance, doesn't save money. The thinking is as long as nuts are preloaded for zero backlash, the scales will determine accuracy. Instead, torque varies excessively making process machines run noisily with servosystem instability, leading to inconsistent production processes.

Two fundamental differences in manufacturing rolled and ground screw threads help explain why the two types perform differently. Rolled screws are shaped by forcing round bar stock through rotating dies to form threads. Although cutting the bars before rolling may seem like an option, this produces inaccuracies near the rod ends. To prevent this, the bars are cut and heat treated after rolling. Centers and bearing journals are machined only after finishing the threads. This generally makes it difficult to maintain concentricity between ball threads and bearing journals on rolled screws. Groundscrew manufacturers, on the other hand, machine journals before grinding threads. This ensures precise concentricity with ball threads.

The second difference lies in how each production method affects accuracy. Rolling is a onestep process that involves heavy forming and significant material stresses. All inaccuracies caused during traditional rolling and heat treating remain in the finished product and can't be corrected. Heat treatment produces stress that tends to lengthen screws, often in an inconsistent and unpredictable manner. Lead errors typically accumulate, so check the manufacturer's definition of lead accuracy. The relatively rough finishes of rolled screws can also lead to excessive noise and vibration, especially during high-speeds. Rolled-screw finishes also generate high torque variations due to variable preloads as nuts

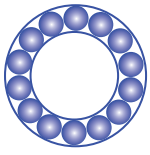
traverse the screws. Grinding ball screws, on the other hand, finishes functional surfaces (the ball-thread OD and the thread itself) one at a time. Grinding can maintain concentricity and squareness because the same centers are used to grind all critical surfaces. Grinding also lets manufacturing partition the job into smaller steps and insert procedures, such as QC, restraightening, or heat treating to release material stresses. The order of steps can also be adjusted. For example, threads can be finished after all rough machining. This improves overall accuracy and addresses the various specifications one at a time. Performing in-process inspection before finishing also reduces scrap, improves quality consistency, and reduces costs.

Ground screws also give designers greater flexibility than rolled screws. Rolled screws often cannot provide full shoulders or oversized journals unless the screws comprise several joined parts, such as shrunk collars or frictionwelded journals. In general, however, "assembling" ball screws using welded journals is not recommended.

Although grinding is still widely believed to be more expensive than rolling, this is not always true. Recent manufacturing developments combine grinding with special prerolling processes to gain advantages from both. Manufacturers preroll screws, which partially forms threads, and then touch up the screws on thread-grinding machines to eliminate inaccuracies from rolling. The process also minimizes stresses released from heat-treated material. The idea is to remove less material during grinding to achieve more consistent results in terms of lead error, straightness, and thread profile. The accuracy of such screws equals that of conventional ground screws, yet prerolling maintains the economical advantages of rolling.

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CHAPTER 5:

SELECTING A LUBRICANT FOR

BALL SCREWS

Using the right lubricant on a ball screw extends its life and improves performance while keeping contaminants at bay.

First published April 22, 2016

Jeff Johnson, Randy Hamper Sr., and Kelvin Kellond,
Thomson Industries

Lubricants on ball screws are as important to their performance and life as are their operating loads, speeds, accuracies, environments, and power requirements. Lubricant reduces the already low friction by minimizing contact between the balls and grooves, thus adding torque and increasing efficiency, while extending the screw's life by a factor of 10. Proper selection and application of lubricants also affects contamination, a leading

cause of premature ball-screw failure.

One of the first choices engineers must make is whether to use oil or grease.

Oil or Grease

The right choice of oil or grease for ball screws reduces unscheduled downtime and repairs by ensuring the assemblies deliver their expected service lives. Pumps and metering devices deliver oil; grease gets applied through fittings on the ball nut or attachment flange. The main application differences are in flow control, risk of contamination, and cost.

It is easier to direct oil exactly to where it is needed. It will also clean out moisture and other contaminants as it runs through the ball nut and provide cooling. On the downside, oil requires an investment in pumps and meters, and excess oil can introduce contaminants, for example, by mixing with the cutting fluid in a machine.



The author, Jeff Johnson, uses the correct lubrication method to apply Thomson's™ Linear Lube to a ball screw.



Thomson recommends regular lubrication via the lubrication hole to ensure long lifetime and high performance.



Ball screws come in a variety of sizes and capabilities, but they all need to be properly lubricated to get the expected service life. It also helps them deliver smooth motion and withstand heat generated during operation.

Grease gets applied directly to the screw's threads near the root of the ball track or pumped directly into the ball nut if there are lube holes. Grease fittings contain lubrication and repel contamination. They also cost less and are cleaner than oil pumps and meters. But grease is hard to keep inside the ball nut and tends to accumulate at the ends of ball-nut travel, where it attracts chips and abrasive particles.

Excess grease must be removed, leaving only a thin lubricating film on the screw shaft. Wipers may be needed to keep the grease inside the ball nut, but it is crucial to re-lubricate the assembly with grease at least every 600 to 800 hr for most applications. Incompatibility of old grease with re-lubrication grease could become another problem.

Both oil and grease fittings can be equipped with filters if precise motion and smooth, quiet operations are needed. Filtration also improves the homogeneity of the thickening agent and removes virtually all particulate matter.

Lubrication methods are designed at the manufacturer, so it is important

to understand the tradeoffs before specifying a vendor product.

Selecting the Right Oil

Viscosity and application rate are key variables in selecting oil lubricants and they vary with temperature, load, and speed. The oil lubrication will influence the ball screw's temperature rise and assembly's life. Oil that is too viscous, or if there's too much of it, raises operating temperature. Oil that is not viscous enough, or if there's not enough of it, increases friction and wear.

The following guidelines apply to the most common temperature, load, or speed conditions.

To determine the appropriate viscosity at 40°C, for example, consider the mean speed of the ball screw, its diameter, and the temperature at which the ball nut is likely to stabilize. In the graph above, it shows how different grades of oil vary in viscosity across different temperatures. Viscosities are shown in centistokes (1 cSt = 1mm²/sec), and grades are designated according to their viscosity at a given temperature.

So, for example, the VG32 curve on the graph shows how oil with a 32-centistoke viscosity at 40°C would heat up as the speed increases. The dn_m factor is the product of ball-screw diameter in mm and screw mean rotary speed in rpm.

To determine the oil's nominal viscosity for an application, an engineer must first establish the ball screw's mean rotational speed, and then the dn_m factor. It is also necessary to factor in the temperature at which the ball nut will likely stabilize.

Mean speed of rotation accounts for the ball screw's duty cycle:

$$n_m = n_1(q_1/100) + n_2(q_2/100) + n_3(q_3/100) + \dots$$

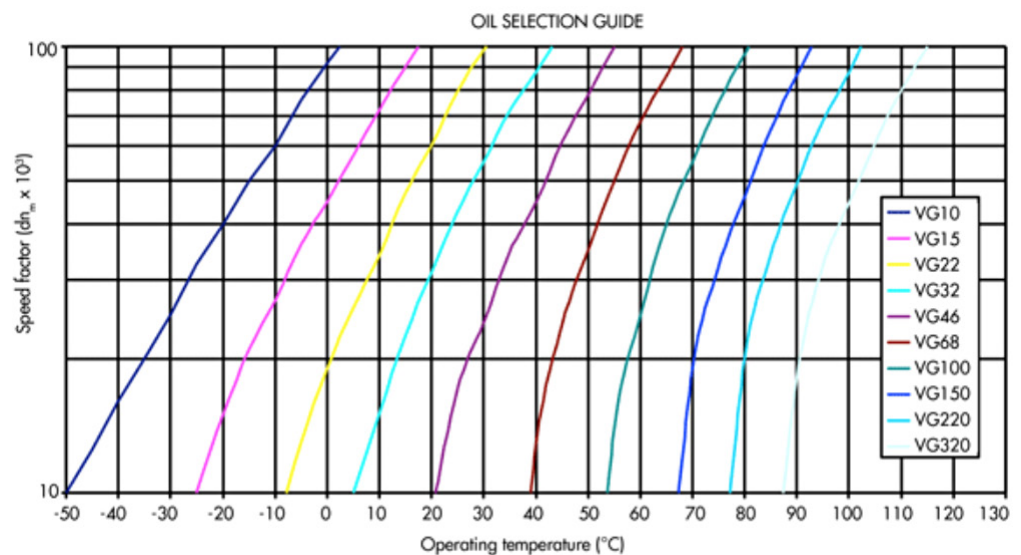
where n_m = mean speed (rpm); $n_1, 2, 3, \dots$ = speed for time $q_1, 2, 3, \dots$ (rpm); and $q_1, 2, 3, \dots$ = time at speed $n_1, 2, 3, \dots$, (% of total)

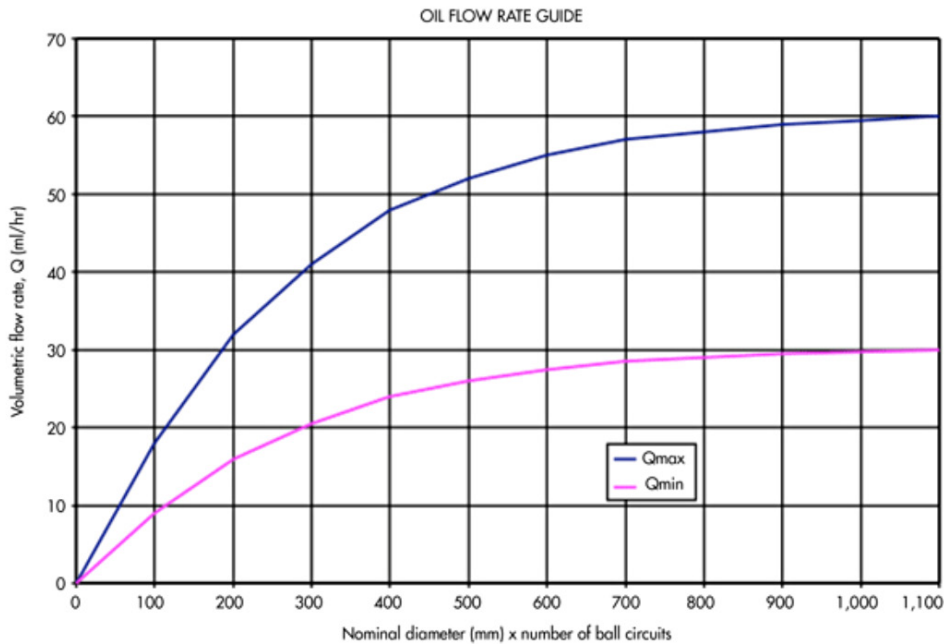
For typical applications, nm ranges from 200 to 500 rpm. The dnm factor is given by:

$$dn_m = (d)(n_m)$$

where d = ball-screw nominal diameter (mm).

Typical values of dnm range from 5,000 to 25,000. Values of





dn up to 160,000, where n is the maximum speed of rotation, are becoming more common. In such cases, the lower viscosity oil should be used or a grade midway between two adjacent viscosity curves, such as VG32 and VG46.

The ball-nut temperature should be about 20°C when it is operating, but this is seldom the case. Usually, ball nuts stabilize a few degrees above the screw shaft's operating temperature. If you can't measure nut temperature, assume it is 30°C for the initial selection of oil viscosity.

The required oil flow rate is a function of the number of ball circuits, ball-screw orientation, load, speed, operating environment, and judgments based on knowledge of the application.

The oil flow rate guide (above) helps determine oil flow rate. Engineers multiply the ball screw's nominal diameter times the number of ball circuits, then find the maximum and minimum flow rates, Q_{max} and Q_{min} , respectively, from the values on the Q_{max} and Q_{min} curves. For example, for a ball nut with six circuits and a 25-mm nominal diameter, the product, 150 mm, corresponds to a flow rate ranging from a minimum (Q_{min}) of 13 mL/hr to a maximum (Q_{max}) of 26 mL/hr.

The actual rate you should select within this range, however, depends on operating condition:

- If the ball screw is vertical, add 25% to Q_{min} to account for orientation; if horizontal, add nothing.
- If the application is dirty and wet, add 25% to Q_{min} ; if not, add nothing.
- If the screw is subject to high loads or speeds, add 50% to Q_{min} ; if it is not, add nothing.

For example, a 25-mm-diameter ball screw with six-circuit ball nut is used in a vertical application (add 25% to the minimum of 13 mL/hr); it is clean and dry (add 0%); and it is heavily loaded (add

another 50%):

$$Q_{required} = 13 + (13 \times 0.25) + (13 \times 0) + (13 \times 0.50) = 22.75 \text{ mL/hr}$$

Because it is best to supply small amounts of oil at regular intervals, and there will be heavy loads in this example, apply oil about every minute:

$$(22.75 [\text{mL/hr}]) (1/60 [\text{hr/min}]) = 0.38 [\text{mL/min}]$$

Without the heavy load, application every five minutes would be adequate.

A slightly thinner oil than indicated could be used with no problems. However, if the application calls for a VG46 oil, but a VG10 is all that can be used, revise the oil delivery by replacing spot delivery with continuous flow of the lighter oil.

Selecting the Right Grease

Selecting the proper grease is a bit more complex than oil specification. Greases consist of mineral or synthetic oil, additives, and thickening agents such as lithium, bentonite, aluminum, and barium complexes. Some issues to consider are synthetic versus mineral-based, additives, and environmental conditions. Note that speed is not a criterion for grease selection because, unlike oil, it can handle dn values as high as 1,000,000, which is about 10 times higher than dn 's typically found in ball screws.

Synthetic vs. mineral based: Synthetic greases offer performance advantages over mineral-based lubricants. They function over wider temperature ranges, offer greater stability, and retain the viscosity needed for adequate film thickness through a range of



Lubricants, such as Thomson's™ TriGel, are usually available in a variety of packages to meet different application needs. And TriGel was developed to lubricate a wide range of linear-motion systems for the best performance.

NLGI GRADES OF GREASE			
NLGI Grade	Work penetration after 60 strokes @25°C (0.1 mm)	Appearance	Consistency
000	445 to 475	Fluid	Cooking oil
00	400 to 430	Fluid	Applesauce
0	355 to 385	Very soft	Brown mustard
1	310 to 340	Soft	Tomato paste
2	265 to 295	Moderately soft	Peanut butter
3	220 to 250	Semi-fluid	Vegetable shortening
4	175 to 205	Semi-hard	Frozen yogurt
5	130 to 160	Hard	Smooth pate
6	85 to 115	Very hard	Cheddar cheese spread

operating temperatures, speeds, and loads.

Additives: Special additives improve the ability to resist contaminants and reduce wear in the presence of load and vibration. Other additives reduce friction, decrease noise, and increase load capacity. Avoid greases with graphite or molybdenum disulfide, though, because they reduce friction to the point where it promotes ball skid and interferes with the ball bearings' rolling process.

Specialty products: Specialty greases, including vacuum and food

grade, as well as those for clean rooms or extreme temperatures, should be selected based on performance requirements.

To help engineers sort through the options, the *National Lubricating Grease Institute* (NLGI) identifies nine grades based on consistency (left). Although the list is not enough to specify which type of grease is right for a particular application, it does provide a useful qualitative measure.

The lower grades are softer and flow better. Higher numbers are firmer, tend to stay in place, and are a good choice when leaks are a concern. Grades 000 to 1 would typically be used in applications requiring low viscous friction. Grades 0, 1, and 2 are used in highly loaded gearing, and grades 1 through 4 are often used in rolling contact bearings, with Grade 2 being the most commonly used in that range.

The decision to lubricate with oil or grease can critically affect ball-screw performance, durability, and the total cost of owning and operating it. Running without lubrication is just not an option.

In some cases the final decision is dictated by other key specifications, but wherever possible, designers of ball-screw applications should consider lubricant options as an important factor in decisions to specify one vendor product over another. And once the decision to go oil or grease is made, other choices must be made.

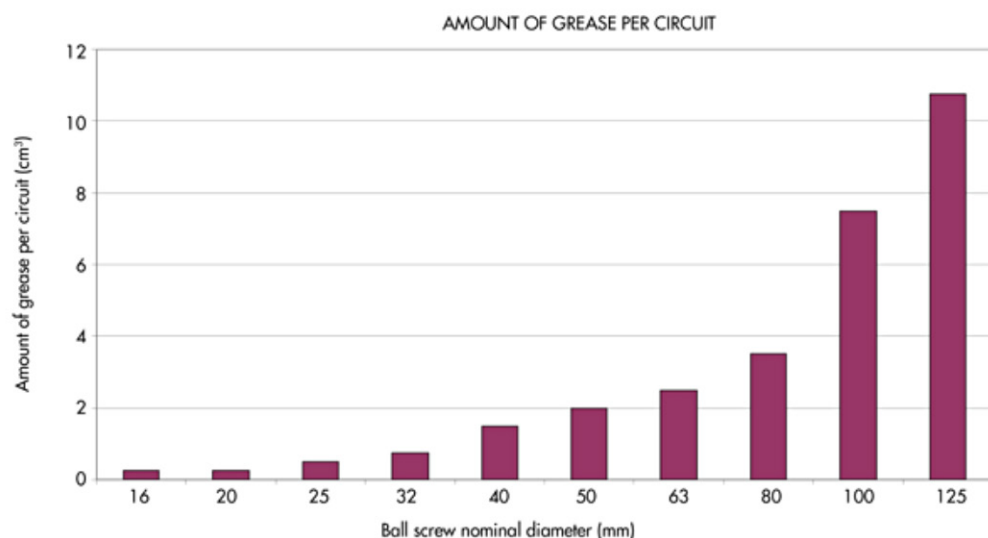
Oil lubricants tend to be easier to control, run cleaner, and are better at flushing out contaminants, but they can also require more costly pumping and metering support, and often introduce contaminants into the system. After oil is chosen, the challenge is to select the proper viscosity for the application, which can be calculated from the temperature, load, and speed by applying a standard equation.

Grease tends to be less expensive, has better heat resistance, and has a wider range of consistency, which can help effectively accomplish your lubrication goals. Grease is cleaner in terms of

having fewer contaminants, but it also tends to pick up additional contamination as excess oozes from the nut. And, as with oil, once the choice is made, the next decision is selecting the right type of grease for the application. The NLGI (above) provides some guidelines to map grease consistency to applications.

Because options may vary with the vendors, especially for specialty applications, it is always a good idea to get complete specifications from them. It is also important to remember that proper maintenance is critical to performance.

This article was authored by Jeff Johnson, Global Product Line Manager, Screws, Randy Hamper Sr., Design Engineer, and Kelvin Kellond of Thomson Industries Inc., Wood Dale, Ill.



The chart above gives recommendations on how much grease per circuit to use based on the ball screw's nominal diameter. A 25-mm-diameter screw with six circuits, for example, requires 0.4 cm³/circuit, or 2.4 cm³ total.

The tables below matches some of the leading grease brands to applications based on the NLGI guidelines and information published by grease or ball-screw manufacturers. While by no means a complete list, it should provide some useful guidance.

APPLICATION GUIDE FOR GREASES		
Light-duty grease	Temp (°C)	Notes
Nye Rheolube 362F	-54 to 125	Low viscosity, PTFE fortified, synthetic, lithium
Nye NyoGel 744	-40 to 125	PTFE fortified, synthetic, w/tackifier
Neo UniFloor 8512	-50 to 225	Resists chemicals, fluorinated, wide temperature range
Timken All Purpose	-40 to 149	General-purpose lithium grease

Heavy-duty grease	Temp	Notes
Thomson TriGel	125 (max)	Thomson-approved ball-screw grease
Nye Rheolube 380	-50 to 130	EP fortified, lithium, synthetic and ester
Nye Rheolube 363	-54 to 125	Multi-purpose synthetic
Nye NyoGel 744F-MS	-40 to 125	Fortified synthetic molybdenum disulfide
Nye NyeUniflor 8511R	-50 to 225	Resists chemicals, inhibits rust, wide temperature range
Shell Albida EP	150 (max)	Excellent mechanical stability
Shell Lube EP	-40 to 250	PTFE fortified, thermally stable
Mobile Mobilith SHC 220	-40 to 150	Synthetic base
Timken Synthetic	-46 to 180	Multi-purpose lithium grease

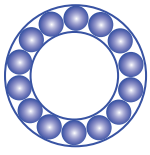
High speed	Temp	Notes
Nye Rheolube 733F, Ultra	-54 to 125	EP & PTFE fortified, low temperature, low noise
Nye Instrument 732C	-54 to 150	Ester based, wide temperature
Nye Rheolube 374C	-40 to 150	Synthetic, lithium
Kluber IsoFlex NBU 15	-40 to 130	Good pressure absorption capacity
Shell Alvania RL	130(max)	Multi-purpose
Mobil Mobilith SHC 100	-40 to 150	Synthetic base
Timken Ultra High Speed	-40 to 149	Designed for speed factors over two million
Timken Ball Bearing	-40 to 163	No EP additives

Vacuum grade	Temp.	Notes
Thomson TriGel 1200SC	250 (max)	Light to moderate loads
Thomson TriGel	125 (max)	Moderate loads
Nye NyeTorr 5200	-45 to 125	Ultrafiltered, PTFE thickened, low noise
Nye NyeTorr 5300	-65 to 250	Ultrafiltered, resists chemicals, wide temperature range
DuPont Krytox LVP	-15 to 300	Chemically inert, wide temperature range

Food grade	Temp.	Notes
Dupont Krytox FG30	-40 to 150	Inert
Dupont Krytox FG32	-60 to 260	High temperature
Super Lube H-1	-40 to 230	USDA registered for incidental food contact
Timken Food Safe	-40 to 149	USDA compliant for incidental food contact

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CHAPTER 6:

PROTECTING BALL SCREWS

PAYS OFF

Keeping balls screws lubricated and free from contaminants extends their life and productivity.

First published November 21, 2013

Alexander Beck | President

George A. Jaffe | Executive Vice President

Steinmeyer, Burlington, Mass.

Today's machines tools routinely operate on a 24/7 basis with little, if any, downtime allowed for routine maintenance. They're also working faster with increased metal-removal capabilities and are more versatile in terms of machining capabilities. But machining faster means higher accelerations and metal-cutting speeds, as well as fast traversing motions. Higher speeds place greater demands on machine tools' linear drives. At the same time, high-speed cutting and dry-machining hardened and exotic materials generate lots of fine particles, which can accelerate wear on unprotected drives.

Wear in ball screws

Precision-ground ball screws continue to be the preferred drive for machine tools. Their compact design, economical cost, and efficiency are key advantages, especially for high-speed machines. However, the life of a drive screw no longer depends solely on its rated load capacities in relation to the mean applied load. Two other factors must now be considered when designing modern high-speed machines — lubrication and contamination-induced wear.

For steel balls rolling between ground-steel surfaces, there are generally three types of friction. One is direct contact or so-called solid friction if there is no lubricant between them. The other is electrohydrodynamic (EHD) friction, which arises if there is always an oil film between balls and race. And mixed friction means there is some oil film acting as a lubricant but also some direct contact between balls and race.

Compared to other machine components, such as deep-groove or angular-contact ball bearings (or even plain bearings), ball

screws exhibit more sliding and twisting. Sliding stems from the lack of retainers holding balls in place. It can be reduced by adding ball chains or plastic spacers to reduce friction between adjacent rolling balls, but both are subject to design limitations. Ball chains, for example, have to fit through ball returns. Twisting is due to the inclined contact lines similar to those found in angular-contact ball bearings. There is also more mixed friction due to lower relative speeds. Ball returns in which balls do not roll uniformly cause additional friction.

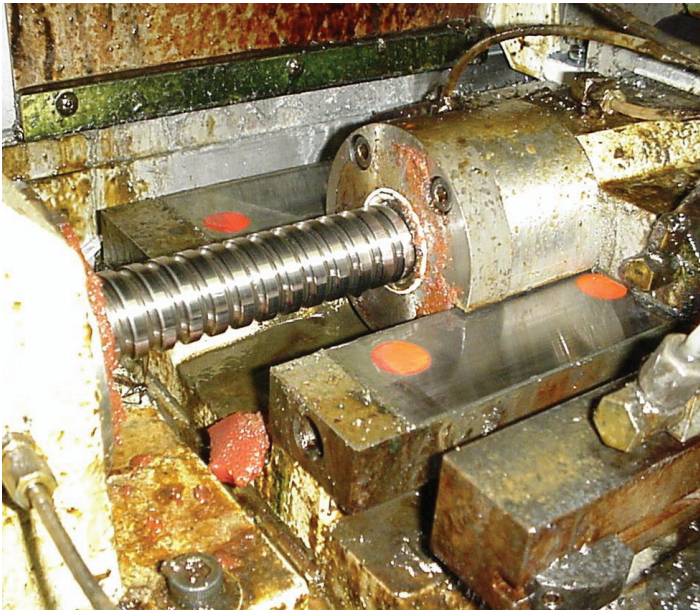
Ball screws are usually sized based on the Hertzian pressure of an applied load and the number of load cycles (the classic L10 life equations). The applied load causes material fatigue over time. This is reflected in the equation commonly used to calculate life expectancy:

$$L_{10} = (C_a / F_m)^3 \times 10^6,$$

where F_m = mean equivalent load, C_a = dynamic load rating, and L_{10} = number of hours or revolutions 90% of the bearing will survive.



To get the most out of ball screws, they must be protected from coolants and debris.



Ball screws in machine tools can be exposed to a wide variety of unexpected contaminants, most of which shorten their operational lives.

From this equation, an engineer might conclude that either reducing F_m or increasing the load rating by using a larger unit should increase a bearing's useful life. This would be a valid conclusion for conventional, slower-turning bearings. Modern machinery moves much faster, a regime where abrasion and adhesion, factors left out of the classic L_{10} equation, become more important.

Abrasive wear is caused by contamination inside the ball-screw nut. Adhesive wear stems from microwelding — a result of the lubricant-film breakdown. The effect of these wear factors is premature failure from loss of preload. Because advanced servodrives are sensitive to changes in friction, avoiding preload loss becomes critical.

Therefore, to extend the life of ball screws, cleanliness and lubrication to reduce abrasion and adhesion must be considered, as well as dynamic-load capacity.

Lubrication and sealing

Cutting tools can lead extended lives if they are made of ceramic or carry hard coatings. And ball-screw life can be improved with better sealing and lubrication.

It is normally not possible to cover or house ball screws tightly enough to completely keep out contaminants such as dust and finer particles. In many cases, wipers seal nuts from abrasive particles. Regular, noncontacting wipers (labyrinth seals) will not keep out small particles because they inherently have a gap of several tenths of a millimeter between the seal and shaft. Brush wipers are also ineffective in keeping out contaminants.

Lip seals made of elastic materials are substantially better. Like shaft seals, they provide a tight fit. But because these seals typically include a lip that must slide against the screw with considerable pressure to ensure a tight seal, it causes high friction and wear. And

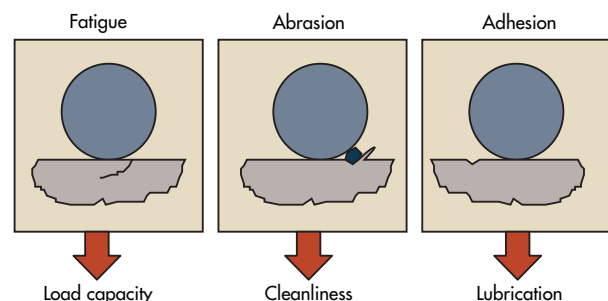


Plastic wiper “fingers” should precisely fit into the surface of the screw thread to clean them prior to passing through the ball screw. Note the spring used to preload or tension them against the screw threads.

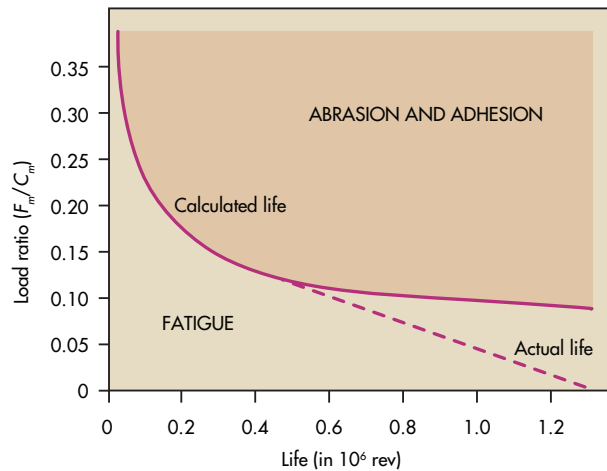
in large-pitch ball screws, the lip seals may flex axially, compromising their effectiveness.

Currently, the best solution is segmented plastic wipers with several edges oriented at approximately right angles to the direction of motion. The wipers mount on both ends of the nut and must fit closely because their effectiveness depends largely on their line of contact with the screw. Segments must be stiff enough to remove tough dirt from the screw but remain flexible enough to stay in contact despite the spring preload.

When specifying segmented wipers, ensure that wipers with protruding “fingers” do not contact the elastic end of travel bumpers. In such cases, flush mounted wipers are necessary. Wedge-shaped segments or beveled edges are best when large amounts of dirt are present.



Conventional calculations for the life of a machine tool usually only factor in material fatigue to determine operational life. But for high-speed devices, abrasive and adhesive wear should be included.



Wear on a rolling element like a ball screw includes material fatigue and, at high speeds, abrasion and adhesion (microwelding).

Combining seals and lubrication

Wipers with the added ability to store and distribute lubricant are becoming increasingly popular, especially as environmental regulations on oil disposal become more restrictive. This type of wiper substantially reduces lubricant consumption yet still properly lubricates the ball nuts. Even though the amount of lubricant lost using these wipers is less than that from conventional auto-lubrication devices, regular replenishment of the reservoir is still necessary — and close attention must be paid to cleanliness. As a general rule, when lubricant flow is reduced, sealing must be improved, as the ball nut is no longer flushed with fresh lubricant.

Segmented plastic wipers, combined with felt rings, have proven to be an especially effective combination. The first “stage” in combination wipers can be made from plastics with the mechanical properties to create the right amount of contact with the shaft and guide contaminants away from the screw. The second “stage” is a felt ring that stores lubricant and distributes it as a thin, even film. Felt rings can store up to 75% of their volume in lubricant and are easily refilled.

Another advantage of combination wipers, besides reducing oil consumption, is that they can be used with any liquid lubricant — liquid grease or oil. Liquid grease is especially well suited for applications with short-stroke oscillating moves or low speeds.

As an added bonus, the felt absorbs tiny particles that may get past the plastic wiper, letting it work as a second wiper. This is especially beneficial in applications with fine, abrasive dust or sludge, such as grinding machines. Note, however, that felt cannot be used alone as a wiper, except in relatively clean conditions, as it absorbs coolant and particles. Thus, felt ensures trouble-free operation and enables a 90% reduction in lubricant consumption, but only when used with a good plastic wiper.

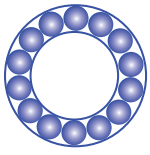
Other products on the market combine sealing and lubricant dispensing within a polymer ring. But unlike felt, the polymer needs

heat to operate properly — thus adding undesirable friction. The ring, impregnated with oil, forms a seal around the thread, often aided by a spring preload. Friction created by the plastic ring rubbing on the rotating thread warms the ring which lets oil flow out of the polymer. The polymer can reabsorb some of the oil as it passes over the thread, but there is no reservoir to refill. Therefore, these polymer wipers are often used in multiple sets, greatly increasing ball-nut length, to provide enough lubricant. And there is no choice between grease and oil — you must use whatever oil is embedded in the plastic.

Substantial improvement in ball-screw life is possible, even in the most demanding applications, if you provide adequate lubrication and protection from abrasive contamination. A combination wiper that can store and replenish lubricant, together with an effective finger type seal, also improves ball-screw reliability. The cost for this option is minor compared to the downtime from unexpected and premature failures. And, in some cases, long-term lubrication or even “for-life” lubrication may be feasible if the proper lubricant is selected.

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CHAPTER 7:

WHAT YOU OUGHT TO KNOW ABOUT

BALL SCREWS

Whether the goal is high precision or low cost, ball screws are often the best option for linear actuation.

First published July 22, 1989

By **JOHN DEGENOVA**

Thomson Saginaw Ball Screw Co.

Saginaw, Mich.

Miniature ball screws are an efficient low-cost option for linear actuation. The mechanisms are used in a variety of automotive applications and come in sizes as small as 0.375-in. diameter and 0.125-in. lead with 90% efficiency. (Acme screws are typically just 30 to 60% efficient.) Single-nut screws have 170-lb dynamic load capacity and 1,600-lb static load capacity. Load capacities double when using two nuts.

The next time you're faced with a design project that calls for linear actuation and you're considering "old standbys" like hydraulic or pneumatic cylinders, think a little longer. Ask yourself practical questions like, "Do I really want to deal with pneumatic noise?" Or, "If a hydraulic line breaks how much time and money will the messy cleanup demand?" If the answers to these questions lead to second thoughts about your plans, think about ball screws as well.

Ball screws should be the method of choice in linear-actuation applications. Ball screws convert rotary input to linear motion and offer several advantages over other actuators, such as Acme screws, hydraulic or pneumatic systems, and belt, cable, or chain drives. For example, ball screws are up to three times more efficient than Acme screws. This lowers system power requirements and allows using smaller gears, clutches, and motors. Ball screws cost less than hydraulic or pneumatic systems, operate more quietly, and don't require pumps, hoses, fluids, or shop air. And although belt, cable, or chain drives are often less expensive than ball screws, they also are less precise and stretch as they wear, which leads to inaccurate positioning.

BALL-SCREW BASICS

Ball screws are force and motion-transfer devices in the family of power-transmission screws. They operate like conventional power screws but the rolling friction of bearing balls replaces sliding friction. Ball screws consist of a screw, nut, and balls that operate similarly to bearing components.

The screw has a precision ground or rolled helical groove acting as the inner race. The nut has internal grooves that act as the outer race. Circuits of precision steel balls recirculate in the grooves between the screw and nut. Either the screw or nut turns while the other moves in a linear direction. This converts torque to thrust. A simple calculation determines the torque required to drive a ball screw: $T = L P / 5.65$, where T = torque (lb-in.), L = screw lead (in.), and P = axial load, (lb).

For example, consider a ball screw with a 1.875-in. lead moving a 535-lb load. The torque required is:

$$\begin{aligned} T &= L P / 5.65 \\ &= (1.875 \ 535) / 5.65 \\ &= 177.54 \text{ lb-in.} \end{aligned}$$

After selecting a screw-and-nut combination, other ball-screw components are needed, such as ball returns and wipers. Ball returns either internally or externally carry balls from the end of their path back to the beginning to complete their circuit. The type of ball return often depends on space constraints and the number of redundant circuits.

Wipers keep contaminants out of critical internal ball-screw components and keep lubricants applied to them. In many applications wipers extend ball-screw life and enhance machine reliability. Wipers are either internally or externally mounted.

A RANGE OF APPLICATIONS

Ball screws are used in a variety of jobs. Their high efficiency

makes them useful in high and low-load applications. Off-the-shelf models have load limits ranging from 170 to 200,000 lb.

High-precision ball screws are used heavily in commercial and military aircraft. Commercial planes use ball screws in mechanisms such as engine thrust reversers and propeller pitch controls. On many commercial aircraft several ball screws position multiple wing flaps using a single drive. Military aircraft use ball screws in horizontal stabilizers, main landing gears, and variable engine inlet and exhaust-nozzle actuators.

Though aircraft applications represent some of the most advanced technology, ball screws are also used in slightly less demanding industrial and automotive applications. Industrial ball-screw applications include milling-machine tables, robotics, and semiconductor wafer transport systems. Miniature ball screws in ABS automotive brakes rapidly open and close valves that apply and release fluid pressure to brake pads. This creates a pumping effect to help prevent brake lock-up.

DESIGN FOR RELIABILITY

Manufacturers use various design features when applications require high reliability. Aside from using wipers to prevent contaminant ingress, another way manufacturers increase reliability is with redundant load paths. An example of a load-path redundancy is the use of two or more circuits of balls within a ball

nut. This increases reliability because if one circuit malfunctions the ball screw will continue to operate.

Screw threads with multiple starts also provide redundancy. Double-start screws have two threads concentric with each other allowing independent circuits of balls to operate in each path. When multiple circuits are combined with double-start architecture, many redundancies are possible. For instance, two circuits in each of two starts produce four independent load paths.

Aviation and aerospace applications often require ball screws with several redundant load paths. Although a ball screw's projected life drops with each lost circuit, structural integrity and function are preserved. A ball screw with four circuits in normal operation, for example, might be designed to operate for 209,000 cycles. The screw can still function for 2,600 cycles with just one circuit operating.

Sometimes standard ball screws won't provide the right solution for a particular application. In many cases a variation of conventional ball screws can solve multiple problems. Hollow ball screws, for instance, convert torque to thrust while allowing a path for coolant flow or wiring. Coolants running through the screw shaft can either help maintain tolerances in precision ball-screw operations or lubricate cutting tools. The hollow screws also have lower rotational inertia than solid screws, which can dramatically increase starting and stopping speeds. Cross-sectional properties

End-flange single nuts are compact and offer easy mounting.	Double-nut vernier preload is adjustable to let users optimize performance.
Semiconductor wafer elevators use ball screws to transport wafers for processing and inspection. The elevators also connect to robotic wafer arms or move wafers into furnaces.	High-helix single nut arrangements achieve high travel rates with minimum rpms.
High-helix double nuts provide additional capacity and load redundancy compared to their single-nut counterparts	High-helix single nuts are also available for precision-rolled ball screws providing high lead accuracy at a lower cost than high-helix double nuts.
Although ball screws inevitably wear over time, worn screws can often be reconditioned several times throughout their life. Reconditioning costs up to 50% less than new equipment.	Lube-for-life ball screws use a self-lubricating element mounted on each end of the nut. The element continuously dispenses a thin film of lubricant on the moving balls and screw threads. This saves money and hassle by eliminating the need for oil lubrication.
Although many preloaded ball nuts contact rolling balls at four points, designs with two-point ball contact have several advantages. Four-point contact may be acceptable in applications carrying low loads, but otherwise it can cause erratic ball rotation and skidding. This can lead to excessive heat generation and high torque requirements. Thomson Saginaw designs, on the other hand, use two-point contact to nearly eliminate skidding. This lowers wear, increases positioning accuracy, and extends travel life.	

of hollow ball screws also allow higher operating speeds than those of similar solid screws.

Although solid ball screws reach lengths exceeding 70 ft, sometimes space constraints limit their lengths. In applications requiring long travel in tight spaces, telescoping ball screws are a handy solution. A hollow outer screw in these mechanisms surrounds a solid or hollow inner screw. The inner screw extends from the outer screw, increasing the screw's reach. Three or more screws can be combined this way for even longer travel. Telescoping ball screws are widely used in machinery and are required on aircraft to actuate leading-edge wing flaps.

Another space-saving technique combines ball screws with electric motors. Performance Pak Actuators have a motor output shaft connected, through a gear transmission, to a ball screw. The screw is enclosed in a sealed tube with a mounting bracket that connects to the load and extends from the outer tube. Actuating the motor extends or retracts the screw to push or pull a load. The devices are used in positioning applications, such as commercial satellite dishes or hospital beds, in material handling, and in applications requiring simple lifting, opening, or closing operations. The actuators can also hold a load stationary without consuming power, or in power-off situations.

FIGHTING BACKLASH

Backlash is free axial motion of ball nuts along screw threads. Designers who need to avoid backlash use preloaded nuts instead of standard nuts. Preloading bearing balls loads them in the direction opposite the working load. This, in turn, applies opposing pressure to shaft threads and stiffens operation.

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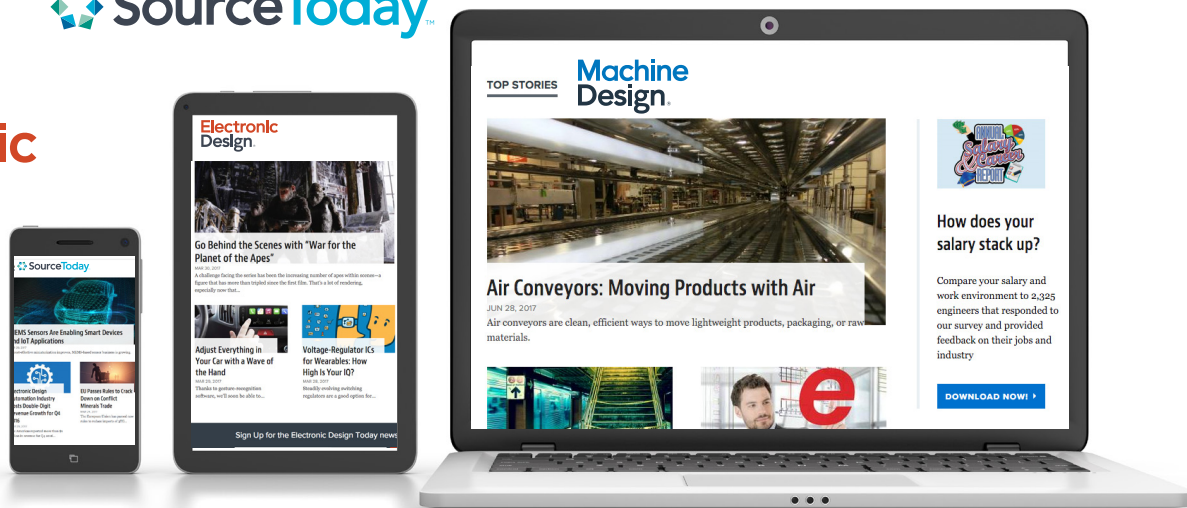
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