Specifying, Selecting and Applying Linear Ball Screw Drives

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A ball screw drive translates rotational motion to linear motion or vice versa and can apply or withstand high thrust loads - upward of 750,000 lbs static capacity using a Ø6.000" ball screw assembly - with efficiency typically greater than 90%. Ball screws are widely used to guide, support, locate, and accurately move components and products in a wide range of automation applications. Specifying the right ball screw for a given application will ensure machine accuracy, repeatability and life while minimizing the total cost of ownership. This article will provide an overview of ball screw drives and explains how to size them for specific applications.

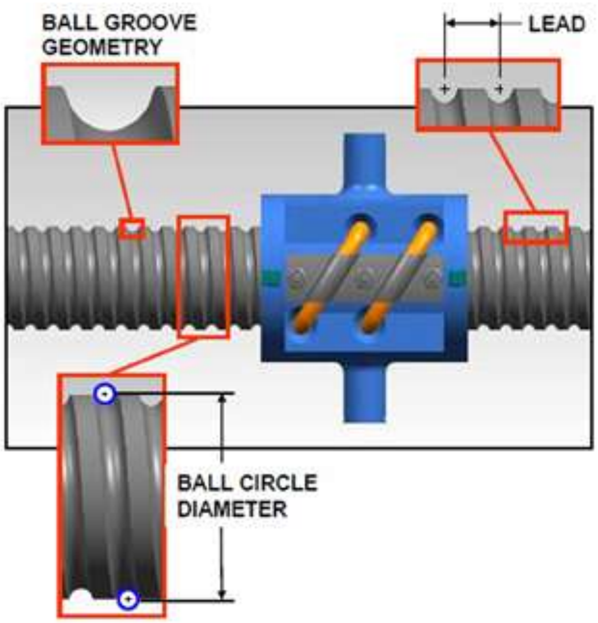

Figure 1: Ball Screw Basics

A ball screw drive consists of a ball screw and a ball nut with recirculating ball bearings. The interface between the screw and the nut is made by ball bearings that roll in the matching forms in the ball screw and ball nut. The load on the ball screw is distributed over a large number of ball bearings so that each ball is subjected to a relatively low load. Because of its rolling elements, the ball screw drive has a very low coefficient of friction which equates to high mechanical efficiency.

The key difference between ball screws and lead screws is the use of recirculating ball bearings in the ball screw to minimize friction and maximize efficiency. Ball screws are more expensive than lead screws but their ability to carry higher loads, achieve faster speeds and achieve predictable life makes them well worth their added cost for many applications. Ball screw drives typically provide mechanical efficiency greater than 90% so their cost is often offset by reduced power requirements. For end users, the increased load capacity, longer life, and predictable reliability of ball screws are advantages over lead screws.

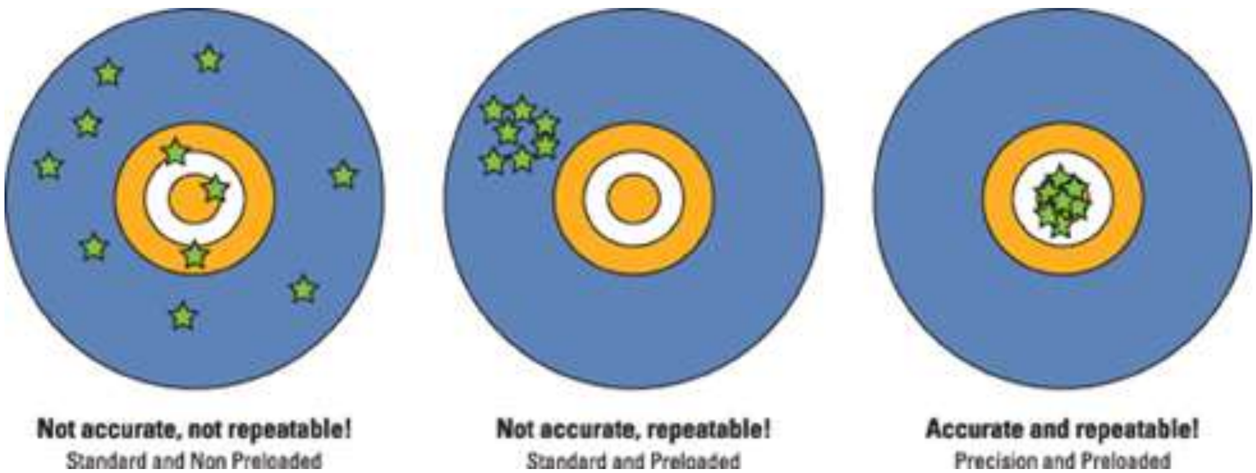

Figure 2: Accuracy vs. Repeatability

Repeatability and accuracy

A key advantage of ball screw drives is that they provide excellent repeatability (backlash, defined in detail below, is dependent upon ball bearing diameter, but typically ranges from .005 to .015") and accuracy (±.004"/ft for precision ball screws and ±.0005"/ft for precision plus ball screws). Accuracy is a measure of how closely a motion system approaches a command position. Accuracy is defined as the maximum error between the expected and actual position. Repeatability is defined as the ability of a positioning system to return to a location during operation.

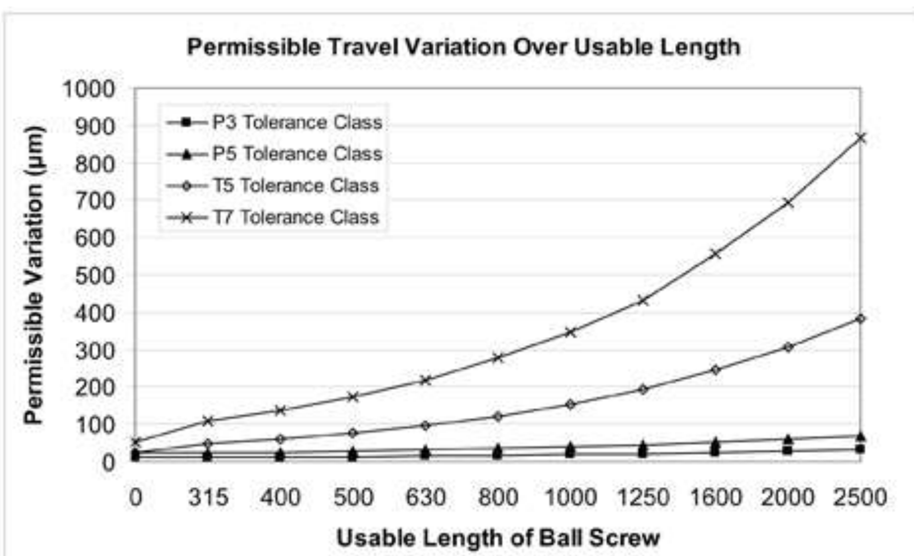

Figure 3: Lead Accuracy vs. Length

Lead accuracy is the most common measure of ball screw accuracy. Lead refers to how far a non-rotating ball nut will travel with a single 360 degree turn of the screw. Lead accuracy is measured as the permissible travel variation (actual position vs. theoretical position) per foot (inch product) or per 300 mm (metric product). Ball screws are offered in precision plus and transport grades, with the precision plus grade tightly controlling lead error accumulation over full length of travel.

Backlash is the free movement between the nut and screw, and can be measured axially and/or radially. The best way to measure axial backlash is to secure the screw from movement and axially push and pull on the ball nut while measuring its movement with a dial indicator. Backlash can also be measured by putting a dial indicator on the ball nut in the system and driving it 1 in. forward and back to the original position. The variation from zero is the backlash. Repeatability is simply the quantitative value of the backlash of a ball screw.

A non-preloaded ball nut has internal clearances between components, meaning that backlash exists. A preloaded ball nut has no axial clearance and therefore eliminates backlash and subsequently increases stiffness. Preload also increases the torque required to turn the screw and is measured by the percentage of preload to dynamic capacity (a ball nut with a dynamic capacity of 1500 lbs and a preload rating of 10% has a 150 lb internal preload). Precision thread ball screws are generally used without pre-load. Pre-loading a ball screw improves repeatability by removing backlash, but does not affect accuracy.

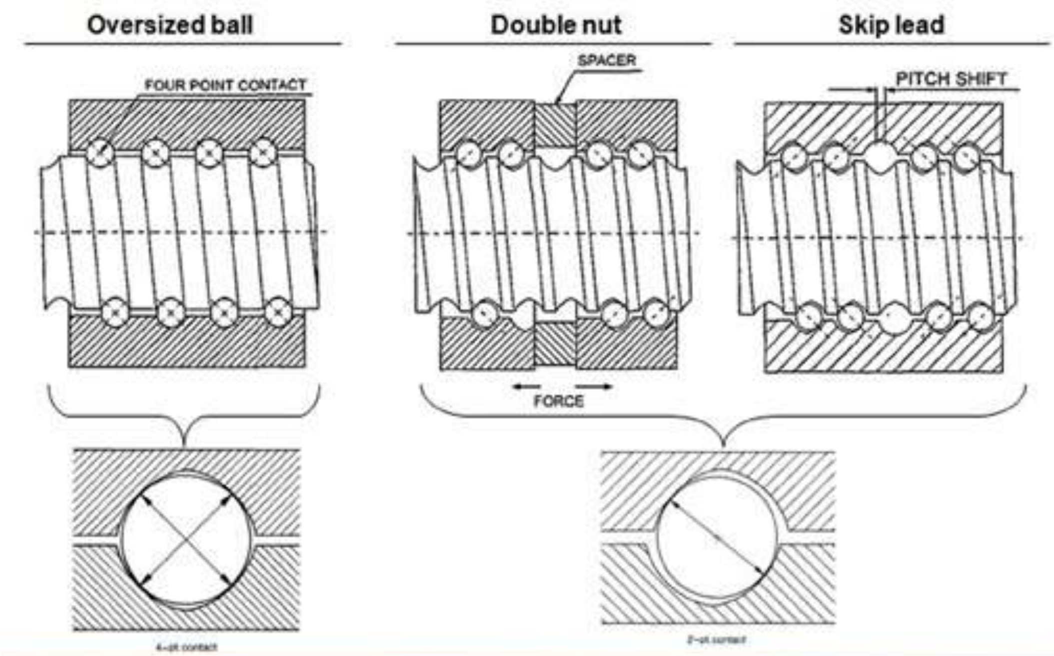

Figure 4: Three main preload types with 2-Point Contact and 4-Point Contact

Preloaded ball nuts are available on precision plus screws and select precision screw products. Their cost is higher than non-preloaded nuts due to complexity, additional machining, assembly, and verification/measurement. Ball screw assemblies can be preloaded with double or single nut configurations. There are three major types of preload – single nut oversized ball (4 point contact), single nut skip lead (2 point contact) and double nut (2 point contact). Single nut preload maintains the smallest package size while maintaining full load capacity. Skip lead ball nuts have half the capacity of similar sized single nuts as only half the ball bearings are loaded in each direction. Double nut preload assemblies have the same load capacity as a single nut as only one ball nut is loaded in each direction.

There are many methods for manufacturing ball screws although they are typically classified into two categories; precision and precision plus. The race of a precision thread ball screw is formed by a cold rolling process. The nut is machined to match the screw performance capability. This approach provides moderate accuracy, on the order of ±0.004 inch per foot lead accuracy on transport inch series screws. The screw and nut of precision plus thread ball screws are produced by precision grinding. Precision plus thread ball screws offer a much higher accuracy of ±0.0005 inch per foot lead accuracy on precision plus inch series screws. The cost of precision plus thread ball screws is higher than precision screws due to higher processing time.

Figure 5: Ball Screw Return Systems

Ball return systems
Three different types of ball return systems are commonly used. External return tubes, typically used in inch screws, are cost effective and easy to install, maintain and repair. Internal button return systems are typically used on low lead screws. They are compact, with no external radial protrusions to complicate mounting and offer less noise and vibration than external returns. Internal button return systems are often used in 4-point contact, single nut, and preload assemblies. Internal end cap returns are typically used on high lead screws. They are compact with no external radial protrusions to complicate mounting. Their noise and vibration is also low compared to external returns.

Ball screw selection
The ball screw assembly that provides the specified load capacity and life required for a specific application must be selected through an iterative process. The design load, system orientation, travel length, required life, and required velocity, are used to determine the diameter and lead of the ball screw assembly. Individual ball screw components are then selected based on accuracy and repeatability requirement, dimensional constraints, mounting configuration, available power requirements, and environmental conditions.

Start by determining the positional accuracy and repeatability required of the application. Inch ball screws are produced in two main grades – Transport and precision plus. Transport grade ball screws are used in applications requiring only coarse movement or those utilizing linear feedback for positional location. Precision plus grade ball screws are used where accurate and repeatable positioning is critical. Differences between Transport and precision plus grades are highlighted in Figure 3. Transport grade screws allow greater cumulative variation over the useful length of the screw. Precision plus grade screws contain accumulation of lead error to provide precise positioning over the screw's entire useful length.

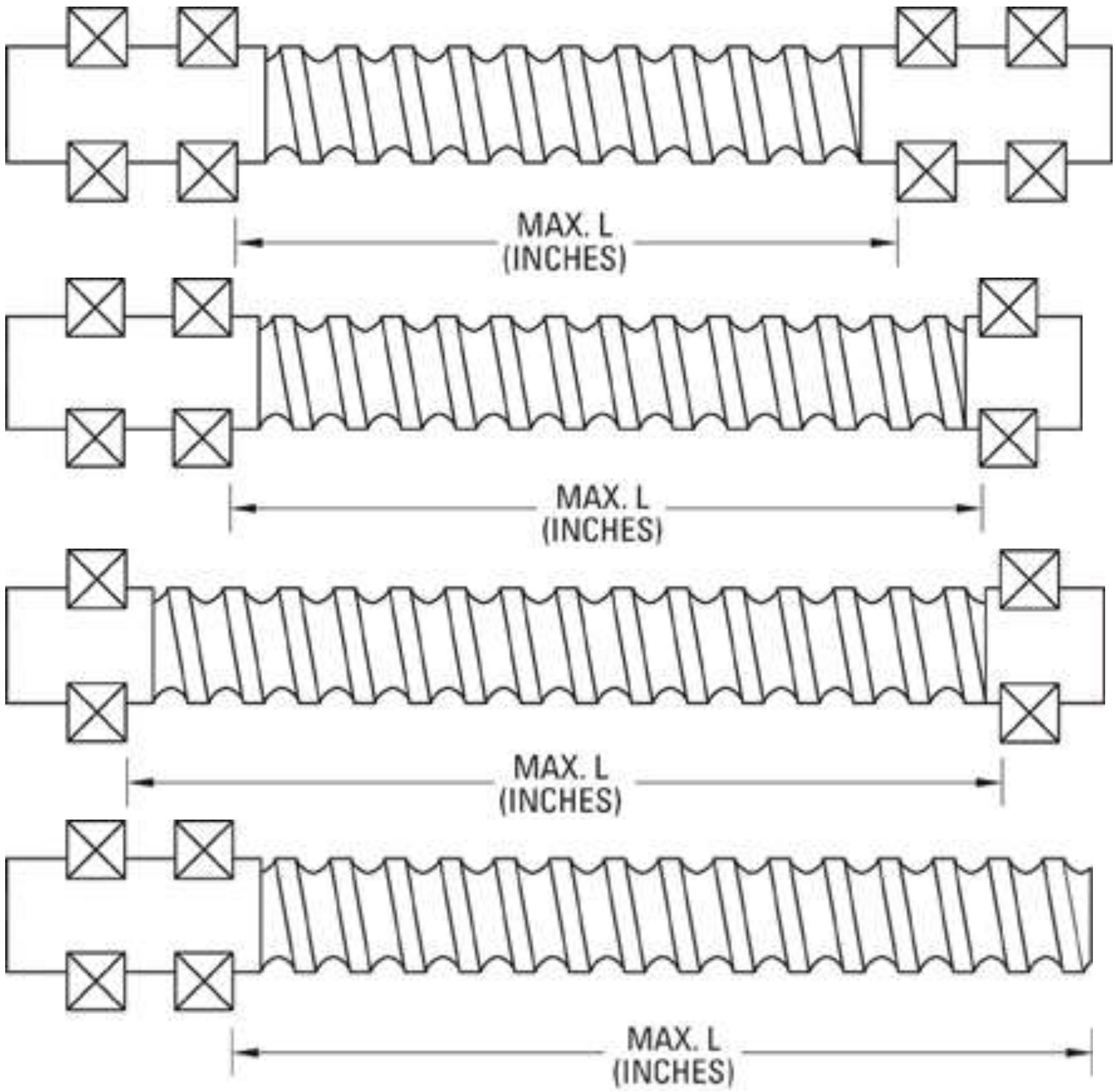

Figure 6: End Fixity Factors

Determine how the ball screw assembly will be mounted into the machine. The configuration of the end supports and the travel distance will dictate the load and speed limitations of the ball screw.

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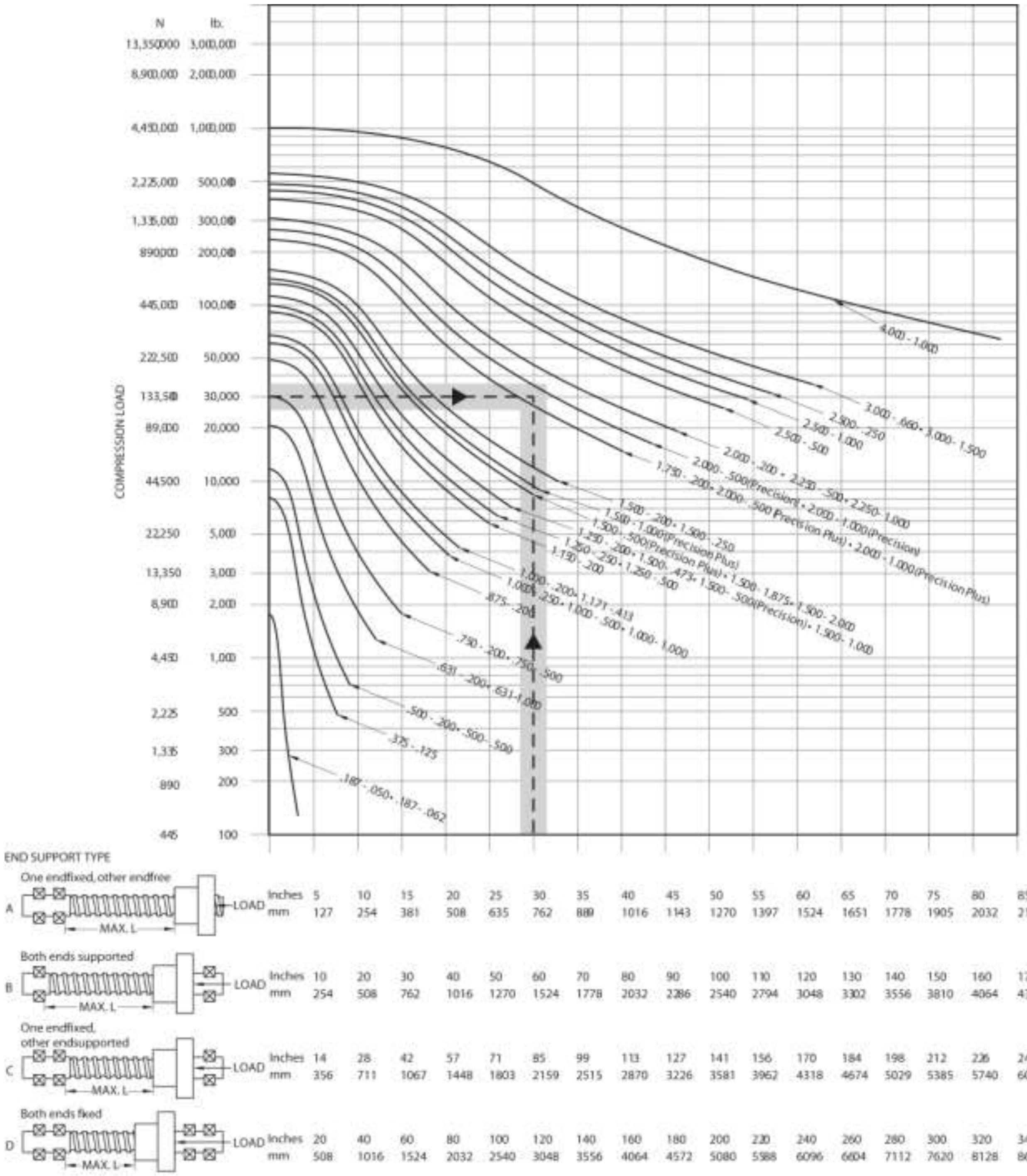

Figure 7: Compression Load vs. Length

A ball screw in tension can handle loads up to the rated capacity of the nut. For a ball nut in compression, use the compression loading chart in Figure 9 to select a ball screw diameter that meets or exceeds the design load. All screws with curves which pass through or above and to the right of the plotted point are suitable for the example. The suitable compression loads shown in this graph are not to exceed the maximum static load capacity as given in the rating table for the individual ball nut assembly. For example; at a length of 85 in. (2159mm), a system load of 30,000 lb. (133,500 N) and with an end fixity of one end fixed and the other end supported - the minimum selection is a 1.750 x .200 precision plus inch ball screw assembly.

$$Lead(in.) = \frac{TravelRate(in.\min.^{-1})}{rpm}$$

Calculate the lead of the ball screw that will produce the speed requirement using the formula shown above.

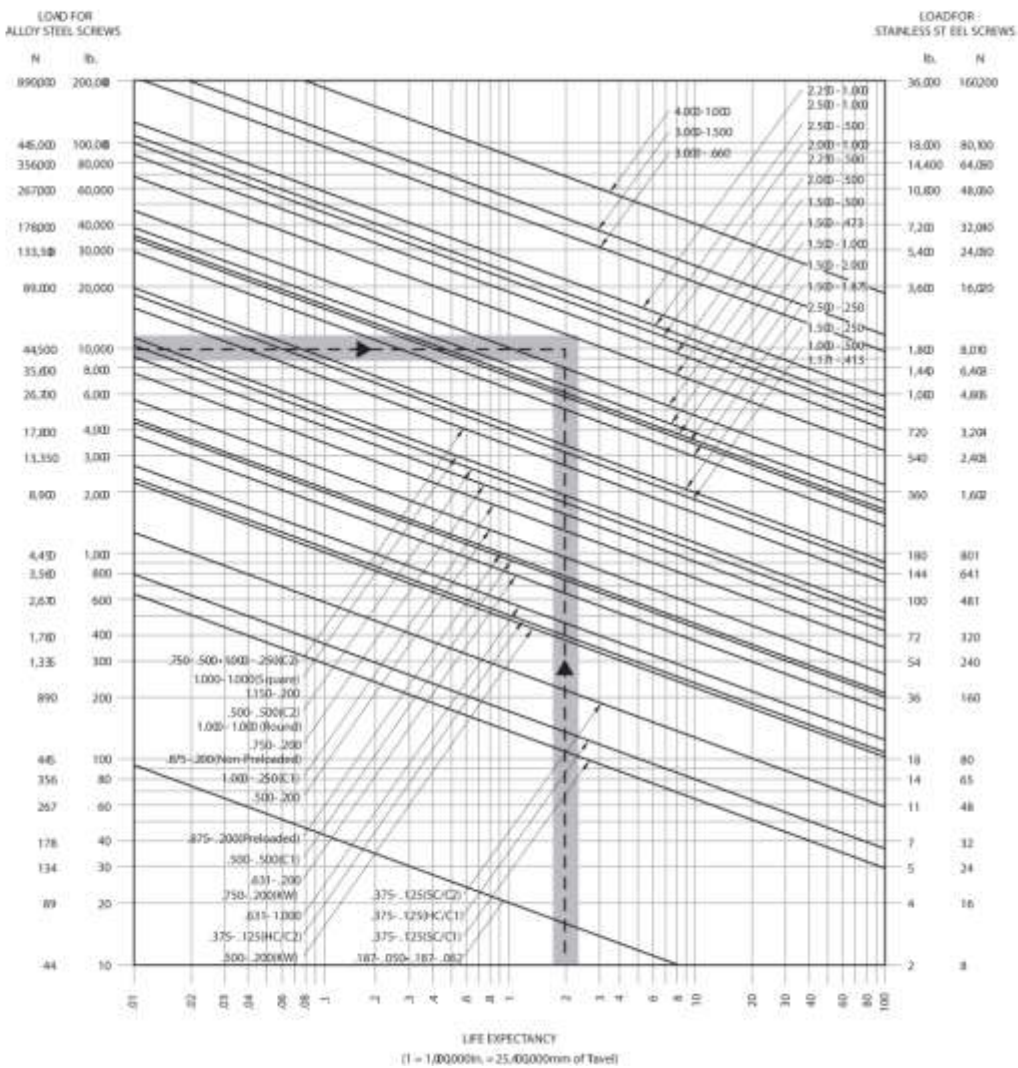

Figure 8: Application Life Expectancy
C1 = Single Circuit C2 = Double Circuit SC = Standard Capacity HC = High Capacity

Determining application life expectancy
The assembly life can be calculated using the dynamic load rating specified for each ball nut. All ball nuts with curves which pass through or are above the plotted point are suitable for the example. The suitable life expectancies shown in this graph are not to exceed the maximum static load capacity as given in the rating table for the individual ball nut assembly. In the example shown by the arrows in Figure 8, application life expectancy (total travel) desired is 2 million in. (50.8 million mm). Then maximum normal operating load is 10,000 lb. (44,500 N).

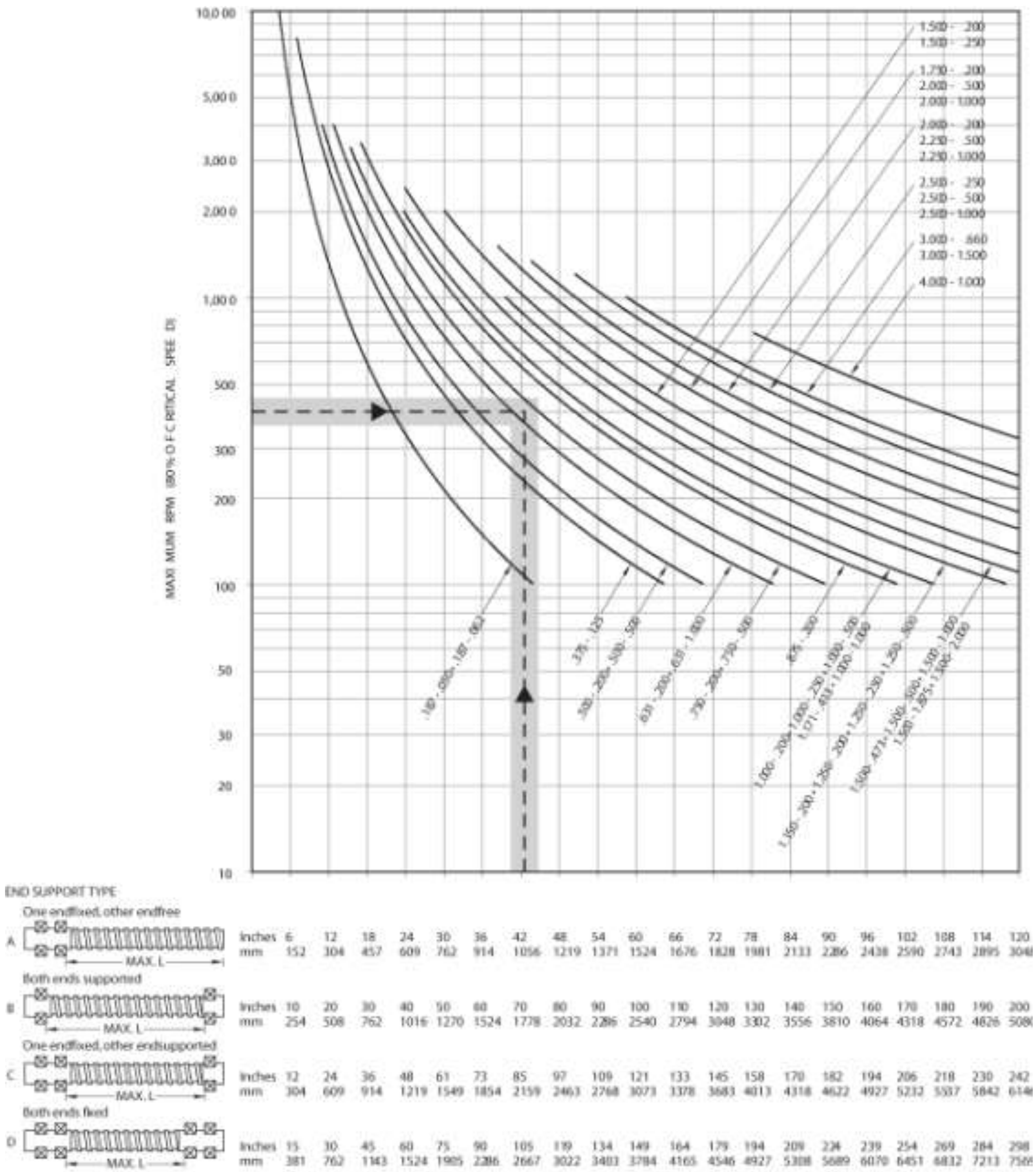

Figure 9: Acceptable Speed vs. .Length

Determining screw critical speed
Critical screw speed is the condition where the rotary speed of the assembly sets up harmonic vibrations. The critical speed is dependent on the screw's root diameter, unsupported length and the end support configuration. Figure 11 shows the acceptable speed versus length for ball screws. All screws with curves which pass through or above and to the right of the plotted point are suitable for the example. The four end fixity drawings on the bottom of the figure show the bearings configurations for supporting a rotating shaft, and the chart shows the effect of these conditions on critical shaft speed for the unsupported screw length. The acceptable velocities shown by this graph apply to the screw shaft selected, and are not indicative of the velocities attainable of all of the associated ball nut assemblies.

If the load, life and speed calculations confirm that the selected ball screw assembly meets or exceeds the design requirements, then proceed to the next step. If not, larger diameter screws will increase the load capacity and increase the speed rating. Smaller leads will decrease the linear speed (assuming constant input motor speed), increase the motor speed (assuming constant linear speed), and decrease the input torque required. Higher leads will increase the linear speed (assuming constant input motor speed), decrease the input motor speed (assuming constant linear speed), and increase the input torque required.

Determine how the ball nut will interface into the application. A ball nut flange is the typical method of attaching the ball nut to the load. Threaded ball nuts and cylindrical ball nuts are alternative ways to provide the interface.

Additional design considerations and features are also available. Preloaded ball nuts are available to eliminate system backlash and increase stiffness. Wiper kits to protect the assembly from contaminants and to contain lubrication are standard on some units and optional on most others. Bearing supports and end machining are also available as options for most ball screws.

Balls screws need to be carefully handled prior to proper installation. Shocks to the ball bearings can damage the bearing races through brinelling or cracking. High loads or flexing of the screw can lead to bending. It is important to keep the assembly packaged and lubricated and stored in a clean, dry area because debris and contamination can jam recirculation tracks, and high humidity or rain can cause corrosion.

System mounting is another important consideration. The ball nut should be loaded axially only as any radial loading significantly reduces the performance of the assembly. The assembly should also be properly aligned with the drive system, bearing supports, and load to achieve optimal performance and life.

Ball screw lubrication
The ball screw assembly should never be run without proper lubrication. Lubricants maintain the low friction advantage of ball screw assemblies by minimizing the rolling resistance between balls and grooves and sliding friction between adjacent balls. Lubricants are often taken for granted but the right choice for each application ensures a ball screw that performs properly for its calculated life.

Oil can be applied at a controlled flow rate directly to the point of need, and it will clean out contaminants as it runs through the ball nut. It can also provide cooling. On the other hand, a pump and metering system is needed to apply oil properly, as oil also has the potential of contaminating process fluids.

Grease is less expensive and requires less frequent application than oil, and it does not contaminate process fluids. On the other hand, grease is hard to keep inside the ball nut and has a tendency to build up at the ends of ball nut travel, where it accumulates chips and abrasive particles. Incompatibility of old grease with re-lubrication grease can create a problem, so it's important to check compatibility. A load-carrying grease can help extend the life of an assembly, but the overall load rating will not change.

Noise is an important consideration in some applications. Larger ball screws utilize larger ball bearings and are therefore inherently noisier. External return systems are also inherently noisier than internal return system. The use of spacer balls can reduce the noise of a ball nut but reduces the load capacity. The selection and proper application of grease can also reduce the overall noise level. Minimizing or even eliminating backlash can also reduce noise in an assembly.

Ball screws should periodically be inspected in an effort to avoid downtime and maximize life. Check for metal fragments that may cause damage and could be an indication of broken balls or component wear. Measure lash to verify component wear. Check the races for wear, spalling, brinnelling and contamination. Check to make sure the screw is lubricated and free of contamination and corrosion. Check that all connections are tight and that there are no vibration issues. Check the drive system to make sure that drive torque is constant and the ball screw is operating smoothly and quietly. Noise levels should be the same as on the first day of operation. The ball nut travel should be smooth and regular. Any change in noise level or "feel" is an indication of internal damage.

Ball screws provide an excellent method for translating rotational motion to linear motion for many applications, including those where high loads and close tolerances are involved. In order to apply the correct type of ball screw in a particular application, the design engineer must consider the advantages and capabilities of each. Selecting the right technology can reduce design complexity, improve performance and reduce the overall cost of the assembly.

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