GLOSSARY AND TECHNICAL DATA

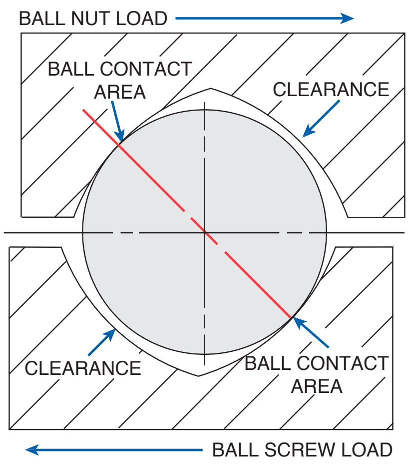
BALL SCREW FORM TERMS

INTRODUCTION

Ball screws offer an efficient means of converting rotary motion to linear motion. A ball screw is an improvement over an acme screw just as an antifriction ball bearing is an improvement over a plain bushing.

Ball screw assemblies have a number of bearing balls that transfer the load between the nut and screw. The thread form in which the bearing balls ride is an ogival shape formed from two arcs of the same radius with offset centers. This form is also referred to as a gothic arch. **(SEE FIG. 1)**

FIG.1



BEARING BALL CIRCUIT

The closed path that the bearing balls follow through the ball nut. Ball nuts may have one or more circuits.

RETURN GUIDE

When bearing balls circulate in a ball nut, a ball enters the ball path between the nut and screw carrying the load one or more turns around the screw. The bearing ball is then picked up and returned to the beginning of the circuit through the return guide.

LOAD CARRYING BALLS

The bearing balls in contact with ball nut and ball screw sharing the load.

LAND DIAMETER

The outside diameter of the screw. This diameter is less than the ball circle diameter.

BALL CIRCLE DIAMETER

The diameter of the circle generated by the center of the bearing balls when in contact with the screw and nut.

ROOT DIAMETER

The diameter of the screw measured at the bottom of the thread. This is the diameter used for column strength, critical speed calculations and end machining considerations.

PITCH

The axial distance between threads. Pitch is equal to the lead in a single start screw.

LEAD

The axial distance the nut advances in one revolution of the screw. The lead is equal to the pitch times the number of starts.

PITCH x STARTS = LEAD

SCREW STARTS

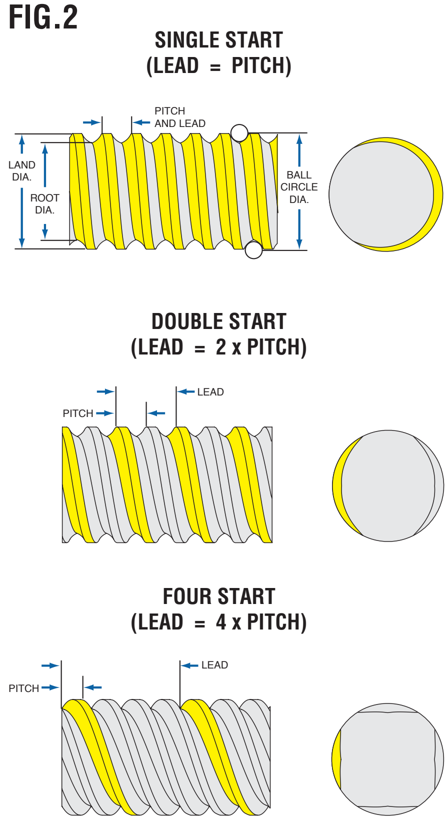
The number of independent threads on the screw shaft; typically one, two or four. **(SEE FIG. 2)**

LEAD ACCURACY

Lead accuracy is the difference between the actual distance traveled versus the theoretical distance traveled based on lead. For example: A screw with a .5 inch lead and ±.001 inch per foot lead accuracy rotated 24 times theoretically moves the nut 12 inches.

24 Revolutions X .500 inches per revolution = 12.000 inches of travel with a Lead accuracy of .001 per foot, actual travel could be from 11.999 to 12.001 inches.

FIG.2



PowerTrac™ SRT Ball Screws will not deviate from nominal lead by more than ±.004 inch/foot on screws through 2 1/2" diameter and ±.008 inch/foot on screws 3" and over.

PowerTrac™ XPR Ball Screws will not deviate from nominal lead by more than ±.001 inch/foot.

PowerTrac™ SGT Ball Screws will not deviate from nominal lead by more than ±.0005 inch/foot.

MATCHED LEAD

When multiple screws are used to move a load with precise synchronicity, screws of similar lead accuracy can be factory selected and supplied as sets. Consult factory for matched lead set tolerances.

GLOSSARY AND TECHNICAL DATA

STRAIGHTNESS

Although PowerTrac™ Ball Screws are manufactured from straight, cylindrical material, internal stresses may cause the material to bend or yield. When ordering random lengths or cut material without end machining, straightening is recommended. Handling or machining of screws can also cause the material to bend or yield. Before, during and after machining, additional straightening is required.

When ordering screws with machined ends from Nook Industries, the following straightness tolerances can be expected:

PowerTrac™ SRT and XPR Ball Screws are straight within .010 inch/foot when shipped from the factory, and do not exceed .030 inch in any 6 foot section.

PowerTrac™ SGT Ball Screws are straight within .001 inch/foot when shipped from the factory.

LIFE

A ball screw assembly uses rolling elements to carry a load similar to an anti-friction (ball) bearing. These elements do not wear during normal use. Therefore, ball screw life is predictable and is determined by calculating the fatigue failure of the components.

Proper lubrication, regular maintenance, and operation within specified limits will allow PowerTrac™ Ball Screws to operate to the predicted life.

EFFICIENCY

The low coefficient of friction of the rolling elements of PowerTrac™ Ball Screws and Nuts results in an operating efficiency greater than 90%.

BACKDRIVING

Normally, ball screws are used to convert rotary motion into linear motion. Backdriving is the result of the load pushing axially on the screw or nut to create rotary motion.

All ball screws, due to their high efficiency, will backdrive. The resulting torque is known as "backdriving torque" and is the torque required to hold a load in position.

CAUTION - When using ball screws, applications should be analyzed to determine the necessity of a brake, especially when the possibility of injury may occur.

BACKLASH

Backlash (lash) is the relative axial movement between a screw and nut without rotation of the screw or nut. The axial movement between a new PowerTrac™ SBN or SGN ball nut and screw will range from .003" to .015" depending on size. Lash in ball screws will remain constant during normal use.

SELECTIVE FIT

When less than standard lash (listed above) is desired, SBN and SGN ball nuts can be custom-fit to a specific screw with selected bearing balls to minimize lash to .003" to .005" depending on ball size. Select fitting may result in lower life.

LOAD DEFINITIONS

STATIC LOAD

The maximum thrust load – including shock – that can be applied to the ball nut without damaging the assembly.

DYNAMIC LOAD

The thrust load in pounds which, when applied to the ball nut and rotating screw assembly will result in a minimum life of 1,000,000 inches of travel. Metric screw designs are per ISO 3408 and show the load ratings in kilonewtons for 1 million revolutions of the screw. For inch or metric rotating nut designs, contact Nook Industries at 800-321-7800.

TENSION LOAD

A load that tends to "stretch" the screw. **(SEE FIG. 3)**

COMPRESSION LOAD

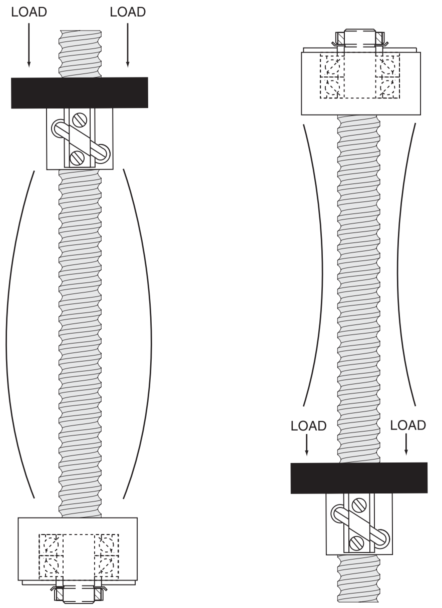
A load that tends to "squeeze" the screw. **(SEE FIG. 3)**

OVERTURNING LOAD

A load that tends to rotate the nut

FIG.3

COMPRESSION LOAD **TENSION LOAD**

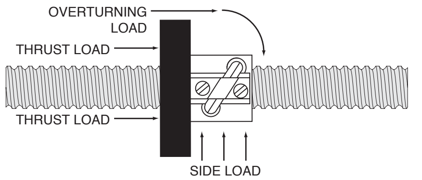


around the longitudinal axis of the screw. **(SEE FIG. 4)**

SIDE LOAD

A load that is applied radially to the nut. **(SEE FIG. 4)**

FIG.4



CAUTION - Although a side load will not prevent the ball screw from operating, the nut is not designed to operate with a side load, such as those generated from pulleys, drive belts, misalignment, etc. See "Load Definition" section for further information.

THRUST LOAD

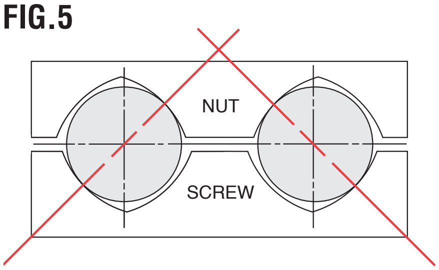
A load parallel to and concentric with the axis of the screw. **(SEE FIG. 4)**

PRELOAD

Preload is an internal force introduced between a ball nut and screw assembly that eliminates free axial and radial lash. Preloaded assemblies provide excellent repeatability and increased system stiffness.

Preloading is achieved either by using two nuts and forcing them apart or by shifting the circuits within a single nut. Nook Industries has a variety of preload ball nut designs available. **(SEE FIG. 5)**

FIG.5



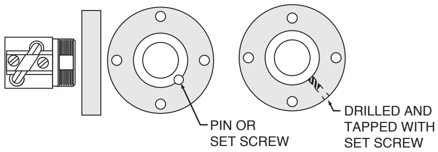
DESIGN CONSIDERATIONS

MOUNTING AND PINNING OF BALL NUT FLANGE

If a flange is used, it must be permanently fixed to the nut. Since mounting methods usually require the disassembly of the ball nut from the screw, it is best to order the nut and flange factory assembled.

The preferred method of locking a flange to a nut is a pin or set screw parallel to the screw which intersects the flange/nut mounting thread. Because of the dissimilarity of materials, the hole may need to be milled, not drilled. **(SEE FIG. 6 & 7)**

FIG.6



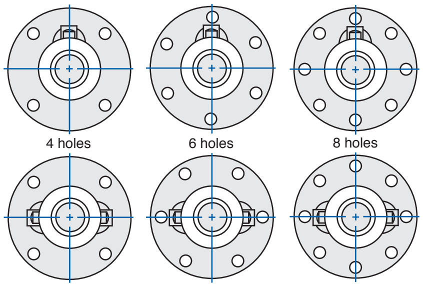
Alternatively, the flange may be drilled and tapped radially for a setscrew. After assembly of the flange to the nut, spot drill the nut threads through the flange and install a dog point set screw from the flange O.D. into the nut O.D. threads. Avoid getting metal chips in the nut when drilling.

Commercially available thread adhesives may be used for light load applications. Follow the manufacturers recommendations to ensure a satisfactory bond. Avoid getting the adhesive onto the ball tracks.

STANDARD FLANGE ORIENTATION

Standard flange orientation varies with the number of holes in the flange. Unless otherwise specified, a factory-assembled flange will be oriented on the nut as shown. **(SEE FIG. 8)**

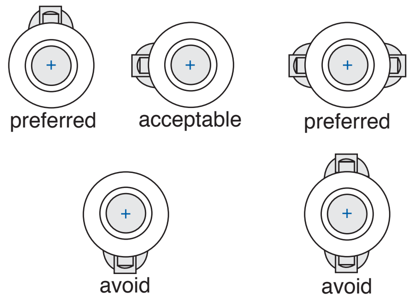
FIG.8



PROPER BALL NUT ORIENTATION

When a ball screw assembly is used in an orientation other than vertical, it is important to orient the return tubes to optimize ball nut operation. **(SEE FIG. 9)**

FIG. 9



Ball nuts run best with the return guides up. Horizontal guide orientation is also acceptable. Return guides down should be avoided.

Some ball nut designs have return guides on both sides of the nut. In this case the preferred guide orientation is horizontal.

FIG.7

DIAMETER	DESCRIPTION	QUANTITY
Up to 1	3/16 x 1/2 Slotted Spring Pin	1
1.125	3/16 x 1/2 Slotted Spring Pin	2
1.5	5/16 - 18 x 1/2 Set Screw	2
2.25 to 3.0	3/8 - 16 x 3/4 Set Screw	2
4	1/2 - 13 x 1 Set Screw	2

Note: Ball Nuts are case hardened.

TRANSFERRING BALL NUTS FROM SHIPPING ARBOR

When not ordered as part of an assembly, ball nuts are shipped on arbors. Transferring the ball nut from the arbor to the ball screw is achieved by placing the arbor against the end of the screw thread and carefully rotating the ball nut onto the screw from the arbor.

If the inside diameter of the arbor is too small to slip over the outside diameter of the journal, apply tape to the journal to bring the outside diameter up to the root diameter of the screw to prevent the bearing balls from falling out of the ball nut. The ball nut can then be transferred across the taped journal onto the ball screw. **(SEE FIG. 10)**

CAUTION - Removal of the arbor from the ball nut will result in the loss of the bearing balls. All of the bearing balls in a ball nut are matched. If any balls are lost during this transfer, they all must be replaced.

INSTALLING SEL, SAR, AND SAG BALL NUTS

These nuts must be transferred from the arbor to the screw without preload. Be sure to keep the ball return tubes aligned with each other and make sure the coupling tangs line up with the slots in the ball nut.

Center the adjusting nut on the coupling. Before preloading these ball nuts, all the coupling threads, spring washers/spacers and ball grooves should be lubricated.

Position the ball nut on the center of the screw shaft. It is a good idea to place retainers (tape, tie-straps, etc.) on the screw to prevent the ball nut from over-traveling. With the ball return tubes facing upward, tighten the adjusting nut against the spring washer or spacer by hand until it cannot be turned. While holding the ball nut with tubes facing up, rotate the screw several turns in both directions.

Running torque can be measured by means of a spring scale. The force reading multiplied by the lever arm length yields the running torque value.

Make adjustments to achieve desired preload and recheck running torque value up and down the screw shaft. Do not tighten the adjusting nut to a point that fully collapses the spring washers.

After the system is adjusted, secure the adjusting nut with the set screws provided.

LUBRICATION

Proper and frequent lubrication must be provided to achieve predicted service life. A 90% reduction in the ball screw life should be anticipated when operating the nut and screw without lubricants.

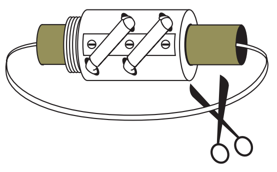
Standard lubrication practices for antifriction bearings should be followed when lubricating ball screws. A light oil or grease (lithium-based) is suitable for most applications. Lubricants containing additives such as molydisulfide or graphite should not be used.

E-900, Nook Ball Screw Lubricant, is oil that has been developed specifically for ball screws and is available as a spray or liquid. See page 95.

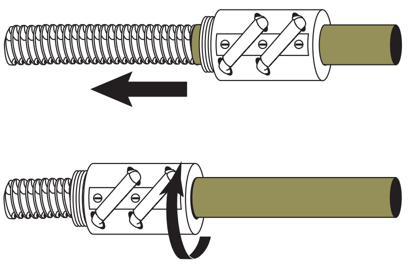
Lubrication intervals are determined by the application. It is required that screw assemblies are lubricated often enough to maintain a film of lubricant on the screw.

FIG.10

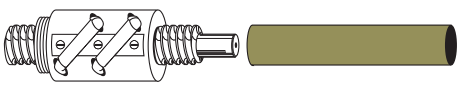
1. Remove any ball nut retainer from arbor. Hold arbor firmly end to end with the screw. Make certain the arbor end is centered on the screw shaft end.



2. Slide the ball nut down the screw shaft and rotate counter to the thread until you feel the balls drop into the screw thread. Then rotate with the screw thread until the ball nut completely clears the end of the screw shaft adjacent to the arbor.



3. Remove the arbor.



To transfer the ball nut from screw to arbor, reverse the above procedure.

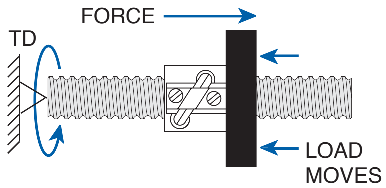
CAUTION: Extreme care must be taken to prevent the ball nut from sliding off the end of the screw shaft during installation and handling. Temporary stops can be made by wrapping tape around shaft balls grooves at each end. Be sure to remove tape and any residual adhesive after the ball screw assembly is properly installed.

DRIVING TORQUE

Driving torque is the amount of torque required by the ball screw to move a load. To simplify this calculation a "torque to raise one pound or one kN" value is provided in the technical data for each ball screw size. **(SEE FIG. 11)**

To determine the required torque to move a load, multiply the load to be moved by the "torque to raise one pound or kN". For more information on drive torque, see the application example at the end of the section.

FIG.11



$$T_d = \frac{P \times L}{2\pi\ e} = .177\ P \times L$$

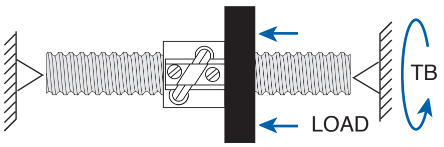
WHERE:

T_d = Drive Torque (pound-inches)
P = Load (lbs.)
L = Screw Lead (inches/turn)
e = Ball Bearing Screw Efficiency (90%)

BACKDRIVING TORQUE

Due to the efficiency of a ball screw, a load applied to the ball nut will generate backdriving torque on the ball screw. The torque required to hold the load in position can be calculated by the following formula. **(SEE FIG. 12)**

FIG.12



$$T_d = \frac{P \times L \times e}{2\pi} = .143\ P \times L$$

WHERE:

T_d = Drive Torque (pound-inches)
P = Load (lbs.)
L = Screw Lead (inches/turn)
e = Ball Bearing Screw Efficiency (90%)

TEMPERATURE

PowerTrac™ Ball Nuts will operate between -65°F and 300°F with proper lubrication. PowerTrac™ ball nuts equipped with elastomeric wipers are limited to operation between -20°F and 180°F.

END MACHINING

To obtain optimum performance of your ball screw assembly, it is recommended that the machining be performed at the Nook Industries factory. Screws may be purchased machined to your specifications or to standard end machining designs shown on pages 212-213.

Annealed ends can be provided on SRT screws to facilitate end machining of journals.

EZZE-MOUNT™

Ball screws in operation generate an axial load and a radial load; therefore, end mounts must be designed to accommodate these loads. Nook Industries has designed precision end mounts to work specifically with lead screws. For a detailed description of these bearing supports see pages 214-218.

An EZZE-MOUNT™ can be shipped pre-assembled to a PowerTrac™ Ball Screw. For complete PowerTrac™ Ball Screw Assemblies refer to pages 145-147.

OPTIONAL SURFACE COATINGS

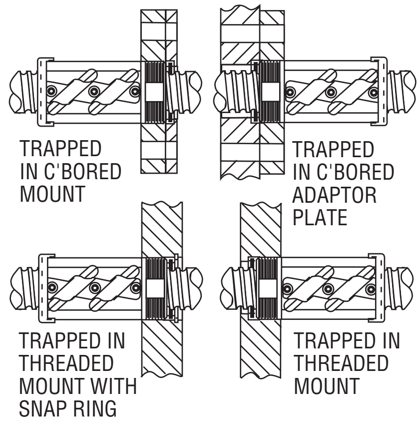
PowerTrac™ Ball Screws are available with optional corrosion resistant and/or lubricated finishes like Nickel, Teflon, or Hard Chrome; consult Nook Industries for detailed specifications.

WIPER KITS

It is recommended that wipers be used with ball nuts to prevent contamination from foreign materials. The product pages detail the different types of wipers available for or standard with each ball nut. Brush wipers may require customer-supplied retention. For the different ways that this can be achieved **(SEE FIG. 13)**.

FIG.13

SOME EXAMPLES OF HOW TO ATTACH WIPERS TO V-THREAD END



BOOTS AND BELLOWS

For contaminated environments, use of a boot or metal cover to protect the ball screw assembly is recommended.

POWERTRAC™ MATERIAL SPECIFICATIONS

PowerTrac™ Ball Screws are manufactured from high quality alloy steel, induction hardened to Rc 58-60.

PowerTrac™ Ball Nuts are manufactured from carburized steel with ball tracks heat treated to Rc 58-60.

SRT ball screws less than 16 ft. are given a protective black oxide finish. XPR and SGT ball screws are provided with a polished finish. Selected sizes are available in heat-treated stainless steel (Rc 40-45) for applications in corrosive environments. **(SEE FIG. 14 on following page)**

GLOSSARY AND TECHNICAL DATA

BALL SCREW SELECTION

The selection of the correct ball screw and nut for a particular application involves five interrelated factors. Before attempting to determine the ball screw and nut combination, the following values must be known:

- Load measured in pounds or newtons
- Speed measured in inches or millimeters per minute
- Length between bearings measured in inches or millimeters
- Life expectancy
- End fixity type

LOAD

The loads that need to be considered are the static loads, dynamic loads, reaction forces and any external forces affecting the screw. See Load definitions section above for details.

SPEED

The travel rate (linear speed) is the rpm at which the screw or nut is rotating multiplied by the lead of the screw.

LENGTH

Unsupported length of the screw.

LIFE EXPECTANCY

The dynamic load ratings shown on the product specification pages indicate the load that can be carried for 1,000,000 inches of travel.

The charts on pages 90-91 relate life to load. In applications where the load is relatively constant over the entire stroke, use the highest load to select the ball screw to provide a factor of extra life. For applications where the loads vary significantly, an equivalent load can be calculated using the following formula:

$$L_m = \sqrt[3]{\frac{\%_1 (L_1)^3 + \%_2 (L_2)^3 + \%_3 (L_3)^3 + \ldots + \%_n (L_n)^3}{100}}$$

WHERE:

L_m = equivalent load

L_n = each increment of load

$\%_n$ = percent of stroke at load L_n

FOR EXAMPLE:

L_1 = 150# $\%_1$ = 30%

L_2 = 225# $\%_1$ = 45%

L_3 = 725# $\%_1$ = 25%

$$L_m = \sqrt[3]{\frac{30 (150)^3 + 45 (225)^3 + 25 (725)^3}{100}}$$

L_m = 466 lbs.

The life required is determined by multiplying the total stroke in inches by the total number of strokes required for the designed life of the equipment.

To calculate the travel life for a ball nut other than at rated load use the formula **(SEE FIG. 15)**.

FIG.15

$$T_x = \left(\frac{F_r}{F_x}\right)^3 \times T_r$$

WHERE:

T_x = Travel other than rated load. Life is given in inches or meters

F_r = Rated Load in pounds or kilonewtons

F_x = Actual or Equivalent load in pounds or kilonewtons

T_r = Rated Travel Life. For inch screws this is equal to 1,000,000 inches. For Metric Screws this is equal to the ball nut lead in meters times one million revolutions.

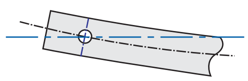
END FIXITY

End fixity refers to the method by which the ends of the screw are supported. The degree of end fixity is related to the amount of restraint of the ends of the screw.

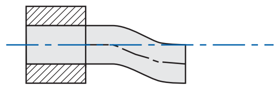
Three basic types of end fixity are:

Free No support.

Simple Shaft supported at a single point.



Fixed Shaft rigidly restrained against axial rotation.



"Simple" end fixity can be provided through a single bearing support. Multiple or spaced pairs of bearings are more rigid than a "simple" support, but, because of their inherent compliance are not truly "fixed".

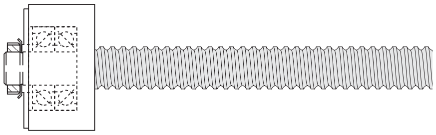
A screw can be supported with different combinations of end fixity. **(SEE FIG. 16)**

FIG.14

	ALLOY			STAINLESS STEEL
	SRT	XPR	SGT	
MATERIAL	4150 Series*	4150 Series*	4150 Series*	17- 4 PH
HARDNESS	Rc 58-60 Case Hardened	Rc 58-60 Case Hardened	Rc 58-60 Case Hardened	Rc 40-45 Thru Hardened
TENSILE	120,000 psi	120,000 psi	120,000 psi	150,000 psi
LEAD ACCURACY	±.004"/ft. thru 2-1/2" Dia.	±.001"/ft. thru 2-1/2" Dia.	±.0005"/ft. thru 2-1/2" Dia.	±.004"/ft.
FINISH	Roller Burnished, Black Oxide Finish(16 ft. or less)	Precision Roller Burnished	Precision Ground	Roller Burnished

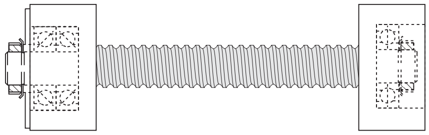
*or equivalent

FIG. 16: A- D

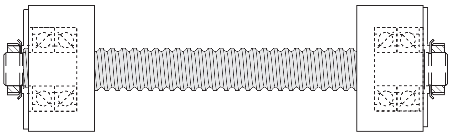


A: One end supported with a Double Bearing EZZE-MOUNT™, other end Free. Use Line "A" in reference to the charts shown on pages 92-93 and 152-153.

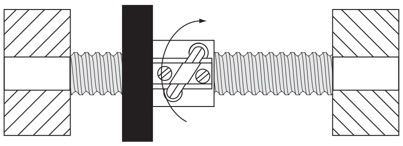
NOTE: Not recommended for any application other than short travels and slow speeds.



B: One end supported with a Double Bearing EZZE-MOUNT™, other supported with a Single Bearing EZZE-MOUNT™. Use Line "B" in reference to the charts shown on pages 92-93 and 152-153.



C: Both ends supported with a Double Bearing EZZE-MOUNT™. Use Line "C" in reference to the charts shown on pages 92-93 and 152-153.



D: Both ends rigidly mounted with a rotating nut or both ends mounted with a double preloaded angular contact bearing spaced apart by at least 1.5 time the diameter of the mounting journal. Use Line "D" in reference to the charts shown on pages 92-93 and 152-153.

CRITICAL SPEED

The speed that excites the natural frequency of the screw is referred to as the critical speed. Resonance at the natural frequency of the screw will occur regardless of the screw orientation (vertical, horizontal etc.) or if the system is designed so the nut rotates about the screw.

The critical speed will vary with the diameter, unsupported length, end fixity and rpm. Since critical speed can also be affected by shaft straightness and assembly alignment, it is recommended the maximum speed be limited to 80% of the calculated critical speed. The theoretical formula to calculate critical speed in rpm is:

$$N = \frac{C_s \times 4.76 \times 10^6 \times d}{L^2}$$

WHERE:

- N = Critical Speed
- d = Root Diameter of Screw
- L = Length Between Bearing Supports
- C_s = .36 for one end fixed, one end free
  - 1.00 for both ends simple
  - 1.47 for one end fixed, one end simple
  - 2.23 for both ends fixed

The critical speed chart on page 93 or 153 is provided to quickly determine the minimum screw size applicable for Nook EZZE-MOUNT™ designs.

Maximum travel rate is also limited by ball velocity. The ball velocity is a function of the ball circle diameter and rotational speed. Ball velocity is limited by a maximum DN (ball circle diameter x rpm). The charts show the maximum speed based on the DN value for each screw in parentheses.

If the selected ball screw does not meet the speed criteria, consider the following options:

a) Increase screw lead (reduce rpm)
b) Change end fixity (e.g. simple to fixed)
c) Increase ball circle diameter

The final consideration should be to recheck the selected screw against all three of the design criteria: life, column strength and critical speed.

COLUMN STRENGTH

When a screw is loaded in compression (see compression load definition on page 82), its limit of elastic stability can be exceeded and the screw will fail through bending or buckling.

The theoretical formula to calculate the column strength in pounds is:

$$P_{cr} = \frac{14.03 \times 10^6 \times F_c \times d^4}{L^2}$$

WHERE:

- P_{cr} = Maximum Load
- F_c = End Fixity Factor
  - .25 for one end fixed, one end free
  - 1.00 for both ends supported
  - 2.00 for one end fixed, one end simple
  - 4.00 for both ends rigid
- d = Root Diameter of Screw
- L = Distance between nut and load carrying bearing

The column strength chart, on page 92 or 152, may be used to verify that the screw can carry the required load without buckling.

The charts show the theoretical limitations of each screw on a separate line. The lines are limited horizontally by the slenderness ratio and vertically by the maximum static capacity of the nut. Actual load is limited by the maximum nut capacity.

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

a) Change end fixity (e.g. simple to fixed)
b) Design to use screw in tension
c) Increase screw diameter