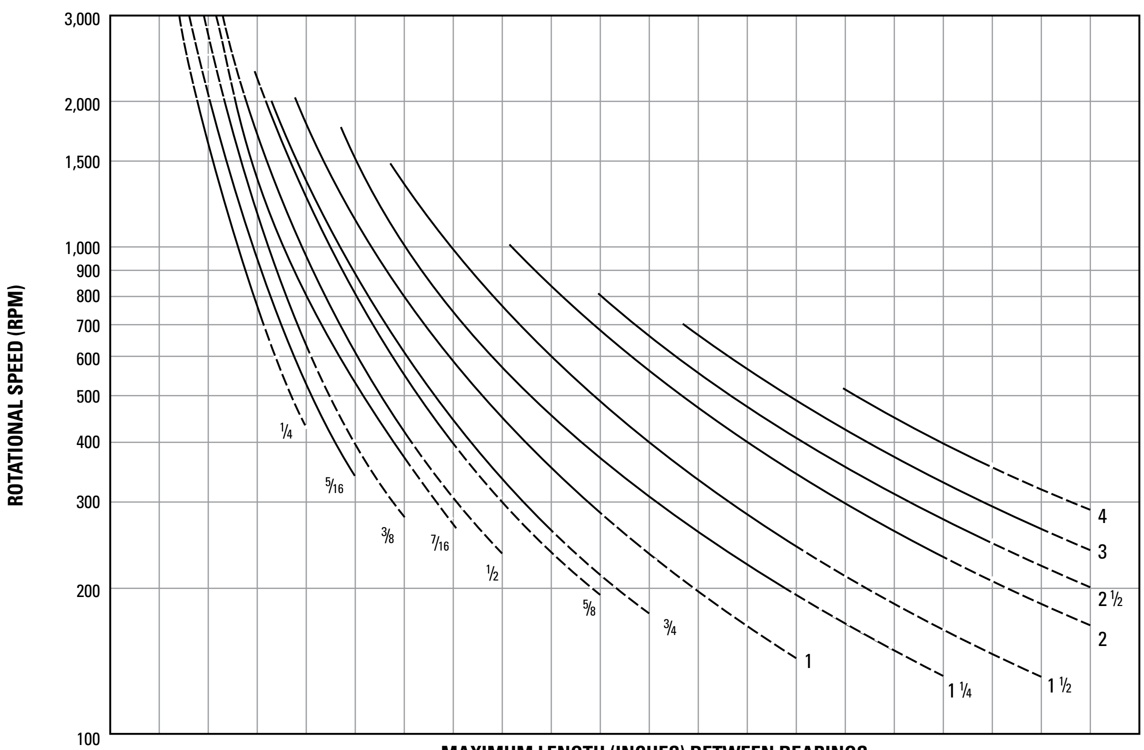
Engineering Guidelines for Ball and Lead Screws

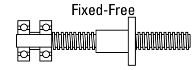
Critical Speed Limits Chart for Lead Screws and Rolled Ball Screws

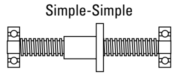
Every screw shaft has a rotational speed limit. That is the point at which the rotational speed sets up excessive vibration. This critical point is modified by the type of end bearing support used.

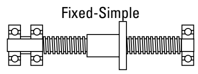
To use this chart, determine the required rpm and the maximum length between bearing supports. Next, select one of the four types of end support shown below. The critical speed limit can be found by locating the point at which rpm (horizontal lines) intersects with the unsupported screw length (vertical lines) as modified by the type of supports selected below. We recommend operating at no more than 80% of the critical speed limit to allow for misalignment and/or lack of screw straightness. If speed falls into dotted line, consult factory.

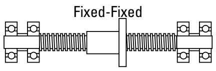
Warning: Curves for the screw diameters shown are based on the smallest root (minor) diameter of the standard screws within the nominal size range and truncated at the maximum ball nut rotational speed. DO NOT EXCEED this rpm regardless of screw length.



Fixed-Free


Simple-Simple


Fixed-Simple


Fixed-Fixed


A	Inches	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	120	126
	mm	152	304	457	609	762	914	1056	1219	1371	1524	1676	1828	1981	2133	2286	2438	2590	2743	3048	3200
B	Inches	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
	mm	254	508	762	1016	1270	1524	1778	2032	2286	2540	2794	3048	3302	3556	3810	4064	4318	4572	4826	5080
C	Inches	12	24	36	48	61	73	85	97	109	121	133	145	158	170	182	194	206	218	230	242
	mm	304	609	914	1219	1549	1854	2159	2463	2768	3073	3378	3683	4013	4318	4622	4927	5232	5537	5842	6146
D	Inches	15	30	45	60	75	90	105	119	134	149	164	179	194	209	224	239	254	269	284	298
	mm	381	762	1143	1524	1905	2286	2667	3022	3403	3784	4165	4546	4927	5308	5689	6070	6451	6832	7213	7569

Load Life Relationship

Column Loading Capacities

For Ball Screws

Ball screws are rated for 1,000,000 inches of travel at the rated dynamic load. This is the load at which 90% of a group of identical ball screws will run without flaking for their lifetime. However, they will travel farther than this at lower limits. These load-life relationships are analogous to the B10 rating common in the ball bearing industry. The relationship of load to life is an inverse cube relation. For example, reducing the load by 1/2 increases life eight times. Doubling the load decreases life by 1/8. Every attempt should be made to design for loads that do not exceed the dynamic load rating of the nut.† Never exceed twice the rated dynamic load rating of the nut while in motion.

To use the load/life equation, look up the rated dynamic load for the assembly you are interested in. Use a diagram load that covers your typical worst case loading and compute the predicted theoretical design life as follows:

$$L = \left(\frac{Fr}{D \bullet f_w}\right)^3 \times 1 \times 10^6$$

L = life in inches
D = Design Load
Fr = Dynamic Load Rating
f_W = 1.2–1.5 Nominal Operation
1.5–3.0 Operation with impact or vibration

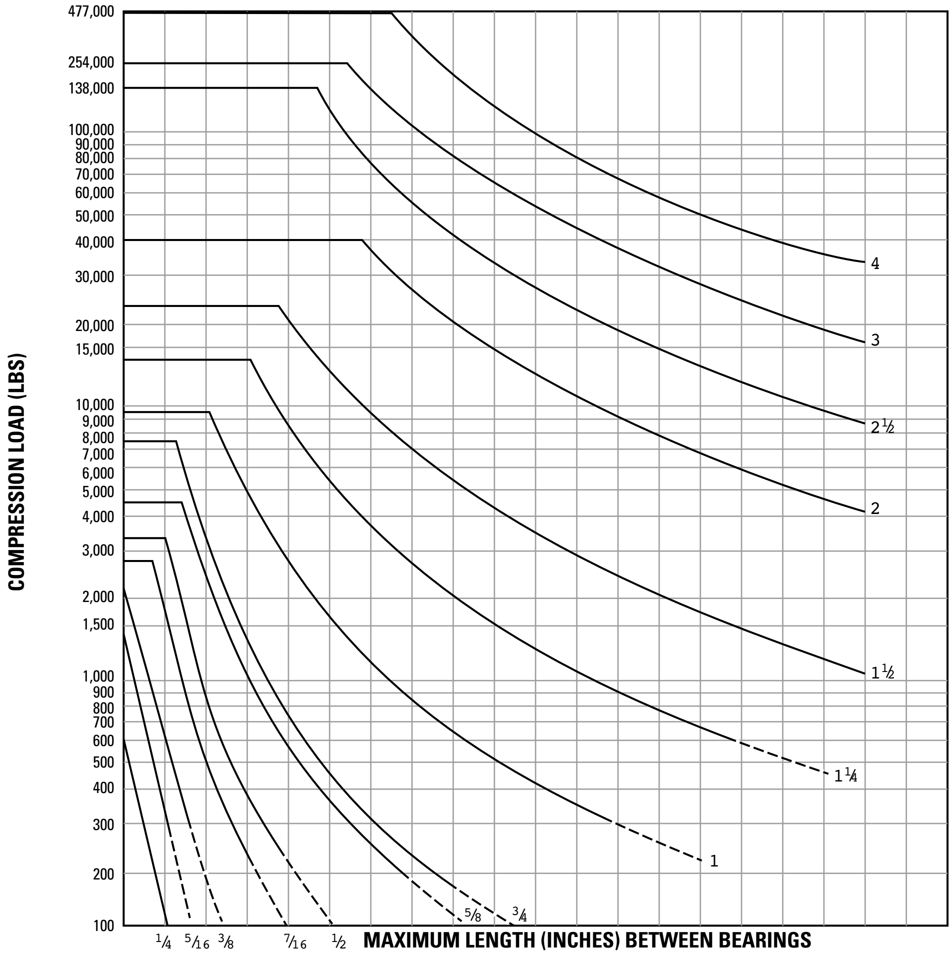
† BSA assumes no liability for assemblies used at above the dynamic load rating of the nut.

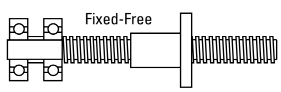
Engineering Guidelines for Lead Screws

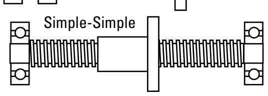
Column Loading Capacities Chart for Lead Screws and Ball Screws

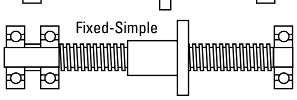
Use the chart below to determine the Maximum Compression Load for Screw Shaft. Usually, screw operated in tension can handle loads up to the rated capacity of the nut, providing the screw length is within standard lengths. End supports have an effect on the load capacity of screws. The four standard variations are shown below with corresponding rating adjustments. Find the point of intersecting lines of load (horizontal) and length (vertical) to determine the minimum safe diameter of screw. If loads fall into dotted lines, consult factory.

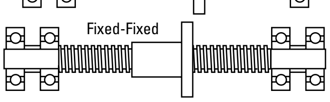
Warning: DO NOT EXCEED ball nut capacity. Curves for the screw diameters shown are based on the smallest root (minor) diameter of the standard screws within the nominal size range.



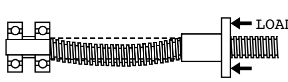
A


B


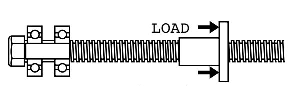
C


D


A	Inches	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
	mm	127	254	381	508	635	762	889	1016	1143	1270	1397	1524	1651	1778	1905	2032	2159	2286	2413
B	Inches	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
	mm	254	508	762	1016	1270	1524	1778	2032	2286	2540	2794	3048	3302	3556	3810	4064	4318	4572	4826
C	Inches	14	28	42	57	71	85	99	113	127	141	156	170	184	198	212	226	240	255	270
	mm	356	711	1067	1448	1803	2159	2515	2870	3226	3581	3962	4318	4674	5029	5385	5740	6096	6477	6858
D	Inches	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380
	mm	508	1016	1524	2032	2540	3048	3556	4064	4572	5080	5588	6096	6604	7112	7620	8128	8636	9144	9652



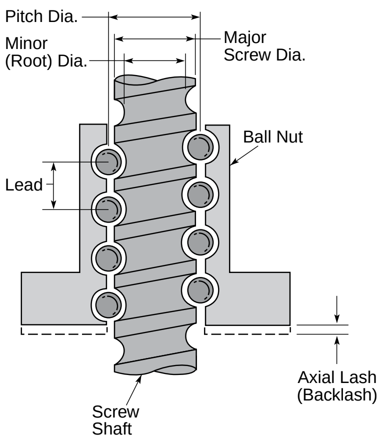
Compression (Column) Load



Tension (Pulling) Load

Glossary

General Definitions



AXIAL LASH/BACKLASH
The axial free motion between the ball nut and screw; a measure of system stiffness.

BEARING BALL CIRCUIT
The closed path of recirculating balls within the ball nut assembly. A multiple circuit nut with two or more individual circuits has a greater load carrying capability than a single circuit ball nut assembly of the same diameter.

CYCLE
The complete forward and reverse motion of the screw (or nut) when moving the load. One cycle is equivalent to two load carrying strokes (one forward and one backward).

DIAMETER—MAJOR
The outside diameter of the ball bearing screw shaft. In dealing with ball bearing screws, this is the basic measurement.

DIAMETER—MINOR (ROOT)
Diameter of the screw measured at the bottom of the ball track.

DIAMETER - PITCH
The nominal diameter of a theoretical cylinder passing through the centers of the balls when they are in contact with the ball bearing screw and ball nut tracks.

EFFECTIVE BALL TURNS
The number of ball groove revolutions within the ball nut body; a ball nut with seven effective ball turns will have a higher load carrying capability than one with five, all other characteristics being equal.

LEAD
The axial distance a screw travels during one revolution.

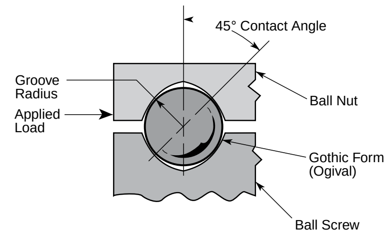
LEAD TOLERANCE
The maximum variation from nominal, measured in inches per foot, cumulative.

LOAD CARRYING BALLS
The balls in contact with the ball grooves of both the nut and the screw for load carrying purposes.

RIGHT HAND THREAD
The direction of the threads on the screw shaft causing the ball nut to travel away from the end viewed when rotated in a counter clockwise direction.

SCREW STARTS
The integral number of independent threads on the screw shaft; typically one, two or four.

Ball Contact



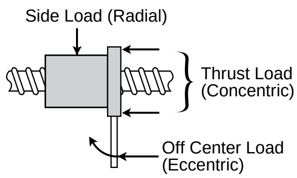
GOTHIC (OR OGIVAL) GROOVE
A ball track cross-section shaped like a Gothic arch.

CONFORMITY RATIO
Ratio of the ball track radius to the ball diameter.

CONTACT ANGLE
Nominal angle between a plane perpendicular to the screw and a line drawn between the theoretical points of tangency between a ball and the ball tracks and projected on a plane passing through the screw axis and the center of the ball. The angle at which the ball contacts the groove.

Glossary

Loading



DYNAMIC LOAD RATING
Dynamic load rating is the maximum load which a ball bearing screw assembly can maintain for a prescribed length of travel.

STATIC LOAD
Static load is the maximum non-operating load capacity above which brinelling of the ball track occurs.

THRUST LOAD
Thrust load is loading parallel to and concentric with the centerline of the screw shaft which acts continuously in one direction. Thrust loading is the proper method of attaching the load to the ball bearing screw assembly.

PRELOAD
The use of one group of bearing balls set in opposition to another to remove axial lash or backlash and increase ball bearing screw stiffness. All axial freedom is eliminated in preloading.

TENSION LOAD
Tension load is a load which would tend to stretch the ball screw shaft.

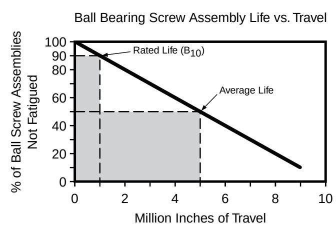
COMPRESSION LOAD
Compression load is a load which would tend to compress or buckle the ball screw shaft.

OFF CENTER LOAD (ECCENTRIC)
A load tending to cock the ball nut on the screw, reducing the rated life. This must be considered in the selection of the ball bearing screw assembly.

SIDE LOAD (RADIAL)
A load from the side that will reduce the rated life and must be considered in the selection of the ball bearing screw.

Load/Life

A rolling contact device such as a ball bearing screw is said to have reached the end of its usable life at the first sign of fatigue on the rolling surfaces. Fatigue results from the repeated flexing of metal as the balls pass over any given point under load.

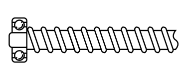


LOAD/LIFE RATING
The usable life of a ball bearing screw assembly measured in inches of travel under a specific load. The length of travel that 90 percent of a group of ball bearing screws will complete, or exceed, before the first evidence of fatigue develops. (B10)

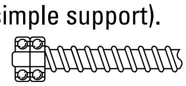
MOUNTING-ENDS

END BEARING SUPPORT (END FIXITY)
The three basic bearing configurations that are commonly used to support the ends of a ball screw are:

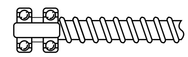
a) A single journal or ball type bearing (simple support).



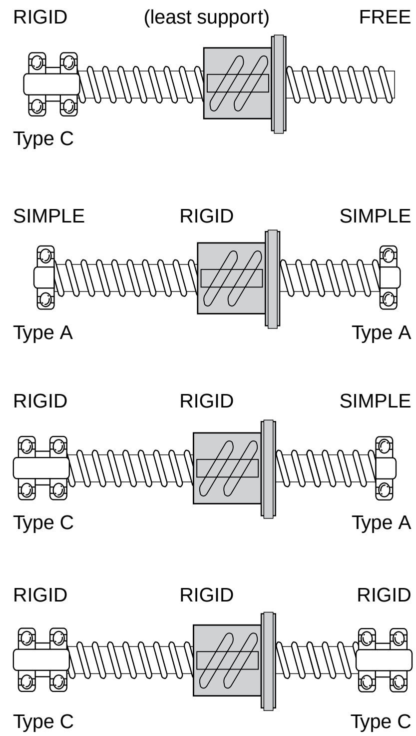
b) A pair of back-to-back, angular contact bearings to control end play (simple support).



c) A pair of spaced bearings for added rigidity (rigid support).



Four combinations of bearing supports are used throughout this catalog for selection purposes. They are:

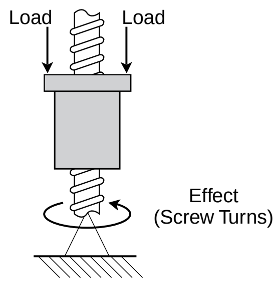


ANNEALED ENDS
A manufacturing process which removes brittleness while softening screw stock to allow for machining of end journals.

Glossary

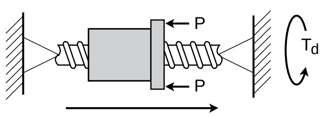
Backdriving

Ball bearing screws can be backdriven. A load on the nut will drive the screw because of the inherent high efficiency (90%).



If backdriving is required in a particular application, the lead of the screw should be at least one third the screw diameter. Ideally the lead should be equal to the screw diameter.

DRIVING TORQUE



The amount of effort, measured in pound-inches, required to turn the ball screw and move the load.

$T_d = \frac{P \times L}{2 \pi e} = .177\ P \times L$ (lb-inches)

T_d = Direct Torque (lb-inches)
P = Load
L = Screw Lead (inches/turn)
e = Ball Bearing Screw Efficiency (90%)

BACKDRIVING TORQUE

The backdriving torque (Tb) is the torque created by an applied load.

$T_b = .143\ (P)\ (L)$ = in-lbs

PRELOAD TORQUE

$$T_{PL} = \frac{P_{PL} \times L \times .2}{2\pi}$$

or

$$T_{PL} = .032 \times P_{PL} \times L$$

T_{PL} = Torque (lb-inches)
P_{PL} = Preload setting (pounds)
L = Lead

ANGULAR VELOCITY

$$\text{RPM} = \frac{\text{Velocity (inches/min.)}}{\text{Lead (inches/rev.)}}$$

HORSEPOWER

$$\text{HP} = \frac{\text{RPM} \times \text{Torque (in-lbs)}}{63{,}000}$$

ROTATIONAL TORQUE

To accelerate the screw

$$T_r = \frac{WR^2\ (\text{RPM})}{3700\ (t)} = \text{lb-in}$$

T_r =Torque (lb-in)
WR^2 = Inertia (lb-in)
t = Time to accelerate (sec.)

ACCELERATION TORQUE

Under load

$$Ta = \frac{(p/g)\ (A)\ (L)}{2\pi e} = \text{lb-in}$$

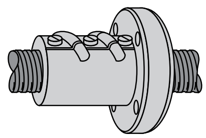
A = Acceleration (in/sec^2)
g = 386 in/sec2
p =Load (lb)
L = Screw lead (in/turn)

Thermal expansion of screw
= 6.25×10^{-6} in/in/°F

Design Considerations

Most Frequently Asked Questions About Ball Screws

Question How do you restrict the flange from turning off the nut in reversing load applications?



Answer The flange may be held to the nut by three alternative methods:

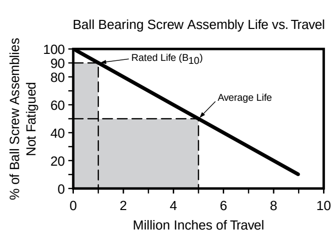
a) The most positive method of holding the flange to the nut is to order factory “drill and pin” prior to bearing loading. The flange and nut are drilled to accept a roll pin from the flange face.

b) The flange may be drilled and tapped from the O.D. into the nut threads. A carbide spade drill may be used to drill into the hardened nut threads. Avoid getting metal chips into the nut.

c) Commercially available adhesives such as Loctite may be used. Take care to avoid getting adhesive on the ball track. (Light loads only).

Question How do you calculate application life requirement in inches?

Answer Each ball bearing screw application will have an expected life given the stroke length, duty cycle, years of required service and load.



a) Life expectancy is the total inches of travel that an assembly will provide under a stated load. (Life is sensitive to load.) Use the Load Life Relationship on page 85 to calculate the expected life of a particular assembly in inches.

b) To determine the inches of required life: multiply inches of stroke x two (only on vertical applications) x cycles per hour x hours of operation per day x number of working days per year x years of expected service.

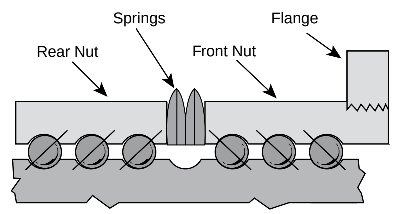
c) Compare the expected life to the required life. Expected life can be increased by choosing a ball screw with a larger load rating.

Question Is lubrication necessary?

Answer Proper and frequent lubrication must be provided for satisfactory service and life. A 90% reduction in ball bearing screw life should be allowed where dry operation is unavoidable. Lubricants reduce abrasive wear and dissipate heat caused by metal-to-metal contact between bearing surfaces. See page 78 for BSA lubricants.

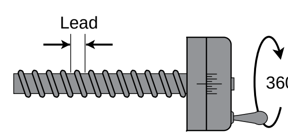
Question How are torque requirements for preload nuts calculated?

Answer Driving torque increases only slightly with preload since a preload unit continues to be highly efficient.



First, determine the driving torque for a single nut working at a given load. Second, determine the torque required for the preload load setting. Add the driving torque and preload torque together to determine total torque requirement.

Question What is meant by lead error?



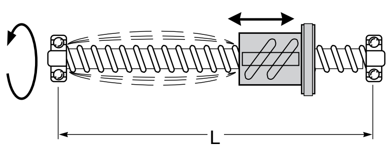
Answer Lead error is the average deviation from the nominal lead that occurs in one foot of nut displacement. Most screws are offered in standard and precision grades. (See pages 41 – 59 for more details.)

Design Considerations

Question How are ball bearing screws synchronized?

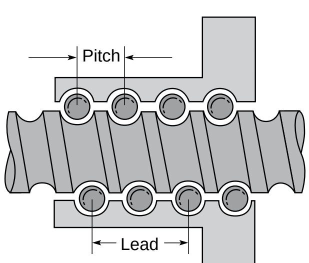
Answer Screw synchronizing is achieved by selecting screws with similar lead error and driven by a positive single source drive. "Matched sets required" should be specified when ordering screws that should be timed to run together without binding because of lead mismatch. (Special factory order).

Question What can be done to exceed calculated critical speed?



Answer The chart for critical speed is on page 84. Critical speed is a function of unsupported screw length, mean diameter of screw and bearing supports. Rigid/rigid screw mounting is the optimum support for high speeds. Consider a faster lead to reduce the RPM required. If higher speed is still necessary, go to a larger diameter screw.

Question What is the difference between pitch and lead?



Answer Pitch is the measurable distance between screw grooves. Lead is the linear travel the nut makes per screw revolution. The pitch and lead are equal with single start screws. The pitch is 1/2 the lead in two start screws, etc.

Question What is the standard straightness on machined screws with standard ends or screws machined to customer prints?

Answer The threaded portion is .005 T.I.R. per foot and not to exceed .010 T.I.R. total length of screw.

Question What is meant by tangential design nuts?

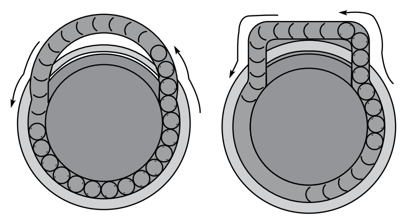


FIGURE 1 FIGURE 2

Answer The tangential circuit (Fig. 1) consists of a pickup finger (or yoke deflector) geometry which allows the circuit balls to enter and leave the load carrying portion of the ball screw circuit in a straight line path—along the tangent to the pitch diameter.

The standard ball nut design (Fig. 2) places the return tube holes closer together resulting in a circuit which requires a change in direction of the ball travel as the return tubes are entered and exited.

Question What is the backlash of single nuts?

Answer The backlash range in a single nut is as follows:

Model	Max. Backlash
R-0308 to R-0705	.007"
R-0702 to R-1105	.009"
R-1501 to R-1502	.013"
R-2202 to R-2502	.015"
R-3066	.018"

Question Can backlash be minimized?

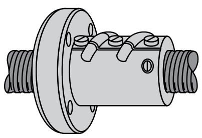
Answer Yes, backlash can be minimized or eliminated completely by using a preloaded ball bearing screw. See pages 44, 48, and 52.

Question What is a load locking spring and how does it work?

Answer The load locking spring is a coil that is turned into the inactive portion of the nut and conforms to the ball track. The spring does nothing in normal operation and does not touch the screw. In the event the ball bearings are lost from the nut, the load locking spring will not allow the load carrying nut to free-fall down the screw.

Design Considerations

Question Where is the lube hole in the large size nuts and what is the thread size?



Answer A 1/8-27 NPT pipe thread tapped hole is standard on most nuts from R-1502 through R-3066.

Question How do you size a ball bearing screw?

Answer Select the screw that will satisfy the most critical requirement of the application, such as high RPM, heavy load, duty cycle, column loading or zero backlash. Design for the worst case. See page 42.

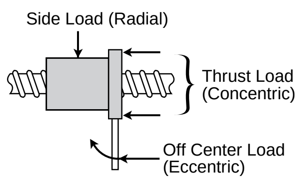
Question How is a hardened screw annealed?

Answer The ball bearing screws are case hardened to Rockwell C56 minimum. The screw ends are coil annealed after they are cut to length to reduce the case hardness to a machinable state. Screws may be annealed in the field by heating the ends to a cherry red with a torch, then putting the ends in sand to cool.

Question How should ball bearing screws be protected from dirt and contaminates?

Answer The brush wipers help prohibit contaminates from entering the nut as it translates along the screw. For heavily contaminated environments, metal shields, bellow type enclosures or extensions are recommended to be used with wipers.

Question What causes premature failure?



Answer Premature failure may be caused by any of the following:

a) Misalignment of ball nut to screw which results in side loading or eccentric loading will reduce life. This may cause the bearing balls to split or get flats on them. The bearings may even break out of the tubes.

b) Metal Chips or Dirt in the ball nut will not allow the bearings free circulation. The bearing balls may get flats on them because of skidding and spalling.

c) Lack of Lubrication Proper lubrication will help dissipate heat and reduce metal-to-metal wear of components.

d) High speed operation Shaft speeds resulting in screw surface speeds above 8,000 IPM will reduce rated life.

Question What is the normal operating temperature range for ball bearing screws?

Answer The normal operating temperature range is –65°F to 300°F (–55°C to 149°C) with suitable lubrication. Temperatures in excess of this may make the screw brittle, warped or annealed.