



HOW TO SIZE A BALL SCREW

ABOUT BALL SCREWS

A ball bearing screw is just that: a screw which runs on ball bearings. The screw and nut have matching helical grooves or races, and the ball bearings recirculate in these races. There is no physical contact between the screw and the nut. As the screw or nut rotates, and the rolling balls reach the trailing end of the nut, they are deflected or guided from this “pitch” contact by means of a return tube and returned to the leading end of the circuit. There, the cycle resumes and the balls recirculate continuously.



Major Diameter (Land Diameter) The outside diameter of the screw thread.

Minor Diameter (Root Diameter) The diameter of the screw shaft as measured at the bottom of the ball thread track. This diameter is used in column load and critical speed calculations. Minor diameter also is a consideration in support bearing selection.

Ball Pitch Diameter (Ball Circle Diameter) The theoretical cylinder passing through the center of the balls when they are in contact with the ball screw and ball nut races.

Lead The axial distance the screw or nut travels in one revolution.

Lead Error (Accuracy) The difference between the actual distance traveled compared to the theoretical travel based on the lead of the screw. The lead error for a standard screw will not exceed $\pm .007$ ” per foot and a premium grade screw will not exceed $\pm .003$ ” per foot. Lead error is cumulative based on the actual length of the ballscrew thread. Ref. Class 7-8 ANSI B5.48-1977. Lead charts describing incremental lead deviation offsets can be supplied (upon request). These incremental offsets can be input into motion controllers for lead error compensation.

Pitch The distance from one thread on the screw to a corresponding point on the next thread parallel to the screw axis. Pitch is equal to the lead on single start screws.

Screw Starts The number of independent threads on the screw shaft. The lead of the screw is calculated by dividing the threads per inch by the number of starts.

Backlash The axial free motion between the nut and the screw. It determines the amount of lost motion between the nut and screw on a horizontal application. Backlash on standard nuts range from .005 to .015, depending on the size of the screw.

Selective Fit The process of selecting a unique ball size for reducing backlash to as little as .001 inches.

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Efficiency Expressed as a percentage and is the ability of a ball screw assembly to convert torque to thrust with minimal mechanical loss. Rockford Ball Screws operate in excess of 90% efficiency.

Dynamic Load The maximum thrust load under which a ball screw assembly will achieve a minimum of 1,000,000 inches of travel before first signs of fatigue are present.

Static Load The maximum non-operating load capacity above which permanent damage of the ball track occurs.

Tension Load A load that tends to stretch the ball screw. This is the preferred mode of attaching the load since column loading limitations would not effect the screw.

Compression Load A load which would tend to compress or buckle the screw shaft. Use column load calculations to determine safe compression loads.

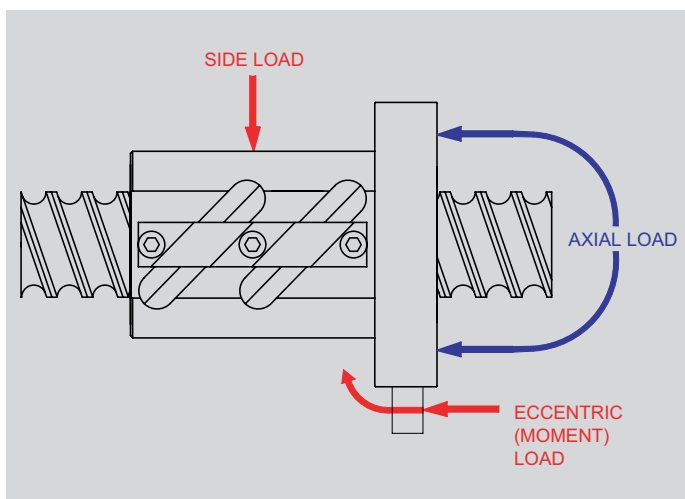
Axial Loading The recommended method of attaching the load to the ballnut. This load should be parallel to the centerline of the screw shaft and equally distributed around the mounting surface.

Eccentric (Moment Loading) A load tending to cock the ballnut on the screw and therefore reducing the rated life.

Side Loading (Radial Loading) A load that is applied perpendicular to the screw shaft. This type of loading will also reduce the rated life of the ball screw assembly.

Ball Screw Life (Life Expectancy) Expressed as total accumulated inches of travel under a constant rated thrust load (with proper lubrication and clean environment) before first evidence of fatigue develops (1,000,000 inches under stated rated loads). Ball screw life is rated similar to ball bearings (L10). The L10 life rating states that 90% of a similar group of screws will achieve this life. Although 10% will not achieve the life, 50% could exceed life by 5 times.

Applied Dynamic Loading Each unique application needs to be evaluated such that ALL force components are realized and accounted for. The force components might include: weight of the sliding mechanism (if vertical), weight of the sliding mechanism multiplied by the coefficient of sliding friction (if horizontal), any direct forces resisting the linear motion (such as tool cutting loads), and any other applicable force components.



$$P = W_f * \mu + F_p$$

- P = Applied Dynamic Load (LBS)
- Wf = Weight of Sliding Load (LBS)
- μ = Coefficient of sliding friction
(=1 if load orientation is vertical)
- Fp = Force component pushing directly against the sliding mechanism

Coefficient of sliding friction for non-vertical loading applications

Steel on Steel	~.58
Steel on Steel (greased)	~.15
Aluminum on Steel	~.45
Gibb Ways	~.50
Dove Tail Slides	~.20
Linear Bearing (Ball Bushings)	<.001

Frictional coefficients are included for reference purposes only and may vary in accordance with actual operating conditions.

Equivalent Load This calculation is used in applications where the load is not constant throughout the entire stroke. This equivalent load can be used in life calculations. In cases where there is only minor variation in loading, use greatest load for conservative life calculation. Please note that the drive torques and horsepower requirements should always be based on the greatest thrust load encountered.

$$P_e = \sqrt[3]{\frac{\%_1(P_1)^3 + \%_2(P_2)^3 + \%_3(P_3)^3 + \%_n(P_n)^3}{100}}$$

Pe = Equivalent Load (lbs)
Pn = Each Increment at Different Load (lbs)
%n = Percentage of stroke at load increment

Example: 450 lb. load for 25% of stroke
 760 lb. load for 50% of stroke
 200 lb. load for 25% of stroke

$$P_e = \sqrt[3]{\frac{25(450)^3 + 50(760)^3 + 25(200)^3}{100}}$$

Equivalent Load (Pe) = 625 lbs.

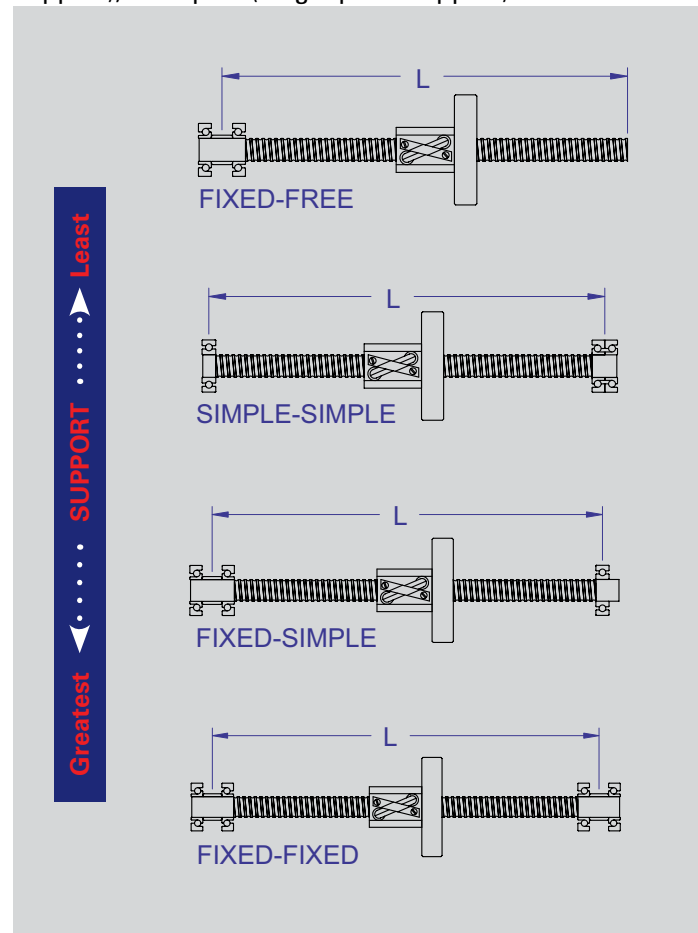
Life At Loads (Other than Rated) Based on the inverse cube ratio in that by operating at 1/2 the rated load you will get 8 times the life or operating at twice the rated load you will get 1/8 the life.

$$\left(\frac{\text{Rated Load}(P_r)}{\text{Actual Load}(P_i)}\right)^3 * 10^6 = \text{Life of assembly under actual load}$$

Design Life Objective Design Life Objective is the number of inches that a ball screw will travel during the desired life of the machine. Generally it is ultimately stated in terms of years of life but we need to compare inches of travel to inches of calculated life.

Length of stroke = 6 inches
 Cycle rate of machine = 20 Strokes/hr.
 Hours of operation /day = 16 hours
 Number of working days per year = 250 days
 Number of years machine is designed for = 5 years
 6 * 20 * 16 * 250 * 5 = 2,400,000 inches of life

End Fixity End Fixity (Bearing Mount Support Configuration) refers to the method by which the ends of the screws are supported. The end fixity basically describes the bearing configuration being used to support the rotational axis of the screw. The end fixity combinations are determined as a result of critical speed, column loading and system stiffness calculations. There are three basic end fixity styles that can be used in four combinations. The ends styles are "free" (no support), "Simple" (single point support) and "Fixed"





ABOUT BALL SCREWS

Critical Speed Critical Speed is the theoretical linear velocity (inches per min.) which excites the natural frequency of the screw. As the speed of the screw approaches the natural frequency (critical speed), the screw shaft begins to resonate which leads to excessive vibration. The resulting resonance can occur regardless of whether the screw or nut rotates or regardless of screw orientation. R/B/S recommends limiting the maximum linear velocity to 80% of the calculated critical speed value.

Column Load Strength Column Load Strength is the ability of the screw shaft to withstand compressive forces. The fundamental limit occurs when a compressive load exceeds the elastic stability of the screw shaft. Exceeding the column load will result in bending and buckling of the screw. This mode of failure can only occur when the screw shaft is in compression and never in tension. R/B/S recommends limiting the maximum compressive load to 80% of the calculated column load strength.

$$C_s = \frac{F_e * 4.76 * 10^6 * D_{min} * S_L * F_s}{L^2}$$

- Cs = Critical Speed (Inches/min.)
- Dmin = Minor Diameter (root) of Screw (In.)
- SL = Screw Lead (In.)
- L = Distance between bearing supports
- Fe = End Fixity Variable
 - = .36 for Fixed-Free Support Configuration
 - = 1.00 for Simple-Simple Configuration
 - = 1.47 for Fixed-Simple Configuration
 - = 2.23 for Fixed-Fixed Configuration
- Fs = Factor of Safety (80% recommended)

$$P_c = \frac{F_e * 14.03 * 10^6 * D_{min}^4 * F_s}{L^2}$$

- Pc = Maximum Column Load (lbs.)
- Dmin = Minor Diameter (root) of Screw (In.)
- L = Distance (max.) between load and bearing in compression (inches)
- Fe = End Fixity Variable
 - = .25 for Fixed-Free Support Configuration
 - = 1.00 for Simple-Simple Configuration
 - = 2.00 for Fixed-Simple Configuration
 - = 4.00 for Fixed-Fixed Configuration
- Fs = Factor of Safety (80% recommended)

Critical Ball Speed (DN Value) is the critical ball velocity within the ball nut. Exceeding this value can have a detrimental effect on the life of the ball screw assembly.

$$DN = (3000 / \text{Screw Nominal Diameter}) * \text{Lead (inches / revolution)}$$

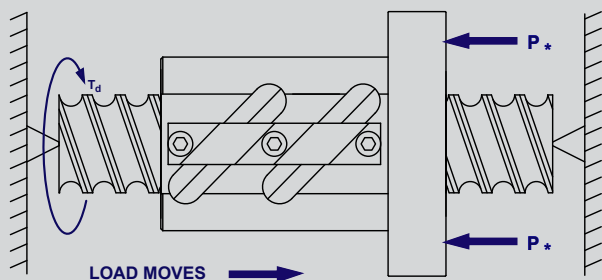
Drive Torque Drive Torque is the amount of torque (inch pound) required by the ball screw to move the load. This torque does not take into account any inertial loading required for acceleration.

$$T_d = \frac{S_L * (P * \mu)}{2\pi \text{Eff}} = .177 * S_L * (P * \mu)$$

T_d = Drive Torque (Inch pounds)
P = Applied Dynamic Load (LBS)
S_L = Lead of Screw (Inches)
μ = Coefficient of Sliding Friction
 (=1 if load orientation is vertical)
Eff = Ball Screw Efficiency (90%)

Coefficient of sliding friction for non-vertical loading applications

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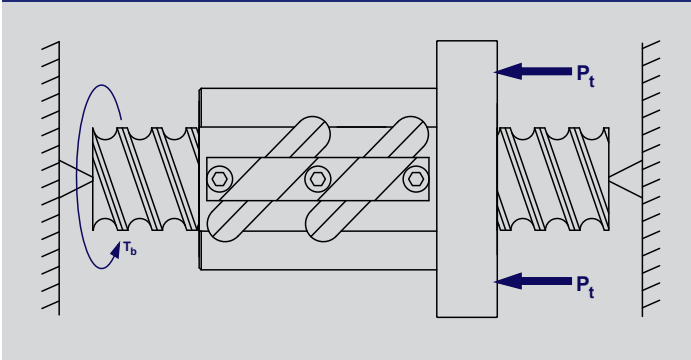


Frictional coefficients are included for reference purposes only and may vary in accordance with actual operating conditions.

Back Drive Torque The torque produced through the screw shaft by a thrust load on the ball nut. Ball screws can coast or backdrive due to the high efficiency of the mechanism (90%). If back driving is not acceptable, a method to resist the overturning backdriving systemic torque, such as a brake, will be required to hold the load. If backdriving is desired, the lead of the screw should be at least 1/3 of the screw diameter. Ideally the lead should be equal to the screw diameter. This calculated torque is the minimum amount of braking torque to hold the load in position.

$$T_b = \frac{S_L * P_t * \text{Eff}}{2\pi} = .143 * S_L * P_t$$

T_b = Backdrive Torque (Inch pounds)
P_t = Thrust Load applied to Nut (LBS)
S_L = Lead of Screw (Inches)
Eff = Ball Screw Efficiency (90%)



ABOUT BALL SCREWS

Power Requirements The power (HP) to drive a ball screw assembly is a function of required drive torque and motor R.P.M. Horsepower should be calculated based on the maximum torque required during the stroke or cycle. The highest torques generally are during acceleration due to inertial loading.

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

$$\text{Horsepower} = \frac{\text{RPM*Drive Torque (in.lbs)}}{63,000}$$

Materials and Hardness Most screws and nuts are made from alloy steel and case hardened to Rc 56 minimum. Our stainless steel models are made of 17-4ph precipitation hardenable stainless steel with a surface hardness of Rc 38 minimum.

Screw Straightness Screw straightness is extremely important in minimizing screw vibration. Our ball screw stock is straight to .010" per foot not to exceed .025" over the entire length. We can hold straightness on machined screws to as little as .002"/foot (screw diameter and length dependent).

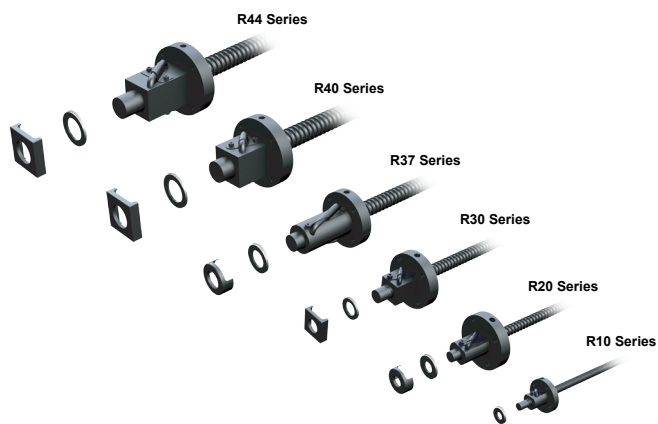
Temperature Range Temperature range for our ball screws is between -65°F. (-54°C) and 300°F. (149°C) with suitable lubricants.

Lubrication Lubrication is required to achieve optimum life for a ball screw assembly. Ball screws that are not lubricated can experience up to a 90% reduction in calculated life. In general, standard lubrication practices for anti-friction rolling element bearings apply. Grease, oil or dry film lubrication can be used.

Ball Screw Finish Ball Screw Finish is a black oxide coating to help prevent corrosion during shipping and brief storage. Long term corrosion resistance is accomplished by the rust inhibiting properties of the screw lubricant.



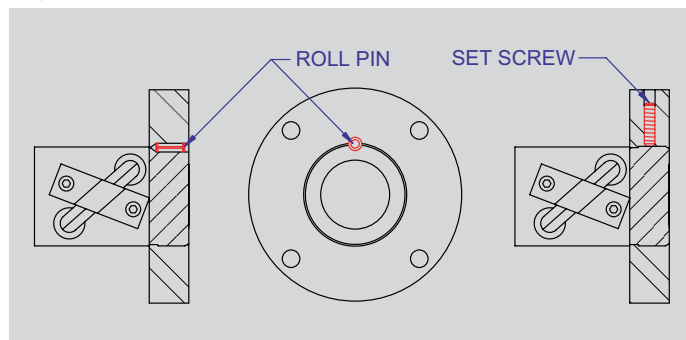
Wiper Kits Wiper kits are available for all standard ball screw models. The nylon brush wiper is designed to keep large particulates from entering the ball nut. However for harsh environments, the use of boots or bellows to enclose the screw is recommended.



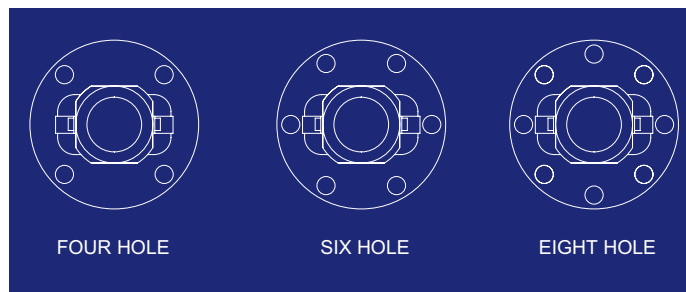
Safety Springs The safety spring is a coiled spring installed in the inactive part of the ball nut and conforms to the ball screw thread. The spring is inactive during normal operation and does not contact the screw. In the rare event that the balls are lost from the ball nut, the safety spring will assume the load and prevent the nut from “free falling” down the screw. The spring is not designed to maintain normal operation and the ball screw assembly should be taken out of service after first engagement of spring. Safety springs are available for R20-44 ball screw models. The safety spring is mandatory if the screw is being used to lift, support or otherwise transport people.



Mounting Flanges If a mounting flange is used instead of the standard v-thread on the ball nut body, it must be permanently attached to prevent disengagement during operation. The two standard methods of retaining the flange is pinning and retaining with a set screw. Commercial thread locking adhesives may also be used (light loads only).



Flange Orientation The orientation of the flange bolt holes to the return tube components varies with the number of holes in the flange. Unless otherwise specified, the following illustrations represent the standard orientations.





CHARACTERISTICS

EFFECT OF CHANGE IN PARAMETER

INCREASE IN	EFFECTS	HOW
Screw Length	Critical Speed Column Load	Decreases Decreases
Screw Diameter	Critical Speed Inertia Stiffness Spring Rate Load Capacity Column Load	Increases Increases Increases Increases Increases Increases
Lead	Torque Input Load Capacity Positioning Accuracy Angular Velocity Ball Diameter	Increases Increases Decreases Decreases Increases
Angular Velocity	Critical Speed	Decreases
Mounting Rigidity	Critical Speed System Stiffness	Increases Increases
Load	Life	Decreases
Nut Length (7 1/2 Turn Max)	Load Capacity Stiffness	Increases Increases
Number of Balls	System Stiffness Load Capacity	Increases Increases
Preload	Positioning Accuracy System Stiffness Drag-Torque	Increases Increases Increases
Ball Diameter	Life Stiffness Load Capacity	Increases Increases Increases



HOW TO SIZE A BALL SCREW

Ball Screw Selection Example:

Specification:

Equipment: Transfer Table
 Screw Orientation: **Horizontal**
 Load Supported on Dove Tail Ways: **.20** Coefficient of friction
 Load is **2500** lbs. Max (combined weight of product and table)
 Stroke Length: **24"**
 Travel rate: **600** inches per minute (Max.)
 Input RPM: **600**
 Duty Cycle: **20** cycles per hour, **16** hours per day, **250** days per year
 Required Life: **5** years

Given Specification in GOLD
Resultant Calculation in RED
Catalog Product Data in PURPLE

Specifications to be used to select proper ball screw assembly

Steps:

1 Determine Required Life (Inches):

$$24"/\text{stroke} * 2 \text{ strokes/cycle} * 20 \text{ cycles/hr} * 16 \text{ hrs/day} * 250 \text{ days/year} * 5 \text{ years} = 19,200,000 \text{ inches}$$

2 Determine Thrust Load on Ball Screw – Multiply the thrust load by the coefficient of sliding friction (for horizontal application):

$$2500 \text{ lbs.} * .20 \text{ Coefficient of Friction} = 500 \text{ lbs.}$$

Use this load for life calculations. (If load varies during the stroke or cycle, an equivalent load calculation can be utilized page 9)

3 Determine Required Ball Screw Dynamic Axial Loading to Achieve Required Life:

Using formula on page 9, input the **500** lbs. thrust load (Or equivalent load) and the required life.

$$\left(\frac{\text{Rated Load}(P_r)}{\text{Actual Load}(P_t)} \right)^3 * 10^6 = \text{Life of assembly under actual load}$$

$$\hookrightarrow \left(\frac{P_r}{500\text{lbs}} \right)^3 * 1,000,000 = 19,200,000\text{in.}$$

The result is the minimum rated load for a ball screw to achieve the required life.

$$\hookrightarrow \frac{P_r^3}{500^3} = \frac{19,200,000}{1,000,000} \rightarrow P_r = \sqrt[3]{19.2 * 500^3} = 1,339\text{lbs}$$

4 Determine Lead of the Screw:

Travel Rate (pg 12):

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

$$\hookrightarrow \frac{600"/\text{min Travel Rate}}{600\text{RPM}} = 1.000" \text{ per revolution (Lead)}$$

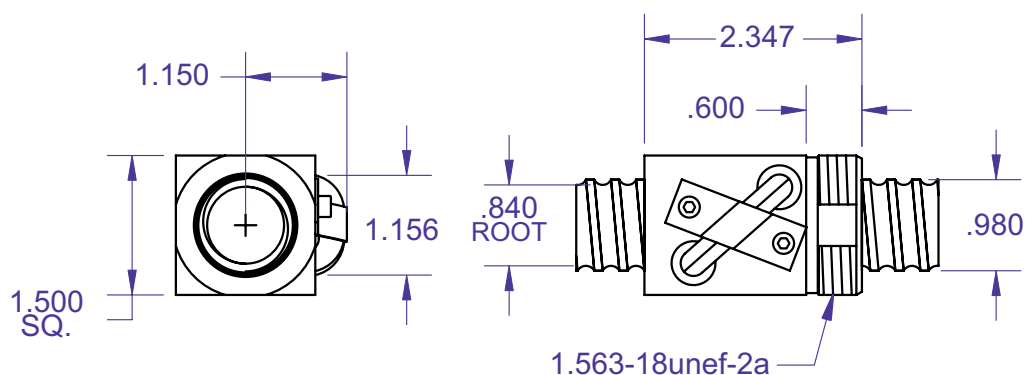
USE THIS QUICK REFERENCE CHART TO SELECT APPROPRIATE BALL SCREW MODEL

MODEL	SCREW DIA. X LEAD	SCREW RATED LOAD	SCREW MINOR DIA.
R10	.375x.125	150	0.300
R20	.500x.500	850	0.400
R30	.631x.200	825	0.500
R37	.750x.500	3,400	0.630
R40	1.000x.250	1,625	0.840
R44	1.000x1.00	2,300	0.840



Ball Screw Selection:

Load Rating: Requires Ball Screw Operating Load Capacity of **1,339** lbs. Minimum
 Smallest diameter screw with **1,339** lbs. (min.) Operating load and a **1.000"** lead is the R44 (page 39)



5 Calculate Length Between Bearing Supports:

Length between bearings = Stroke length + ballnut length + Desired over-travel

24" stroke + **3.000** nut length + **1"** over-travel = **28.000"** between bearings
 (use this length for column load and critical speed calculations)

6 Calculate End Fixity Based on Critical Speed Limits:

Using formula for Critical Speed, rearrange to solve for Fe (End Fixity Variable)

$$C_s = F_e * 4,760,000 * F_s * \left(\frac{D_{\min} * S_L}{L^2} \right)$$

Cs = Critical Speed (Inches/min.) = **600 in./min.**

Dmin= Minor Diameter (root) of Screw (In.) = **.840** (pg 47) (STEP #4)

Sl = Lead of Screw (In.) = **1.000 Lead** (pg 47) (STEP #4)

L = Distance between bearing supports = **28.000"** (STEP #5)

Fe = End Fixity Variable (Maximum Value)

= .36 for Fixed-Free Support Configuration

= 1.00 for Simple-Simple Configuration

= 1.47 for Fixed-Simple Configuration

= 2.23 for Fixed-Fixed Configuration

Fs = Factor of Safety (80% recommended)

Equations below will solve for the minimum end fixity factor based on Travel Rate (**600 in/min.**)

$$600 \text{ in/min} = F_e * 4,760,000 * .8 * \left(\frac{.840 * 1.00}{28.000^2} \right)$$

$$F_{e(\min)} = \frac{600 * 28.000^2}{4,760,000 * .8 * .840 * 1.00} = \mathbf{0.147} \text{ Select End Fixity Factor larger than } \mathbf{0.15}$$



Thus a Simple-Simple (**Fe = 1.00**) is the proper selection

7 Actual Calculated Critical Speed:

This calculated critical speed is based on the Simple-Simple end fixity arrangement. It is the maximum safe linear speed with this mounting arrangement, screw model and between bearing supports distance. If greater speed is required, a Fixed-Simple arrangement can be used, recalculate maximum speed based on a fixed-simple end fixity configuration (Fe=1.47).

$$C_s = 1.00 * 4,760,000 * .8 * \left(\frac{.840 * 1.00}{28.000^2} \right) = \mathbf{4,080 \text{ in/minute}}$$

(maximum attainable safe linear speed)

8 Calculate Critical Ball Speed (DN):

Critical ball speed is the maximum safe linear speed of this model regardless of screw length. In this example DN should not be less than 687" per minute.

$$DN = \left(\frac{3000}{\text{Ball Screw Diameter}} \right) * \text{Lead}$$

$$DN = \frac{3000}{1.00} * 1.00 = 3000 \text{ in/minute safe linear speed}$$

9 Calculate Column Load Limit:

This calculated column load is the maximum safe compression load allowable based on mounting arrangement, screw model and distance between bearings. In this example the calculated column loading should be greater than **500 lbs. (Step#2)**.

$$P_c = F_e * 14,030,000 * F_s * \left(\frac{D_{min}^4}{L^2} \right)$$

P_c = Maximum Compressive Column Load (lbs.) allowable for the given length

D_{min} = Minor Diameter (root) of Screw (In.) = .840" (Step #4)

L = Maximum unsupported length in compression (inches) = **28.000"** (Step #5)

F_e = End Fixity Variable

= .25 for Fixed-Free Support Configuration

= 1.00 for Simple-Simple Support Configuration

= **2.00 for Fixed-Simple Support Configuration**

= 4.00 for Fixed-Fixed Support Configuration

F_s = Factor of Safety (80% recommended)

$$P_c = 1.00 * 14,030,000 * .8 * \left(\frac{.840^4}{28.000^2} \right) = 7,128 \text{ lbs (max)}$$

10 Calculate Drive Torque:

$$T_d = \frac{S_L * P_t}{2\pi \text{ Eff}} = .177 * S_L * P_t$$



.177 * 500 * 1.000 = 88.5 in. lbs torque at constant velocity

T_d = Drive torque (in. lbs)

S_L = Lead of screw in inches = 1.00"

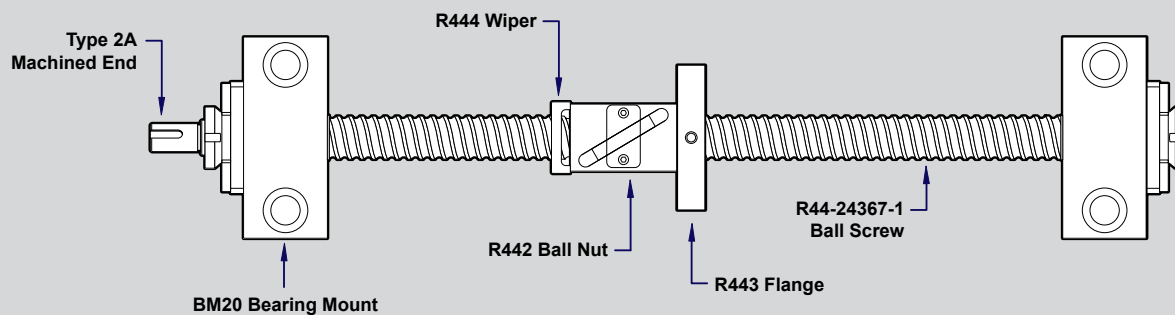
P_t = Thrust Load (lbs.) = 500 lbs.

Eff = Efficiency 90% (min.)

11 Calculate H.P. Required at Constant Velocity:

$$\text{Horsepower} = \frac{\text{RPM} * \text{Drive Torque (in.lbs.)}}{63,000} \rightarrow \frac{600(\text{RPM}) * 88.5(\text{in.lbs.})}{63,000} = .84\text{H.P. min.}$$

12 Specifying Proper Ball Screw Assembly:



Model Size: **R44** Ballnut #: **R442** Mounting Flange #: **R443**

Wiper Kit #: **R444**

Bearing Mount Part #: **BM20** (Simple support) drive end

BM20 (Simple support) non-drive end

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