



Chapter 1

What is a Ball Screw?

- ❑ **Lesson 1: What is a Ball Screw?**
 - Section 1: Variety of Screws
 - Section 2: Construction of Ball Screw

- ❑ **Lesson 2: Characteristics of Ball Screws and Application Examples**

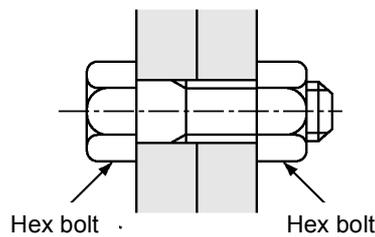
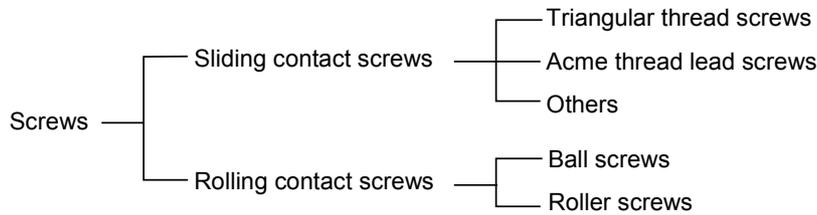
NSK Ltd.

Precision Machinery & Parts
e-Project Team

Lesson 1: What is a Ball Screw?

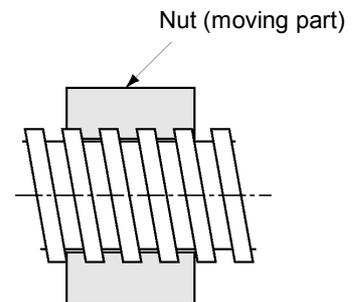
We discuss construction of the ball screws in this section.

Section 1 Variety of Screws



Triangular thread screws

- Used to fasten two objects.
- Move a nut linearly by rotating a screw.



Acme thread lead screw

- Used to move things or to transfer forces.
- Screw portion of a jack, one of the tools furnished with a car, is a good example.

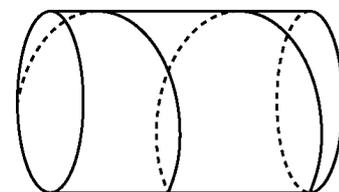


↓
Would like to operate it more easily!
↓
Development of ball screw

◆ Clipping data ◆ What is a screw?

When you rotate a ball nut around its axis, the ball nut moves in its axial direction since screw grooves are continuously provided in a helical form.

Namely, the screw is a mechanical element that converts a rotational motion into a linear motion. These screws that move things or transmit forces are the means to convert small rotational force into large thrust (a force to push).

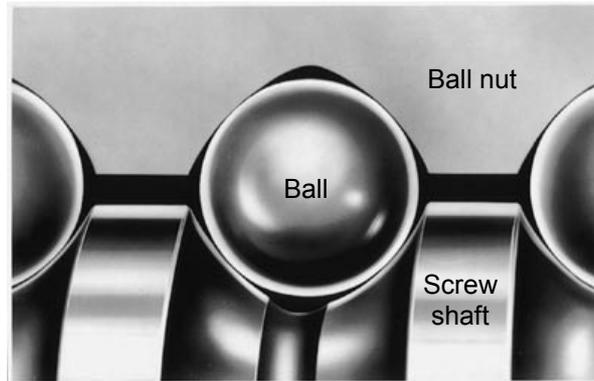


Section 2 Construction of Ball Screw

1 “Would like to rotate the screw more lightly and smoothly!”



By providing steel balls in between the screw shaft and the nut (grooves), and the balls roll on the grooves (i.e., Change to rolling contact from sliding contact to reduce friction. Refer to the illustration below.).

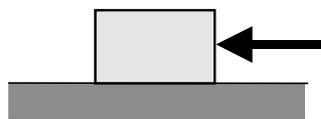


■ Note ■ What is friction force? (Sliding and rolling friction)

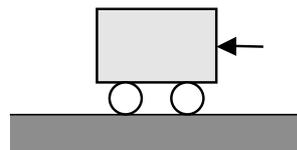
◇When you want to slide a box sitting on a floor, it does not move while your pushing force is yet too small (static frictional force). But, it starts moving when the pushing force has reached a certain level. In order to keep the box moving on, you need to maintain your pushing force at its dynamic frictional force, which is far less than the static frictional force.

As described above, the **friction force** is the force that two objects exert upon each other through their contact surface and hinder each other's relative movement when they are in contact.

◇The intensity of frictional force varies with the state of contact. A friction force of rolling contact is usually smaller than that of sliding contact.



Sliding friction ↔ Acme thread screw
(Requires larger force)



Rolling friction ↔ Ball screw
(Requires far less force)

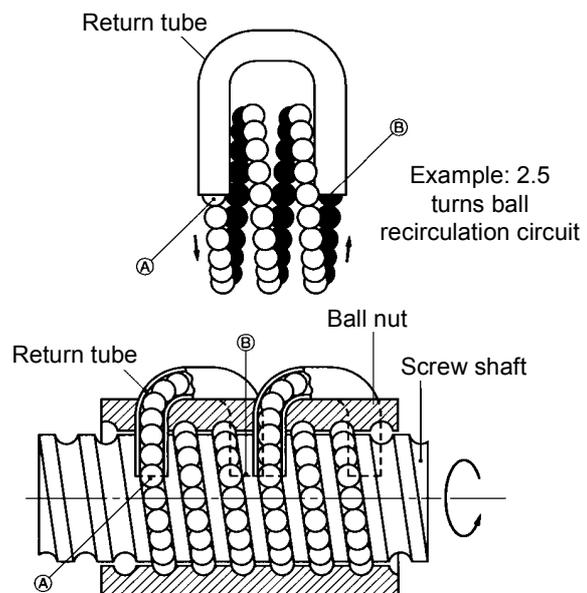
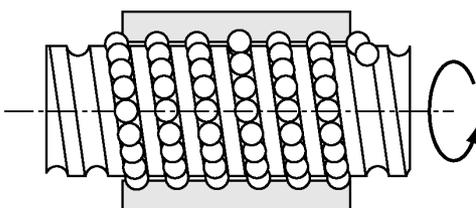
- 2 The ball nut moves on the screw shaft. (Stroke) → It requires a means to prevent ball from falling off the ball nut. → Mechanism to recirculate balls.

◆ Clipping data ◆ Why do the ball screws require ball recirculation parts?

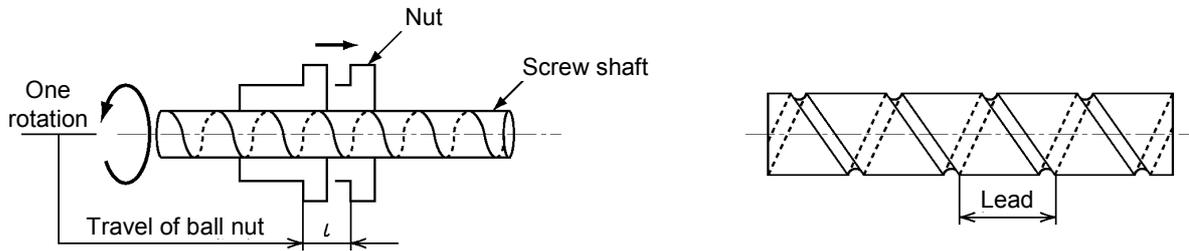
In case of a ball bearing, its steel balls roll only in a circular groove, thus there is no way for steel balls to go out of it. However, since the groove in the ball screw is helical, its steel balls roll along the helical groove, and then, they may go out of the ball nut unless they are arrested at a certain spot. Thus, it is necessary to change their path after they have reached a certain spot by guiding them, one after another, back to their “starting point” (formation of a recirculation path). The recirculation parts play that role.

- 3 The way the steel balls recirculate endlessly (in the case of return-tube type)

When the screw shaft is rotating, as shown in the illustration, a steel ball at point (A) travels 2.5 turns of screw groove, rolling along the grooves of the screw shaft and the ball nut, and eventually reaches point (B). Then, the ball is forced to change its pathway at the tip of the tube, passing back through the tube, until it finally returns to point (A). Whenever the nut strokes on the screw shaft, the balls repeat the same recirculation inside the return tube.

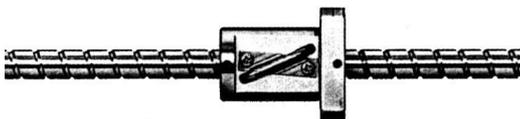


4 Ball screw lead

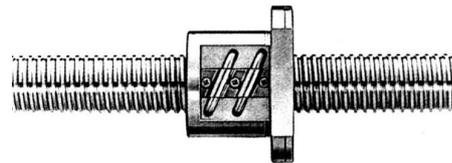


◆ Lead sizes: The lead is classified into two categories to suit various application.

- High helix lead (Large lead) : With this, the ball nut travels a longer distance when the screw shaft makes one rotation (or the ball nut makes one revolution). This is suited to high speed operation.
- Fine pitch lead : The ball nut travels a shorter distance when the screw shaft makes one rotation (or the ball nut has made one revolution). This is suited to highly accurate positioning.



High helix lead
(inter-groove distance is larger.)



Fine pitch lead
(inter-groove distance is narrower.)

■ Learn the Math! ■ Relation between lead and rotational speed of screw shaft

[Example]

What is the travel speed of a ball nut with a lead of 10 mm, when its screw shaft rotates at 2000 rpm.?

$$(10 \text{ mm/revolution}) \times 2000 \text{ revolutions/min.} = 20000 \text{ mm/min. (= 20 m/min)}$$

☕ Coffee Break ☕ The History of the Ball Screw

According to a literature in the 19th century, there was an attempt to replace sliding friction with rolling friction by means of balls inserted between a male screw and a nut, namely this is a concept of the ball screw, in order to rotate a screw of driving mechanism more lightly (illustrated below). Because of technological level of those days, however, they could not practically apply the idea. The Saginaw Division of General Motors in the United States used ball screws practically for the first time in automobile steering gears in the 1940's. Since then design and production technology for ball screws have made great advancement.

In Japan, as mechanical industries advanced, the call for ball screws grew louder. Responding to these voices, NSK took the initiative to develop ball screws using its expertise in ball-bearing design and manufacturing, and the company eventually succeeded in launching the first ball screw type automobile steering gears in Japan in 1958.

Although the main application target for the precision ball screws was NC machine tools, the first job for which it was used was to convert acme thread lead screws of the X, Y and Z axes of a milling machine called K5, manufactured by Makino Milling Machine Co. Ltd., into ball screws. This K5 model was the best-selling brand in the industry back then, and over fifty machines were produced monthly. The NSK precision ball screws were used for the first time in them.

Thereafter, due to ever-progressing improvement in design techniques and manufacturing technologies, as well as needs for streamlining production in general, the high performance characteristics of ball screws soon made them one of the vital elements of NC machines, laborsaving machinery, and so on.

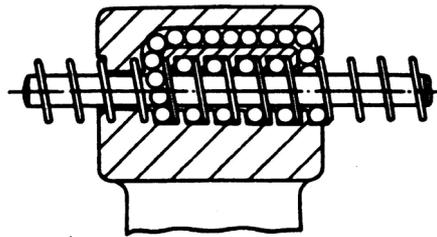


FIG. 1.30

A.D. 1898. In *The Practical Engineer* for 9th and 10th December, 1898, there appeared an article entitled "The Design and Construction of Ball Bearings" by C. H. Benjamin, which

Fig. 1.30 shows what may perhaps be considered the most ingenious application of balls yet made—a ball bearing screw and nut. The balls follow each other like sheep through a hole in the wall, travelling all the windings of the screw, and finally returning through the by-pass only to begin over again through interminable windings.

Introduction of ball screw in *The Practical Engineer*, December 1898
(R. K. Allan, Rolling Bearings)

Lesson 2: Characteristics of Ball Screws and Application Examples

Since ball screws feature application of rolling friction, they have various advantages (features) compared with sliding contact screws. Given below are explanations, with emphasis on the application.

1 High mechanical efficiency

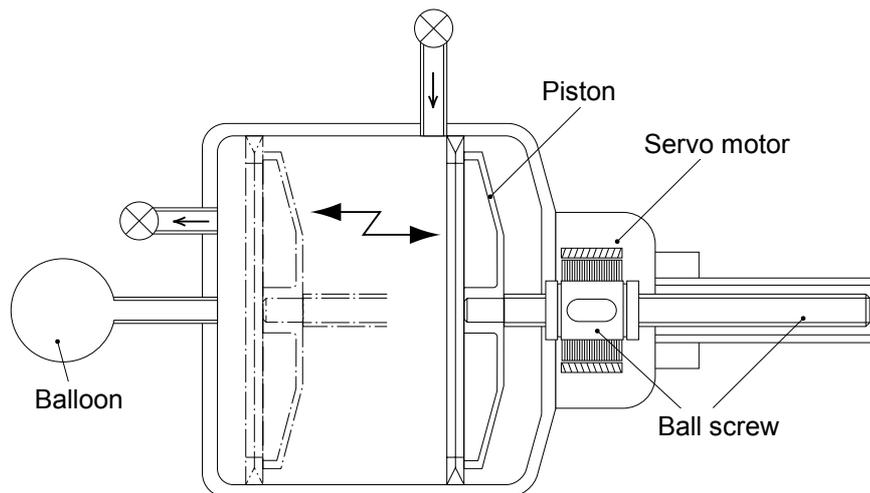
Most (90% or more) of the force used to rotate the screw shaft can be converted to the force to move the ball nut. (Since friction loss is extremely low, the amount of force used to rotate the screw shaft is as low as one third of that needed for the acme thread lead screw.)



Ball screws are used where motion direction must be changed (converted).

- From rotations to linear motion
- From linear motion to rotations

[Example 1] Artificial Respirator



A piston connected with the screw shaft moves while the ball nut is driven by a servo motor. This illustration shows a case in which the ball nut rotates and the screw shaft moves. There is also another case of this application in which the screw shaft rotates and the ball nut moves.

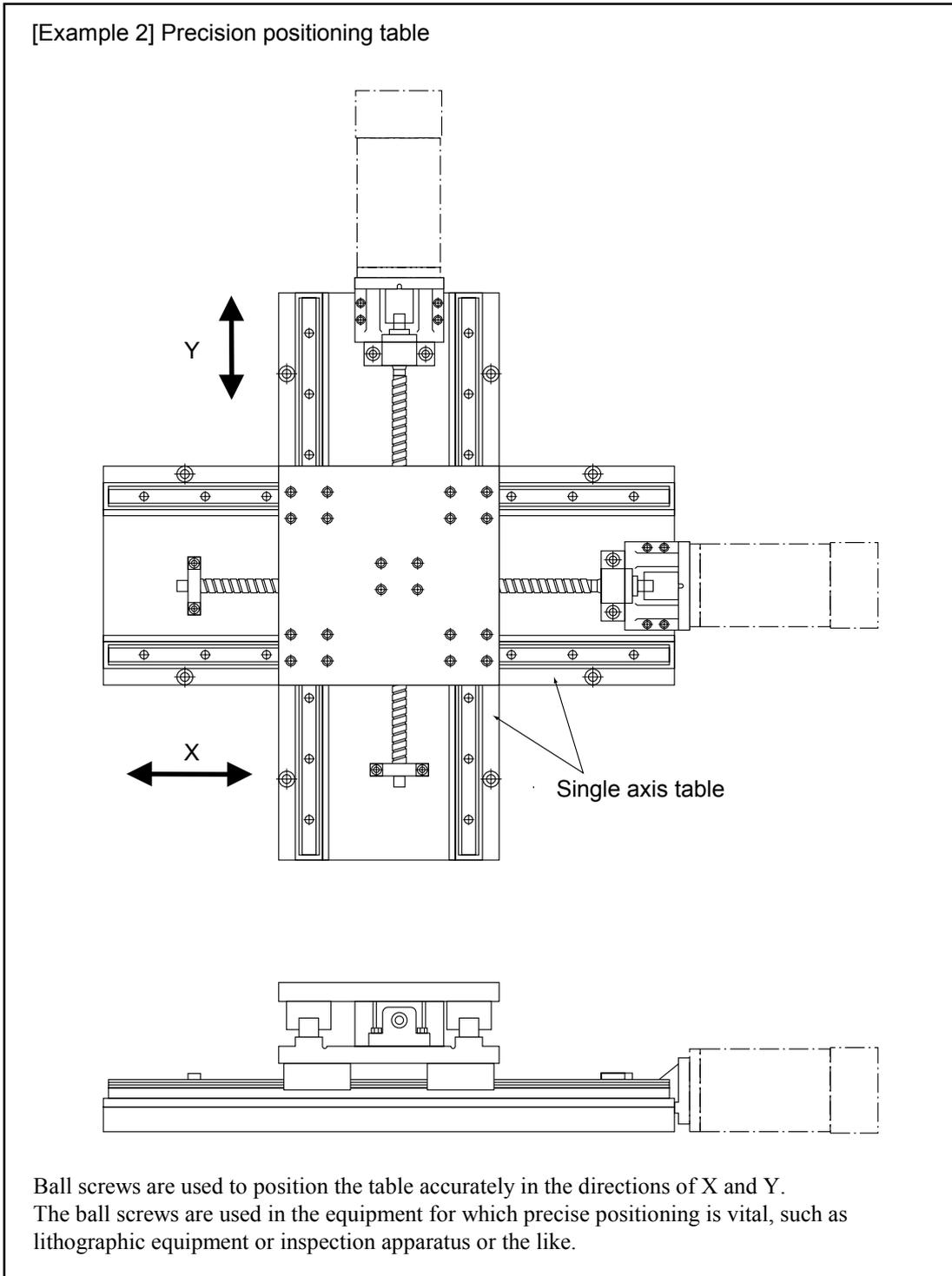
2 Low in wear

Because of rolling contact, wear is far less than that of sliding contact.

→ Thus, deterioration of accuracy is extremely low.



This is used for application that calls for precise positioning.



3 Low in wear

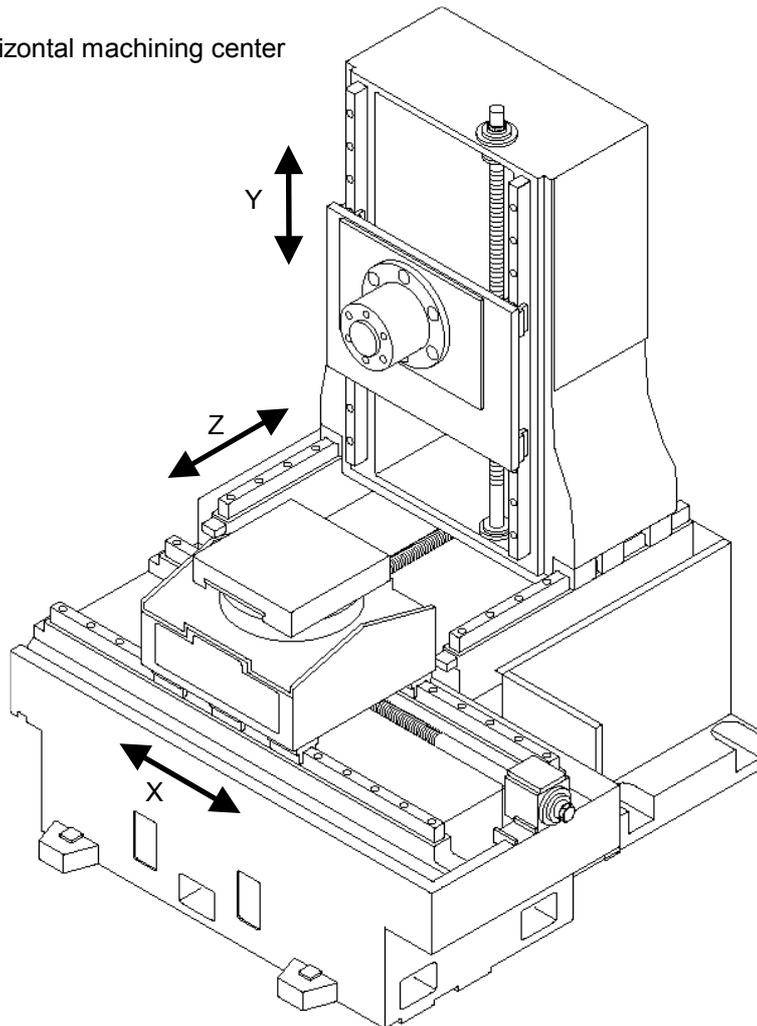
Ball screws move smoothly enough under very slow speed. They run smoothly even under a load.



- Used when a light, smooth motion is needed.
- Used when precise positioning is required.
- Used when heavy items must be moved lightly.

[Example 3] Machine tools

Horizontal machining center



Ball screws are used to move each table in X, Y and Z directions. Generally, heavy cutting force acts on the ball screws in cutting machines, such as machining center and NC lathe.

4 Estimation of life is possible.

Estimation of fatigue life of ball screw under given conditions is possible because the basics of life estimation are the same as those of rolling element bearings.



- It is possible to design a machine based on required life.
- Decision of ball screw specifications is easy.

5 Ball screw lead

The specifications of ball screws are standardized in ISO, JIS, etc.

NSK

Chapter 2 Construction of Ball Screws and Their Functional

- Lesson 1: Component Parts of Ball Screws**
 - Section 1: Screw Shaft
 - Section 2: Ball Recirculation Systems and Their Parts
 - Section 3: Steel Balls
 - Section 4: Seals

- Lesson 2: Accuracy of Ball Screws**
 - Section 1: Lead Error
 - Section 2: Accuracy Grade of Lead Error
 - Section 3: Mounting Accuracy

- Lesson 3: Preload and Rigidity of Ball Screws**
 - Section 1: Preload of Ball Screws
 - Section 2: Rigidity of Ball Screws
 - Section 3: Preloading Systems

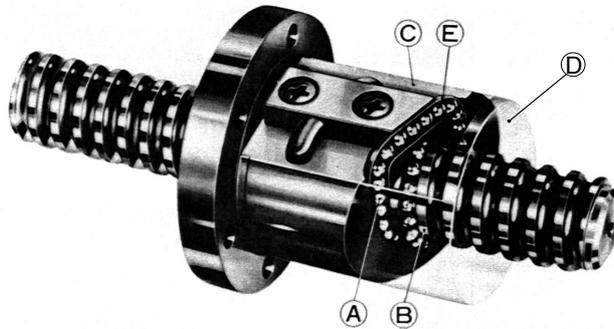
- Lesson 4: Combination of Shaft Diameter and Lead**

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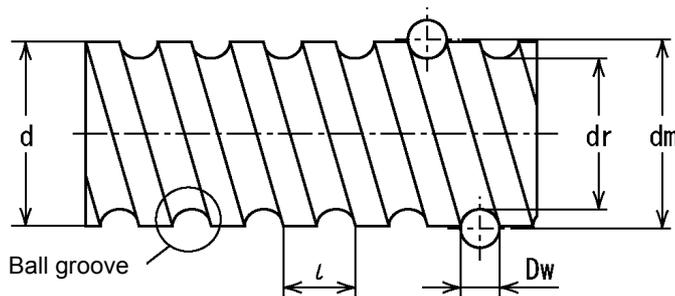
Lesson 1: Component Parts of Ball Screws

In this chapter, you will learn what components a ball screw is made of, and technical terms related to those components.



- A: Steel ball
- B: Screw shaft
- C: Ball nut
- D: Seal (both sides of ball nut)
- E: Recirculation parts (return tube, etc.)

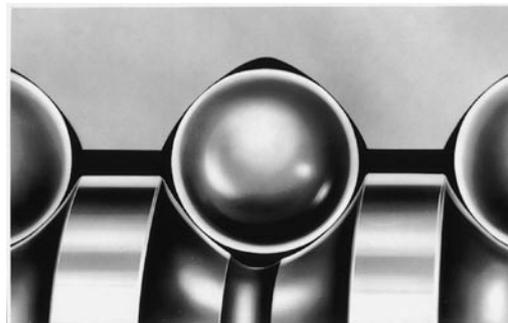
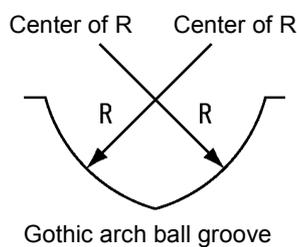
Section 1 Screw Shaft



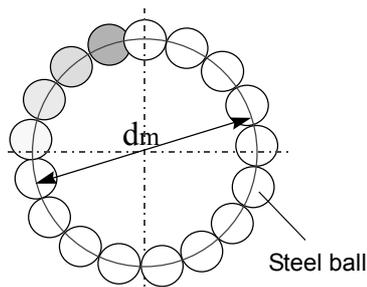
- D : Screw shaft diameter
(Nominal diameter)
- d_m : Pitch circle diameter of balls
- d_r : Root diameter of screw shaft
- L : Lead
- D_w : Ball diameter

1 Profile of ball groove

The profile of ball groove looks like the shape of the roofs that are characteristic to Gothic-style buildings. It is called “Gothic arch” ball groove.



2 Ball pitch circle diameter



This is the diameter of a circle formed by the center of recirculating balls. This dimension is needed for studies on permissible rotational speed (explained in Chapter 4). It is the measurement listed in the dimension tables in catalogues.

3 Root diameter of screw shaft

This refers to the diameter formed by the bottom of ball grooves on the screw shaft. This is thinnest part of the ball screw, and it is needed to calculate the critical speed of a screw shaft. The measurement is listed in the dimensions table.

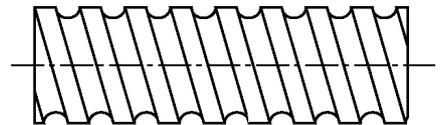
4 Direction of turns of ball screw thread

There are two directions of turn, right and left hand screws. Mostly, right turn screws are used.

◆ Right hand screw

If you trace the groove in clockwise looking at the screw shaft in its axial direction, the ball thread is away from you. (In the illustration, the spiral goes away from an end of the shaft.) Such screws are called right hand screws. As the illustration shows, the groove slants to the right.

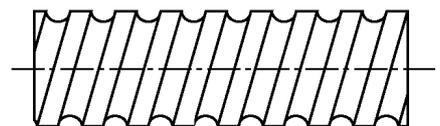
Right hand screw



◆ Left hand screw

If you trace the groove in clockwise looking at the screw shaft in its axial direction, the ball thread approaches to you. (In the illustration, the spiral comes near to an end of the shaft.) Such screws are called left hand screws. As the illustration shows, the groove slants to the left.

Left hand screw



Section 2 Ball Recirculation Systems and Their Parts

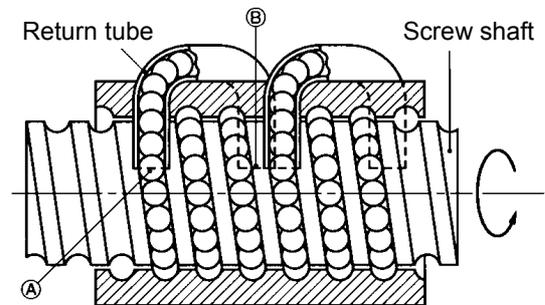
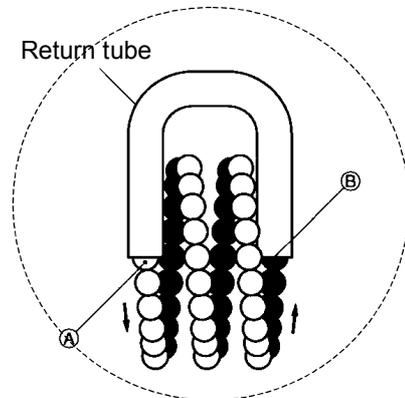
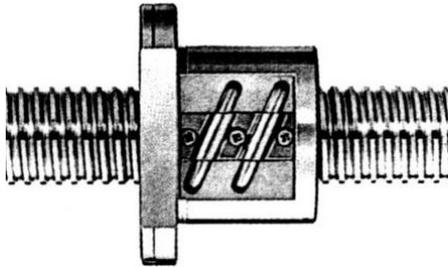
NSK ball screws utilize three different recirculation systems.

1 Profile of ball groove

◆ Ball recirculation part: Return tube

◆ Feature

- Applicable to wide range of combinations of shaft diameter and lead.
- Good const performance.
- Adaptability to mass production: Excellent
- Number of turns of balls/circuit: Generally 1.5 ~ 3.5 turns.

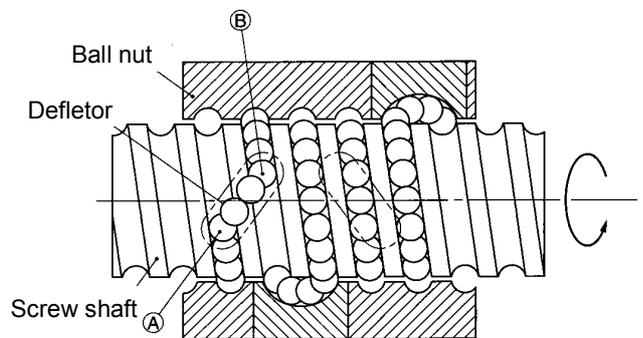
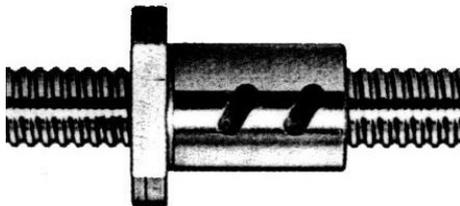


2 Ball pitch circle diameter

◆ Ball recirculation part: Deflector

◆ Features

- Suits for fine pitch lead. Compact in ball nut diameter.
- Adaptability to mass production: Poor
- Number of turns of balls/circuit: One turn only.



◆ Clipping data ◆

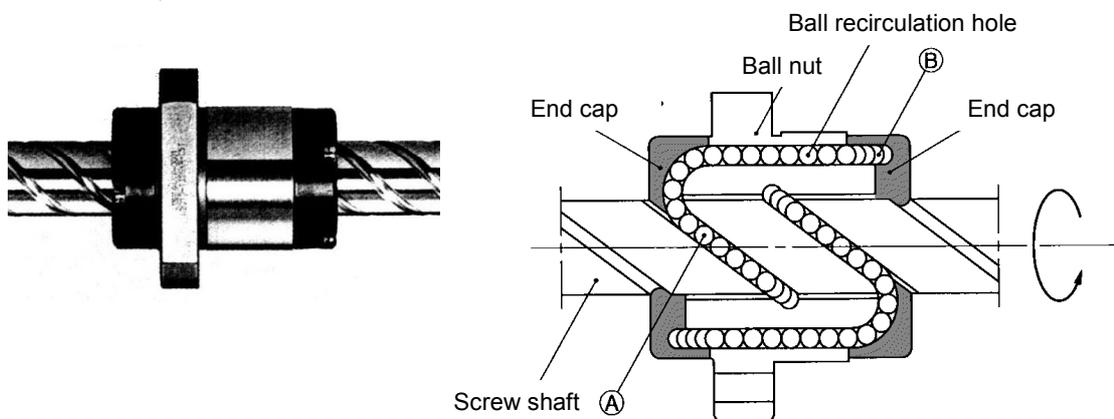
- Circuit: A circuit in which steel balls circulate endlessly around their screw shaft.
 - Number of turns: The number of ball grooves in a single circuit where steel balls are circulating around (in contact with) the screw shaft.
- (Effective number of turns: [number of turns] × [number of circuits] i.e., the total number of turns of steel balls that can bear loads in the axial direction of the shaft)

3 End cap type

◆ **Recirculation part: End cap (Ball recirculation hole is provided in the ball nut.)**

◆ **Feature**

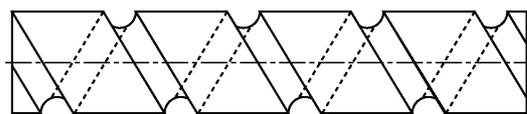
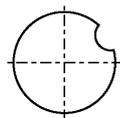
- For high helix leads for which the return tube and the deflector type are not applicable.
- Not versatile in production as a die mold is required for respective models.
- Adaptability to mass production: Moderate
- Number of turns of balls/circuit: 0.7 and 1.7 turns (Generally, it is applied to a multi start thread ball screw)



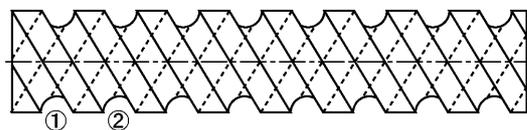
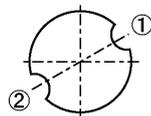
★ **Point! “What is a multi-start thread screw?”**

In general, there is one ball groove in one screw shaft. This is called a “single start thread” screw. When two or more ball grooves are involved, such screws are collectively called “multi-start thread” screws.

Single start screw



Double start screw



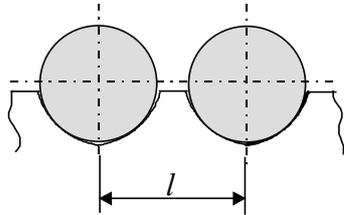
Phase of first and second threads is 180° apart.

As the lead becomes larger, the spaces between ball grooves become wider. In addition, as the lead becomes larger, it is more difficult to maintain the number of effective turns of balls. (The nut cannot be made longer because of some limitations associated with the manufacturing reasons.) In order to have the maximum number of effective turns, we have to increase the number of ball grooves. By adding extra ball grooves to the inter-groove spaces (a more effective utilization), you can have more effective turns of balls. This is the reason why the multi start screws are used for high helix lead ball screws.

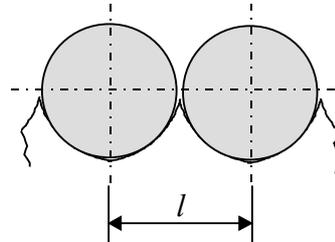
Section 3 Steel Balls

◆ Diameter of steel ball

The diameter of steel balls is determined, after giving due consideration to the balance between the screw shaft diameter and lead (l), rigidity, load capacity, smooth operation, etc.



When ball diameter fits for the lead
(Flat at the crest of the screw thread is maintained between two adjacent grooves.)

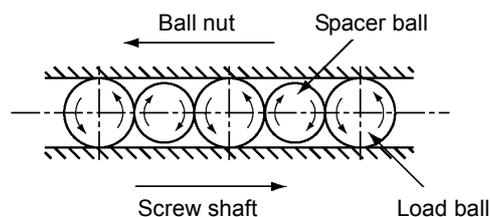
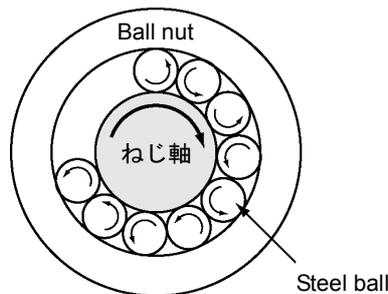


When ball diameter is too large for the lead
(No flat at the crest of the screw thread between two adjacent grooves.)

◆ Insertion of balls

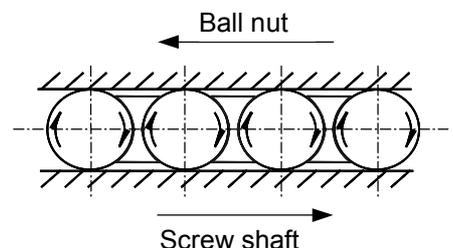
- Steel balls roll along the ball grooves formed between the screw shaft and the nut. Since there are no such retainers to hold steel balls as those provided for rolling element bearings, adjacent steel balls will come into contact each other, and, as the result, a ball screw tend to be jammed when clearances between balls is lost.
- On the other hand, we sometimes insert steel balls, that are just several tens of micrometers smaller than regular steel balls, between regular steel balls to function as a retainer in order to improve smoothness of a ball screw (refer to the illustration below). These small steel balls are called “spacer balls.” However, the load capacity will decrease by half since the number of balls that can bear loads decreases to half.

To differentiate from balls that work as “spacer balls,” regular steel balls are called “load balls.”



● NSK S1 Series™ ball screws

We have marketed S1 Series ball screws in which “retaining pieces” are inserted between load balls instead of the spacer balls. The size of the retaining piece is far less than the spacer ball and thus, reduction of load balls in S1 series are kept at the minimum. Therefore, reduction in load carrying capacity and rigidity is maintained in 10 to 15 % of the full load ball specification. As the retaining piece eliminates direct ball to ball contact, substantial improvement in smoothness and noise level reduction compared to the spacer ball specification have been attained. We will discuss the S1 Series ball screws in Chapter 4.

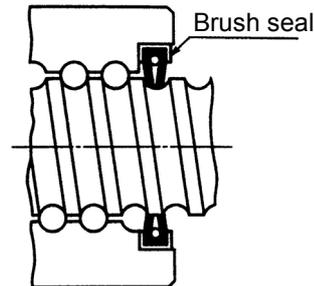
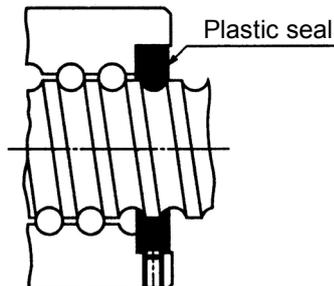


Section 4 Seals

When debris or foreign matter enter the inside of the nut, it could affect smoothness in operation or cause premature wearing, either of which could adversely affect the ball screw's functions. To prevent such things from occurring, seals are provided to keep contaminants out.

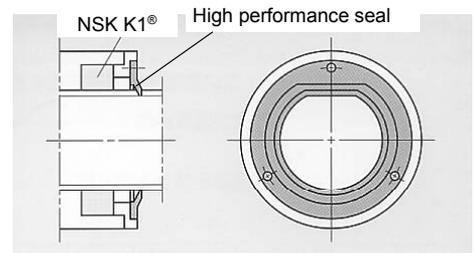
1 Standard seal

Type of seal (1) Plastic seal (General or standard ball screws / Non-contacting type)
(2) Brush seal (Rolled ball screws / Contacting type)



2 High performance seal

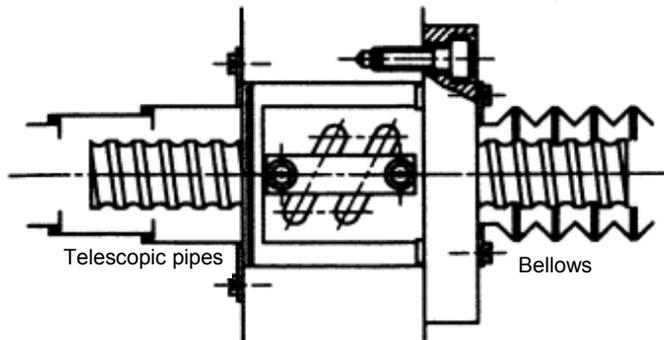
- Sealing capability is enhanced by adding a lip of which shape is very similar to cross section of the screw shaft to minimize an increase in torque.
- With bottom recess areas eliminated, the ball grooves in the screw shaft are designed to a special shape to contribute to improved sealing performance.
- For better dust prevention and durability, it is a standard feature to use NSK K1[®] lubrication unit.
- Effects: According to in-house evaluation test results compared with conventional seals;
 - (1) Foreign matter contamination is reduced to one-fifteenth, and
 - (2) The life of ball screws are more than quadrupled.
- Applicable types: These products shall be made upon user's request since most appropriate seal shapes must be designed and manufactured according to the specific screw shaft diameter and lead.
- Accuracy and preload are the same as for the regular products. Dynamic friction torque, however, will increase slightly.
- Applications: Woodworking machines, laser cutting machine, welding machine for automobile manufacturing lines, and others, which are used in areas prone to dust or foreign matter.



Installation of high performance seal

3 Other

Bellows or telescopic pipes (provided by customer) should be used when the seals cannot withstand the application atmosphere to completely cover the screw shaft.

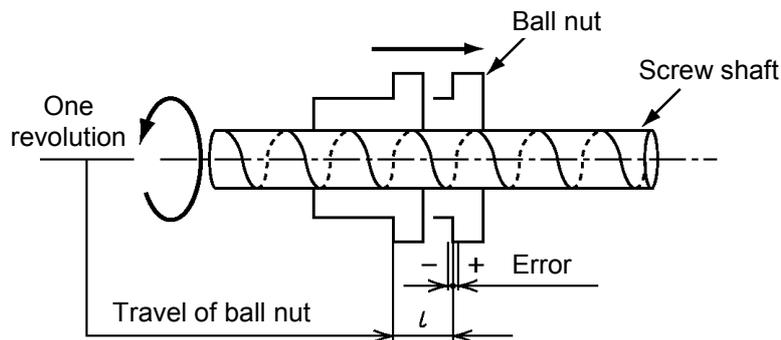


Lesson 2: Accuracy of Ball Screws

“Lead accuracy” and “mounting accuracy” are two accuracy items that allow ball screws to accomplish their functions as feed screws. A basic explanation of those items is given in this section.

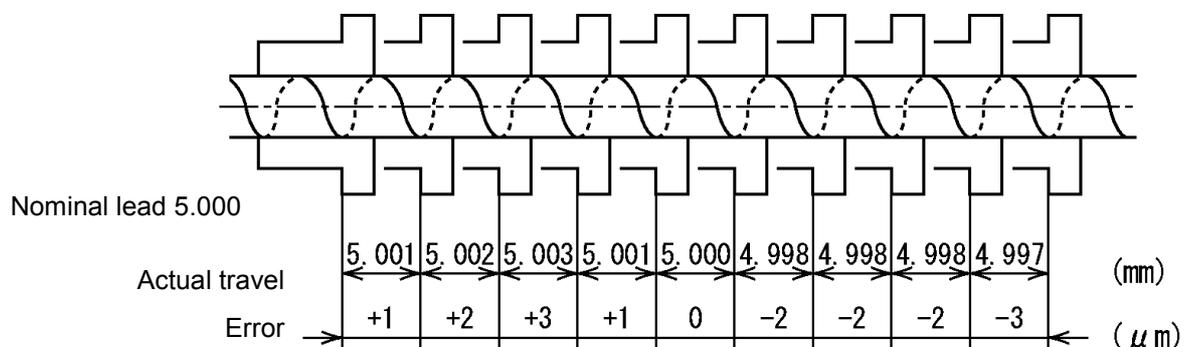
Section 1 Lead Error

Definition of the lead error is “the accuracy of a distance (nut travel accuracy) that the nut has traveled when the screw shaft has rotated.” It is completely dependent on manufacturing accuracy of the ball grooves in their feed direction.



For example, suppose that one ball screw has been manufactured with an intended lead of $l = 5.000$, you may still get $l = 4.998$ or $l = 5.005$. As such, a plus or minus error is actually involved.

In addition, as illustrated below, errors could vary from one lead to another.



Since such lead errors could directly affect a driving system in variation of feeding velocity or positioning inaccuracy, there are detailed rules and criteria for the accuracy of ball screws in the relevant industrial standards, such as ISO, JIS, etc.

Section 2 Accuracy Grade of Lead Error

Category \ Item	Positioning series				Transportation series		
Accuracy grade	C0	C1	C2	C3	C5	Ct7	Ct10
v_{300}	3.5 μm	5 μm	7 μm	8 μm	18 μm	52 μm	210 μm
Quality	High accuracy ←						

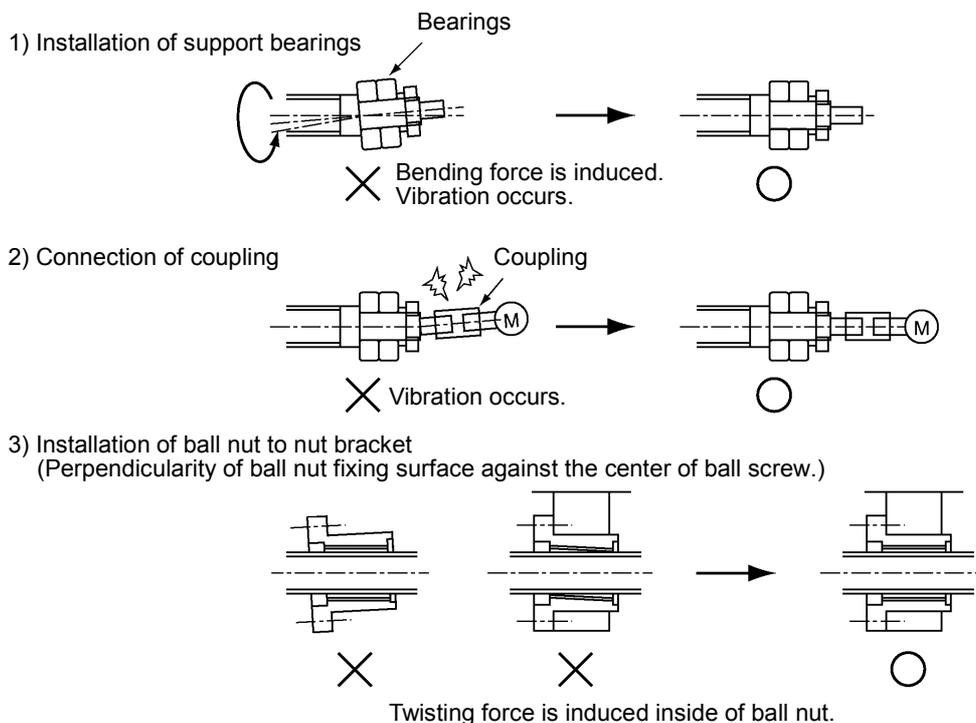
Occasionally, a customer may ask that a product have accuracy of “10 μm or less in v_{300} ,” instead of specifying an accuracy grade.

◆ Clipping data ◆

v_{300} : This is the largest variation (travel variation) in lead errors over any 300-mm interval within the effective travel length. We learn more details in Chapter 5, Lesson 1.

Section 3 Mounting Accuracy

Even a ball screw has an excellent lead accuracy, it won't give the benefit of the accuracy to a machine when a ball screw is not mounted accurately. Inaccurate mounting of ball screw may cause noise, vibrations, and a reduced service life. As a matter of course, the mounting accuracy of ball screws requires a wider range of considerations, including support bearings, couplings and a motor. Yet, for ball screw itself, accuracy of the bearing seats and shaft ends for pulley or coupling, in which those parts are installed, is still important to have assemble accuracy.



* In addition to mounting errors described above, other error such as bending of screw shaft, and diameter errors on screw shaft to which the bearings are inserted (fitness for bearing bores) shall be considered.

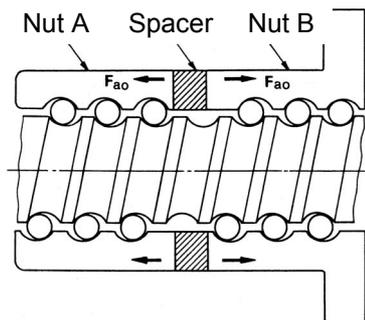
Lesson 3: Preload and Rigidity of Ball Screws

Here, we are going to discuss the purposes of preload and its effect, and preloading systems.

Section 1 Preload of Ball Screws

◆ What is a preload?

Preload is to create elastic deformations (deflections) in steel balls and ball grooves in the nut and the screw shaft in advance by providing an axial load (preload F_{a0}).



◆ Clipping data ◆

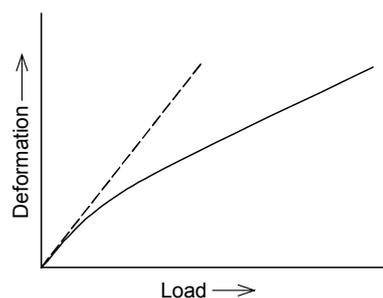
When removing an applied force that has caused deformation, the deformation disappears. When you grasp a rubber ball, it deforms. But, when you release it, it recovers its original shape. This type of deformation is called “elastic deformation.”

◆ Purpose of preload (effects)

- It eliminates axial play between a screw shaft and a ball nut. (Zero backlash)
- It minimizes elastic deformation caused by external force. (Enhances rigidity.)

◆ Principle of preload (primitive explanation)

A typical curve of ball screw deformation versus load is shown by the figure below. It can be seen from the figure that as the load is increased uniformly, the increasing rate of deformation declines. Therefore, it would be advantageous with regard to deformation under load to operate above the “knee” (inflection point) of the load-deformation curve. Preloaded ball screw realizes this condition.



◆ Setting preload value (load)

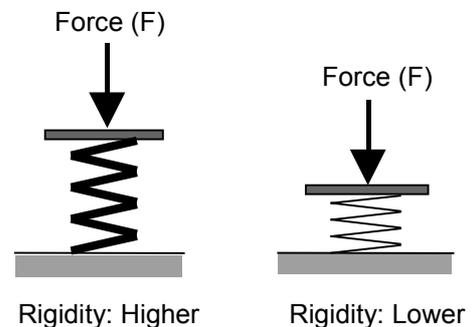
It's important to stay within the appropriate amount of preload for a given purpose. Don't set preload more than required.

Although rigidity increases when preload forces are increased, the following problems are induced;

- Requires more torque for rotation. (Larger force is required to rotate.)
- Increases heat generation. (→ a higher temperature rise → a larger thermal expansion in the screw shaft → effects upon the positioning accuracy and increases load to the support bearing)
- Shortens service life.

Section 2 Rigidity of Ball Screws

Rigidity is a “characteristics” that defines resistance (within a range of elastic deformation) to its deformation when external forces act on a ball screw, or a “level” of such resistance. If taking a coil spring as an example, it is equivalent to their spring constant. For rigidity of respective series, sizes or preloads, look into the catalogues.

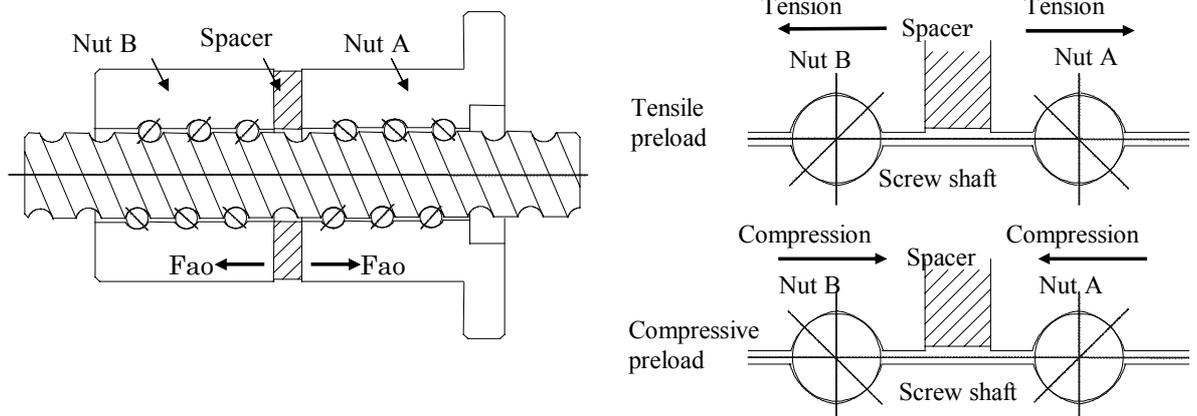


Section 3 Preloading Systems

NSK ball screws employ four different preloading systems, each of which is selected depending on the individual application.

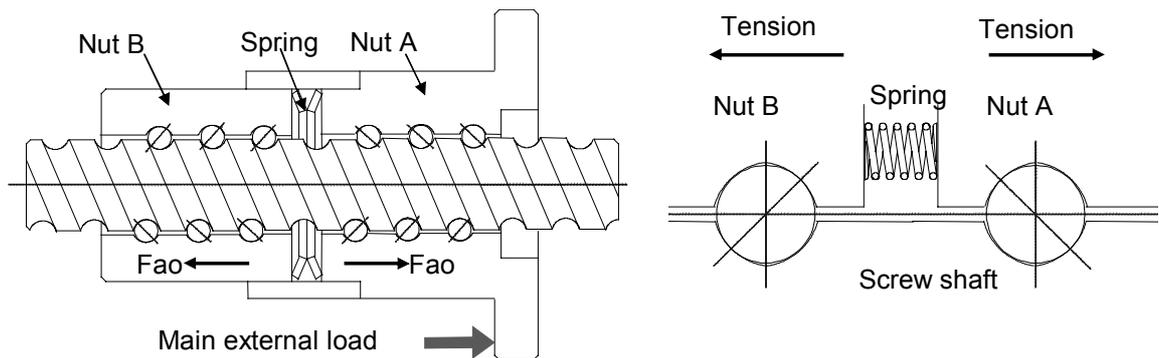
1 Double nut preloading system

- A spacer is inserted between two nuts for preloading.
- In general, a spacer is thicker by the deformation equivalent to the preload than the actual space between two ball nuts. (Tensile preloading system)
- There is another method in which a thinner spacer by the amount of preload is inserted so that it pulls the two nuts together (Compressive preloading system). This is a very rare usage.
- This preload system is suitable for setting a large amount of preload.



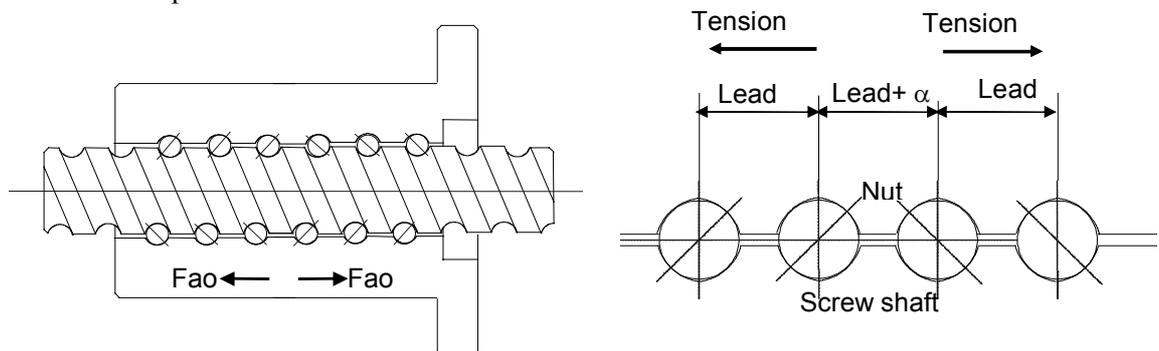
2 Double nut spring preloading system (J-Preload)

- In this system, the spacer mentioned to the D-preload system above is replaced with a spring (dish spring or coil spring). – A system where spring force works as a preload.
- Springs play the role of a damper, thus, deviation in ball groove pitch diameters of shaft and nut, and changes of diameters of steel balls and ball grooves over time due to wear are absorbed. This system is to have minimized torque variation over an extended time period.
- Since springs are used, the rigidity obtained varies depending on the load direction. This type of system can be used only when the application loads are limited to stay in the direction of “main external load” as illustrated below.



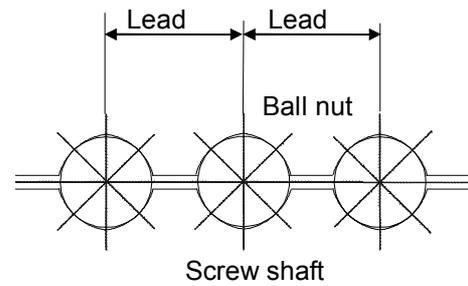
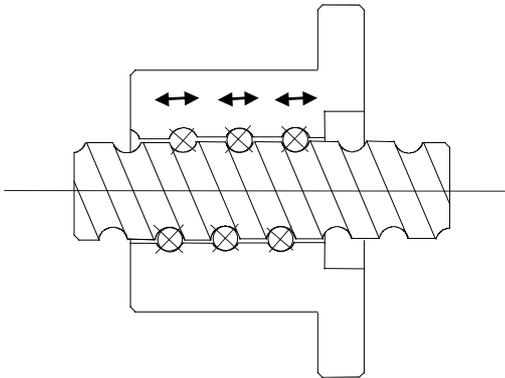
3 Offset Lead Preloading System

- A system where preload is provided by increasing, by the amount of preload (α), one of the leads that is located in the middle of two ball recirculation circuits. (This is similar to D-preload, but with a single nut used. As for function, it is the same as D-preload.)
- Since no spacer is used, this system will provide more compact ball nut and cost effective products.
- However, since the nut length becomes longer, there are limitations to the number of circuits because of production reasons.



4 Oversize ball preloading system

- Preload is caused by assembling steel balls larger, by the amount of preload, than the spaces within ball grooves, and assuring that each individual ball is in four-point contact.
- Since this system can have the shortest nut length among the four systems, the nut will be quite compact.
- However, this system cannot create too large of a preload.



Lesson 4: Combination of Shaft Diameter and Lead

A combination of nominal screw shaft diameters and nominal leads according to JIS are shown below (basic combinations).

Nominal shaft diameter d_0	Nominal lead P_{h0}														
	1	2	2.5	3	4	5	6	8	10	12	16	20	25	32	40
6	1	2	2.5												
8	1	2	2.5	3											
10	1	2	2.5	3	4	5	6								
12		2	2.5	3	4	5	6	8	10	12					
16		2	2.5	3	4	5	6	8	10	12	16				
20			3	4	5	6	8	10	12	16	20				
25				4	5	6	8	10	12	16	20	25			
32				4	5	6	8	10	12	16	20	25	32		
40					5	6	8	10	12	16	20	25	32	40	
50					5	6	8	10	12	16	20	25	32	40	
63					5	6	8	10	12	16	20	25	32	40	
80						6	8	10	12	16	20	25	32	40	
100								10	12	16	20	25	32	40	
125								10	12	16	20	25	32	40	
160									12	16	20	25	32	40	
200										12	16	20	25	32	40

◆ Clipping data ◆ There are blank spaces in the above table. Why is that?

- For larger leads

Some leads are too large for a given shaft diameter, thus, production is more difficult or even impossible. In such cases, they are not listed.

- For smaller leads

Some leads are too small for a given shaft diameter, therefore, they are not useful (in terms of load capacity and feed speed). Such cases are not included on the list.



Chapter 3

How to Use Ball Screws

□ Lesson 1: How to Use Ball Screws

- **Section 1: Mounting Ball Screws**
- **Section 2: Influence of Ball Screw Mounting Errors**
- **Section 3: Type of Ball Nut and Its Features**
- **Section 4: Configuration of Screw Shaft End**

□ Lesson 2: Accessories of Ball Screw

- **Section 1: Support Units**
- **Section 2: Locknuts**
- **Section 3: Grease Units**
- **Section 4: Stoppers**

□ Lesson 3: Handling Precautions for Ball Screws

- **Section 1: Lubrication**
- **Section 2: Precautions When Using**
- **Section 3: Storage**

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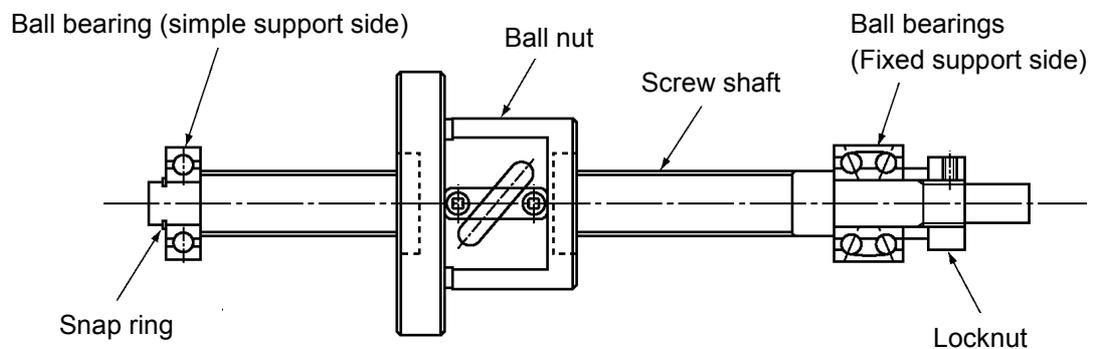
Lesson 1: How to Use Ball Screws

This explanation will include how to mount ball screws and how they are used.

Section 1 Mounting Ball Screws

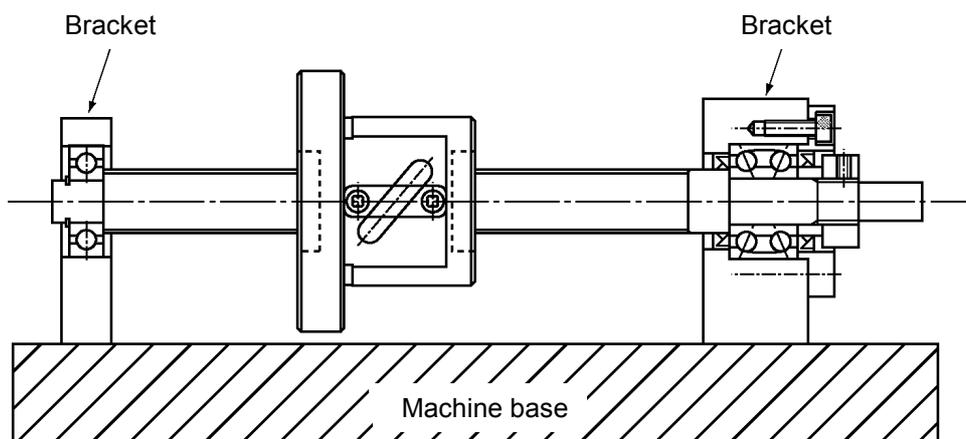
The ball screws are used mainly as feed screws. In other words, ball screws are used as the mechanical elements to convert a rotational motion into a linear motion, or vice versa. Needless to say, the ball screws can accomplish their objectives only when they are used properly in combination with various other mechanical elements. These aspects are explained below, although not necessarily in the order of assembly procedure.

[1] It's necessary to support screw shafts so that they can rotate. Usually, rolling element bearings are used.

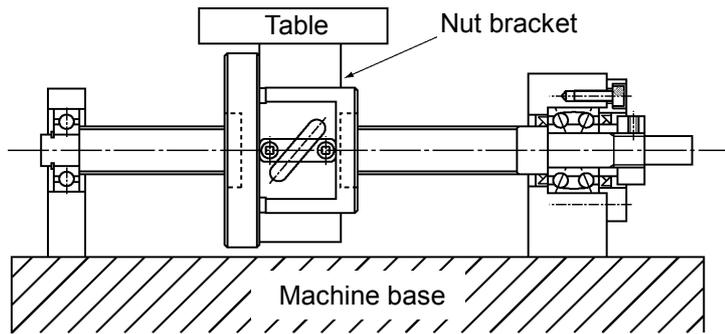


There are various ways to support ball screws. See the catalogues for details. Rolling element bearings are secured to the screw shaft with locknuts, etc.

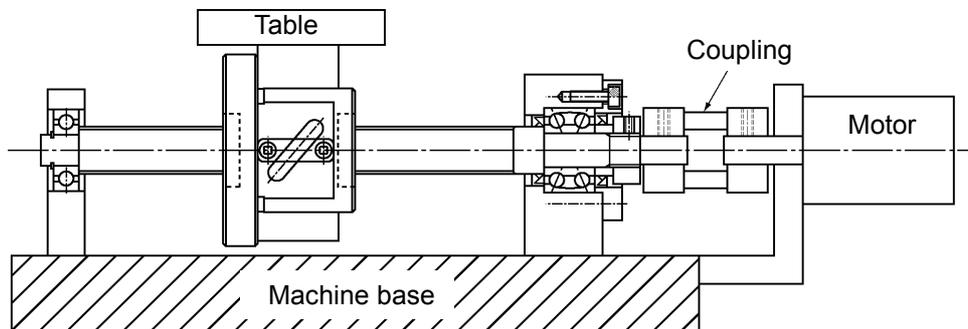
[2] Brackets are needed to support the bearings, and attach them onto the machine base. The position of the screw shaft is thus determined.



[3] A nut bracket is needed to attach the nut onto a table.

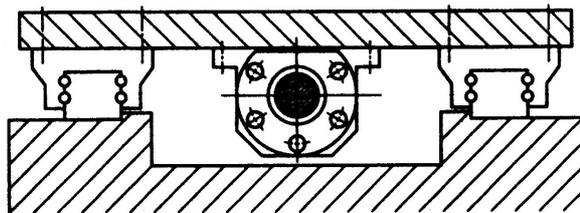


[4] A means to rotate the screw shaft is required. Namely, it is necessary to couple the screw shaft with a motor. A power source to drive the motor and an encoder to control the positioning are also required for some application.



Although the illustration above shows one way to connect a motor using a coupling, other method using a pulley or a gear may be employed.

[5] Furthermore, guide ways are needed to maintain the table position precisely. Recently, use of rolling element linear guide bearings, such as linear guides, are increasing.



The following components are the minimum requirements for using ball screws;

1. Support units (bearings, bearing brackets)
2. Nut bracket
3. Drive system (coupling, pulley, motor, etc.)
4. Linear Guides

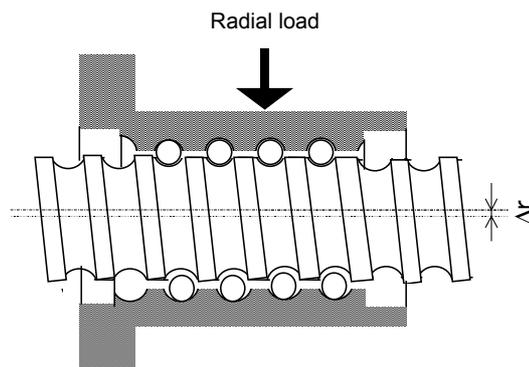
Section 2 Influence of Ball Screw Mounting Errors

When there are mounting errors, distortion forces (such as a radial load and/or moment load) may be generated between the screw shaft and the nut, as illustrated below. This could cause the following problems or failures:

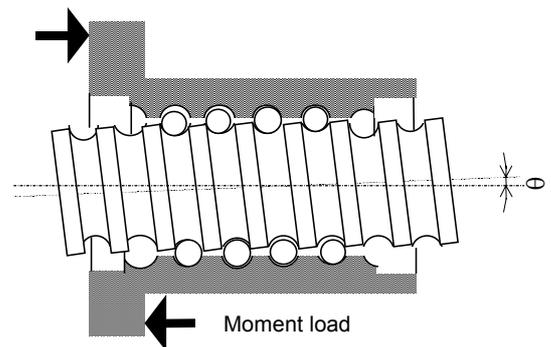
- A shortened service life,
- Adverse effect on smooth operation
- Adverse influence on positioning accuracy,
- Generation of noise or vibrations,
- Breakage of screw shaft ends, etc.

Therefore, care should be taken with mounting accuracy. The following is the control values (allowable limits) that NSK recommends as the criteria for mounting tolerances;

- ◆ Inclination error: 1/2000 max.
- ◆ Eccentricity: 20 μm max.



<<Eccentricity>>

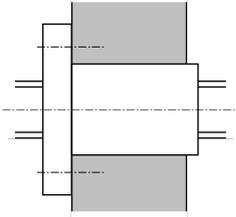


<<Inclination error>>

Section 3 Type of Ball Nut and Its Features

Shape of the nuts vary with the way they are mounted on their housings. A “flanged nut” is recommended because it has the best features for accurate mounting.

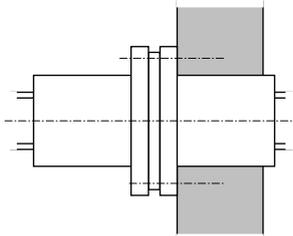
Flanged nut



Flanged nut

- It is easy to adjust (align) the nut to its required accuracy.

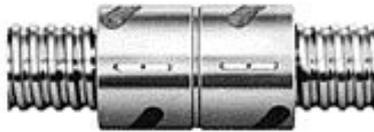
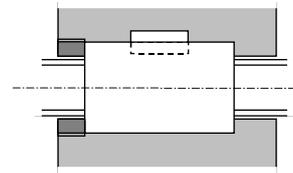
Flanged to flanged double nut



Flanged to Flanged Double Nut

- It is easy to adjust (centering) the nut to its required accuracy.
- Since the mounting flanges are somewhat thick, fixing bolts for nut are longer. Thereby, the as-mounted rigidity can be compromised (due to greater elongation of bolts).

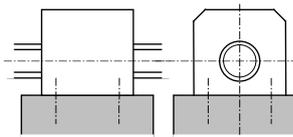
Cylindrical double nut



Cylindrical double nut

- It requires a mounting bracket for preloading. The bracket is compact just to the extent that no flanges are involved.
- It is rather difficult to expect a proper preloading.
- Therefore, we do not recommend this type.

Square nut (face mount)



Square nut (face-mount)

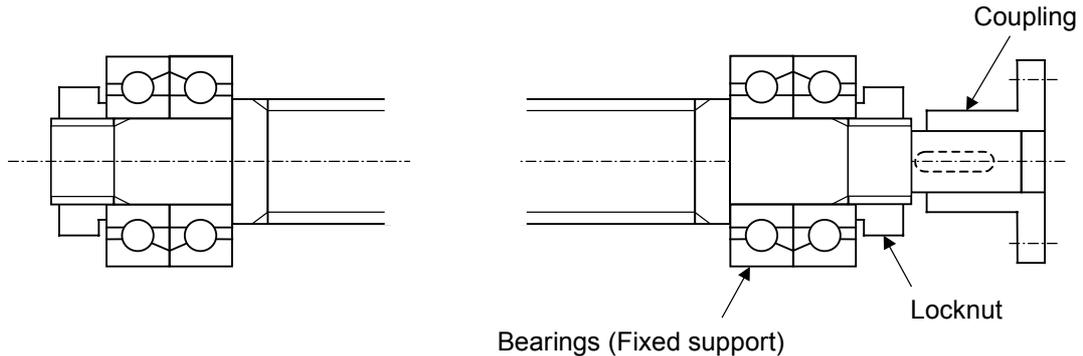
- Adjusting the nut mounting accuracy (center height adjustment) is difficult.
- Since this type can be directly attached to a table without brackets, the entire system will be compact.
- Yet, we do not recommend this type, either.

Section 4 Configuration of Screw Shaft End

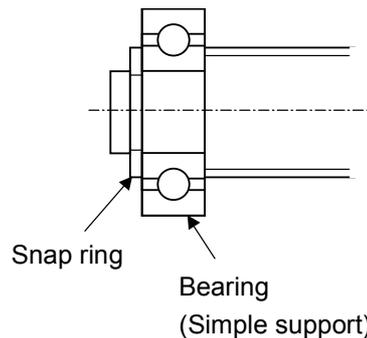
The shaft end configurations vary depending on the size of a screw shaft, its mounting method, drive method, running conditions, etc. Hence, there is no standard configuration. Check the catalogues for examples of screw shaft end configuration typically required when NSK Support Units (See Lesson 2) are used.

1 Way of supporting screw shaft

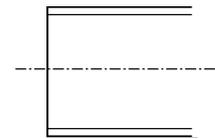
(1) Bearings (Fixed support)



(2) Bearing (Simple support)



(3) Free



<<Support bearing configuration opposite to drive side>>

(1) Fixed support

- This support configuration is used when a large axial direction rigidity, load capacity and increase in the limit of critical speed for high speed operation (see Chapter 4, Lesson 2) are required for functionality (i.e., operation conditions).
- Angular contact ball bearings are usually used.
- Mounting cost: High

(2) Simple support

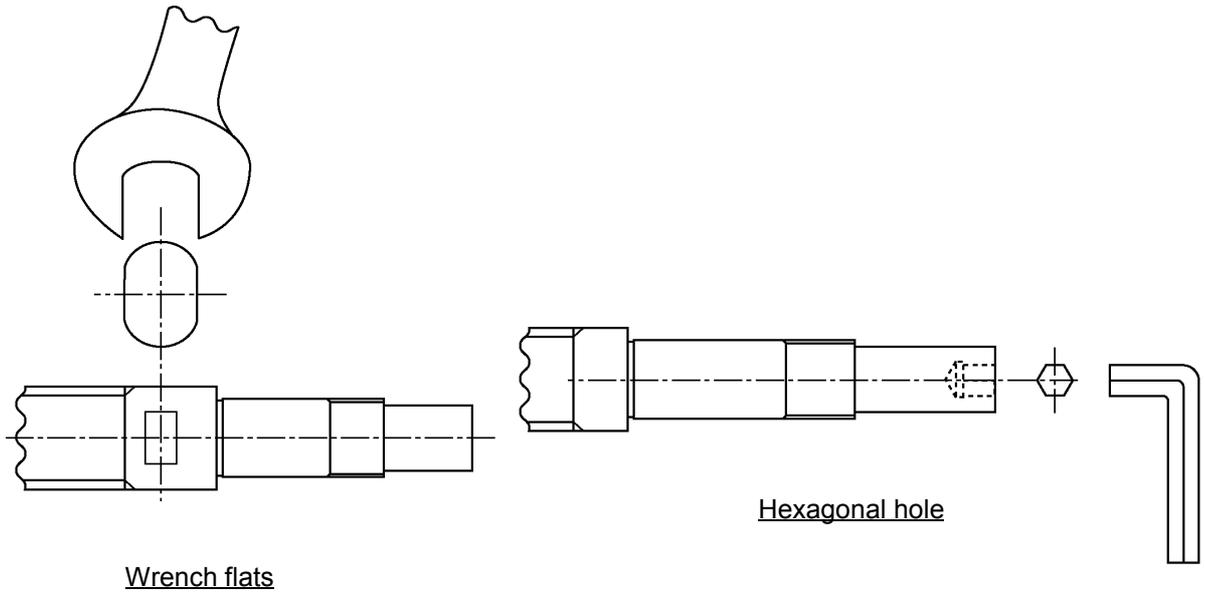
- Deep groove ball bearings are usually used.
- Simply put, this choice is positioned in between the “Fixed ” and “Free” support.
- Mounting cost: Moderate

(3) Free

- This is used when there is no problem with shaft vibration or critical speed.
- Generally speaking, this is used when the screw shaft length is relatively short for the shaft diameter, and, when the shaft rotation is not too high.
- Mounting cost: Low

2 Double flat faces or a hexagonal hole

In order to fix bearings of the fixed support configuration to shaft end, a locknut is used. It is necessary to hold the screw shaft to prevent it from rotating while fastening the lockout. (This phenomenon is much the same when you want to fasten something with a bolt and a nut. You cannot fasten it unless you fix either the bolt or the nut.) To avoid this problem, there are wrench flats (for a spanner) somewhere close to the shaft end or a hexagonal hole (for a hexagonal wrench key) on a shaft end. NSK recommends using of a hexagonal hole because of the cost.



Lesson 2: Accessories of Ball Screw

Here, the accessories that are useful for mounting and using ball screws are explained. Remember them so that you can offer your customers these accessories together with ball screws.

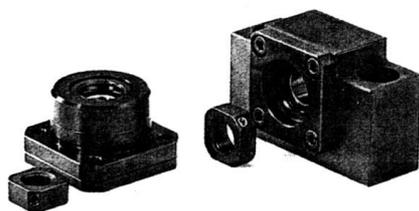
Section 1 Support Units

This component integrates bearings and housing for mounting a screw shaft. It is likely that designing a support bearing system for mounting screw shafts are not easy for customers. Hence, these units are useful to them.

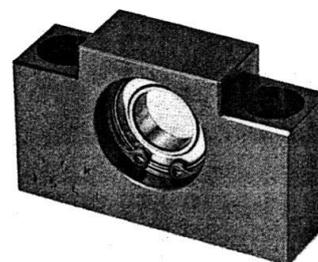
- They are standard stock items, offering a short lead time for delivery.
- There are two different types depending on the application.
- They correspond to “Standard Stock Series” ball screws.
- All bearings are packed with lubrication grease.

1 Support units for small equipment, light-load applications

- The internal diameter of the bearings range from $\phi 4$ to $\phi 25$ mm.
- There are two different types: One is for the “fixed support” end side (round and square versions), while the other is for the “simple support side.”



Fixed support side



Simple support side

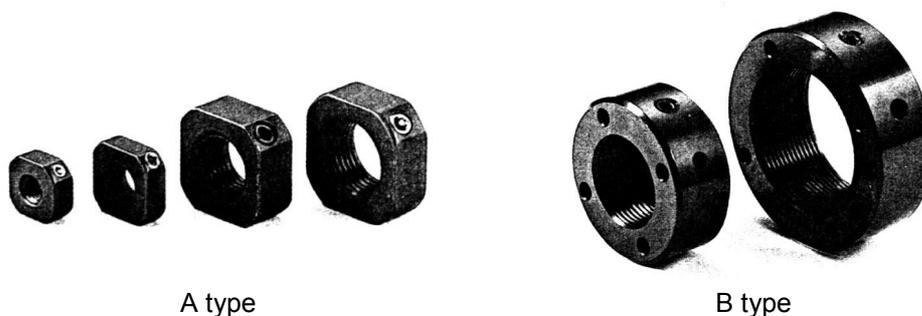
2 Support units for machine tools or heavy-load application

- The bore of bearings range from $\phi 17$ to $\phi 40$ mm.
- Available only for the fixed support end side.



Section 2 Locknuts

Ball screw support bearings must be mounted with the minimum inclination. To help that happen, NSK can offer locknuts to be used exclusively with high accuracy ball screws. They are standard stock items. There are two kinds of locknuts, A and S-type. Please recommend that your customers use this accessory when fixing the support bearings.



- A-type: Same as those furnished in support units for small equipment, light-load application.
- S-type: Same as those furnished in support units for machine tools, heavy-load application.

Section 3 Grease Units

NSK offers various greases packed in a bellows tube (net 80 g) to be used for ball screw lubrication, and a hand grease pump as well.

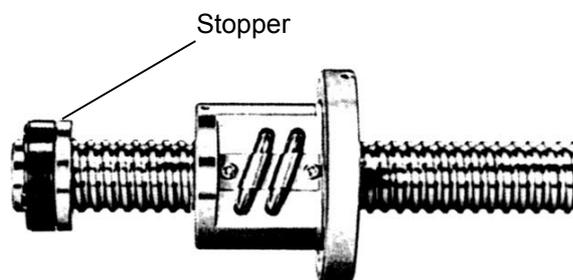
- It is very easy to use since a bellows tube can be loaded into a grease pump in a simple one touch motion.
- When the grease will not be used for a while, take it out of the pump, and put the lid of the bellows tube on to prevent grease from deteriorating.

Name	Application	Color of tube
NSK grease AV2	Heavy duty	Brown
NSK grease PS2	High speed/light load	Orange
NSK grease LR3	High speed/medium load	Green
NSK grease LG2	Clean environment	Blue



Section 4 Stoppers

- Machine failure or human error during operation may sometimes cause a nut to overrun screw thread. Stoppers can be installed as a safety measure for a ball screw.
- NSK offers a series of “shock absorbing type” stoppers. They are not sold as single units, but shall be ordered in combination with ball screws.



Lesson 3: Handling Precautions for Ball Screws

This section describes major precautions that are required when handling ball screws.

Section 1 Lubrication

- ◆ **Lubrication status of Standard Stock Series items differs from one series to another. A ball screw which is not packed with grease must be greased before it is used.**

Series	Status at shipping	Requirement of lubrication prior to operate
MA, FA, and V	Packed with grease	Not required (Use as is.)
SA, KA, MS, FS, SS, RMA, RMS and Rolled screws	Not packed with grease	Requires lubrication (either grease or oil)

- ◆ **“Custom made ball screws” are delivered after anti-rust oil application unless grease lubrication is specified when ordering. Prior to use, lubrication shall be made with either grease or oil.**

- ◆ **Merits and drawbacks of grease and oil lubrications**

Item	Grease lubrication	Oil lubrication
Housing construction, Lubrication sealing	Can be simplified.	More complicated, and therefore, due attentions are required for maintenance.
Cooling performance, Cooling effects	None.	Heat can be effectively released, when circulating oiling is adopted.
Fluidity of lubricant	Poor	Excellent
Replacement of lubricant	Rather complicated	Relatively simple.
Filtration of debris	Difficult to achieve.	Easy.
Pollution due to lubricant leakage	Little	Not suitable for applications where oil pollution shall be avoided.

- Although oil lubrication is the superior of the two, grease lubrication has two distinctive advantages:
 - (1) No complicated lubrication system (such as a piping and pump) is needed.
 - (2) Only a small amount of lubricant is used.
 Accordingly, grease lubrication is used more often.

Section 2 Precautions When Using

- ◆ When ball screws are used in an environment that is not clean, appropriate measures are required to prevent foreign matters from attaching to the screw shaft or entering the inside of the nuts. Discuss environmental conditions with customers before they are used.
- ◆ Individual ball screws have a limitation with respect to allowable rotational speeds (detailed explanations are given in Chapter 4). Therefore, ball screws shall be used within their specified allowable rotational speeds.
(Otherwise, it results in breakage of ball-recirculation parts, vibrations of screw shafts which trigger chain reaction in vibrations of entire machine body, damage on rolling surfaces and other failures.)
- ◆ The service temperature limit is 80°C.
If the customer's use conditions exceed this limit, special measures will be necessary for the ball screws.

Section 3 Storage

- ◆ Please instruct customers to store the ball screws as packaged by NSK for delivery. If the interior packing is damaged or packaging has been opened, ball screws may be contaminated, and rusting may occur.
- ◆ We recommend taking the following measures to protect stored products:
 - Store them horizontally as originally packaged by NSK.
 - Store them horizontally over ground beams, or the like, in a clean space.
 - Store them hanging vertically in a clean space.



Chapter 4

Selection of Ball Screws

<Primary Course>

Lesson 1: Classification and Series of NSK Ball Screws

Lesson 2: Selecting Ball Screws

- Section 1: Selection Flowchart
- Section 2: User's Requirements (Use Conditions)
- Section 3: Selection Example (1)
- Section 4: Selection Example (2)

Lesson 3: Selecting Ball Screws

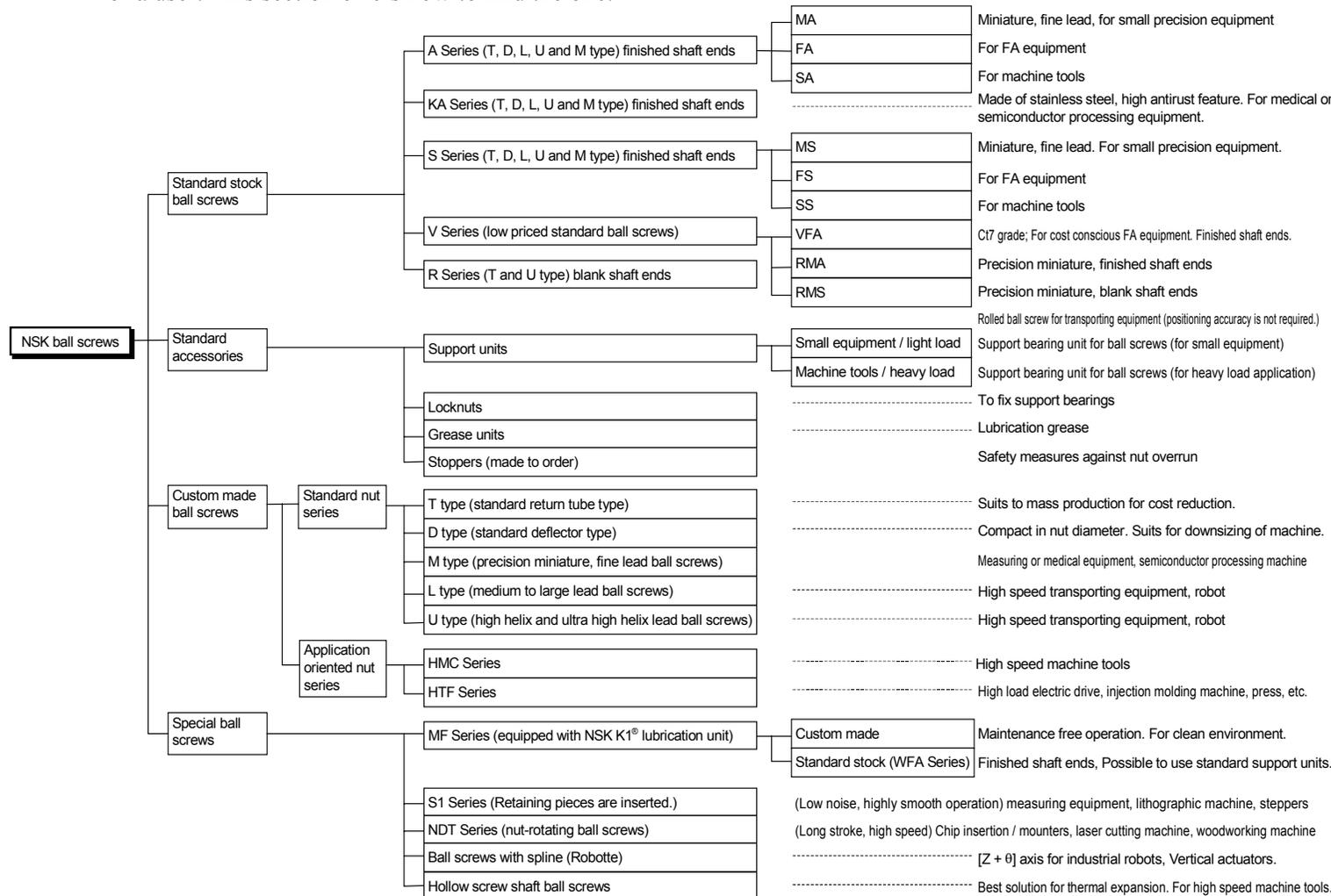
- Section 1: Outline of Special Ball Screws
- Section 2: HMC Series
- Section 3: HTF Series
- Section 4: NDT Series (Nut Rotating Ball Screws)
- Section 5: Ball Screws With Spline "Robotte"
- Section 6: S1 Series
- Section 7: MF Series
- Section 8: Hollow Shaft Ball Screws

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Lesson 1: Classification and Series of NSK Ball Screws

NSK ball screws have many series and types as shown below. Wide variety of the series will help you to find a specific ball screw which suites for the needs of a user. This section offers how to find the one.



◆ Basic types of NSK ball screws

Type	Lead classification	Recirculation type	Preload system
T type	Fine / Medium	Return tube type	D, P, Z preload
D type	Fine / Medium	Deflector type	
L type	Medium / High helix	Return tube type	
U type	High helix/Ultra high helix	Return tube or End cap type	P preload
M type	Fine	Deflector type	

◆ Lead Classification

Group	Lead ratio k (k = Lead/Shaft diameter)
Fine	$k < 0.5$
Medium	$0.5 \leq k < 1$
High helix	$1 \leq k < 2$
Ultra high helix	$2 \leq k$

1 Standard stock series

These are off-the-shelf type standard series for prompt delivery.

◆ Finished shaft end ball screws

- Both ends of a screw shaft are finished so that the bearings and drive components, such as pulleys and coupling, can be easily mounted onto the screw shaft.
- No additional machining is required (these ball screws can be mounted into the machine as delivered).



◆ Blank shaft end ball screws

- The ball thread grooves which are time consuming process to grind are all finished.
- Yet, neither end of the screw shaft are finished (i.e., not quenched and left simply in blank), and, therefore, allowing for freedom of choice when selecting shaft-end shapes.
- Prior to mounting, these products must have shaft ends finished.
- This is the second choice for customers who cannot find the item they require among the finished shaft end ball screws.



2 Custom made ball screws

- This category shall be considered when no Standard Stock Series items provide a solution. (Made to special orders.)
- Production of these items begins only after all specifications have been finalized and relevant drawings have been exchanged with customers for confirmation.
- This is a time-consuming procedure as it begins with raw materials.

3 Special ball screws

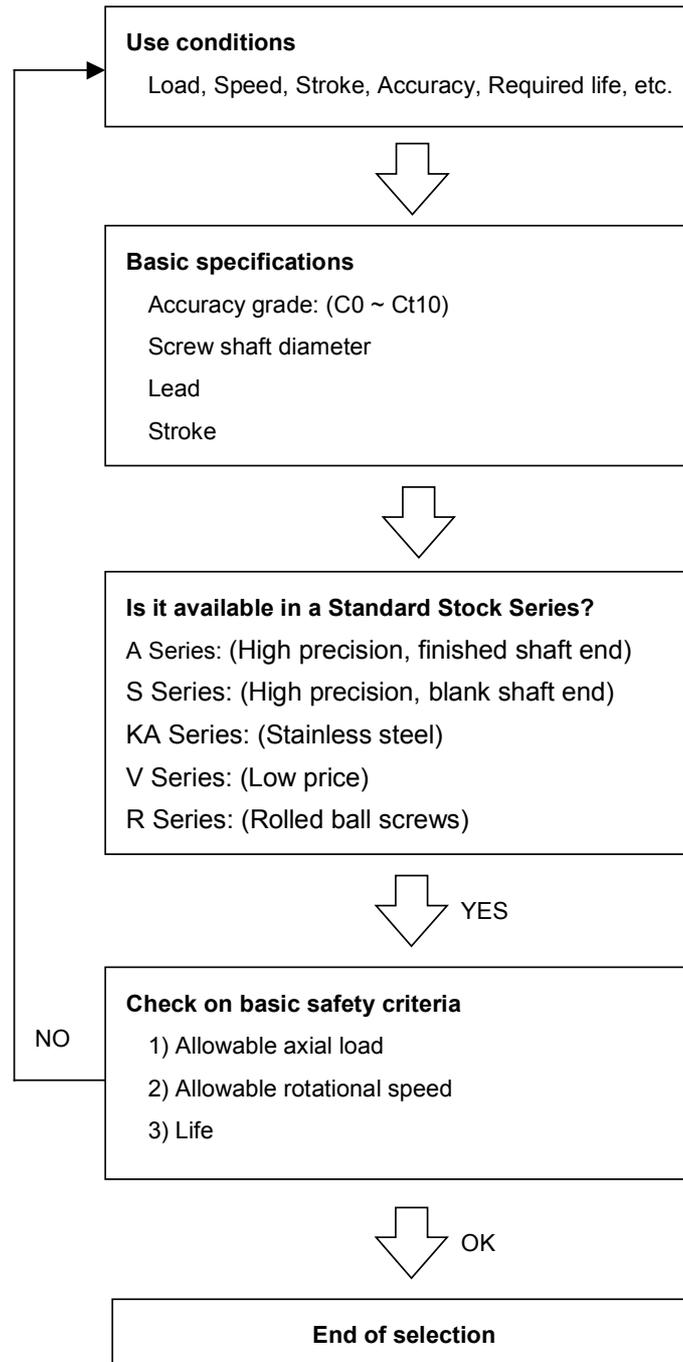
These are products with special value-added functions, such as being maintenance free, ease for the environment, highly efficient, etc. For more details, see Lesson 3.

Lesson 2: Selecting Ball Screws

Let's work together to select a ball screw that meets the requirement of a certain customer.

Section 1 Selection Flowchart

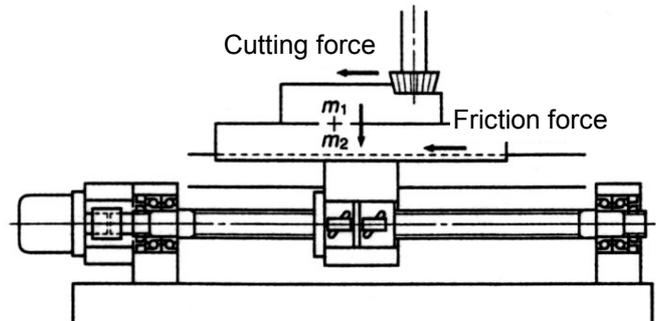
Shown below is an example of selection procedures for Standard Stock Series ball screws that feature in good delivery lead times, low cost, etc.



Section 2 User's Requirements (Use Conditions)

1. Loads (external loads)

This refers to the loads that apply to the ball screw in use. For example, cutting forces while machining a work piece, friction resistance forces generated by the guide ways.

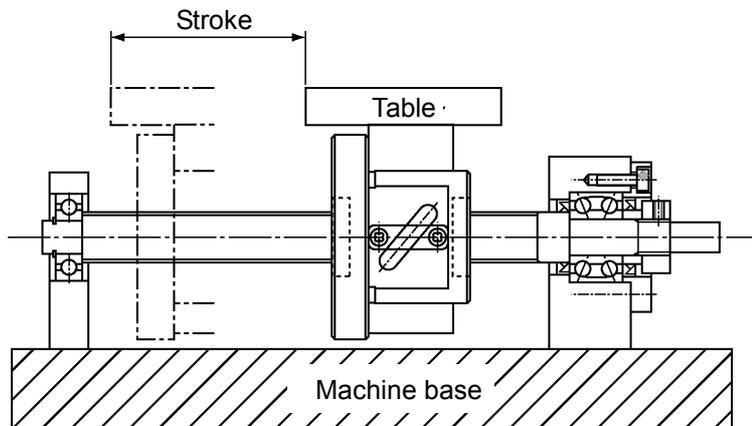


2. Speed

This refers to the travel speed of the table (i.e., the nut), expressed in 20 m/min, for example. Sometimes, the speed is expressed in a rotational speed of screw shaft (e.g., 2000 min^{-1}).

3. Stroke

This is the travel distance of the table attached to the nut.



4. Accuracy

This information is indicated by the grade of lead accuracy (e.g., C3, C5, etc.).

5. Required life

Expressed in total travel time (e.g., 20000 hours), or total travel distance (e.g., 5000 km).

6. Basic specifications

- Screw shaft outside diameter (mm): Defined as the outside diameter of the threaded portion. Expressed as “ $\phi 40$,” for example. [ϕ (pronounced “fai”) is a symbol mark for the diameters.]
- Lead (mm): Indicated, for example, as “lead 10.”

Section 3 Selection Example (1)

1 Proposed conditions:

- External load: 1000 N
- Speed: 20 m/min, max.
- Stroke: 1000 mm
- Accuracy class: C5
- Screw shaft outside diameter: $\phi 32$ mm
- Lead: 10 mm
- Other: Immediate delivery is required since the customer will use this for a prototype.

2 Process of Selection

- 1) Since the customer requested “immediate delivery,” select from Standard Stock Series ball screws. Focusing upon the A-Series with finished shaft ends from “Lesson 1: Classification and Series of Ball Screws“, check the table in Page B39 of the Catalog “Precision Machine Component (No. E3155).”
- 2) Based on the conditions of screw shaft diameter of $\phi 32$ mm and lead of 10mm, the appropriate ball screws can be found on Pages B125 and B127. Turn to those pages.
- 3) Required accuracy grade C5 is satisfied.
- 4) There are two choices for the nut shape (Z-preload and D-preload). Z-preload is recommended because it is compact and cost effective.
- 5) Now, study the shaft length. Select the nominal stroke length of 1050mm that is closest to the required stroke length (1000 mm). W3211SA-5Z-C5Z10 is the choice.
- 6) Remarks on page B125 indicate that WBK25DF-31 (for both shaft ends) is recommended for the support units.

3 Check on basic safety criteria

1) Allowable axial loads

Defined as the limit level of the external loads under which neither breakage of the screw shaft nor permanent deformations on the contact surfaces between steel balls and ball grooves occur. If a choice from Standard Stock Series ball screws has external load below “the basic load rating - dynamic load rating, C_a ”, there should be no problem with that choice (since, theoretically, there is no direct relationship between the allowable axial load and C_a , this can only be used as a rule of thumb.).

For this exercise, C_a of 25 500 N is shown in the table of “Ball Screws Specifications” on Page B126. The external load, 1000 N, is smaller than that, so there is no problem with the selection.

2) Allowable rotational speed

This is determined by examining two aspects;

- “dm·n” value which could influence breakage of ball recirculation parts.
- “Critical speed” which could influence resonance of the screw shaft.

◆ dm·n value

[dm: ball pitch circle diameter (mm) (See Chapter 2, Lesson1), n: revolutions per minute (rpm)]
This is obtained by multiplying dm with n to express the velocity of the steel balls moving in a recirculation circuit. When the velocity of the recirculating steel balls grows, its impact may cause damage to recirculation parts, and, in a worst-case situation, the steel balls may stop circulating and lock up the screw shaft.

Accuracy grade: C0 ~ C5, Ct7	Standard	$dm \cdot n \leq 70\,000$
	High speed specification	$dm \cdot n \leq 100\,000$
Accuracy grade: Ct10 (Rolled ball screw, etc)		$dm \cdot n \leq 50\,000$

<<Note>> “High-speed specification” is only available in the custom made ball screws.

◆ Critical speed

Since the screw shaft is usually mounted so that the slender shaft is fixed on its two ends, it begins to vibrate due to resonance when the number of rotations increases. This vibration of the shaft could develop into a vibration or noise in the entire machine, and eventually damage the rolling surfaces of steel balls. In the worst case, the screw shaft would break.

In this selection example, the screw shaft rotational speed is calculated at 2 000 rpm. (See Chapter 1, Lesson 1, Section 2 “Learn the Math!”)
Page B126 on the catalog “Precision Machine Components” (No. E3155) shows that the allowable rotational speed is 2120rpm. So, there is no problem with the selection.

3) Life expectancy

Since no information on the required life has been given, we will not consider it here.

Accordingly, we are going to offer the following to the customer.

- Ball screw: W3211SA-5Z-C5Z10
- Support unit: WBK25DF-31 (for both ends)

Section 4 Selection Example (2)

1 Proposed conditions:

The customer has asked us to further restudy the selection we made in Example (1) above.

- The ball screw portion is acceptable, but the shaft ends are not.
- The ball screw with the requested configuration of shaft ends is needed for immediate shipping.

2 Selection process

- 1) Since the customer requires an “immediate delivery,” we are going again to select from Standard Stock Series items. Focusing upon the S-series: Blank shaft end ball screws shown in Lesson 1: Classification and Series of Ball Screws, look at the table on Page B181 of “Precision Machine Components” Catalog (No. E3155).
- 2) Based on the screw shaft diameter of $\phi 32$ mm and lead of 10 mm, there are some possibilities on pages B125, B127 and B129. So, open those pages.
- 3) There is a nut shape that is same as the original selection example on page B217.
- 4) We understand that the accuracy grade is C5, based on its “Ball screw number.”
- 5) Here, we are going to study the shaft length. “Max. stroke length” of 1 300 mm that can cover the required stroke length of 1 000 mm is selected. The reference number is W3214SS-1Z-C5Z10.
- 6) Additional shaft end processing will be made either at NSK or the customer.

Lesson 3: Outline of Special Ball Screws

We are going to discuss selection of custom-made ball screws in Chapter 5 latter. Included here are outlines for both application oriented nut series and special ball screws to help your better understanding the entire picture of NSK ball screws.

With the ever-expanding customer needs, it's important for every one of you to become familiar with these series so that you can effectively respond to customer needs.

Section 1 High Helix / Ultra High Helix Ball Screws

<<Major Features>>

- 1) It can feed a machine at a high speed.
- 2) With feed speeds the same, the advantage of this series is its critical speed, temperature rise and lower noise as compared to standard items. (Since its lead is larger, the number of rotations can be reduced.)
- 3) Accuracy grade: C3, C5 and Ct7.

<<Application examples>>

Laser beam machines, punching presses, electronic parts mounter, high speed and high precision transporting equipment, robots, etc.

<<Precautions for Selection>>

It will increase load on a drive motor. (Accordingly, a motor with a larger torque rating is required.)

This is not suitable for highly accurate positioning operation.

Section 2 HMC Series

- This is a series developed specifically for high speed machine tools in general, and machining centers in particular.
- A number of NSK proprietary designs have been integrated into this series to obtain the following features (details are omitted):

<<Major Features>>

- 1) It is capable of feeding at a high speed, 40 to 100m/min.
- 2) High rigidity, high load capacity (as compared with conventional items: Rigidity: 1.8 times; Rated load: 1.6 times higher)
- 3) Compact nuts (Outside diameter: small; Length: short)
- 4) Low in vibration and noise.
- 5) Accuracy grade: C3 and C5.

Section 3 HTF Series

- This series is especially for heavy load drive applications.
- Its major target lies in replacing the hydraulic cylinder-driven mechanism with an electric motor-driven mechanism.
- A number of NSK proprietary designs are integrated into the products to obtain the following characteristics (details are omitted);

<<Major Features>>

- 1) Extra high load capacity. (In the case of $\phi 80$ and lead 20, approximately twice as high as the corresponding existing items)
- 2) Excellent durability.
- 3) Rich in variation (in a combination of shaft diameters and leads, and full support for a variety of shaft end configuration).
- 4) Accuracy grade: C5, Ct7

<<Application examples>>

Motor-driven injection molding machines, punching presses, IC molding presses, servo cylinders, etc.

<<Precautions for Selection>>

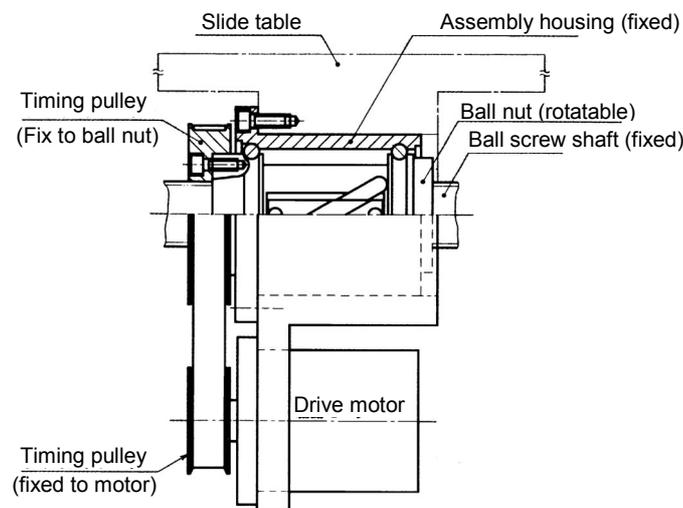
Selection of grease is an important point in terms of durability.

Section 4 NDT Series (Nut Rotating Ball Screws)

- This series has been developed to accomplish high-speed feeding over a long stroke.

<<Structure>>

- 1) The screw shaft is fixed and only the nut is allowed to rotate so that more than one nut can be driven on a single screw shaft.
- 2) Since it can be mounted to a drive table, the nut is integrated with support bearings and a bearing housing around the nut.
- 3) A drive pulley (supplied by the customer) is directly mounted on the side of the nut.
- 4) A vibration damper can be equipped as an option.
(Vibration damper: A mechanism to absorb vibration energy of the shaft. → This allows high-speed operation exceeding the critical speed.)



Example of installation

<<Major Features>>

- 1) More than one nut can be driven independently on a single screw shaft. (→ increase in productivity)
- 2) Most suited to long-stroke, high-speed drive.
- 3) Easy to mount onto the table.
- 4) Nuts are designed for their low inertia. (→ decrease of load to driver motor)
- 5) Accuracy grade: C3, C5, and Ct7.

<<Application Examples>>

Electronic-parts mounting machines, laser beam machines, punching presses, woodworking machines, robots, transporting equipment, etc.

<<Precautions for selection>>

- The approach to the allowable rotational speed shall be considered in the same way as screw-shaft rotation.
- Although integration of a vibration damper allows the application machine to operate exceeding the critical speed, it is not allowed to operate beyond its allowable “dm-n value.”

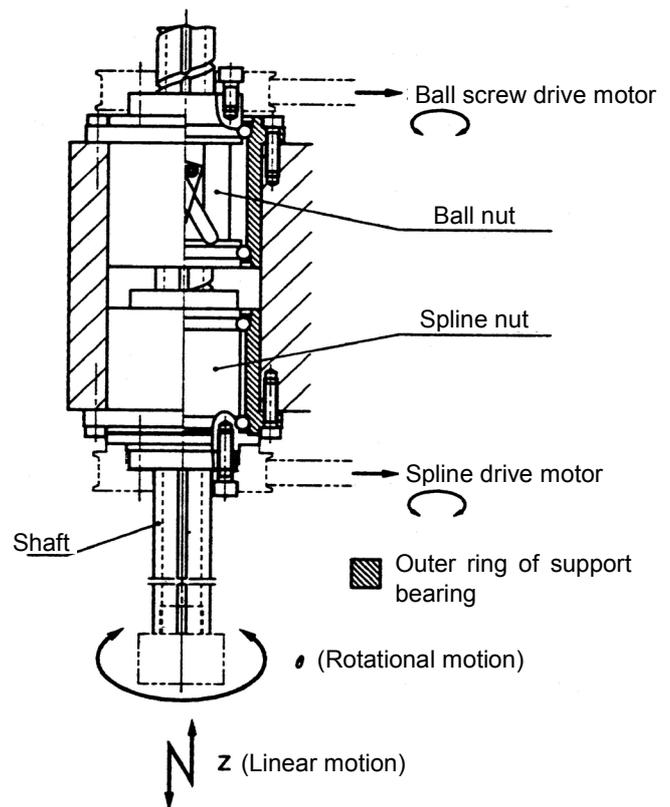
Section 5 Ball Screws With Spline “Robotte”

<<Structure>>

- 1) One ball screw (as a feeding mechanism) and another ball spline (as a guide) are integrated on a single screw shaft.
- 2) Support bearings and their housings are all integrated into one piece, which facilitate mounting of the entire set into the application machine.
- 3) A structure that allows the drive pulley to be directly mounted on the end of nut (by the customer).

<<Major Features>>

- 1) High performance: Respective motions in linear (move in and out of the shaft) and rotation (θ), of which mechanisms are integrated in a single shaft, are possible.
- 2) Compact and lightweight (← integrated support bearings, housings, and a hollow shaft)
- 3) Rich in variations: A wide selection is available to satisfy specific motion functions and performance.
- 4) Nut of the ball screw nut is designed to low inertia. (→ Decrease of load to a driver motor)
- 5) Accuracy grade (ball screw portion): C3, C5, and Ct7.



<<Application Examples>>

SCARA type and Cartesian type robots, semiconductor fabrication systems, Z-axis and “Z+ θ ” axis actuators, etc.

<<Precautions for Selection>>

The total shaft length is limited to 25 times of the shaft diameter due to manufacturing reasons.

Section 6 S1 Series

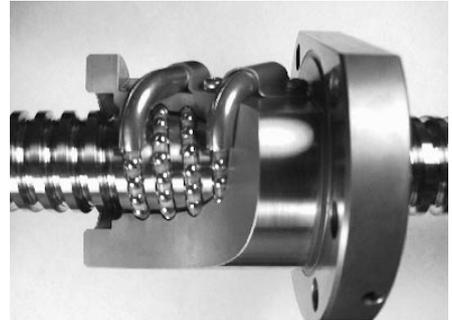
- ◆ This series has been developed to offer ball screws featuring low-noise (for the environment) and highly smooth rotation.

<<Structure>>

In order to avoid collision and jamming among steel balls, a plastic retaining piece is introduced between steel balls.

<<Major Features>>

Low noise, better tone (not harsh for human ears), low vibration
 Smooth operation
 High load capacity, high rigidity (as compared with those with spacer balls)
 Nut dimensions are interchangeable with existing items
 Accuracy grade: C0 to C5



<<Application examples>>

Measuring equipment, scanners, lithographic machine, steppers, wire electric discharge machines, etc.

<<Precautions for Selection>>

- A ball recirculation method is available only in the return tube type.
- Although P-preload is the standard system, both Z-preload and D-preload are also available.
- Allowable service temperature is limited to 50° C max. for normal use, and 80°C max. for instantaneous exposure.

Section 7 MF Series

- ◆ These are ball screws furnished with “NSK K1[®]”lubrication unit.

<<Major Features>>

- 1) Maintenance free for a long period of time.
- 2) No oil to pollute the environment (maintains a clean environment).
- 3) Long-lasting in an environment where lubricants are washed away by water (a longer life)
- 4) Long-lasting functions maintained even in an environment with oil-absorbing dust (a longer life)
- 5) WFA-Series is available as a Standard Stock Series item (short lead time; accuracy grade: C5 only)
- 6) Specifications on accuracy, clearance and preload are all the same as for conventional types.

<<Application Examples>>

Machine tools, semi-conductor/liquid crystal display manufacturing equipment, food/medical equipment, automobile manufacturing systems, woodworking/paper production/ apparel machinery, robots, etc.

<<Precautions for Selection>>

- Since NSK K1[®] lubrication unit makes the total length of the nut longer, pay due attention to the available effective stroke length when replacement is considered for existing items.
- The addition of NSK K1[®] will mean a slight increase in friction torque.
- The allowable service temperature is 50°C max. for normal use, and 80°C max. for instantaneous exposure.
- Don't use the unit in an organic solvent capable of washing out grease or oil, such as hexane, thinner, kerosene, or rust-preventive oils which contain kerosene.

Section 8 Hollow Shaft Ball Screws

- ◆ Ball screws with hollow shaft so that fluid for forced cooling can flow through the shaft.
- ◆ This is an option to minimize deterioration in positioning accuracy by reducing thermal expansion (influential lead accuracy) due to heat generation.

<<Effects>>

- 1) Stabilizes positioning accuracy.
- 2) Restricts thermal deflection of ball screw-related parts.
- 3) Maintains lubrication performance (since thermal deterioration of lubricant is minimized.)

<<Precautions for Selection>>

- The inside diameter of a hollow shaft and total screw shaft length are limited for fabrication reasons. (Depending on the application, please contact the NSK Technical Department.)

NSK

Chapter 5 Selection of Ball Screws <Intermediate Course>

□ Lesson 1: Terminology and Data for Selecting Ball Screw

- Section 1: Glossary of Lead Accuracy
- Section 2: Features, Criterion of Preload Value and Application
Example of Preloading Systems
- Section 3: How to Assure Preload Value
- Section 4: Combination of Accuracy Grade and Axial play
- Section 5: Allowable Axial Load

□ Lesson 2: Selection of Ball Screws

- Section 1: Selecting Flowchart
- Section 2: Accuracy Grades and Specific Application
- Section 3: Assembly and Mounting of Linear Guides
- Section 4: Production Capability of Ball Screw Shafts
- Section 5: Rigidity of Driving Screw System
- Section 6: Heat Generation in Ball Screws
- Section 7: Application Example

NSK Ltd.

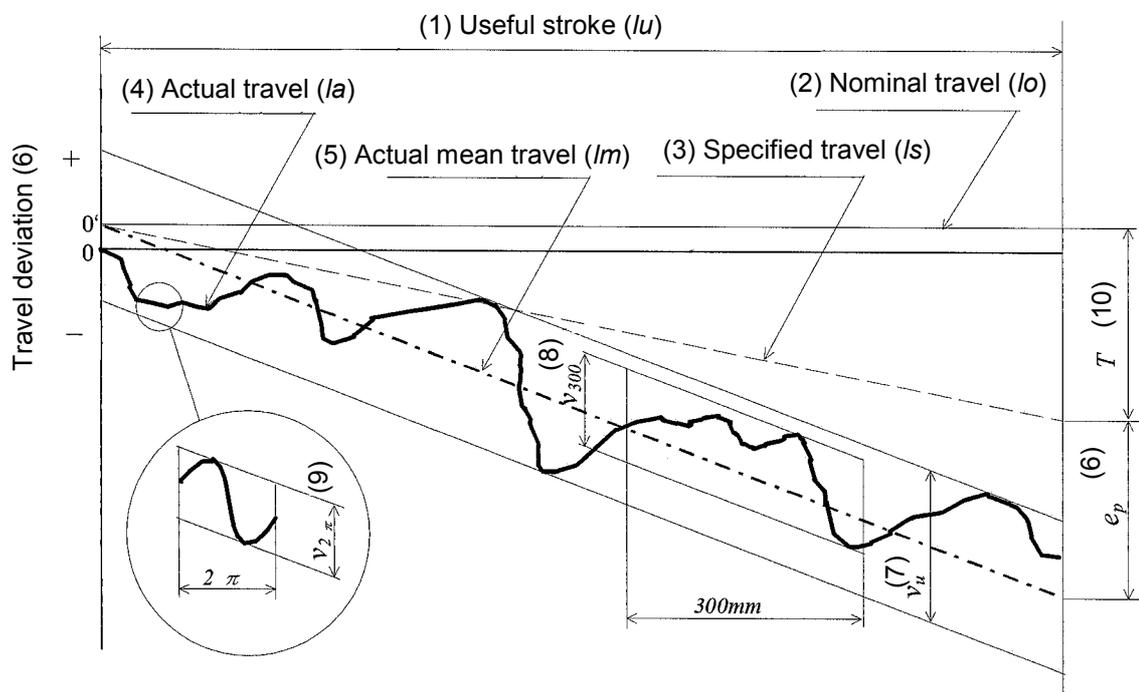
Precision Machinery & Parts
e-Project Team

Lesson 1: Terminology and Data for Selecting Ball Screw

We provide here explanations of technical terminology and data that are frequently referred for selecting ball screw. These are the bare necessities when responding to requests from customers, and when communicating with the Technical Department.

Section 1 Glossary of Lead Accuracy

Lead accuracy of NSK precision ball screws (Grade: C0 through C5) is determined by four characteristics (their codes are e_p , v_u , v_{300} , and $v_{2\pi}$) which are defined in ISO and JIS. Explanations of characteristics and associated technical terminology are given below.



- | | |
|------------------------------------|---|
| (1) Useful thread length (l_u) | : The length of the useful screw portion of a screw shaft. This length is used to specify tolerance of the axial travel of a ball screw. |
| (2) Nominal travel (l_o) | : The travel distance in the axial direction achieved during a given number of rotations based on the nominal lead. (This nominal lead represents a part of the specification of ball screws, thus, it has no tolerance.) |
| (3) Specified travel (l_s) | : The travel distance in the axial direction achieved during a given number of rotations based on the specified lead. (The specified lead: slightly different from the nominal lead, which is often selected to compensate for an elongation caused by an increase in temperature or a load.) |
| (4) Actual travel (l_a) | : Actual axial travel of the ball nut relative to the screw shaft, or vice versa. |

- (5) Actual mean travel (lm) : A straight line that represents the overall tendency of actual travel. (A line is derived from actual travel curves by means of the method of least squares or any other simple and appropriate approximations.)
- (6) Tolerance on specified travel (e_p) : The difference between the actual mean travel (lm) and the specified travel (ls). This characteristic affects positioning accuracy.
- (7) Travel variation (v_u) : The maximum width between two straight lines that are placed in parallel with the actual mean travel line (lm) to sandwich the actual travel (la) line.
- (8) Travel variation (v_{300}) : The maximum width of an actual travel (la) curve, over a 300mm interval within the useful stroke, between the two straight lines sandwiching the actual travel curve and being placed in parallel with its actual mean travel line (lm).
- (9) Travel variation ($v_{2\pi}$) : The maximum width of an actual travel (la) curve, over one single rotation within any position of the useful stroke, between the two straight lines sandwiching the actual travel curve and being placed in parallel with its actual mean travel line (lm).
- (10) Travel compensation (T) : A specified lead is set up based on this figure. This is to compensate for an expected elongation caused by an increase in temperature or load. The figure is determined based on experiments and experience.

◆ Clipping data ◆ Travel compensation

- Although the specified travel of a ball screw generally equals its nominal travel ($T = 0$), the specified lead of a screw shaft is set towards its plus or minus side in case corrections are needed for the screw shaft against its elongation caused by the generated heat during operation or by compression that appears due to external load. The Travel compensation (T) used for some machine tools is shown in the right table for an example.
- The specified lead of SA-series and SS-series, that are the Standard Stock Series items, is set up towards its minus side, and their travel compensation (T) figures are listed in the relevant dimension tables.

Machine	Axis	Travel compensation
NC lathe	X	-0.02 ~ -0.05mm
	Z	-0.02 ~ -0.03mm
Machining center	X, Y	-0.03 ~ -0.04mm
	Z	(varies depending on structure.)

Section 2

Features, Criterion of Preload Value and Application Example of Preloading Systems

◆ Features, Criterion of preload value and application examples of preloading systems

Preloading system	Major features					Criterion of preload value	Major application
	Rigidity	Size	Smoothness	Durability	Cost		
Double nut	A	C	B	B	C	$3 \sim 10\% \times Ca$	<ul style="list-style-type: none"> • Medium/heavy load application • Large machine tools
Double nut spring preloading	C	C	A	A	C	$3 \sim 10\% \times Ca$	<ul style="list-style-type: none"> • When load is working in one direction only. • When smooth operation is essential. • When anti-wear characteristic is required. • Grinding machine (Miniature ball screws)
Offset lead	A	B	B	B	B	$3 \sim 7\% \times Ca$	<ul style="list-style-type: none"> • Light/medium load application • Medium size machine tools
Oversize ball	B	A	B	B	A	$\sim 5\% \times Ca$	<ul style="list-style-type: none"> • Light load and small size equipment • Small size machine tools, electro discharging machine • Semiconductor processing equipment

A: Excellent, B: Faire, C:Inferior,

Ca: Basic dynamic load rating of ball screw

◆ Size of ball screw and criterion of preloading system

Shaft diameter (mm)	Ball thread length							
	~200	350	500	800	1250	2000	3150	4000~
6	P							
10	P	P						
12	P	P	P					
16	P, D	P, D	P, D	P, D	P, D			
20	P, D	P, D	P, D	P, D	P, D			
25	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D		
32	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	
40	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	
50	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D
63	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D	P, Z, D
80	D	D	D	D	D	D	D	D
100	D	D	D	D	D	D	D	D
125	D	D	D	D	D	D	D	D

P: Oversize ball preloading, Z: Offset preloading, D: Double nut preloading

[Note]: Ball thread length is not necessarily the manufacturing limitation, but a rule of thumb.

Section 3 How to Assure Preload Value

- Amount of preload is evaluated and verified by a dynamic preload torque.
- The dynamic preload torque is measured and controlled using an NSK continuous torque measurement equipment.
- The dynamic preload torque is specified in ISO and JIS, and is, at NSK, controlled according to the standards.

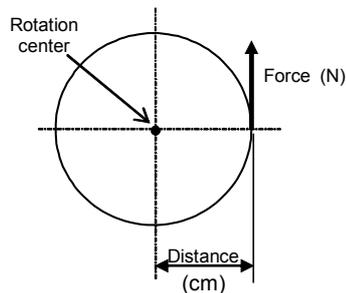
<<Glossary>>

Dynamic preload torque: This is defined as the dynamic torque required to rotate a nut against the screw shaft, or vice versa, with the ball screw preloaded to a certain level, and without external load.

◆Clipping data◆

(1) What is dynamic torque ?

This refers to the force (rotation force) required to continuously rotate the shaft, and its measurement unit is expressed in N-cm (Newton centimeter). More schematically put, this is a state in which a force, apart from its rotation center at a given distance, is acting to cause rotation.



(2) Why do we have to control the preload amount with “dynamic preload torque”?

Since a preload is set in order to assure the required rigidity, the rigidity itself naturally has to be measured. However, it is a time-consuming process to measure rigidity over the entire stroke, and, in reality, it's almost impossible to do so. NSK, using its stock of measurement rigidity and dynamic preload torque data, has established a measuring system for preload amount that is represented by the dynamic preload torque.

★ **A bit technically oriented explanation** ★

(1) The relationship between a preload amount (load) and the dynamic preload torque:

$$T = k \frac{F_{a0} \cdot \ell}{2\pi}$$

T : Dynamic preload torque (N·cm)

F_{a0} : Preload (N)

ℓ : Lead (cm)



Preload torque doubles when the preload is doubled.

(2) The relationship between the preload and rigidity

$$\text{Rigidity of ball screw} \propto \text{Preload}^{1/3}$$



This means that rigidity increases by only 1.26 times when the preload force is doubled.



Section 4 Combination of Accuracy Grade and Axial play

Utilize the figures provided in the following table to combine accuracy grade and axial play. It's important to select a combination that corresponds to the required positioning accuracy.

Accuracy grade \ Axial play	Z	T	S	N	L
	0 (Preloaded)	0.005 or less	0.020 or less	0.050 or less	0.3 or less
C0	C0Z	C0T	-	-	-
C1	C1Z	C1T	-	-	-
C2	C2Z	C2T	-	-	-
C3	C3Z	C3T	C3S	-	-
C5	C5Z	C5T	C5S	C5N	-
Ct7	-	-	C7S	C7N	C7L

* It is meaningless to use a high accuracy ball screw with a large axial play. Reversely speaking, even if its application with large axial play is justified, all it means is that a highly precise lead accuracy is unnecessary for that particular case.

Section 5 Allowable Axial Load

ball screws have a certain amount of load limit that they can bear as structure members. There are two major areas: one is an “allowable axial load” that associates with breakage of a screw shaft, while the other is “fatigue life” that deals with deterioration of the rolling surfaces of steel balls.

1 Allowable axial load

Ball screws are subject only to axial loads because of their intrinsic functions. The following three factors are what determine the limit of axial loads;

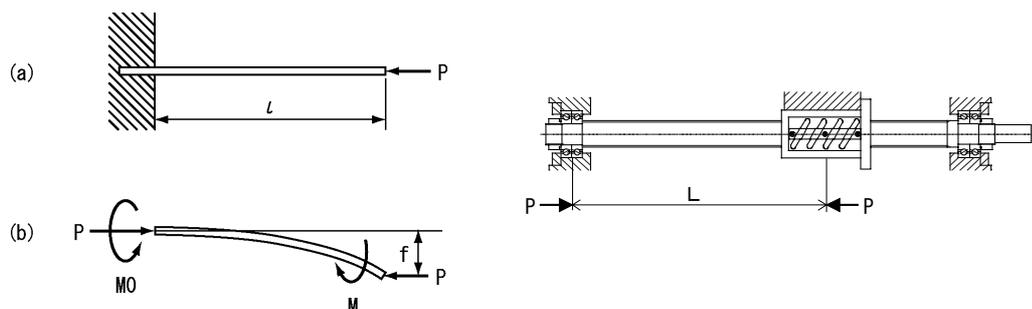
- Buckling of a ball screw shaft (→ buckling load)
- Yielding of a ball screw shaft due to tensile or compression stress (→ allowable tensile or compression load)
- Permanent deformation of contact surfaces on steel balls and ball grooves (→ basic static load rating)

(1) Buckling load

- The allowable axial load applied to compress the screw shaft. If the shaft is loaded with more than this load level, the shaft breaks.
- Although this may sound like an abstract expression, attention must be paid when a large axial load is applied to a shaft that is long and thin.
(As a rough guideline, ask the Technical Department for support in conducting detailed calculations when an axial span between two support points exceeds 60 times the shaft diameter, while the axial load is as high as the basic dynamic load rating.)

★ A bit technically oriented explanation ★ What exactly is buckling?

When a slender shaft is subject to a compression force, as illustrated in the figures below, a certain amount of lateral bending could occur due to the fact that most axial loads do not, in reality, bear down exactly on the center line of a shaft, and the induced stress combines with the axial compression stress. If the load is smaller than a certain level, the bending recovers. However, when the load is larger than such a level, the bending increases, and axial breakage eventually occurs. Such a phenomenon is called “buckling”.



(2) Allowable tensile or compressive load

This refers to the limit of tensile or compression axial load that is applied to the screw shaft. If the axial load goes beyond a certain limit, the shaft will not withstand any more, and starts to show a permanent deformation (a deformation that does not disappear even after the load has been removed). And if it goes further, the shaft will break. (Although this is a rough approach, there is no problem when the axial load is lower than somewhere around the allowable static load rating.)

(3) Basic static load rating

- When an excessive axial load is applied, the contact surface between steel balls and ball grooves create dent which won't recover even after the load has been removed, leaving permanent deformations on each surface. Measures must be taken to limit such deformations within a certain limit. Permanent deformations lead to noise and vibration, and on to deteriorated functionality and shorter service life.
- Based on the basic static load rating, confirm that no permanent deformations will be created on the contact surfaces between steel balls and ball grooves.
- An allowable load rating (P_0) against permanent deformation is as follows;
(An allowable load is approximately one half of the allowable static load rating.)

$$P_0 = C_{0a}/f_s$$

Where, f_s : Static allowable load coefficient (a safety factor)

For regular operation: 1 to 2

If there are vibrations or impact: 1.5 to 3

<<Basic Static Load Rating (C_{0a})>>

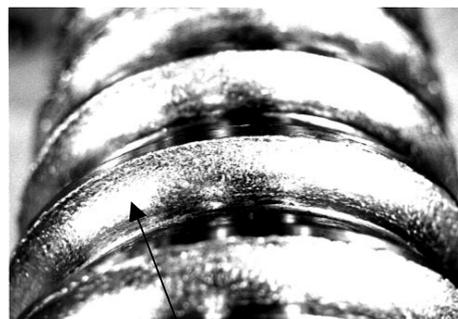
Defined as an axial load that causes the sum of a deformation that is formed on a steel ball and its contacting ball groove surfaces, while in a static state, to exceed 0.01% of the diameter of that steel ball. This figure is listed in the Dimension Tables in the catalogues. A permanent deformation of 0.01% means, however, a dent of only 0.001 mm in the case of a 10 mm steel ball. Therefore, it is almost undetectable.

2 Fatigue life

Even if ball screws are made using the most appropriate design and they are used properly, the surfaces of ball grooves will still start flaking (the surface metal falls apart in the form of scales) after a certain period of time since the steel balls roll on the ball grooves with load applied to them. (This is a material fatigue phenomenon of contact surfaces caused by repetitive compressive stress between steel balls and the ball groove.) The total rotation number (or time period, travel distance) up until the first flaking occurs is called a "fatigue life."



Normal rolling surface



Normal rolling surface

<<Basic dynamic load rating (Ca)>>

Defined as the axial load under which, when a group of identical ball screws are individually rotated under identical conditions, 90% will successfully achieve one million rotations without any flaking. This figure is listed in the dimension tables in the catalogues.

◆ Relationship of basic dynamic load rating, axial load (Fa) and fatigue life (L):

$$L \propto \left(\frac{C_a}{F_a} \right)^3 \Rightarrow$$

- This means that when Ca is doubled, the fatigue life becomes 8 times longer. (Conversely, when Ca is halved, the fatigue life decreases to 1/8.)
- When Fa is doubled, the fatigue life decreases to 1/8. (Conversely, when Fa is halved, the fatigue life becomes 8 times longer.)
- Namely, when a safety factor of which value is more than necessary, is used to estimate an axial load, you will end up selecting a ball screws that are unnecessarily large.

◆ Mean effective load (Fm)

Of the various applications for ball screws, there is a case in which the axial load or feed speed varies with time. (See the following example.) In such a case, obtain a mean effective load to compute life expectancy. It is important to prevent any trouble from occurring by getting detailed operating conditions and as much information as possible from customers.

Example of use conditions

Axial load (N)	Rotational speed (rpm)	Operating time (or ratio to total operation time)
2000	1000	3 sec. (5 %)
3000	500	15sec. (25 %)
1500	2000	3 sec. (5 %)
0	0 (Stopping)	39 sec. (65 %)

◆ Clipping data ◆

Although there are three different ways to express “service life of ball screws” as shown below, “life” means “fatigue life” in most cases.

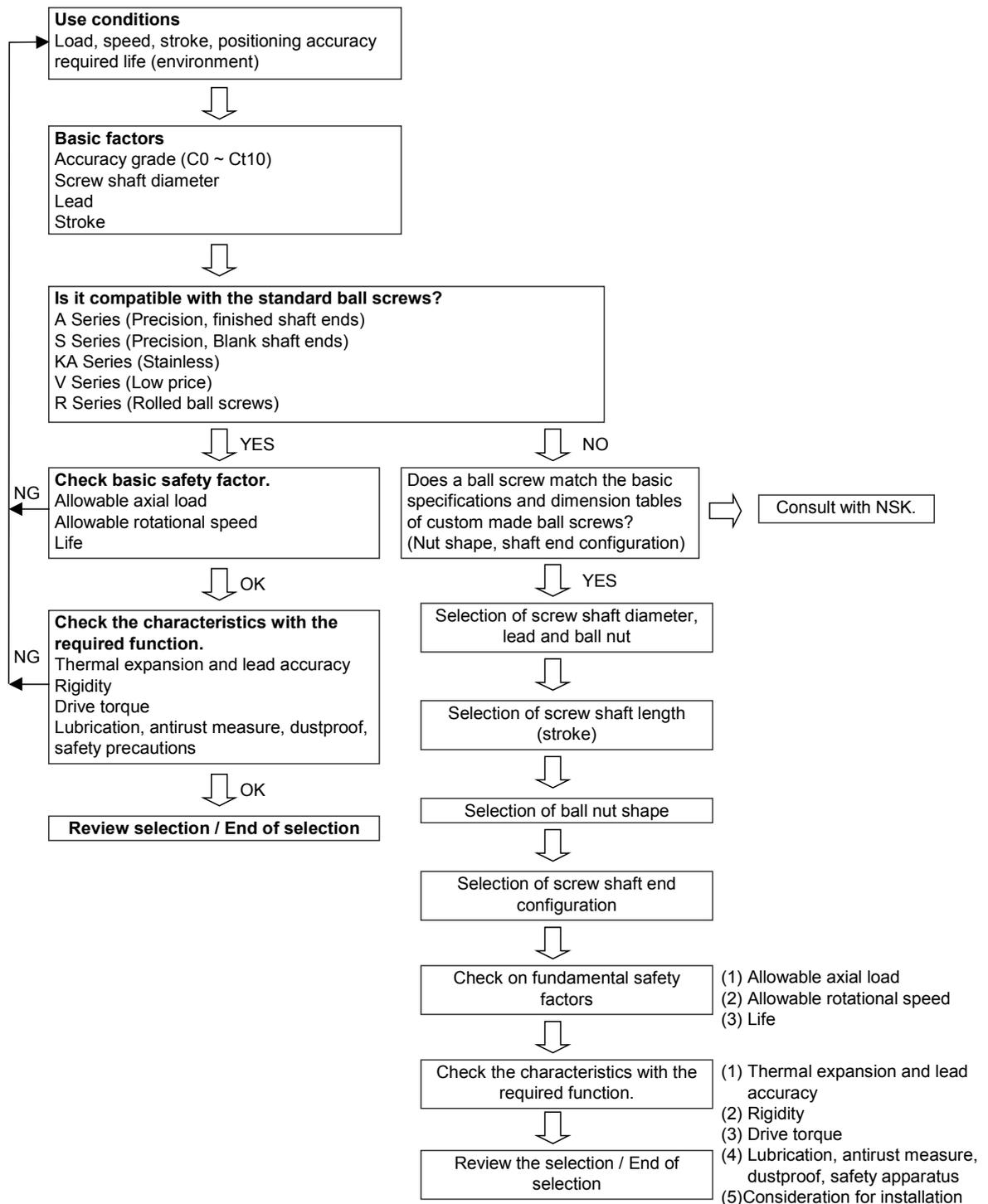
- Accuracy deterioration life: This refers to a case in which the machine has reached its functional limit due to deteriorated accuracy as a result of continued wearing of rolling parts over time. This can be ambiguous because there are other contributing factors, such as matching the accuracy required for the machine and the machine’s components. Environmental conditions can come into play, too.
- Breakdown life: Time until the shaft fails. This includes breakage of a slender shaft caused by buckling, shaft breakage due to bending fatigue or torsion fatigue at the supported points of the shaft, or the resonance of a rotating shaft.
- Fatigue life

Lesson 2: Selection of Ball Screws

If you cannot find a ball screw not in the standard stock ball screws, you have to select the ball screws out of the “custom made ball screws.

Section 1 Selecting Flowchart

The following is the selecting flowchart including the custom made ball screws.



Section 2 Accuracy Grades and Specific Application

The following table shows examples of accuracy grades for various applications selected base on NSK’s experience. They indicate the range of accuracy grades for an individual application category that are marked with a circle (○), and also shows those most frequently used accuracy classes for each application category that are marked with a double circle (◎). You can select from this table the accuracy grade most frequently used for ball screws that meet your specific purposes.

In addition, refer to the Table on “Lead Accuracy” on Page B497 – 498 in the Precision Machine Components (3155B) catalogue regarding the accuracy grade of the ball screw that corresponds to the required positioning accuracy.

Application		NC Machine Tools																			
		Lathe		Milling machine Boring machine		Machining center		Drilling machine		Jig boring machine		Grinder		Electric discharging machine		Wire cutting machine		Punching press	Laser beam machine	Woodworking machine	
Axis		X	Z	XY	Z	XY	Z	XY	Z	XY	Z	XY	Z	XY	Z	XY	Z	XY	XY	Z	
Accuracy grade	C0	○								○	○	○	○								
	C1	○		○		○				◎	◎	○	○	○		○	○				
	C2	○		○	○	○	○					◎	○	○	○	◎	○				
	C3	◎	○	◎	○	○	○	○					◎	○	○	◎	◎	○			
	C5	◎	◎	◎	◎	◎	◎	◎	◎						◎		◎	◎	◎	◎	◎
	Ct7							○													◎
	Ct10																				○

Application		Equipment for semiconductor/printed circuit board processing						Industrial robot				Steel mill	Injection molding machine	3-D measuring machine	Office machine	Image processing equipment	Nuclear power		Aircraft	
		General industrial / specific purpose machine	Lithography machine	Chemical processing equipment	Wire bonding machine	Prober	Electric component mounting machine	Drilling machine for printed circuit board	Assembling	Others	Cartesian type robot						Vertical articulate type robot	SCARA type robot		Fuel rod control
Accuracy grade	C0		○				○													
	C1		◎				◎													
	C2				○		◎													
	C3	○		○			○	◎	○										○	
	C5	◎		○			◎	◎	○	○									◎	
	Ct7	◎		◎				○	◎	○	○								○	○
	Ct10	○		○					○	○	○				○				○	

Section 3 Precautions for Selection

Extremely important issues concerning the selection of ball screws are described in this section. If your application is one of the following cases, please obtain detailed information on the application and then consult with the Technical Department.

1 If there are oscillating motions

In the case of repetitive minute strokes of motions (oscillating), that make less than half of one rotation of balls, lubricant will sooner or later be forced out (insufficient oil film) from the contact surfaces between the balls and ball grooves, and direct metal contact will start to take place. Eventually, an early stage wearing, called fretting, will occur.

Whenever the customers provide operational conditions, confirm whether there are any oscillating motions.

↓ Although there are no perfect answers to such applications, it is possible to moderate the progress of fretting.

- Use an anti-fretting grease.
- Even when using a standard grease, add one long stroke travel (the number of rotations will be equivalent to more than twice the number of turns of ball recirculation – e.g., more than 5 rotations when the number of turns is 2.5) for every several thousands cycles.

2 If an extremely large load is applied during one stroke

The life expectancy when an extremely large load is applied at one particular spot within a stroke could be much shorter than the corresponding fatigue life estimated for the same case based on the mean effective load. Such a situation is caused by a large stress (surface pressure) on the contact surfaces between balls and ball grooves due to a high load. This adversely affects the fatigue life

- ↓
- Practice the life expectancy studies taking into account the size of a surface pressure that could occur.

Section 4 Production Capability of Ball Screw Shafts

The fabrication limit for the length of a screw shaft varies with the screw shaft diameter and accuracy grade. This happens simply because it is quite difficult to fabricate a thin but long shaft with good accuracy. The following table shows the maximum total shaft length for each diameter and for each accuracy grade. Take this limit information into account when making selections.

As for any screw shafts with an extra-large diameter exceeding 100 mm, weight is a limiting factor. Consult the Technical Department in such cases or when the required shaft diameter is beyond the listed diameter range.

Manufacturing capability of screw shaft length

Unit: mm

Screw shaft dia.	Accuracy Grad							Rolled screw (Ct10)
	C0	C1	C2	C3	C5	Ct7		
4	90	110	120	140	140	140	—	
6	150	180	200	250	250	250	—	
8	240	280	340	340	340	340	—	
10	350	400	500	500	500	550	800	
12	450	500	650	700	750	800	800	
14	600	650	750	800	1000	1000	1000	
15	600	700	800	900	1250	1250	1500	
16	600	750	900	1000	1500	1500	1500	
18	—	—	—	—	—	—	1500	
20	850	1000	1200	1400	1900	1900	2000	
25	1100	1400	1600	1900	2500	2500	2500	
28	1100	1400	1600	1900	2500	2500	2500	
32	1500	1750	2250	2500	3200	3200	3000 (4000)	
36	1500	1750	2250	2500	3200	3500	3000	
40	2000	2400	3000	3400	3800	4300	4000 (5000)	
45	2000	2400	3000	3400	4000	4500	4000	
50	2000	3200	4000	4500	5000	5750	4000	
63	2000	4000	5000	6000	6800	7700		
80		4000	6300	8200	9200	10000		
100		4000	6300	10000	12500	14000		
125				10000	14000	14000		

[Remarks]

- The figures given in parentheses for some of the rolled ball screws can be applied to ultra high helix ball screws ($l/d \geq 2$).
- In the case of a fine lead (less than 3), the effective screw length would become a limiting factor.

Section 5 Rigidity of Driving Screw System

If rigidity around the ball screw is low, you cannot attain the required positioning accuracy, or you may end up with vibrations. It is important to give full consideration to the rigidity of the nut and shaft of the ball screw itself, and how it is going to be set up. It is also important to design overall axial rigidity that balances well with various components.

1 Axial rigidity of driving screw system

Axial rigidity (total rigidity) of a driving screw system can be obtained by the following equation;

$$\frac{l}{K_t} = \frac{l}{K_s} + \frac{l}{K_n} + \frac{l}{K_b} + \frac{l}{K_h} \quad (\text{N}/\mu\text{m})$$

Where; K_t : Axial rigidity (total rigidity) of the feed screw system ($\text{N}/\mu\text{m}$)

K_s : Axial rigidity of the screw shaft ($\text{N}/\mu\text{m}$)

K_n : Axial rigidity of the nut ($\text{N}/\mu\text{m}$)

K_b : Axial rigidity of the support bearing ($\text{N}/\mu\text{m}$)

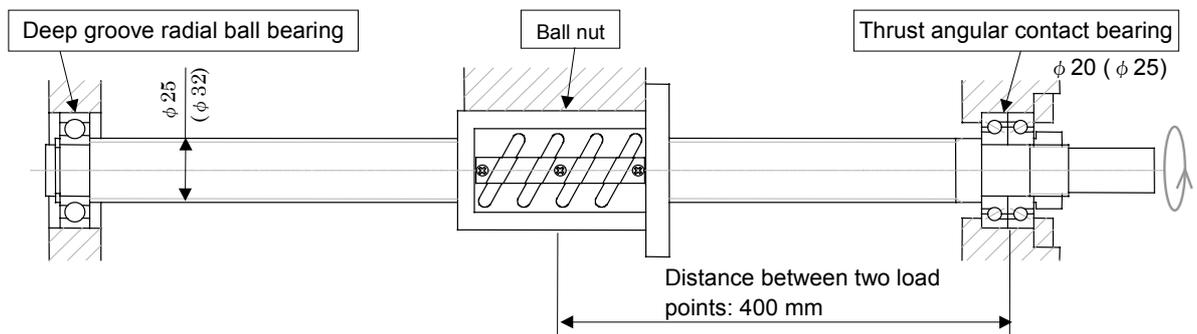
K_h : Axial rigidity of the housing for the nut and support bearing ($\text{N}/\mu\text{m}$)

2 Example of axial rigidity calculation

How can we create a well-balanced design for axial rigidity of ball screw and other components that is to be assembled with various components? Shown below is a specific example for such;

[Ball screw specification]

- Screw shaft diameter: $\phi 25$ and $\phi 32$, lead 5
- Effective turns of balls 2.5 turns \times 2 circuits
- Shaft support: Fixed – simple support



[Calculation result of axial rigidity of driving screw system]Axial rigidity of driving screw system (Unit: N/ μ m)

	(1)	(2)	(3)
Ball screw diameter	$\phi 25$	$\phi 25$	$\phi 32$
Support bearing (Angular ball bearing)	Bore: $\phi 20$	Bore: $\phi 20$	Bore: $\phi 25$
Ball screw: preload	1670N (Ca \times 0.1)	2450N (Ca \times 15)	1670N (Ca \times 0.09)
Rigidity of screw shaft: Ks	176	176	294
Rigidity of ball nut: Kn	873	1000	1020
Rigidity of support bearing: Kb	735	735	980
Rigidity of housing: Kh	980	980	980
Rigidity of driving screw system: Kt	109	111	156

Ca: Basic dynamic load rating

2%

43%

- Columns (1) and (2) for a shaft diameter of $\phi 25$ in the table are preloaded differently, while column (3) shows a result when the shaft diameter is increased to $\phi 32$.
- From the table, it is notable that the screw shaft rigidity is much lower than the rigidity of the other components. (This means that, in most case, the shaft is the component governing the total rigidity of a driving screw system.)
In this particular example, an increase in the shaft diameter has resulted in a 43% increase in total system rigidity.
- When it is necessary to increase the total rigidity of a driving screw system, it is quite common to think about an approach to increase the preload on the nut or support bearings. However, in the case of this particular example, when the preload has been increased by 1.5 times, the total system rigidity has hardly changed at all.
- Increasing the preload of the nut or support bearings for the sake of increasing system rigidity can result in only a small effect, as shown in this example, and it might even lead to adverse effects, such as an increase in friction torque that may further affect the control system, heat generation that may further create a thermal expansion in the shaft. All of which would result in poor positioning accuracy.

Section 6 Heat Generation in Ball Screws

During operation of ball screws, temperature rise due to heat generation in the shaft causes them to elongate themselves (a thermal expansion). Even if the lead of a ball screw has been fabricated to high accuracy, such thermal expansion also causes the lead to expand, thus its accuracy will decrease. With increasing demands for a higher speed operation in the market, possible effects of thermal expansion upon the accuracy are critical issues. It is required, depending on application, to consider an effective countermeasure against thermal expansion when selecting ball screws.

(Reference: With the temperature rise of 1°C, an elongation of 12 μ m per meter takes place in the screw shaft.)

1 Measures against thermal expansion

As to the amount of heat generation, heat generated by a motor or support bearings in a machine is considerably high and it is not practical to consider only the heat generated by ball screws. Yet, when looking only at the heat generated by a ball screw, heat generation is proportional to the product of the friction torque multiplied by the rotational speed.

A summary of measures to cope with thermal expansion of ball screws is shown below;

1) Restraint of heat generation

- Decrease the number of rotations → Increase a lead.
- Optimize preload with ball screws and support bearings.
- Select the proper lubricant, and lubricate properly.

2) Heat release by means of forced cooling

- Cooling from the inside of the screw shaft → Use hollow ball screw shaft.
- Cooling outside surface of screw shaft by means of a lubricant or air.

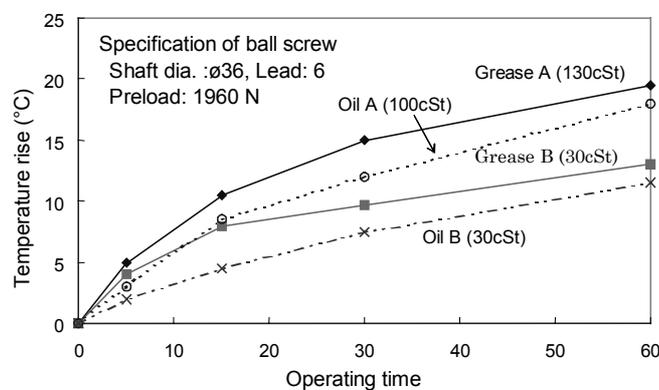
3) Lessen the effect of thermal expansion caused by temperature rise.

- Mount the screw shaft so that it is stretched axially.
- Set the target value of the specified travel to the minus side.
- Use closed loop control.

2 Characteristics of temperature rise in lubricant

As viscose drag or agitation resistance of a lubricant increases with speed, its friction torque increases, resulting in heat generation. Accordingly, lubricant selection is of importance.

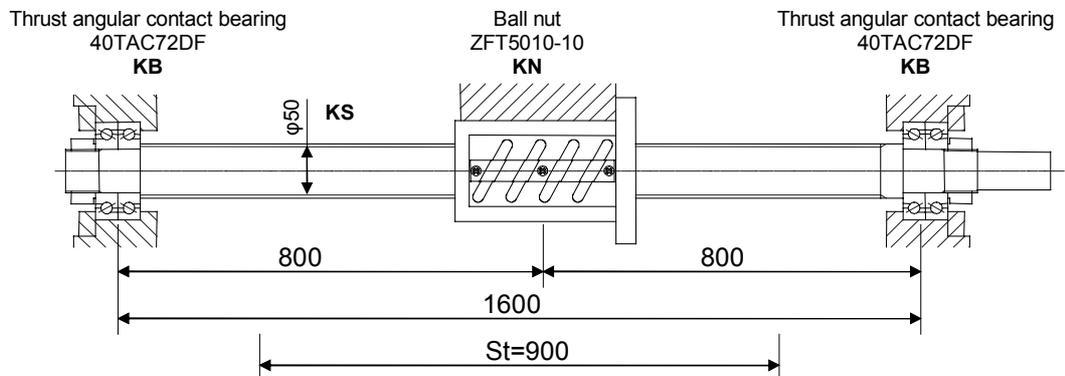
The following figure measures how various lubricants increase temperature over a period of time. It shows how selecting a base oil with a lower kinetic viscosity, either oil or grease lubricant, will minimize heat generation.



Characteristics of temperature rise

3 Preload and temperature rise in ball screws

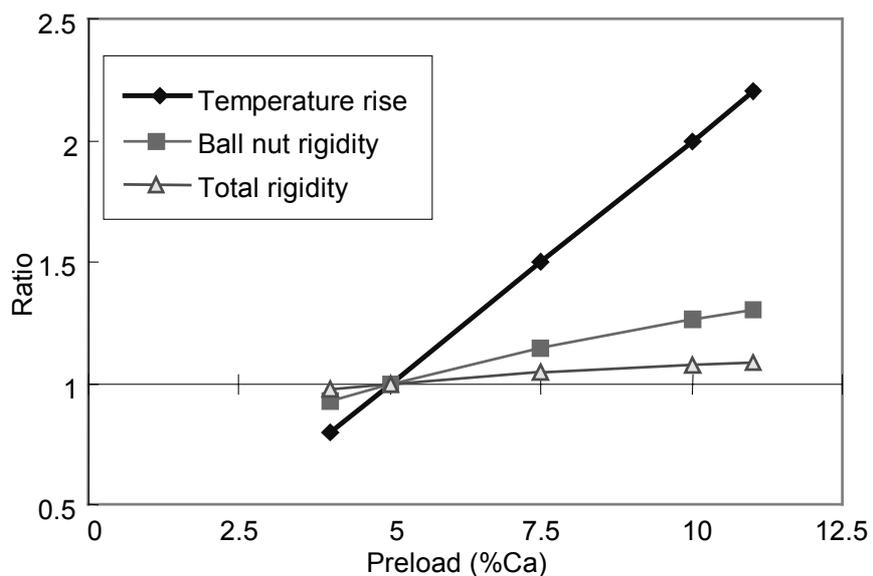
Depending on the amount, a preload can have a great influence on an increase in temperature (thermal expansion). The following shows one example:



- $KS = 794 \text{ N}/\mu\text{m}$, $KB = 2 \times 1225 = 2450 \text{ N}/\mu\text{m}$
- Mean velocity N_m : 5 and 10 m/min

Preload (%Ca)	Nut rigidity: KN N/ μm	Total rigidity N/ μm	Preload torque N·cm	Temperature rise Nm (rpm)	
				500	1000
5880 (10%Ca)	1677	441	187	29°C	40°C
4410 (7.5%Ca)	1524	431	140	22°C	30°C
2940 (5%Ca)	1331	412	94	15°C	20°C

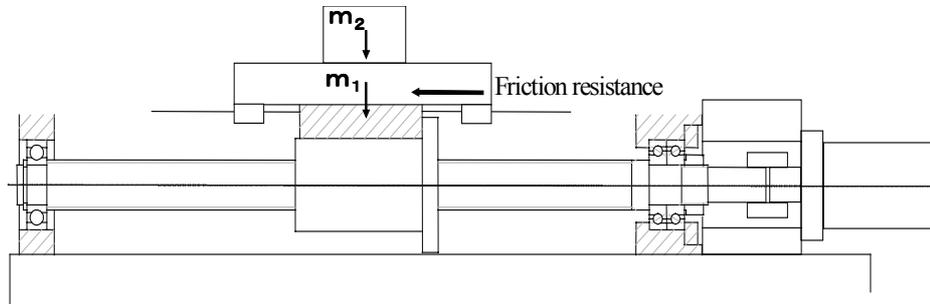
The figure below illustrates the above results in ratios when taking the results of 5%Ca preload to 1. This figure clearly indicates that the size of a preload can induce a great rise in temperature, but it is not effective to improve rigidity.



Preload and temperature rise

Section 7 Application Example

Let's give a try to actually select ball screws for a high speed transporting equipment.



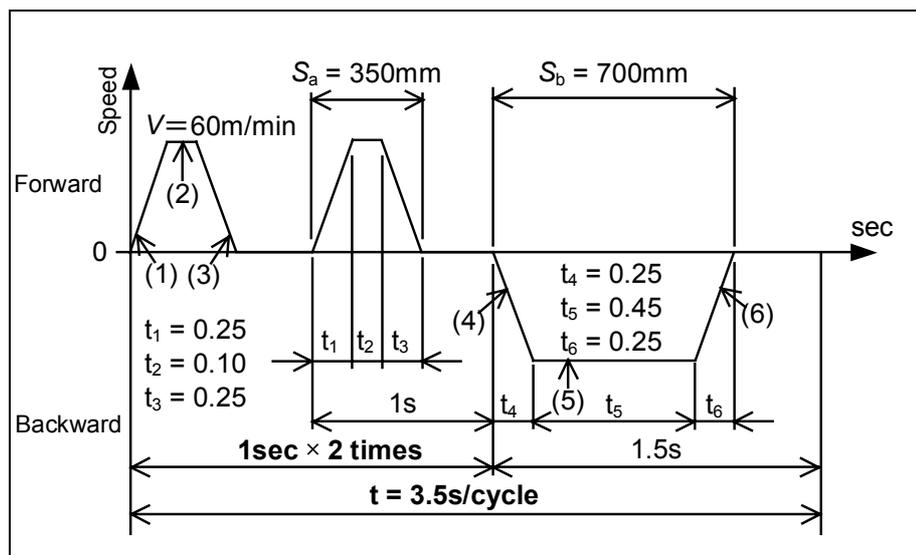
Schematic drawing of equipment

1 Measures against thermal expansion

1) Table specification

Table mass	: $m_1 = 40\text{kg}$
Load mass	: $m_2 = 20\text{kg}$
Maximum stroke	: $S_{\text{max}} = 700\text{mm}$
Maximum speed	: $V_{\text{max}} = 1000\text{mm/s}$ (60m/min)
Positioning accuracy	: $\pm 0.10/700\text{mm}$ (0.01mm/pulse)
Repeatability	: $\pm 0.010\text{mm}$
Required life	: $L_t = 25000\text{h}$ (5 years)
Guide way	: $\mu = 0.01$ (Friction coefficient; rolling element guide way)
Drive motor	: AC servo motor ($N_{\text{max}} = 3000 \text{ min}^{-1}$)

2) Operating conditions



2 Selection of basic specifications

1) Selection of accuracy grade

The accuracy grade suitable for a transporting equipment can be considered to be C5 to Ct10, based on the table for “Accuracy grades used for particular application” in Section 2 on Page 10. The following two design conditions lead to an axial play code of T (0.005 mm or less).

Repeatability: ± 0.010 mm, and

Resolution: 0.01 mm/pulse

From the table <Combination of accuracy grades and axial play> shown below, both the accuracy grade of C5 and the axial play of T (0.005 mm or less) are selected.

<Combination of accuracy grades and axial play>

Axial play \ Accuracy grade	Z	T	S	N	L
	Preloaded	0.005mm or less	0.020mm or less	0.050mm or less	0.3mm or less
C0	C0Z	C0T	-	-	-
C1	C1Z	C1T	-	-	-
C2	C2Z	C2T	-	-	-
C3	C3Z	C3T	C3S	-	-
C5	C5Z	C5T	C5S	C5N	-
Ct7	-	-	C7S	C7N	C7L

2) Selection of lead

Based on the maximum rotational speed of the motor, the lead shall be 20 mm or larger.

$$l \geq \frac{V_{\max}}{N_{\max}} = \frac{1000 \times 60}{3000} = 20 \text{ (mm)}$$

3) Selection of a screw shaft diameter

From Table I-4.5 “Combination of screw shaft diameter and leads” for Standard Stock Series on Page B19 of the “Precision Machine Components” catalogue (No. E3155), the screw shaft diameters with a lead of 20mm or larger range from 15 to 32mm. So, the smallest diameter, 15mm, is selected.

4) Selection of a stroke

As shown in Table I-4.6 “Maximum stroke of standard stock ball screws A- and S-Series” on Page B20 of the “Precision Machine Components” catalogue (No. E3155), a screw shaft with a diameter of 15mm and lead of 20mm can satisfy the maximum stroke of 700 mm.

Primary selection: Shaft diameter : 15 mm Lead : 20 mm Stroke : 700 mm Accuracy grade : C5 Axial play code : T

3 Confirm whether this selection is listed in the standard stock series

We are going to make selection from the A-series items, taking delivery lead time and price into consideration. From Page B71 of the “Precision Machine Components” catalogue (No. E3155), we select the following;

Primary selection: W1507FA-4G-C5T20

(By the way, in case we don't find a candidate among the standard stock series items, we will have to look into custom made ball screws.)

4 Checking on the basic safety factors

1) Check on allowable axial load

(1) Calculation of axial load

Acceleration and deceleration at start-up and slow-down:

$$\alpha_1 = \frac{V_{\max}}{t_1} = \frac{1000}{0.25} = 4000 \text{ (mm/s}^2\text{)} = 4 \text{ (m/s}^2\text{)}$$

- When accelerating; (1) and (4)

$$F_1 = \mu(m_1+m_2) \times g + (m_1+m_2) \times \alpha_1 \\ = 0.01 \times (40+20) \times 9.80665 + (40+20) \times 4 = 246 \text{ (N)}$$

- When running at constant speed; (2) and (5)

$$F_2 = \mu(m_1+m_2) \times g = 0.01 \times (40+20) \times 9.80665 = 6 \text{ (N)}$$

- When decelerating; (3) and (6)

$$F_3 = -\mu(m_1+m_2) \times g + (m_1+m_2) \times \alpha_1 = 234 \text{ (N)}$$

(2) Buckling load

With $P = 246 \text{ (N)}$ and $L = 804 \text{ (mm)}$ (L is obtained from the dimension table on Page B71 of the “Precision Machine Components” catalogue (No. E3155), we are going to study the buckling load. Based on the structure of bearing supports (simply support at one end, and fixed support on the other) and load direction, the actual mounting conditions are going to be “fixed - fixed”.

From equation II-2 on Page B503 of the “Precision Machine Components” catalogue (No. 3155),

$$dr \geq \left(\frac{P \cdot L^2}{m} \times 10^{-4} \right)^{1/4} = \left(\frac{246 \times 804^2}{19.9} \times 10^{-4} \right)^{1/4}$$

$$= 5.3 \text{ (mm)}$$

Although the dimensions table does not list dr , basic dimensions table of custom made ball screws (on Page B401 of the “Precision Machine Components” catalogue (No. E3155) lists the same nut types. Referring to this, dr is 12.2mm, and thus it satisfies the conditions.

Check result: Acceptable

2) Check on allowable rotational speed

The allowable rotational speed listed in the dimensions table (on Page B71 of the “Precision Machine Components” catalogue (No. E3155) is 3000 rpm. Since the maximum rotational speed of the motor is 3000 rpm, the operation is going to be within the criterion.

Check result: Acceptable

3) Check on the life

- When accelerating; (1) and (4)

From result of calculating axial load;

$$F_1 = 246(\text{N})$$

$$N_1 = \frac{n}{2} = \frac{3000}{2} = 1500 \text{ min}^{-1}$$

$$t_a = 2 \times t_1 + t_4 = 0.75 \text{ (s)}$$

- When running at constant speed; (2) and (5)

$$F_2 = 6(\text{N})$$

$$N_2 = 3000 \text{ min}^{-1}$$

$$t_b = 2 \times t_2 + t_5 = 0.65(\text{s})$$

- When decelerating; (3) and (6)

$$F_3 = 234 \text{ (N)}$$

$$N_3 = 1500 \text{ min}^{-1}$$

$$t_c = 2 \times t_3 + t_6 = 0.75(\text{s})$$

Operating conditions	Axial load (N)	Rotational speed (min ⁻¹)	Time (s)
(1) and (4)	$F_1 = 246$	$N_1 = 1500$	$t_a = 0.75$
(2) and (5)	$F_2 = 6$	$N_2 = 3000$	$t_b = 0.65$
(3) and (6)	$F_3 = 234$	$N_3 = 1500$	$t_c = 0.75$

- (1) Mean effective load F_m and mean rotational speed N_m

From formulas (II-11) and (II-12) on Page B513 of the “Precision Machine Components (No. E3155),”

$$F_m = \left(\frac{F_1^3 \cdot N_1 \cdot t_a + F_2^3 \cdot N_2 \cdot t_b + F_3^3 \cdot N_3 \cdot t_c}{N_1 \cdot t_a + N_2 \cdot t_b + N_3 \cdot t_c} \right)^{1/3}$$

$$= 195 \text{ (N)}$$

$$N_m = \left(\frac{N_1 \cdot t_a + N_2 \cdot t_b + N_3 \cdot t_c}{t} \right)$$

$$= 1200 \text{ (min}^{-1}\text{)}$$

(2) Calculation of life

From formulas (II-8) and (II-9) on Page B513 of the “Precision Machine Components (No. E3155),” the estimation of life shall be;

(Where the basic dynamic load rating (C_a) of the axial code T is 5070 (N).)

$$\begin{aligned} L_t &= \left(\frac{C_a}{F_m \cdot f_w} \right)^3 \times \frac{1}{60N_m} \times 10^6 \\ &= \left(\frac{5070}{195 \times 1.2} \right)^3 \times \frac{1}{60 \times 1200} \times 10^6 \\ &\doteq 141200 \leq 25000 \text{ (h)} \end{aligned}$$

Check result: Acceptable

5 Check the results specific to requirements

1) Checking accuracy and axial play

As for the required positioning accuracy of $\pm 0.10/700$ (mm), refer to the table II-1.2 on Page B498 of the “Precision machine Components” catalogue (No. E3155).

Accuracy grade C5

$$e_p = \pm 0.035/800 \text{ (mm)}$$

$$v_u = 0.025 \text{ (mm)}.$$

Accordingly, this satisfies the required functions.

We are going to omit axial play checking here since we have already covered it in [2] Selection of Basic Specifications

Based upon the results above, we offer the following to the user.

Ball screw	W1507FA-4G-C5T20
Support units:	Fixed support side: WBK12-01A or WBK 12-11
Simple support side:	WBK12S-01