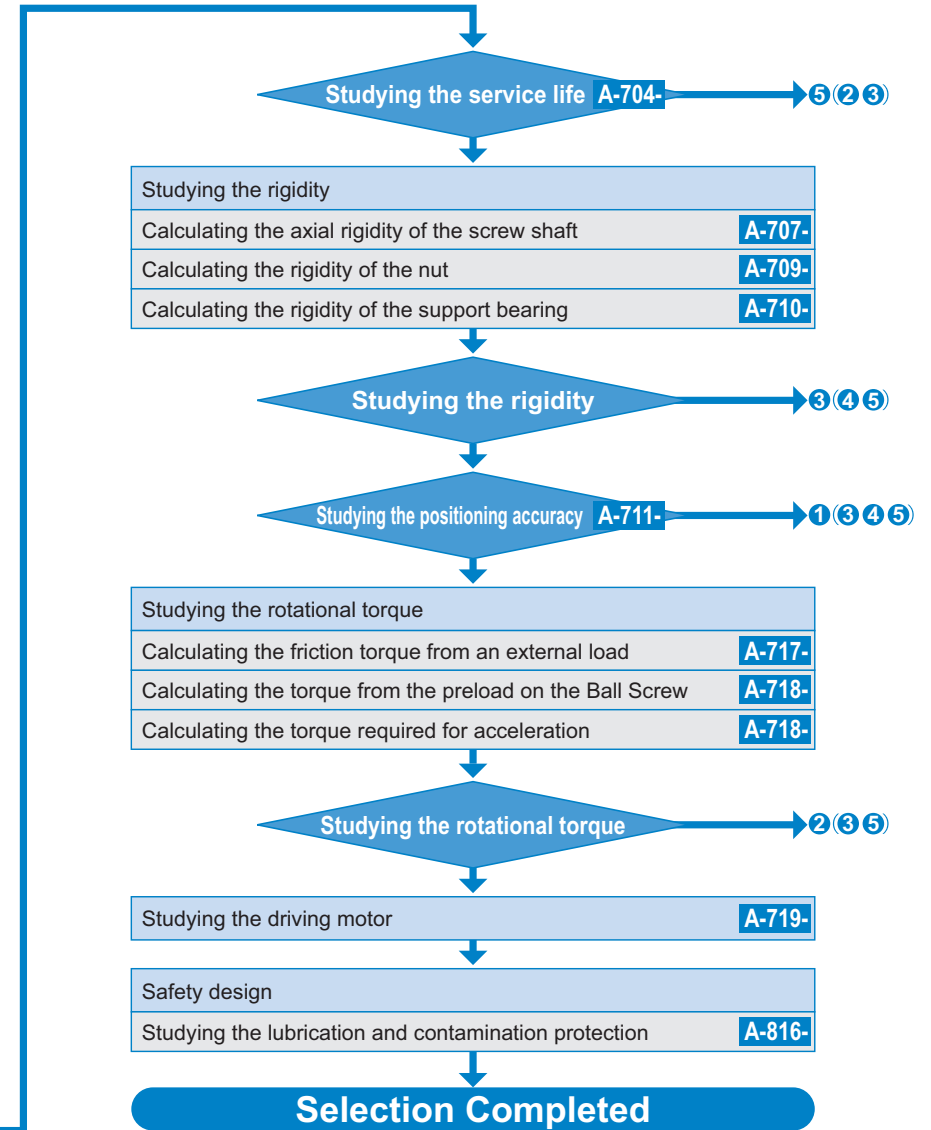
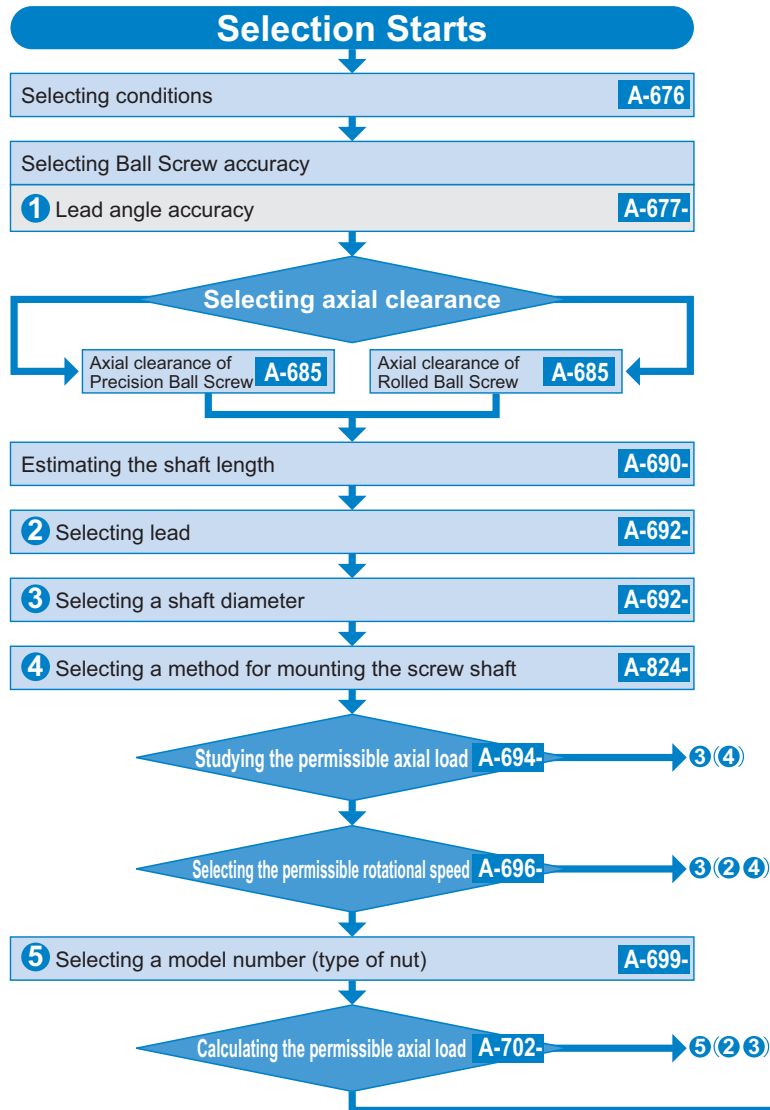


Flowchart for Selecting a Ball Screw

[Ball Screw Selection Procedure]

When selecting a Ball Screw, it is necessary to make a selection while considering various parameters. The following is a flowchart for selecting a Ball Screw.



[Conditions of the Ball Screw]

The following conditions are required when selecting a Ball Screw.

Transfer orientation (horizontal, vertical, etc.)
 Transferred mass m (kg)
 Table guide method (sliding, rolling)
 Frictional coefficient of the guide surface μ (-)
 Guide surface resistance f (N)
 External load in the axial direction F (N)
 Desired service life time L_s (h)

Stroke length l_s (mm) (m/s)
 Operating speed V_{max} (m/s)
 Acceleration time t_1 (s)
 Even speed time t_2 (s)
 Deceleration time t_3 (s)

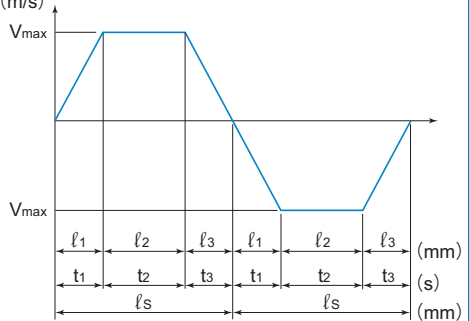
Acceleration $\alpha = \frac{V_{max}}{t_1}$ (m/s²)

Acceleration distance $l_1 = V_{max} \times t_1 \times 1000/2$ (mm)
 Even speed distance $l_2 = V_{max} \times t_2 \times 1000$ (mm)
 Deceleration distance $l_3 = V_{max} \times t_3 \times 1000/2$ (mm)
 Number of reciprocations per minute n (min⁻¹)

Positioning accuracy (mm)
 Positioning accuracy repeatability (mm)
 Backlash (mm)
 Minimum feed amount s (mm/pulse)

Driving motor (AC servomotor, stepping motor, etc.)

The rated rotational speed of the motor N_{MO} (min⁻¹)
 Inertial moment of the motor J_M (kg · m²)
 Motor resolution (pulse/rev)
 Reduction ratio A (-)



Velocity diagram

Accuracy of the Ball Screw

Lead Angle Accuracy

The accuracy of the Ball Screw in the lead angle is controlled in accordance with the JIS standards (JIS B 1192 - 1997).

Accuracy grades C0 to C5 are defined in the linearity and the directional property, and C7 to C10 in the travel distance error in relation to 300 mm.

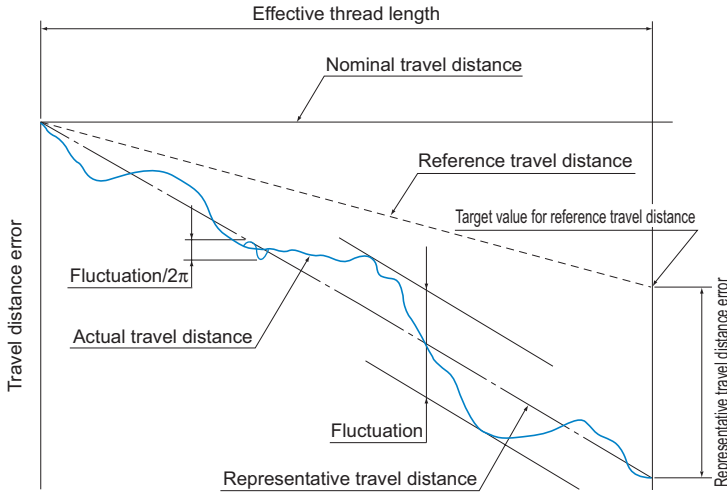


Fig.1 Terms on Lead Angle Accuracy

[Actual Travel Distance]

An error in the travel distance measured with an actual Ball Screw.

[Reference Travel Distance]

Generally, it is the same as nominal travel distance, but can be an intentionally corrected value of the nominal travel distance according to the intended use.

[Target Value for Reference Travel Distance]

You may provide some tension in order to prevent the screw shaft from runout, or set the reference travel distance in "negative" or "positive" value in advance given the possible expansion/contraction from external load or temperature. In such cases, indicate a target value for the reference travel distance.

[Representative Travel Distance]

It is a straight line representing the tendency in the actual travel distance, and obtained with the least squares method from the curve that indicates the actual travel distance.

[Representative Travel Distance Error (in \pm)]

Difference between the representative travel distance and the reference travel distance.

[Fluctuation]

The maximum width of the actual travel distance between two straight lines drawn in parallel with the representative travel distance.

[Fluctuation/300]

Indicates a fluctuation against a given thread length of 300 mm.

[Fluctuation/2 π]

A fluctuation in one revolution of the screw shaft.

Table1 Lead Angle Accuracy (Permissible Value)

Unit: μm

		Precision Ball Screw										Rolled Ball Screw		
		C0		C1		C2		C3		C5		C7	C8	C10
Accuracy grades	Effective thread length	Representa-	Fluc-	Representa-	Fluc-	Representa-	Fluc-	Representa-	Fluc-	Representa-	Fluc-	Travel distance error	Travel distance error	Travel distance error
		tive travel distance error	tuation	tive travel distance error	tuation	tive travel distance error	tuation	tive travel distance error	tuation	tive travel distance error	tuation			
Above	Or less													
—	100	3	3	3.5	5	5	7	8	8	18	18	$\pm 50/300\text{mm}$	$\pm 100/300\text{mm}$	$\pm 210/300\text{mm}$
100	200	3.5	3	4.5	5	7	7	10	8	20	18			
200	315	4	3.5	6	5	8	7	12	8	23	18			
315	400	5	3.5	7	5	9	7	13	10	25	20			
400	500	6	4	8	5	10	7	15	10	27	20			
500	630	6	4	9	6	11	8	16	12	30	23			
630	800	7	5	10	7	13	9	18	13	35	25			
800	1000	8	6	11	8	15	10	21	15	40	27			
1000	1250	9	6	13	9	18	11	24	16	46	30			
1250	1600	11	7	15	10	21	13	29	18	54	35			
1600	2000	—	—	18	11	25	15	35	21	65	40			
2000	2500	—	—	22	13	30	18	41	24	77	46			
2500	3150	—	—	26	15	36	21	50	29	93	54			
3150	4000	—	—	30	18	44	25	60	35	115	65			
4000	5000	—	—	—	—	52	30	72	41	140	77			
5000	6300	—	—	—	—	65	36	90	50	170	93			
6300	8000	—	—	—	—	—	—	110	60	210	115			
8000	10000	—	—	—	—	—	—	—	—	260	140			

Note) Unit of effective thread length: mm

Table2 Fluctuation in Thread Length of 300 mm and in One Revolution (permissible value)

Unit: μm

Accuracy grades	C0	C1	C2	C3	C5	C7	C8	C10
Fluctuation/300	3.5	5	7	8	18	—	—	—
Fluctuation/ 2π	3	4	5	6	8	—	—	—

Table3 Types and Grades

Type	Series symbol	Grade	Remarks
For positioning	Cp	1, 3, 5	ISO compliant
For conveyance	Ct	1, 3, 5, 7, 10	

Note) Accuracy grades apply also to the Cp series and Ct series. Contact THK for details.

Example: When the lead of a Ball Screw manufactured is measured with a target value for the reference travel distance of $-9 \mu\text{m}/500 \text{ mm}$, the following data are obtained.

Table4 Measurement Data on Travel Distance Error

Unit: mm

Command position (A)	0	50	100	150
Travel distance (B)	0	49.998	100.001	149.996
Travel distance error (A-B)	0	-0.002	+0.001	-0.004
Command position (A)	200	250	300	350
Travel distance (B)	199.995	249.993	299.989	349.885
Travel distance error (A-B)	-0.005	-0.007	-0.011	-0.015
Command position (A)	400	450	500	
Travel distance (B)	399.983	449.981	499.984	
Travel distance error (A-B)	-0.017	-0.019	-0.016	

The measurement data are expressed in a graph as shown in Fig.2.

The positioning error (A-B) is indicated as the actual travel distance while the straight line representing the tendency of the (A-B) graph refers to the representative travel distance.

The difference between the reference travel distance and the representative travel distance appears as the representative travel distance error.

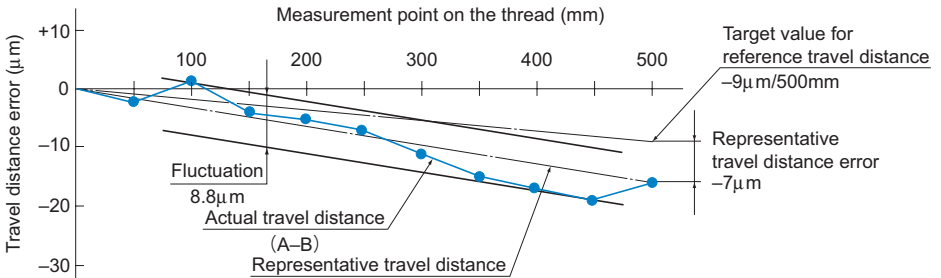


Fig.2 Measurement Data on Travel Distance Error

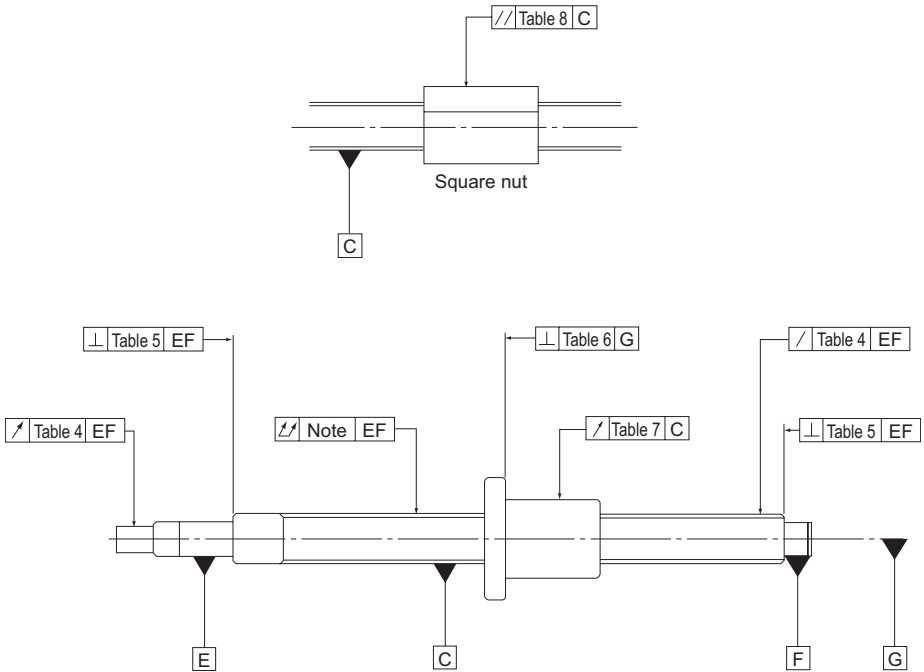
[Measurements]

Representative travel distance error: $-7 \mu\text{m}$

Fluctuation: $8.8 \mu\text{m}$

Accuracy of the Mounting Surface

The accuracy of the Ball Screw mounting surface complies with the JIS standard (JIS B 1192-1997).



Note) For the overall radial runout of the screw shaft axis, refer to JIS B 1192-1997.

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Fig.3 Accuracy of the Mounting Surface of the Ball Screw

[Accuracy Standards for the Mounting Surface]

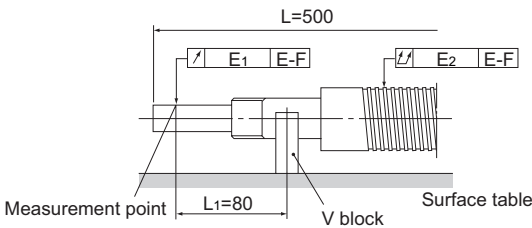
Table5 to Table9 show accuracy standards for the mounting surfaces of the precision Ball Screw.

Table5 Radial Runout of the Circumference of the Thread Root in Relation to the Supporting Portion Axis of the Screw Shaft
Unit: μm

Screw shaft outer diameter (mm)		Runout (maximum)					
Above	Or less	C0	C1	C2	C3	C5	C7
—	8	3	5	7	8	10	14
8	12	4	5	7	8	11	14
12	20	4	6	8	9	12	14
20	32	5	7	9	10	13	20
32	50	6	8	10	12	15	20
50	80	7	9	11	13	17	20
80	100	—	10	12	15	20	30

Note) The measurements on these items include the effect of the runout of the screw shaft diameter. Therefore, it is necessary to obtain the correction value from the overall runout of the screw shaft axis, using the ratio of the distance between the fulcrum and measurement point to the overall screw shaft length, and add the obtained value to the table above.

Example: model No. DIK2005-6RRGO+500LC5



$$E_1 = e + \Delta e$$

e : Standard value in Table5 (0.012)

Δe : Correction value

$$\Delta e = \frac{L_1}{L} \times E_2$$

$$= \frac{80}{500} \times 0.06$$

$$= 0.01$$

E_2 : Overall radial runout of the screw shaft axis (0.06)

$$E_1 = 0.012 + 0.01$$

$$= 0.022$$

Table6 Perpendicularity of the Supporting Portion End of the Screw Shaft to the Supporting Portion Axis

Unit: μm

Screw shaft outer diameter (mm)		Perpendicularity (maximum)					
Above	Or less	C0	C1	C2	C3	C5	C7
—	8	2	3	3	4	5	7
8	12	2	3	3	4	5	7
12	20	2	3	3	4	5	7
20	32	2	3	3	4	5	7
32	50	2	3	3	4	5	8
50	80	3	4	4	5	7	10
80	100	—	4	5	6	8	11

Table7 Perpendicularity of the Flange Mounting Surface of the Screw Shaft to the Screw Shaft Axis

Unit: μm

Nut diameter (mm)		Perpendicularity (maximum)					
Above	Or less	C0	C1	C2	C3	C5	C7
—	20	5	6	7	8	10	14
20	32	5	6	7	8	10	14
32	50	6	7	8	8	11	18
50	80	7	8	9	10	13	18
80	125	7	9	10	12	15	20
125	160	8	10	11	13	17	20
160	200	—	11	12	14	18	25

Table8 Radial Runout of the Nut Circumference in Relation to the Screw Shaft Axis

Unit: μm

Nut diameter (mm)		Runout (maximum)					
Above	Or less	C0	C1	C2	C3	C5	C7
—	20	5	6	7	9	12	20
20	32	6	7	8	10	12	20
32	50	7	8	10	12	15	30
50	80	8	10	12	15	19	30
80	125	9	12	16	20	27	40
125	160	10	13	17	22	30	40
160	200	—	16	20	25	34	50

Table9 Parallelism of the Nut Circumference (Flat Mounting Surface) to the Screw Shaft Axis

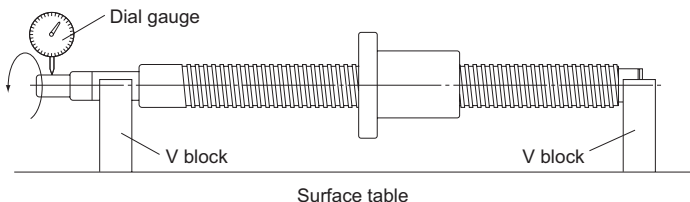
Unit: μm

Mounting reference length (mm)		Parallelism (maximum)					
Above	Or less	C0	C1	C2	C3	C5	C7
—	50	5	6	7	8	10	17
50	100	7	8	9	10	13	17
100	200	—	10	11	13	17	30

[Method for Measuring Accuracy of the Mounting Surface]

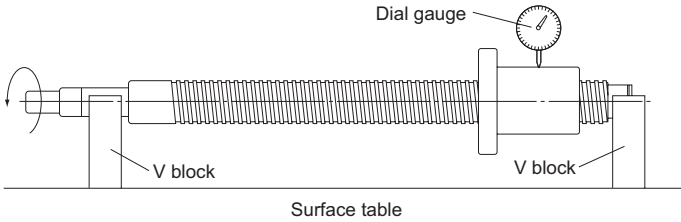
● **Radial Runout of the Circumference of the Part Mounting Section in Relation to the Supporting Portion Axis of the Screw Shaft (see Table5 on A-681)**

Support the supporting portion of the screw shaft with V blocks. Place a probe on the circumference of the part mounting section, and read the largest difference on the dial gauge as a measurement when turning the screw shaft by one revolution.



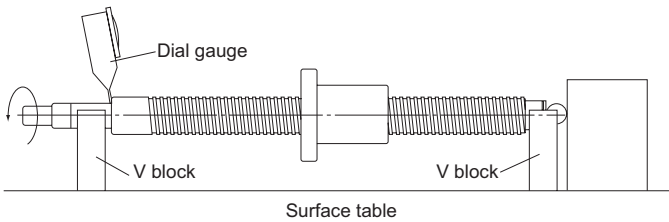
● **Radial Runout of the Circumference of the Thread Root in Relation to the Supporting Portion Axis of the Screw Shaft (see Table5 on A-681)**

Support the supporting portion of the screw shaft with V blocks. Place a probe on the circumference of the nut, and read the largest difference on the dial gauge as a measurement when turning the screw shaft by one revolution without turning the nut.



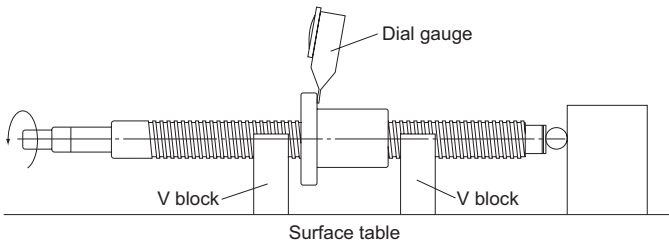
● **Perpendicularity of the Supporting Portion End of the Screw Shaft to the Supporting Portion Axis (see Table6 on A-682)**

Support the supporting portion of the screw shaft with V blocks. Place a probe on the screw shaft's supporting portion end, and read the largest difference on the dial gauge as a measurement when turning the screw shaft by one revolution.



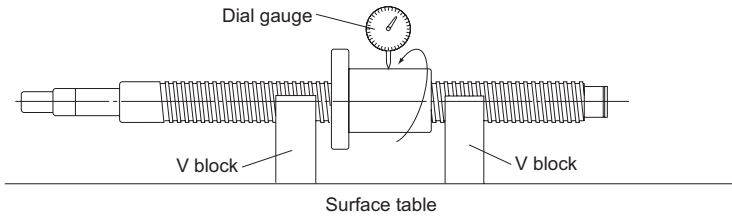
● **Perpendicularity of the Flange Mounting Surface of the Screw Shaft to the Screw Shaft Axis (see Table7 on A-682)**

Support the thread of the screw shaft with V blocks near the nut. Place a probe on the flange end, and read the largest difference on the dial gauge as a measurement when simultaneously turning the screw shaft and the nut by one revolution.



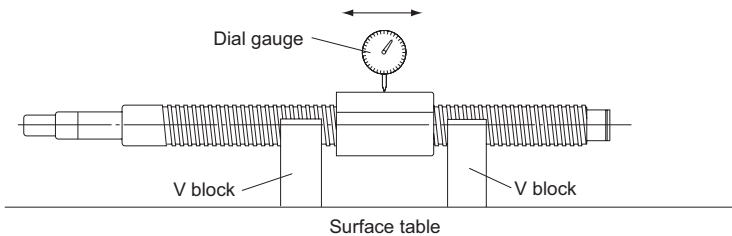
● **Radial Runout of the Nut Circumference in Relation to the Screw Shaft Axis (see Table8 on A-682)**

Support the thread of the screw shaft with V blocks near the nut. Place a probe on the circumference of the nut, and read the largest difference on the dial gauge as a measurement when turning the nut by one revolution without turning the screw shaft.



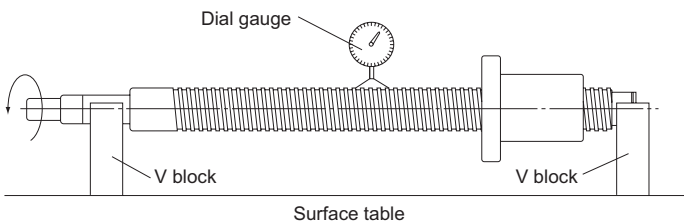
● **Parallelism of the Nut Circumference (Flat Mounting Surface) to the Screw Shaft Axis (see Table9 on A-682)**

Support the thread of the screw shaft with V blocks near the nut. Place a probe on the circumference of the nut (flat mounting surface), and read the largest difference on the dial gauge as a measurement when moving the dial gauge in parallel with the screw shaft.



● **Overall Radial Runout of the Screw Shaft Axis**

Support the supporting portion of the screw shaft with V blocks. Place a probe on the circumference of the screw shaft, and read the largest difference on the dial gauge at several points in the axial directions as a measurement when turning the screw shaft by one revolution.



Note) For the overall radial runout of the screw shaft axis, refer to JIS B 1192-1997.

Axial Clearance

[Axial Clearance of the Precision Ball Screw]

Table10 shows the axial clearance of the precision Screw Ball. If the manufacturing length exceeds the value in Table11, the resultant clearance may partially be negative (preload applied).

Table10 Axial Clearance of the Precision Ball Screw

Unit: mm

Clearance symbol	G0	GT	G1	G2	G3
Axial clearance	0 or less	0 to 0.005	0 to 0.01	0 to 0.02	0 to 0.05

Table11 Maximum Length of the Precision Ball Screw in Axial Clearance

Unit: mm

Screw shaft outer diameter	Overall thread length						
	Clearance GT		Clearance G1		Clearance G2		
	C0 to C3	C5	C0 to C3	C5	C0 to C3	C5	C7
4 to 6	80	100	80	100	80	100	120
8 to 10	250	200	250	250	250	300	300
12 to 16	500	400	500	500	700	600	500
18 to 25	800	700	800	700	1000	1000	1000
28 to 32	900	800	1100	900	1400	1200	1200
36 to 45	1000	800	1300	1000	2000	1500	1500
50 to 70	1200	1000	1600	1300	2500	2000	2000
80 to 100	—	—	1800	1500	4000	3000	3000

* When manufacturing the Ball Screw of precision-grade accuracy C7 with clearance GT or G1, the resultant clearance is partially negative.

[Axial Clearance of the Rolled Ball Screw]

Table12 shows axial clearance of the rolled Ball Screw.

Table12 Axial Clearance of the Rolled Ball Screw

Unit: mm

Screw shaft outer diameter	Axial clearance (maximum)
6 to 12	0.05
14 to 28	0.1
30 to 32	0.14
36 to 45	0.17
50	0.2

Preload

A preload is provided in order to eliminate the axial clearance and minimize the displacement under an axial load.

When performing a highly accurate positioning, a preload is generally provided.

[Rigidity of the Ball Screw under a Preload]

When a preload is provided to the Ball Screw, the rigidity of the nut is increased.

Fig.4 shows elastic displacement curves of the Ball Screw under a preload and without a preload.

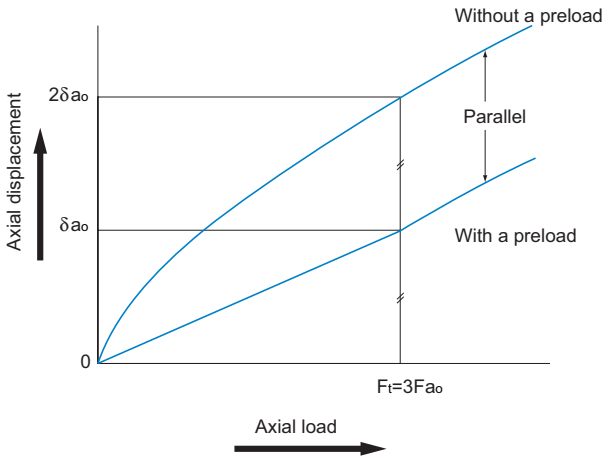
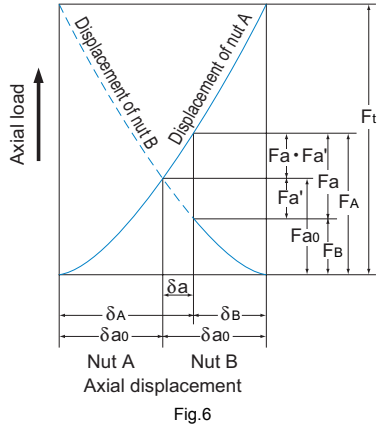
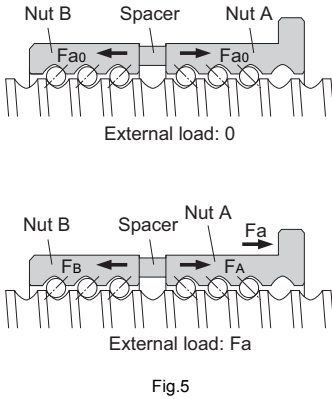


Fig.4 Elastic Displacement Curve of the Ball Screw

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Fig.5 shows a double-nut type of the Ball Screw.



Nuts A and B are provided with preload F_{a_0} from the spacer. Because of the preload, nuts A and B are elastically displaced by δ_{a_0} each. If an axial load (F_a) is applied from outside in this state, the displacement of nuts A and B is calculated as follows.

$$\delta_A = \delta_{a_0} + \delta_a \quad \delta_B = \delta_{a_0} - \delta_a$$

In other words, the loads on nut A and B are expressed as follows:

$$F_A = F_{a_0} + (F_a - F_{a'}) \quad F_B = F_{a_0} - F_{a'}$$

Therefore, under a preload, the load that nut A receives equals to $F_a - F_{a'}$. This means that since load $F_{a'}$, which is applied when nut A receives no preload, is deducted from F_a , the displacement of nut A is smaller.

This effect extends to the point where the displacement (δ_{a_0}) caused by the preload applied on nut B reaches zero.

To what extent is the elastic displacement reduced? The relationship between the axial load on the Ball Screw under no preload and the elastic displacement can be expressed by $\delta_a \propto F_a^{2/3}$. From Fig.6, the following equations are established.

$$\delta_{a_0} = K F_{a_0}^{2/3} \quad (K : \text{constant})$$

$$2\delta_{a_0} = K F_t^{2/3}$$

$$\left(\frac{F_t}{F_{a_0}}\right)^{2/3} = 2 \quad F_t = 2^{3/2} \times F_{a_0} = 2.8F_{a_0} \doteq 3F_{a_0}$$

Thus, the Ball Screw under a preload is displaced by δ_{a_0} when an axial load (F_t) approximately three times greater than the preload is provided from outside. As a result, the displacement of the Ball Screw under a preload is half the displacement ($2\delta_{a_0}$) of the Ball Screw without a preload.

As stated above, since the preloading is effective up to approximately three times the applied preload, the optimum preload is one third of the maximum axial load.

Note, however, that an excessive preload adversely affects the service life and heat generation. As a guideline, the maximum preload should be set at 10% of the basic dynamic load rating (C_a) at a maximum.

[Preload Torque]

The preload torque of the Ball Screw in lead is controlled in accordance with the JIS standard (JIS B 1192-1997).

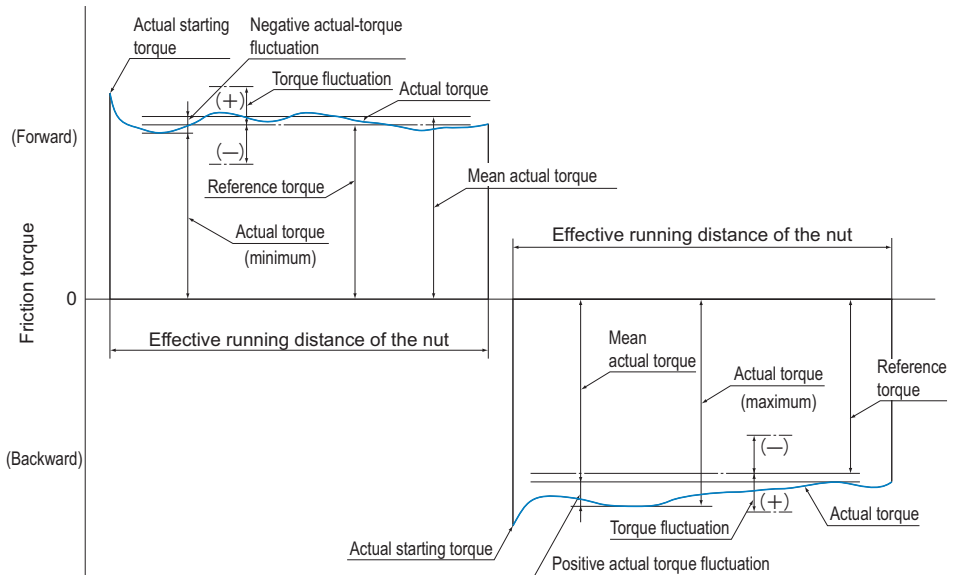


Fig.7 Terms on Preload Torque

● Dynamic Preload Torque

A torque required to continuously rotate the screw shaft of a Ball Screw under a given preload without an external load applied.

● Actual Torque

A dynamic preload torque measured with an actual Ball Screw.

● Torque Fluctuation

Variation in a dynamic preload torque set at a target value. It can be positive or negative in relation to the reference torque.

● Coefficient of Torque Fluctuation

Ratio of torque fluctuation to the reference torque.

● Reference Torque

A dynamic preload torque set as a target.

● Calculating the Reference Torque

The reference torque of a Ball Screw provided with a preload is obtained in the following equation (5).

$$T_p = 0.05 (\tan\beta)^{-0.5} \frac{F_{a0} \cdot Ph}{2\pi} \dots\dots(5)$$

- T_p : Reference torque (N-mm)
- β : Lead angle
- F_{a0} : Applied preload (N)
- Ph : Lead (mm)

Example: When a preload of 3,000 N is provided to the Ball Screw model BNFN4010-5G0 + 1500LC3 with a thread length of 1,300 mm (shaft diameter: 40 mm; ball center-to-center diameter: 41.75 mm; lead: 10 mm), the preload torque of the Ball Screw is calculated in the steps below.

■Calculating the Reference Torque

β : Lead angle

$$\tan\beta = \frac{\text{lead}}{\pi \times \text{ball center-to-center diameter}} = \frac{10}{\pi \times 41.75} = 0.0762$$

F_{a0} : Applied preload=3000N

Ph : Lead = 10mm

$$T_p = 0.05 (\tan\beta)^{-0.5} \frac{F_{a0} \cdot Ph}{2\pi} = 0.05 (0.0762)^{-0.5} \frac{3000 \times 10}{2\pi} = 865 \text{ N} \cdot \text{mm}$$

■Calculating the Torque Fluctuation

$$\frac{\text{thread length}}{\text{screw shaft outer diameter}} = \frac{1300}{40} = 32.5 \leq 40$$

Thus, with the reference torque in Table13 being between 600 and 1,000 N·mm, effective thread length 4,000 mm or less and accuracy grade C3, the coefficient of torque fluctuation is obtained as $\pm 30\%$.

As a result, the torque fluctuation is calculated as follows.

$$865 \times (1 \pm 0.3) = 606 \text{ N} \cdot \text{mm to } 1125 \text{ N} \cdot \text{mm}$$

■Result

Reference torque : 865 N·mm

Torque fluctuation : 606 N·mm to 1125 N·mm

Table13 Tolerance Range in Torque Fluctuation

Reference torque N·mm		Effective thread length									
		4000mm or less								Above 4,000 mm and 10,000 mm or less	
		$\frac{\text{thread length}}{\text{screw shaft outer diameter}} \leq 40$				$40 < \frac{\text{thread length}}{\text{screw shaft outer diameter}} < 60$				—	
		Accuracy grades				Accuracy grades				Accuracy grades	
Above	Or less	C0	C1	C2, C3	C5	C0	C1	C2, C3	C5	C2, C3	C5
200	400	±35%	±40%	±45%	±55%	±45%	±45%	±55%	±65%	—	—
400	600	±25%	±30%	±35%	±45%	±38%	±38%	±45%	±50%	—	—
600	1000	±20%	±25%	±30%	±35%	±30%	±30%	±35%	±40%	±40%	±45%
1000	2500	±15%	±20%	±25%	±30%	±25%	±25%	±30%	±35%	±35%	±40%
2500	6300	±10%	±15%	±20%	±25%	±20%	±20%	±25%	±30%	±30%	±35%
6300	10000	—	—	±15%	±20%	—	—	±20%	±25%	±25%	±30%

Selecting a Screw Shaft

Maximum Length of the Screw Shaft

The maximum length of the precision Ball Screw and the rolled Ball Screw are shown in Table14 and Table15 (A-691) respectively.

If the shaft dimensions exceed the manufacturing limit in Table14 or Table15, contact THK.

Table14 Maximum Length of the Precision Ball Screw by Accuracy Grade

Unit: mm

Screw shaft outer diameter	Overall screw shaft length					
	C0	C1	C2	C3	C5	C7
4	90	110	120	120	120	120
6	150	170	210	210	210	210
8	230	270	340	340	340	340
10	350	400	500	500	500	500
12	440	500	630	680	680	680
13	440	500	630	680	680	680
14	530	620	770	870	890	890
15	570	670	830	950	980	1100
16	620	730	900	1050	1100	1400
18	720	840	1050	1220	1350	1600
20	820	950	1200	1400	1600	1800
25	1100	1400	1600	1800	2000	2400
28	1300	1600	1900	2100	2350	2700
30	1450	1700	2050	2300	2570	2950
32	1600	1800	2200	2500	2800	3200
36	2000	2100	2550	2950	3250	3650
40		2400	2900	3400	3700	4300
45		2750	3350	3950	4350	5050
50		3100	3800	4500	5000	5800
55		3450	4150	5300	6050	6500
63		4000	5200	5800	6700	7700
70				6300	6450	7650
80			7900		9000	10000
100			10000	10000		

Table15 Maximum Length of the Rolled Ball Screw by Accuracy Grade

Unit: mm

Screw shaft outer diameter	Overall screw shaft length		
	C7	C8	C10
6 to 8	320	320	—
10 to 12	500	1000	—
14 to 15	1500	1500	1500
16 to 18	1500	1800	1800
20	2000	2200	2200
25	2000	3000	3000
28	3000	3000	3000
30	3000	3000	4000
32 to 36	3000	4000	4000
40	3000	5000	5000
45	3000	5500	5500
50	3000	6000	6000

Standard Combinations of Shaft Diameter and Lead for the Precision Ball Screw

Table16 shows the standard combinations of shaft diameter and lead for the precision Ball Screw. If a Ball Screw not covered by the table is required,contact THK.

Table16 Standard Combinations of Screw Shaft and Lead (Precision Ball Screw)

Unit: mm

Screw shaft outer diameter	Lead																						
	1	2	4	5	6	8	10	12	15	16	20	24	25	30	32	36	40	50	60	80	90	100	
4	●																						
5	●																						
6	●																						
8	●	●						●	○														
10		●	●					●	○														
12		●		●			●																
13											○												
14		●	●	●			●																
15								●			●			○			○						
16			○	●	○		○			●													
18								●															
20			○	●	○	○	●	○			●						○		○				
25			○	●	○	○	●	○		○	●		○					○					
28				○	●	○	○																
30																			○		○		
32			○	●	●	○	●	○			○				○								
36					○	○	●	○		○	○	○				○							
40				○	○	○	●	●		○	○			○			○			○			
45					○	○	○	○		○	○												
50				○		○	●	○		○	○			○		○		○					○
55								○	○		○	○		○		○							
63								○	○		○	○											
70								○	○			○											
80								○	○			○											
100												○											

- : off-the-shelf products [standard-stock products equipped with the standardized screw shafts (with unfinished shaft ends/finished shaft ends)]
- : Semi-standard stock

Standard Combinations of Shaft Diameter and Lead for the Rolled Ball Screw

Table17 shows the standard combinations of shaft diameter and lead for the rolled Ball Screw.

Table17 Standard Combinations of Screw Shaft and Lead (Rolled Ball Screw)

Unit: mm

Screw shaft outer diameter	Lead																			
	1	2	4	5	6	8	10	12	16	20	24	25	30	32	36	40	50	60	80	100
6	●																			
8		●																		
10		●			○															
12		●				○														
14			●	●																
15							●		●			●								
16				●					●											
18						●														
20				●			●		●							●				
25				●			●					●					●			
28					●															
30																		●		
32							●							●						
36							●		●	●					●					
40							●									●			●	
45								●												
50									●								●			●

●: Standard stock
○: Semi-standard stock

Permissible Axial Load

[Buckling Load on the Screw Shaft]

With the Ball Screw, it is necessary to select a screw shaft so that it will not buckle when the maximum compressive load is applied in the axial direction.

Fig.8 on A-695 shows the relationship between the screw shaft diameter and a buckling load.

If determining a buckling load by calculation, it can be obtained from the equation (6) below. Note that in this equation, a safety factor of 0.5 is multiplied to the result.

$$P_1 = \frac{\eta_1 \cdot \pi^2 \cdot E \cdot I}{l_a^2} \cdot 0.5 = \eta_2 \frac{d_1^4}{l_a^2} \cdot 10^4 \quad \dots\dots\dots(6)$$

P_1 : Buckling load (N)

l_a : Distance between two mounting surfaces (mm)

E : Young's modulus (2.06×10^5 N/mm²)

I : Minimum geometrical moment of inertia of the shaft (mm⁴)

$$I = \frac{\pi}{64} d_1^4 \quad d_1: \text{screw-shaft thread minor diameter (mm)}$$

η_1, η_2 =Factor according to the mounting method

Fixed - free $\eta_1=0.25$ $\eta_2=1.3$

Fixed - supported $\eta_1=2$ $\eta_2=10$

Fixed - fixed $\eta_1=4$ $\eta_2=20$

[Permissible Tensile Compressive Load on the Screw Shaft]

If an axial load is applied to the Ball Screw, it is necessary to take into account not only the buckling load but also the permissible tensile compressive load in relation to the yielding stress on the screw shaft.

The permissible tensile compressive load is obtained from the equation (7).

$$P_2 = \sigma \frac{\pi}{4} d_1^2 = 116d_1^2 \quad \dots\dots\dots(7)$$

P_2 : Permissible tensile compressive load (N)

σ : Permissible tensile compressive stress (147 MPa)

d_1 : Screw-shaft thread minor diameter (mm)

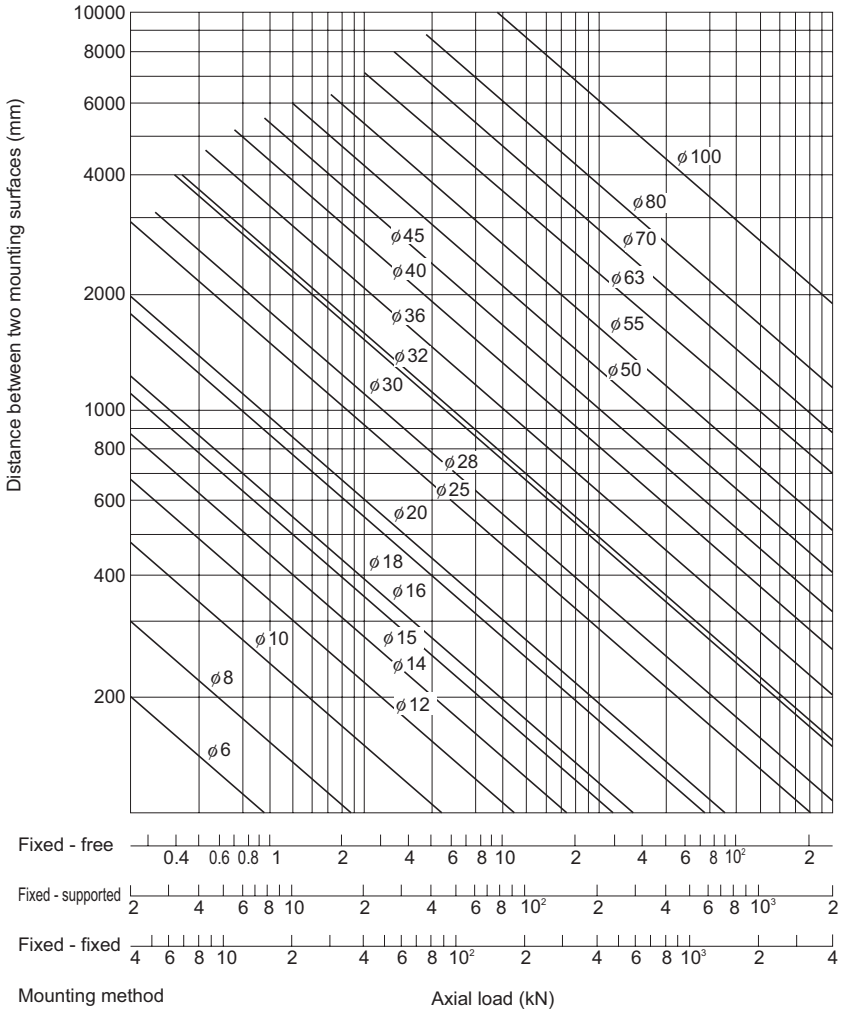


Fig.8 Permissible Tensile Compressive Load Diagram

Permissible Rotational Speed

[Dangerous Speed of the Screw Shaft]

When the rotational speed reaches a high magnitude, the Ball Screw may resonate and eventually become unable to operate due to the screw shaft's natural frequency. Therefore, it is necessary to select a model so that it is used below the resonance point (dangerous speed).

Fig.9 on A-698 shows the relationship between the screw shaft diameter and a dangerous speed. If determining a dangerous speed by calculation, it can be obtained from the equation (8) below. Note that in this equation, a safety factor of 0.8 is multiplied to the result.

$$N_1 = \frac{60 \cdot \lambda_1^2}{2\pi \cdot \ell_b^2} \times \sqrt{\frac{E \times 10^3 \cdot I}{\gamma \cdot A}} \times 0.8 = \lambda_2 \cdot \frac{d_1}{\ell_b^2} \cdot 10^7 \dots\dots(8)$$

- N_1 : Permissible rotational speed determined by dangerous speed (min⁻¹)
- ℓ_b : Distance between two mounting surfaces (mm)
- E : Young's modulus (2.06 × 10⁵ N/mm²)
- I : Minimum geometrical moment of inertia of the shaft (mm⁴)

$$I = \frac{\pi}{64} d_1^4 \quad d_1: \text{screw-shaft thread minor diameter (mm)}$$

$$\gamma : \text{Density (specific gravity)} \quad (7.85 \times 10^{-6} \text{kg/mm}^3)$$

$$A : \text{Screw shaft cross-sectional area (mm}^2\text{)}$$

$$A = \frac{\pi}{4} d_1^2$$

λ_1, λ_2 : Factor according to the mounting method

Fixed - free $\lambda_1=1.875$ $\lambda_2=3.4$

Supported - supported $\lambda_1=3.142$ $\lambda_2=9.7$

Fixed - supported $\lambda_1=3.927$ $\lambda_2=15.1$

Fixed - fixed $\lambda_1=4.73$ $\lambda_2=21.9$

[DN Value]

The permissible rotational speed of the Ball Screw must be obtained from the dangerous speed of the screw shaft and the DN value.

The permissible rotational speed determined by the DN value is obtained using the equations (9) to (13) below.

● **Ball Screw with Ball Cage**

■ **Models SBN and HBN**

$$N_2 = \frac{130000}{D} \dots\dots\dots(9)$$

N_2 : Permissible rotational speed determined by the DN value (min⁻¹(rpm))

D : Ball center-to-center diameter
(indicated in the specification tables of the respective model number)

■ **Model SBK**

$$N_2 = \frac{160000}{D} \dots\dots\dots(10)$$

● **Precision Ball Screw**

$$N_2 = \frac{70000}{D} \dots\dots\dots(11)$$

● **Rolled Ball Screw**

(excluding large lead type)

$$N_2 = \frac{50000}{D} \dots\dots\dots(12)$$

● **Large-Lead Rolled Ball Screw**

$$N_2 = \frac{70000}{D} \dots\dots\dots(13)$$

Of the permissible rotational speed determined by dangerous speed (N_1) and the permissible rotational speed determined by DN value (N_2), the lower rotational speed is regarded as the permissible rotational speed.

If the working rotational speed exceeds N_2 , a high-speed type Ball Screw is available. Contact THK for details.

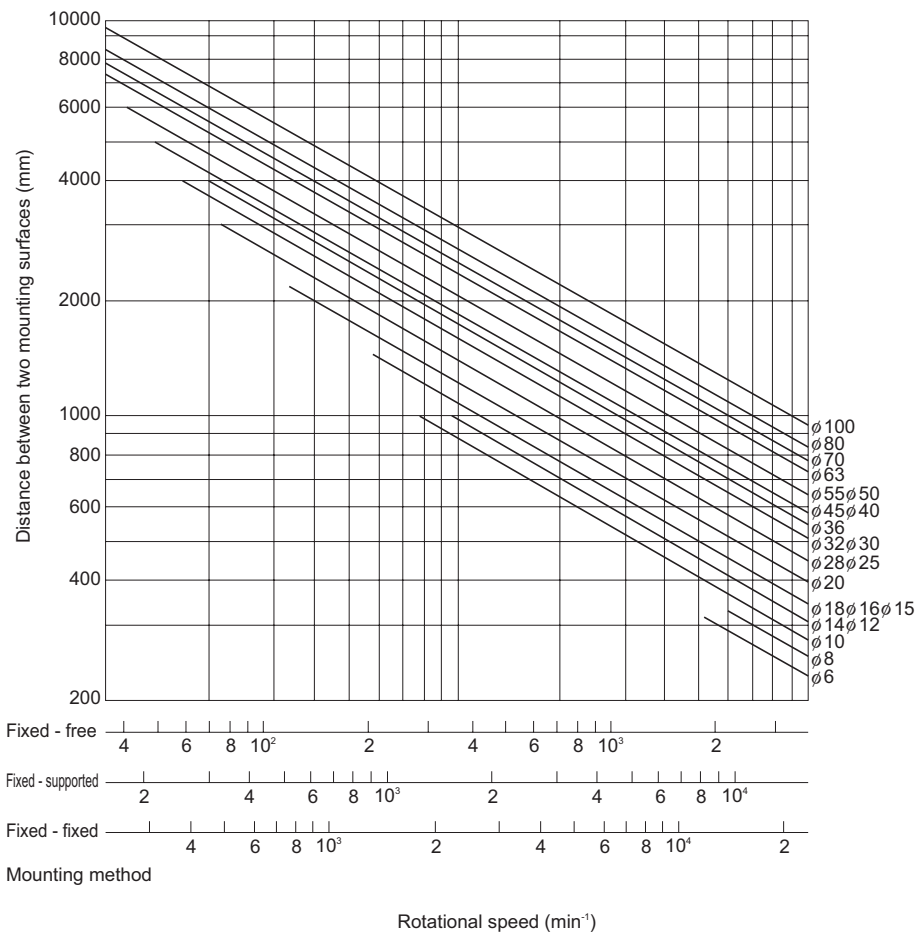


Fig.9 Permissible Rotational Speed Diagram

Selecting a Nut

Types of Nuts

The nuts of the Ball Screws are categorized by the ball circulation method into the return-pipe type, the deflector type and end the cap type. These three nut types are described as follows.

In addition to the circulation methods, the Ball Screws are categorized also by the preloading method.

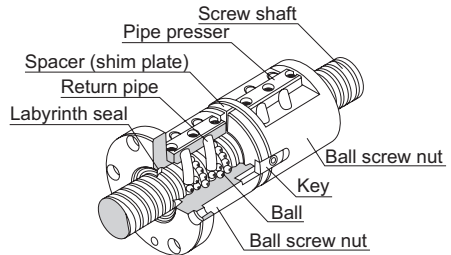
[Types by Ball Circulation Method]

● Return-pipe Type

(Models SBN, BNF, BNT, BNFN, BIF and BTK)

Return-piece Type (Model HBN)

These are most common types of nuts that use a return pipe for ball circulation. The return pipe allows balls to be picked up, pass through the pipe, and return to their original positions to complete infinite motion.

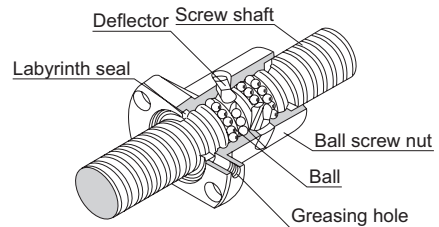


Example of Structure of Return-Pipe Nut

● Deflector Type

(Models DK, DKN, DIK, JPF and DIR)

These are the most compact type of nut. The balls change their traveling direction with a deflector, pass over the circumference of the screw shaft, and return to their original positions to complete an infinite motion.

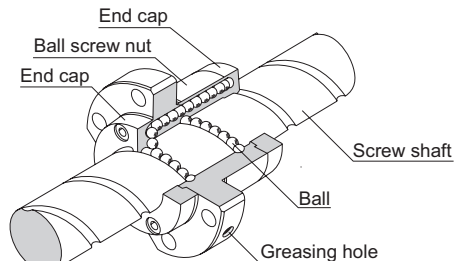


Example of Structure of Simple Nut

● End-cap Type: Large lead Nut

(Models SBK, BLK, WGF, BLW, WTF, CNF and BLR)

These nuts are most suitable for the fast feed. The balls are picked up with an end cap, pass through the through hole of the nut, and return to their original positions to complete an infinite motion.



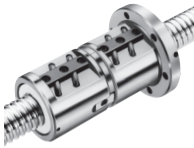
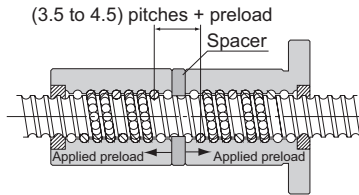
Example of Structure of Large lead Nut

[Types by Preloading Method]

● Fixed-point Preloading

■ Double-nut Preload (Models BNFN, DKN and BLW)

A spacer is inserted between two nuts to provide a preload.



Model BNFN



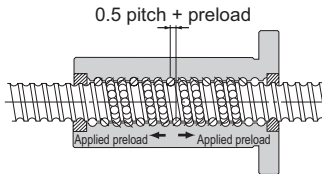
Model DKN



Model BLW

■ Offset Preload (Models SBN, BIF, DIK, SBK and DIR)

More compact than the double-nut method, the offset preloading provides a preload by changing the groove pitch of the nut without using a spacer.



Model SBN



Model BIF



Model DIK



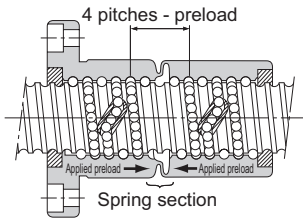
Model SBK



Model DIR

● Constant Pressure Preloading (Model JPF)

With this method, a spring structure is installed almost in the middle of the nut, and it provides a preload by changing the groove pitch in the middle of the nut.



Model JPF

Selecting a Model Number

Calculating the Axial Load

[In Horizontal Mount]

With ordinary conveyance systems, the axial load (F_{a_n}) applied when horizontally reciprocating the work is obtained in the equation below.

$$F_{a_1} = \mu \cdot mg + f + m\alpha \quad \dots\dots\dots (14)$$

$$F_{a_2} = \mu \cdot mg + f \quad \dots\dots\dots (15)$$

$$F_{a_3} = \mu \cdot mg + f - m\alpha \quad \dots\dots\dots (16)$$

$$F_{a_4} = -\mu \cdot mg - f - m\alpha \quad \dots\dots\dots (17)$$

$$F_{a_5} = -\mu \cdot mg - f \quad \dots\dots\dots (18)$$

$$F_{a_6} = -\mu \cdot mg - f + m\alpha \quad \dots\dots\dots (19)$$

V_{max} : Maximum speed (m/s)

t_1 : Acceleration time (m/s)

$$\alpha = \frac{V_{max}}{t_1} : \text{Acceleration} \quad (m/s^2)$$

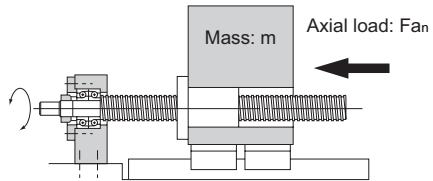
F_{a_1} : Axial load during forward acceleration (N)

F_{a_2} : Axial load during forward uniform motion (N)

F_{a_3} : Axial load during forward deceleration (N)

F_{a_4} : Axial load during backward acceleration (N)

F_{a_5} : Axial load during uniform backward motion (N)



Guide surface
Friction coefficient : μ
Resistance without load : f
Gravitational acceleration: g

F_{a_6} : Axial load during backward deceleration (N)

m : Transferred mass (kg)

μ : Frictional coefficient of the guide surface (-)

f : Guide surface resistance (without load) (N)

[In Vertical Mount]

With ordinary conveyance systems, the axial load (F_{a_n}) applied when vertically reciprocating the work is obtained in the equation below.

$$F_{a_1} = mg + f + m\alpha \quad \dots\dots\dots (20)$$

$$F_{a_2} = mg + f \quad \dots\dots\dots (21)$$

$$F_{a_3} = mg + f - m\alpha \quad \dots\dots\dots (22)$$

$$F_{a_4} = mg - f - m\alpha \quad \dots\dots\dots (23)$$

$$F_{a_5} = mg - f \quad \dots\dots\dots (24)$$

$$F_{a_6} = mg - f + m\alpha \quad \dots\dots\dots (25)$$

V_{max} : Maximum speed (m/s)

t_1 : Acceleration time (m/s)

$$\alpha = \frac{V_{max}}{t_1} : \text{Acceleration} \quad (m/s^2)$$

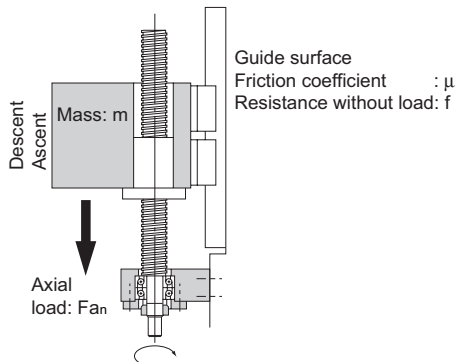
F_{a_1} : Axial load during upward acceleration (N)

F_{a_2} : Axial load during uniform upward motion (N)

F_{a_3} : Axial load during upward deceleration (N)

F_{a_4} : Axial load during downward acceleration (N)

F_{a_5} : Axial load during uniform downward motion (N)



Guide surface
Friction coefficient : μ
Resistance without load: f

F_{a_6} : Axial load during downward deceleration (N)

m : Transferred mass (kg)

f : Guide surface resistance (without load) (N)

Static Safety Factor

The basic static load rating (C_{0a}) generally equals to the permissible axial load of a Ball Screw. Depending on the conditions, it is necessary to take into account the following static safety factor against the calculated load. When the Ball Screw is stationary or in motion, unexpected external force may be applied through an inertia caused by the impact or the start and stop.

$$F_{a_{max}} = \frac{C_{0a}}{f_s} \dots\dots\dots(26)$$

- $F_{a_{max}}$: Permissible Axial Load (kN)
- C_{0a} : Basic static load rating* (kN)
- f_s : Static safety factor (see Table18)

Table18 Static Safety Factor (f_s)

Machine using the LM system	Load conditions	Lower limit of f_s
General industrial machinery	Without vibration or impact	1 to 1.3
	With vibration or impact	2 to 3
Machine tool	Without vibration or impact	1 to 1.5
	With vibration or impact	2.5 to 7

The basic static load rating (C_{0a}) is a static load with a constant direction and magnitude whereby the sum of the permanent deformation of the rolling element and that of the raceway on the contact area under the maximum stress is 0.0001 times the rolling element diameter. With the Ball Screw, it is defined as the axial load. (Specific values of each Ball Screw model are indicated in the specification tables for the corresponding model number.)

Studying the Service Life

[Service Life of the Ball Screw]

The Ball Screw in motion under an external load receives the continuous stress on its raceways and balls. When the stress reaches the limit, the raceways break from the fatigue and their surfaces partially disintegrate in scale-like pieces. This phenomenon is called flaking. The service life of the Ball Screw is the total number of revolutions until the first flaking occurs on any of the raceways or the balls as a result of the rolling fatigue of the material.

The service life of the Ball Screw varies from unit to unit even if they are manufactured in the same process and used in the same operating conditions. For this reason, when determining the service life of a Ball Screw unit, the nominal life as defined below is used as a guideline.

The nominal life is the total number of revolutions that 90% of identical Ball Screw units in a group achieve without developing flaking (scale-like pieces of a metal surface) after they independently operate in the same conditions.

[Calculating the Rated Life]

The service life of the Ball Screw is calculated from the equation (27) below using the basic dynamic load rating (C_a) and the applied axial load.

● Nominal Life (Total Number of Revolutions)

$$L = \left(\frac{C_a}{f_w \cdot F_a} \right)^3 \times 10^6 \quad \dots\dots\dots(27)$$

- L : Nominal life (rev)
(total number of revolutions)
- C_a : Basic dynamic load rating* (N)
- F_a : Applied axial load (N)
- f_w : Load factor (see Table 19)

Table 19 Load Factor (f_w)

Vibrations/impact	Speed(V)	f_w
Faint	Very low $V \leq 0.25\text{m/s}$	1 to 1.2
Weak	Slow $0.25 < V \leq 1\text{m/s}$	1.2 to 1.5
Medium	Medium $1 < V \leq 2\text{m/s}$	1.5 to 2
Strong	High $V > 2\text{m/s}$	2 to 3.5

* The basic dynamic load rating (C_a) is used in calculating the service life when a Ball Screw operates under a load. The basic dynamic load rating is a load with interlocked direction and magnitude under which the nominal life (L) equals to 10^6 rev. when a group of the same Ball Screw units independently operate. (Specific basic dynamic load ratings (C_a) are indicated in the specification tables of the corresponding model numbers.)

● **Service Life Time**

If the revolutions per minute is determined, the service life time can be calculated from the equation (28) below using the nominal life (L).

$$L_h = \frac{L}{60 \times N} = \frac{L \times Ph}{2 \times 60 \times n \times \ell_s} \dots\dots\dots(28)$$

- L_h : Service life time (h)
- N : Revolutions per minute (min^{-1})
- n : Number of reciprocations per minute (min^{-1})
- Ph : Ball Screw lead (mm)
- ℓ_s : Stroke length (mm)

● **Service Life in Travel Distance**

The service life in travel distance can be calculated from the equation (29) below using the nominal life (L) and the Ball Screw lead.

$$L_s = \frac{L \times Ph}{10^6} \dots\dots\dots(29)$$

- L_s : Service Life in Travel Distance (km)
- Ph : Ball Screw lead (mm)

● **Applied Load and Service Life with a Preload Taken into Account**

If the Ball Screw is used under a preload (medium preload), it is necessary to consider the applied preload in calculating the service life since the ball screw nut already receives an internal load. For details on applied preload for a specific model number, contact THK.

● **Average Axial Load**

If an axial load acting on the Ball Screw is present, it is necessary to calculate the service life by determining the average axial load.

The average axial load (F_m) is a constant load that equals to the service life in fluctuating the load conditions.

If the load changes in steps, the average axial load can be obtained from the equation below.

$$F_m = \sqrt[3]{\frac{1}{\ell} (Fa_1^3 \ell_1 + Fa_2^3 \ell_2 + \dots + Fa_n^3 \ell_n)} \dots\dots\dots(30)$$

- F_m : Average Axial Load (N)
- Fa_n : Varying load (N)
- ℓ_n : Distance traveled under load (F_n)
- ℓ : Total travel distance

To determine the average axial load using a rotational speed and time, instead of a distance, calculate the average axial load by determining the distance in the equation below.

$$l = l_1 + l_2 + \dots + l_n$$

$$l_1 = N_1 \cdot t_1$$

$$l_2 = N_2 \cdot t_2$$

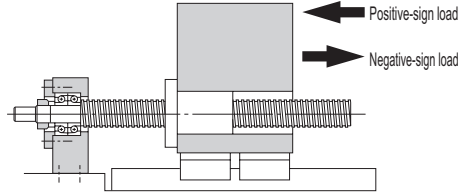
$$l_n = N_n \cdot t_n$$

N: Rotational speed

t: Time

■When the Applied Load Sign Changes

When all signs for fluctuating loads are the same, the equation (30) applies without problem. However, if the sign for the fluctuating load changes according to the operation, it is necessary to calculate both the average axial load of the positive-sign load and that of the negative-sign load while taking in to account the load direction (when calculating the average axial load of the positive-sign load, assume the negative-sign load to be zero). Of the two average axial loads, the greater value is regarded as the average axial load for calculating the service life.



Example: Calculate the average axial load with the following load conditions.

Operation No.	Varying load F_{a_i} (N)	Travel distance l_n (mm)
No.1	10	10
No.2	50	50
No.3	-40	10
No.4	-10	70

The subscripts of the fluctuating load symbol and the travel distance symbol indicate operation numbers.

● Average axial load of positive-sign load

To calculate the average axial load of the positive-sign load, assume F_{a_3} and F_{a_4} to be zero.

$$F_{m1} = \sqrt[3]{\frac{F_{a1}^3 \times l_1 + F_{a2}^3 \times l_2}{l_1 + l_2 + l_3 + l_4}} = 35.5\text{N}$$

● Average axial load of negative-sign load

To calculate the average axial load of the negative-sign load, assume F_{a_1} and F_{a_2} to be zero.

$$F_{m2} = \sqrt[3]{\frac{|F_{a3}|^3 \times l_3 + |F_{a4}|^3 \times l_4}{l_1 + l_2 + l_3 + l_4}} = 17.2\text{N}$$

Accordingly, the average axial load of the positive-sign load (F_{m1}) is adopted as the average axial load (F_m) for calculating the service life.

Studying the Rigidity

To increase the positioning accuracy of feed screws in NC machine tools or the precision machines, or to reduce the displacement caused by the cutting force, it is necessary to design the rigidity of the components in a well-balanced manner.

Axial Rigidity of the Feed Screw System

When the axial rigidity of a feed screw system is K, the elastic displacement in the axial direction can be obtained using the equation (31) below.

$$\delta = \frac{F_a}{K} \dots\dots\dots(31)$$

- δ : Elastic displacement of a feed screw system in the axial direction (μm)
- F_a : Applied axial load (N)

The axial rigidity (K) of the feed screw system is obtained using the equation (32) below.

$$\frac{1}{K} = \frac{1}{K_s} + \frac{1}{K_N} + \frac{1}{K_B} + \frac{1}{K_H} \dots\dots\dots(32)$$

- K : Axial 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 : Rigidity of the nut bracket and the support bearing bracket ($\text{N}/\mu\text{m}$)

[Axial rigidity of the screw shaft]

The axial rigidity of a screw shaft varies depending on the method for mounting the shaft.

● For Fixed-Supported (or -Free) Configuration

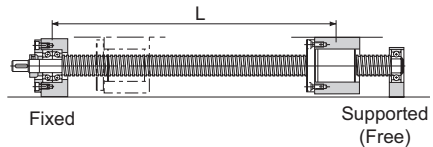
$$K_s = \frac{A \cdot E}{1000 \cdot L} \dots\dots\dots(33)$$

- A : Screw shaft cross-sectional area (mm^2)

$$A = \frac{\pi}{4} d_1^2$$

- d_1 : Screw-shaft thread minor diameter (mm)
- E : Young's modulus ($2.06 \times 10^5 \text{ N}/\text{mm}^2$)
- L : Distance between two mounting surfaces (mm)

Fig.10 onA-708 shows an axial rigidity diagram for the screw shaft.



● For Fixed-Fixed Configuration

$$K_s = \frac{A \cdot E \cdot L}{1000 \cdot a \cdot b} \dots\dots(34)$$

K_s becomes the lowest and the elastic displacement in the axial direction is the greatest at the position of $a = b = \frac{L}{2}$.

$$K_s = \frac{4A \cdot E}{1000L}$$

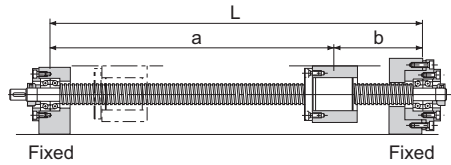


Fig.11 on A-709 shows an axial rigidity diagram of the screw shaft in this configuration.

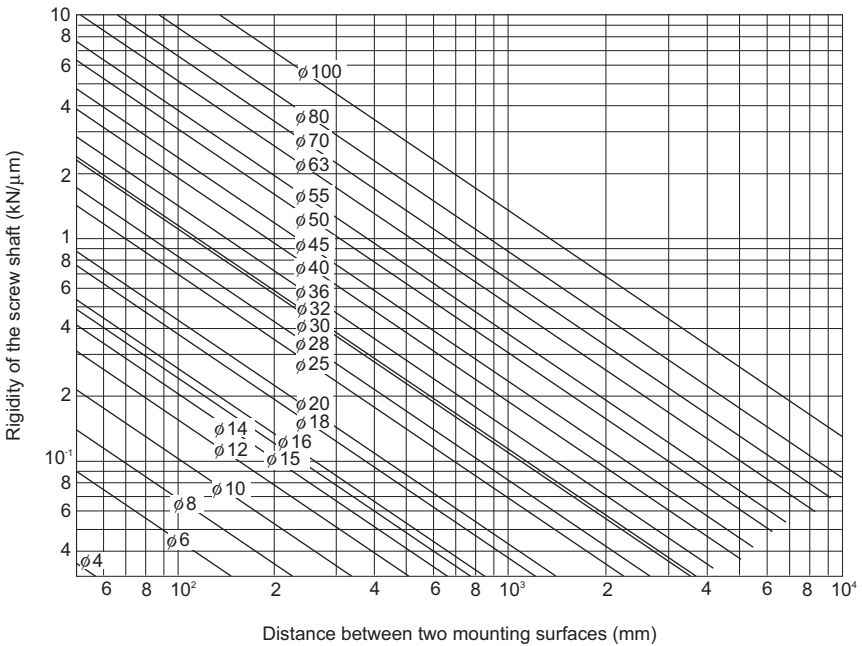


Fig.10 Axial Rigidity of the Screw Shaft (Fixed-Free, Fixed-Supported)

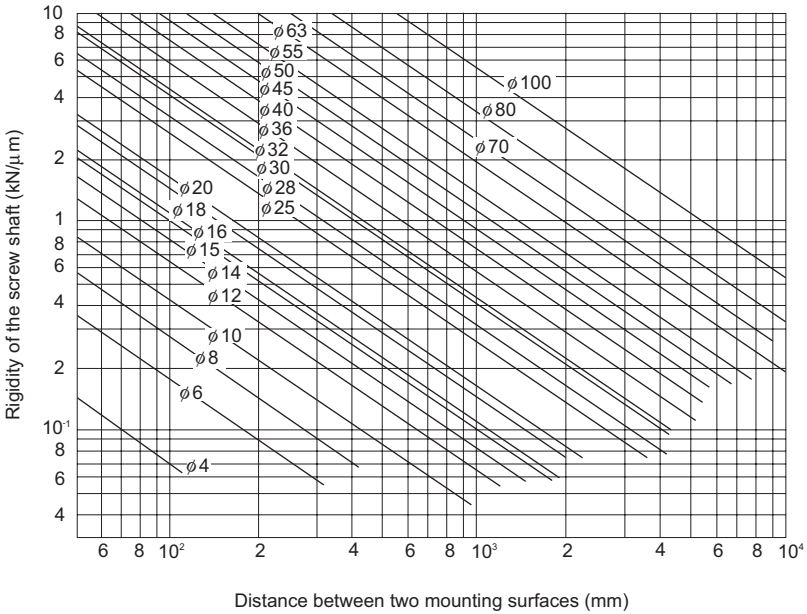


Fig.11 Axial Rigidity of the Screw Shaft (Fixed-Fixed)

[Axial rigidity of the nut]

The axial rigidity of the nut varies widely with preloads.

● **No Preload Type**

The logical rigidity in the axial direction when an axial load accounting for 30% of the basic dynamic load rating (Ca) is applied is indicated in the specification tables of the corresponding model number. This value does not include the rigidity of the components related to the nut-mounting bracket. In general, set the rigidity at roughly 80% of the value in the table.

The rigidity when the applied axial load is not 30% of the basic dynamic load rating (Ca) is calculated using the equation (35) below.

$$K_N = K \left(\frac{F_a}{0.3C_a} \right)^{\frac{1}{3}} \times 0.8 \dots\dots\dots(35)$$

- K_N : Axial rigidity of the nut (N/μm)
- K : Rigidity value in the specification tables (N/μm)
- F_a : Applied axial load (N)
- C_a : Basic dynamic load rating (N)

● Preload Type

The logical rigidity in the axial direction when an axial load accounting for 10% of the basic dynamic load rating (Ca) is applied is indicated in the dimensional table of the corresponding model number. This value does not include the rigidity of the components related to the nut-mounting bracket. In general, generally set the rigidity at roughly 80% of the value in the table.

The rigidity when the applied preload is not 10% of the basic dynamic load rating (Ca) is calculated using the equation (36) below.

$$K_N = \kappa \left(\frac{Fa_0}{0.1Ca} \right)^{\frac{1}{3}} \times 0.8 \quad \dots\dots(36)$$

- K_N : Axial rigidity of the nut (N/μm)
- K : Rigidity value in the specification tables (N/μm)
- Fa_0 : Applied preload (N)
- Ca : Basic dynamic load rating (N)

[Axial rigidity of the support bearing]

The rigidity of the Ball Screw support bearing varies depending on the support bearing used.

The calculation of the rigidity with a representative angular ball bearing is shown in the equation (37) below.

$$K_B \doteq \frac{3Fa_0}{\delta a_0} \quad \dots\dots(37)$$

- K_B : Axial rigidity of the support bearing (N/μm)
- Fa_0 : Applied preload of the support bearing (N)
- δa_0 : Axial displacements (μm)

$$\delta a_0 = \frac{0.45}{\sin\alpha} \left(\frac{Q^2}{Da} \right)^{\frac{1}{3}}$$

$$Q = \frac{Fa_0}{Z \sin\alpha}$$

- Q : Axial load (N)
- Da : Ball diameter of the support bearing (mm)
- α : Initial contact angle of the support bearing (°)
- Z : Number of balls

For details of a specific support bearing, contact its manufacturer.

[Axial Rigidity of the Nut Bracket and the Support Bearing Bracket]

Take this factor into consideration when designing your machine. Set the rigidity as high as possible.