Accuracy of the Ball Screw

Lead Angle Accuracy

The lead angle accuracy of the ball screw is controlled in accordance with the JIS standard JIS B 1192 (ISO 3408).
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.

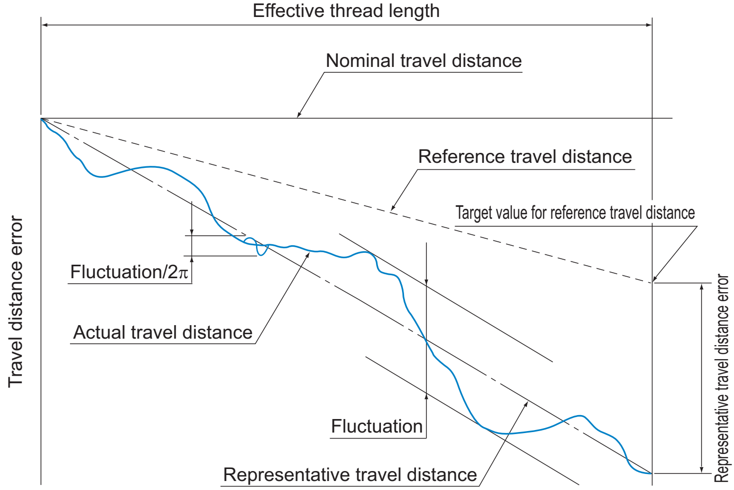


Fig.1 Terms on Lead Angle Accuracy

[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 ±)]
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/2π]
A fluctuation in one revolution of the screw shaft.

Table1 Lead Angle Accuracy (Permissible Value)

Unit: μm

		Precision Ball Screw												
												Rolled Ball Screw		
Accuracy grades		C0		C1		C2		C3		C5		C7	C8	C10
Effective thread length		Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Representative travel distance error	Fluctuation	Travel distance error	Travel distance error	Travel distance error
Above	Or less													
—	100	3	3	3.5	5	5	7	8	8	18	18	±50/ 300 mm	±100/ 300 mm	±210/ 300 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	Grade	Remarks
For positioning	0, 1, 3, 5	ISO compliant
For transport	0, 1, 3, 5, 7, 10	

Example: When the lead of a Ball Screw manufactured is measured with a target value for the reference travel distance of –9 μm/500 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	349.985
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.

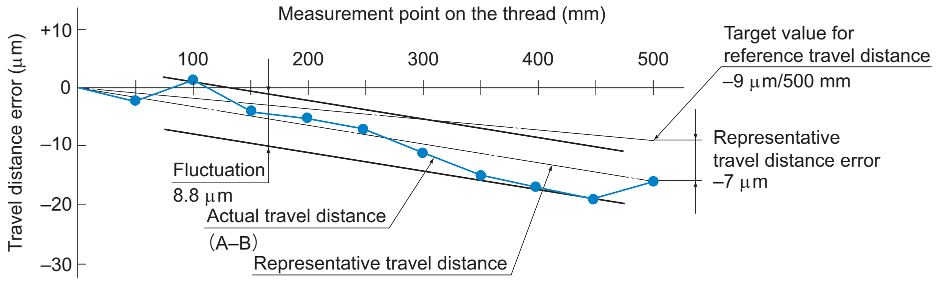
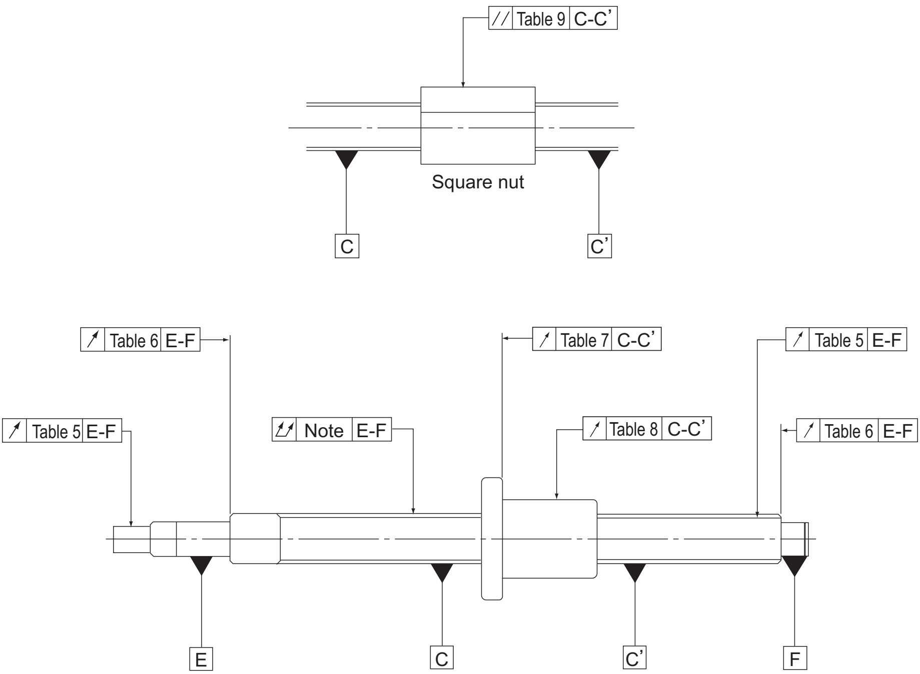


Fig.2 Measurement Data on Travel Distance Error

[Measurements]
Representative travel distance error: -7 μm
Fluctuation: 8.8 μm

Accuracy of the Mounting Surface

The accuracy of the Ball Screw mounting surface complies with the JIS standard JIS B 1192 (ISO 3408).



Note) For the permissible overall radial runout of the outer diameter of the screw in relation to the screw shaft support axis, refer to JIS B 1192 (ISO 3408).

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.

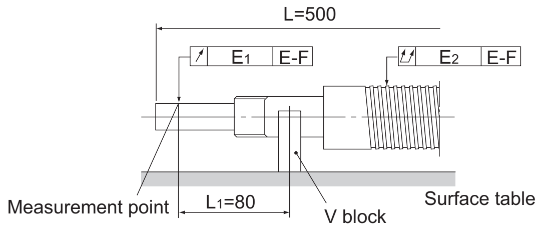
Table5 Permissible Radial Runout of the Grooved Surface of the Screw in Relation to the Screw Shaft Support Axis and the Permissible Radial Runout of the Part-Mounting Surface

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

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

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

$$= 0.01$$

L : Overall screw shaft length

L_1 : Distance between the fulcrum and the measurement point

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

$$E_1 = 0.012 + 0.01$$

$$= 0.022$$

Note) For the permissible overall radial runout of the outer diameter of the screw in relation to the screw shaft support axis, refer to JIS B 1192 (ISO 3408).

Table6 Permissible Radial Runout of the Support End Face in Relation to the Screw Shaft Support Axis

Unit: μm

Screw shaft outer diameter (mm)		Permissible radial runout (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 Permissible Radial Runout of the Flange Mounting Surface in Relation to the Screw Shaft Axis

Unit: μm

Nut diameter (mm)		Permissible radial runout (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 Permissible Radial Runout of the Nut Circumference in Relation to the Screw Shaft Axis

Unit: μm

Nut diameter (mm)		Permissible radial runout					
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 Permissible Parallelism of the Nut Circumference (Flat Mounting Surface) to the Screw Shaft Axis

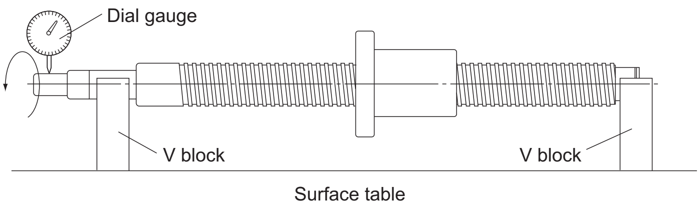
Unit: μm

Mounting reference length (mm)		Permissible parallelism					
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]

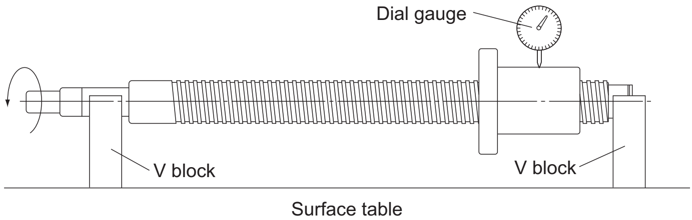
● Radial Runout of the Circumference of the Motor-mounting Shaft-end in Relation to the Bearing Journals of the Screw Shaft (see Table5 on B15-23)

Support the end journal of the screw shaft on V blocks. Place a probe on the circumference of the motor-mounting shaft-end, and record the largest difference on the dial gauge as a measurement while rotating the screw shaft through one revolution.



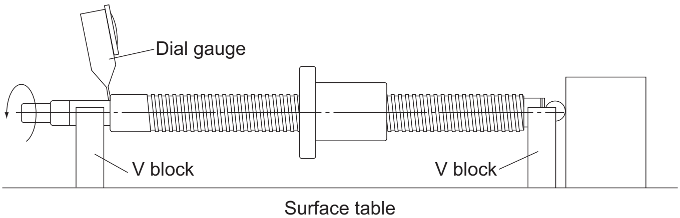
- **Radial Runout of the Circumference of the Raceway Threads in Relation to the Bearing Journals of the Screw Shaft (see Table5 on B15-23)**

Support the end journal of the screw shaft on V blocks. Place a probe on the circumference of the nut, and record the largest difference on the dial gauge as a measurement while rotating the screw shaft by one revolution without rotating the nut.



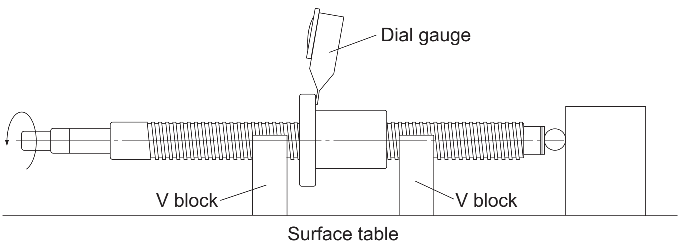
- **Radial Runout of the Support End Face in Relation to the Screw Shaft Axis Support (see Table6 on B15-24)**

Support the bearing journal portions of the screw shaft on V blocks. Place a probe on the screw shaft's supporting portion end, and record the largest difference on the dial gauge as a measurement while rotating the screw shaft through one revolution.



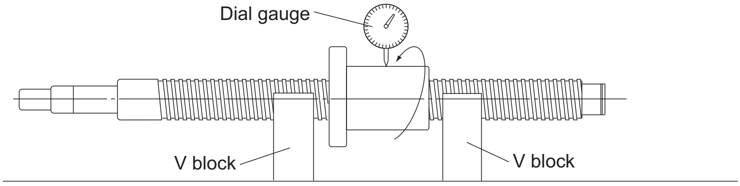
- **Radial Runout of the Flange Mounting Surface in Relation to the Screw Shaft Axis (see Table7 on B15-24)**

Support the thread of the screw shaft on V blocks near the nut. Place a probe on the flange end, and record the largest difference on the dial gauge as a measurement while simultaneously rotating the screw shaft and the nut through one revolution.



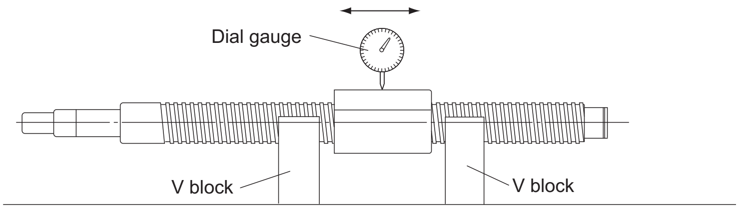
● Radial Runout of the Nut Circumference in Relation to the Screw Shaft Axis (see Table8 on B15-24)

Support the thread of the screw shaft on V blocks near the nut. Place a probe on the circumference of the nut, and record the largest difference on the dial gauge as a measurement while rotating the nut through one revolution without rotating the screw shaft.



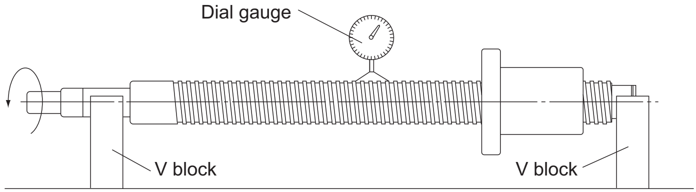
● Parallelism of the Nut Circumference (Flat Mounting Surface) to the Screw Shaft Axis (see Table9 on B15-24)

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



● Overall Radial Runout of the Screw Diameter Relative to the Shaft Support Axis

Support the supporting portion of the screw shaft on V blocks. Place a probe on the circumference of the screw shaft, and record the largest difference on the dial gauge at several points in the axial directions as a measurement while rotating the screw shaft through one revolution.



Note) For the permissible overall radial runout of the outer diameter of the screw in relation to the screw shaft support axis, refer to JIS B 1192 (ISO 3408).

Axial Clearance

[Axial Clearance of the Precision Ball Screw]

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

The manufacturing limit lengths of the Ball Screws compliant with the DIN standard are provided in Table12.

For the axial clearance of the Precision Caged Ball Screw, see A15-76 to A15-93, A15-110 to A15-117, A15-224 to A15-235.

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 Manufacturing Length of Precision Ball Screws by Accuracy Grade

Unit: mm

Screw shaft outer diameter	Clearance GT				Clearance G1				Clearance G2					
	C0	C1	C2•C3	C5	C0	C1	C2•C3	C5	C0	C1	C2	C3	C5	C7
4•6	80	80	80	100	80	80	80	100	80	80	80	80	100	120
8	230	250	250	200	230	250	250	250	230	250	250	250	300	300
10	250	250	250	200	250	250	250	250	250	250	250	250	300	300
12•13	440	500	500	400	440	500	500	500	440	500	630	680	600	500
14	500	500	500	400	500	500	500	500	530	620	700	700	600	500
15	500	500	500	400	500	500	500	500	570	670	700	700	600	500
16	500	500	500	400	500	500	500	500	620	700	700	700	600	500
18	720	800	800	700	720	800	800	700	720	840	1000	1000	1000	1000
20	800	800	800	700	800	800	800	700	820	950	1000	1000	1000	1000
25	800	800	800	700	800	800	800	700	1000	1000	1000	1000	1000	1000
28	900	900	900	800	1100	1100	1100	900	1300	1400	1400	1400	1200	1200
30•32	900	900	900	800	1100	1100	1100	900	1400	1400	1400	1400	1200	1200
36•40•45	1000	1000	1000	800	1300	1300	1300	1000	2000	2000	2000	2000	1500	1500
50•55•63•70	1200	1200	1200	1000	1600	1600	1600	1300	2000	2500	2500	2500	2000	2000
80•100	—	—	—	—	1800	1800	1800	1500	2000	4000	4000	4000	3000	3000

*When manufacturing the Ball Screw of precision-grade accuracy C7 with clearance GT or G1, the resultant clearance is partially negative.
G0 clearance is not available for models HBN-V, HBN-K (KA), HBN, and SBKH.
Accuracy grade C7 is not available when manufacturing a miniature ball screw (screw shaft outer diameter ϕ14 mm or less) with a G0 clearance.

Table12 Manufacturing limit lengths of precision Ball Screws with axial clearances (DIN standard compliant Ball Screws)

Unit: mm

Shaft diameter	Clearance GT		Clearance G1		Clearance G2		
	C3, Cp3	C5, Cp5, Ct5	C3, Cp3	C5, Cp5, Ct5	C3, Cp3	C5, Cp5, Ct5	C7, Cp7
16	500	400	500	500	700	600	500
20, 25	800	700	800	700	1000	1000	1000
32	900	800	1100	900	1400	1200	1200
40	1000	800	1300	1000	2000	1500	1500
50, 63	1200	1000	1600	1300	2500	2000	2000

*When manufacturing the Ball Screw of precision-grade accuracy C7 (Ct7) with clearance GT or G1, the resultant clearance is partially negative.

[Axial Clearance of the Rolled Ball Screw]

Table13 shows axial clearance of the rolled Ball Screw.

Table13 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.

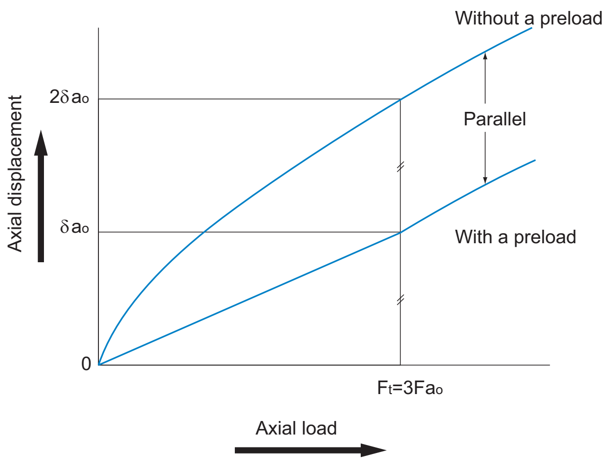


Fig.4 Elastic Displacement Curve of the Ball Screw

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

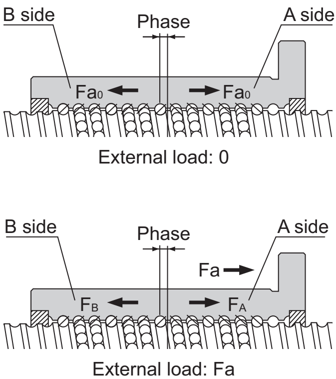


Fig.5

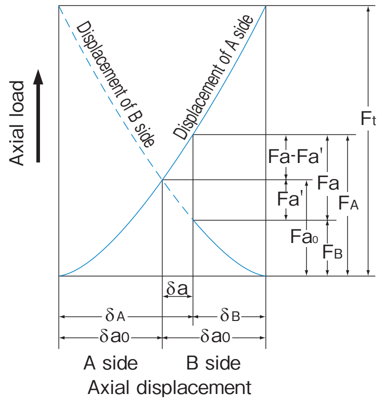


Fig.6

The A and B sides are provided with preload Fa_0 by changing the groove pitch in the center of the nut to create a phase. Because of the preload, the A and B sides are elastically displaced by δa_0 each. If an axial load (Fa) is applied from outside in this state, the displacement of the A and B sides is calculated as follows.

$$\delta_A = \delta a_0 + \delta a \qquad \delta_B = \delta a_0 - \delta a$$

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

$$F_A = Fa_0 + (Fa - Fa') \quad F_B = Fa_0 - Fa'$$

Therefore, under a preload, the load that the A side receives equals to Fa−Fa'. This means that since load Fa', which is applied when the A side receives no preload, is deducted from Fa, the displacement of the A side is smaller.
This effect extends to the point where the displacement (δa_0) caused by the preload applied on the B side 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 $\delta a \propto Fa^{2/3}$. From Fig.6, the following equations are established.

$$\delta a_0 = KFa_0^{2/3} \qquad (K : \text{constant})$$

$$2\delta a_0 = KF_t^{2/3}$$

$$\left(\frac{F_t}{Fa_0}\right)^{\frac{2}{3}} = 2 \quad F_t = 2^{3/2} \times Fa_0 = 2.8Fa_0 \fallingdotseq 3Fa_0$$

Thus, the Ball Screw under a preload is displaced by δa_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 pre-load, the optimum preload is one third of the maximum axial load.
Note that an excessive preload adversely affects the service life and heat generation. The maximum pre-load should be set at 10% of the basic dynamic load rating (Ca) in the axial direction.

[Preload Torque]

The preload torque of the Ball Screw is controlled in accordance with the JIS standard JIS B 1192 (ISO 3408).

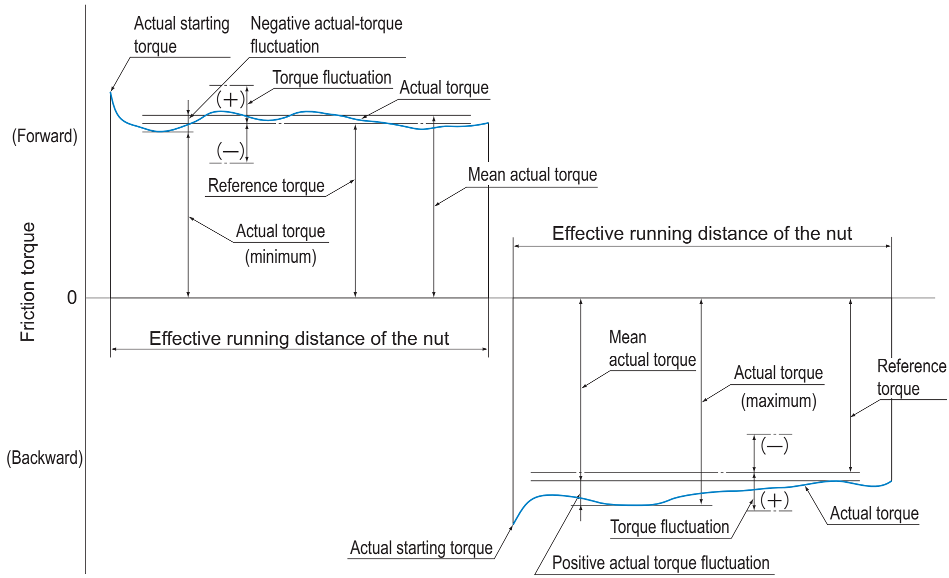


Fig.7 Terms on Preload Torque

● 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 (4).

$$T_p = 0.05\,(\tan\beta)^{-0.5}\,\frac{Fa_0 \cdot Ph}{2\pi} \quad \cdots\cdots\cdots (4)$$

T_p : Reference torque (N·mm)
β : Lead angle
Fa_0 : Applied preload (N)
Rh : Lead (mm)

Example of calculating the preload torque

When a preload of 3,000 N is provided to the Ball Screw model BIF4010-10G0 + 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

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

Fa_0 : Applied preload=3000 N

Ph : Lead = 10 mm

$$T_p = 0.05\,(\tan\beta)^{-0.5}\,\frac{Fa_0 \cdot Ph}{2\pi} = 0.05\,(0.0762)^{-0.5}\,\frac{3000 \times 10}{2\pi} = 865\ \text{N·mm}$$

■Calculating the Torque Fluctuation

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

Thus, with the reference torque in Table14 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 ±30%.

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

865×(1±0.3) = 606 N·mm to 1125 N·mm

■Result

Reference torque : 865 N·mn

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

Table14 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		
		$\frac{\text{thread length}}{\text{screw shaft outer diameter}} \leqq 40$					$40 < \frac{\text{thread length}}{\text{screw shaft outer diameter}} < 60$					—		
		Accuracy grades					Accuracy grades					Accuracy grades		
Above	Or less	C0	C1	C3	C5	C7	C0	C1	C3	C5	C7	C3	C5	C7
200	400	±30%	±35%	±40%	±50%	—	±40%	±40%	±50%	±60%	—	—	—	—
400	600	±25%	±30%	±35%	±40%	—	±35%	±35%	±40%	±45%	—	—	—	—
600	1000	±20%	±25%	±30%	±35%	±40%	±30%	±30%	±35%	±40%	±45%	±40%	±45%	±50%
1000	2500	±15%	±20%	±25%	±30%	±35%	±25%	±25%	±30%	±35%	±40%	±35%	±40%	±45%
2500	6300	±10%	±15%	±20%	±25%	±30%	±20%	±20%	±25%	±30%	±35%	±30%	±35%	±40%
6300	10000	—	—	±15%	±20%	±30%	—	—	±20%	±25%	±35%	±25%	±30%	±35%