Accuracy of the Ball Screw

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 by linearity and direction, and C7 to C10 by error in relation to a 300 mm travel distance.

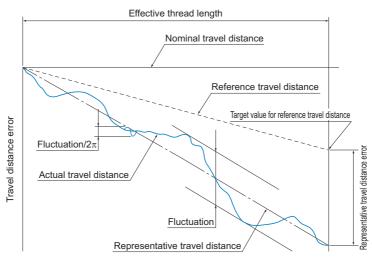


Fig. 1: Lead Angle Accuracy Terminology

Actual Travel Distance

The 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 apply tension in order to prevent screw shaft runout or set a negative or positive reference travel distance value in advance to account for possible expansion or contraction from an external load or temperature change. In such cases, indicate a target value for the reference travel distance

Representative Travel Distance

It is a straight line representing the trend of 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 ±)

Is the difference between the representative travel distance and the reference travel distance.

Fluctuation

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

Fluctuation/300

Indicates the fluctuation in a given threaded portion of length of 300 mm.

Fluctuation/ 2π

Indicates the fluctuation in one revolution of the screw shaft.

Table 1: Lead Angle Accuracy (Permissible Value)

Unit: µm

Table 1. Lead Aligie Accuracy (Lethilosible Value)												Onit. µm		
						Precisio	n ba	II screw						
												Roll	ed ball so	crew
	iracy des	C0		C1		C2		C3		C5		C7	C8	C10
	gui	Representative travel distance	Fluctuation	Travel distance	Travel distance	Travel distance								
Above	Up to	error	Fluct	error	error	error								
_	100	3	3	3.5	5	5	7	8	8	18	18			
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			±210/
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	1,000	8	6	11	8	15	10	21	15	40	27		±100/	
1,000	1,250	9	6	13	9	18	11	24	16	46	30	±50/		
1,250	1,600	11	7	15	10	21	13	29	18	54	35	300 mm	300 mm	300 mm
1,600	2,000	_	_	18	11	25	15	35	21	65	40			
2,000	2,500	_	_	22	13	30	18	41	24	77	46			
2,500	3,150	_	_	26	15	36	21	50	29	93	54			
3,150	4,000	_	_	30	18	44	25	60	35	115	65			
4,000	5,000	_	_	_	_	52	30	72	41	140	77 93 115			
5,000	6,300	_	_	_	_	65	36	90	50	170				
6,300	8,000	_	_	_	_	_	_	110	60	210				
8,000	10,000	_	_	_	_	_	_	_	_	260	140			

Note: Unit of effective thread length: mm

Table 2: Fluctuation in a 300 mm Threaded Portion 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	_	_	_

Table 3: Types and Grades

Туре	Grade	Remarks
For positioning	0, 1, 3, 5	ISO compliant
For transport	0, 1, 3, 5, 7, 10	ISO compliant

Accuracy of the Ball Screw

Example: the following data were obtained by measuring the lead of a ball screw manufactured with a target reference travel distance of $-9 \mu m/500$ mm.

Table 4: 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	

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

-0.017

The positioning error (A-B) is the actual travel distance while the straight line representing the trend of the (A-B) graph indicates the representative travel distance.

-0.019

-0.016

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

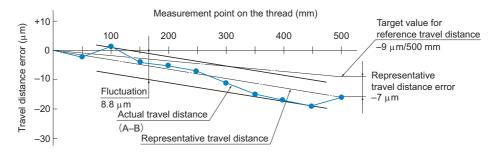


Fig. 2: Measurement Data on Travel Distance Error

Measurements

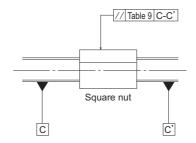
Representative travel distance error: -7 µm

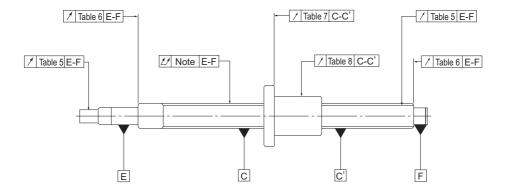
Fluctuation: 8.8 µm

Travel distance error (A-B)

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 Ball Screw Mounting Surface

Accuracy of the Ball Screw

Accuracy Standards for the Mounting Surface

Table 5 to Table 9 show accuracy standards for the mounting surfaces of the precision ball screw.

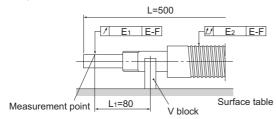
Table 5: Permissible Radial Runout of the Grooved Surface of the Screw and the Motor Coupling Journal in Relation to the Bearing Journals

Unit: µm

	naft outer er (mm)	Runout (maximum)							
Above	Above Up to		C1	C2	СЗ	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 for these items include the effect of the screw shaft's runout. Therefore, it is necessary to use the ratio of the overall screw shaft length to the distance between the fulcrum and the measurement point to obtain the correction value from the overall runout of the screw shaft axis, and then add that value to the value from the table above.

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



$E_1 = e + \Lambda e$

Р : Standard value in Table 5 (0.012)

: Correction value ∆е

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

$$=\frac{80}{500}\times0.06$$

: Overall screw shaft length

= 0.01

L : Distance between the fulcrum and the measurement point : 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 axis at the journal, refer to JIS B 1192 (ISO 3408).

Table 6: Permissible Axial Runout of the Journal End Face in Relation to the Bearing Journals

Unit: µm

	naft outer er (mm)	Permissible axial runout (maximum)							
Above	Up to	C0	C1	C2	СЗ	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		

Table 7: Permissible Axial Runout of the Flange Mounting Surface in Relation to the Screw Shaft Axis

Unit: µm

Nut diam	eter (mm)	Permissible axial runout (maximum)							
Above	Up to	C0	C1	C2	СЗ	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		

Table 8: Permissible Radial Runout of the Nut Circumference in Relation to the Screw Shaft Axis

Unit: µm

Nut diam	eter (mm)	Permissible radial runout								
Above	Above Up to		C1	C2	СЗ	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			

Table 9: Permissible Parallelism of the Nut Circumference (Flat Mounting Surface) to the Screw Shaft Axis

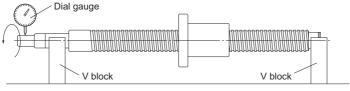
Unit: µm

	reference (mm)	Permissible parallelism							
Above	Above Up to		C1	C2	СЗ	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 Motor Coupling Journal in Relation to the Bearing Journals (see Table 5 on A15-15)

Support the journals of the screw shaft on V blocks. Place a probe on the circumference of the motor coupling journal, and record the largest difference measured by the dial gauge while rotating the screw shaft through one revolution.

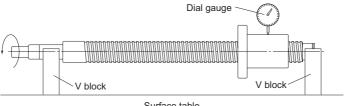


Surface table

Accuracy of the Ball Screw

Radial Runout of the Grooved Surface of the Screw in Relation to the Bearing Journals (see Table 5 on A15-15)

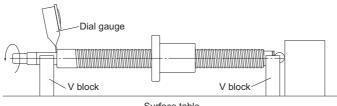
Support the journals of the screw shaft on V blocks. Place a probe on the circumference of the nut, and record the largest difference measured by the dial gauge while rotating the screw shaft by one revolution without rotating the nut.



Surface table

Axial Runout of the Journal End Face in Relation to the Bearing Journals (see Table 6 on A15-16)

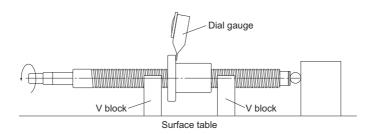
Support the journals of the screw shaft on V blocks. Place a probe on the screw shaft's journal end face, and record the largest difference measured by the dial gauge while rotating the screw shaft through one revolution.



Surface table

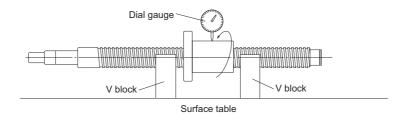
Axial Runout of the Flange Mounting Surface in Relation to the Screw Shaft Axis (see Table 7 on A15-16)

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



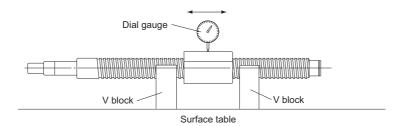
Radial Runout of the Nut Circumference in Relation to the Screw Shaft Axis (see Table 8 on **A15-16**)

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



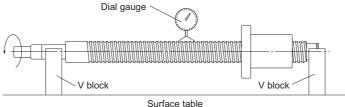
Parallelism of the Nut Circumference (Flat Mounting Surface) to the Screw Shaft Axis (see Table 9 on A15-16)

Support the threaded portion 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 measured by the dial gauge while moving the dial gauge in parallel with the screw shaft.



Overall Radial Runout of the Screw Diameter Relative to the Bearing Journals

Support the journals of the screw shaft on V blocks. Place a probe on the circumference of the screw shaft, and record the largest difference in the axial direction measured by the dial gauge at several points 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 axis at the journal, refer to JIS B 1192 (ISO 3408).

A15-18

Accuracy of the Ball Screw

Axial Clearance

Axial Clearance of Precision Ball Screws

Table 10 shows the axial clearance of the precision ball screw. If the manufacturing length exceeds the value in Table 11, the resultant clearance may partially be negative (preload applied).

The manufacturing limit lengths of the ball screws compliant with the ISO standard are provided in Table 12. For the axial clearance of precision Caged Ball ball screws, see **A15-76** to **A15-93**, **A15-112** to **A15-119**, **A15-246** to **A15-257**.

Table 10: Axial Clearance of the Precision Ball Screw

Unit: mm

Clearance Symbol	J G0	61	61	G2	G3
Axial clearance	0 or less	0 to 0.005	0 to 0.01	0 to 0.02	0 to 0.05

Table 11: Maximum Manufacturing Length of Precision Ball Screws by Axial Clearance and Accuracy Grade Unit: mm

Screw shaft		GT cle	arance			G1 cle	arance				G2 cle	arance		
outer diameter	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	1,000	1,000	1,000	1,000
20	800	800	800	700	800	800	800	700	820	950	1,000	1,000	1,000	1,000
25	800	800	800	700	800	800	800	700	1,000	1,000	1,000	1,000	1,000	1,000
28	900	900	900	800	1,100	1,100	1,100	900	1,300	1,400	1,400	1,400	1,200	1,200
30, 32	900	900	900	800	1,100	1,100	1,100	900	1,400	1,400	1,400	1,400	1,200	1,200
36, 40, 45	1,000	1,000	1,000	800	1,300	1,300	1,300	1,000	2,000	2,000	2,000	2,000	1,500	1,500
50, 55, 63, 70	1,200	1,200	1,200	1,000	1,600	1,600	1,600	1,300	2,000	2,500	2,500	2,500	2,000	2,000
80, 100	_	_	_		1,800	1,800	1,800	1,500	2,000	4,000	4,000	4,000	3,000	3,000

Notes: When manufacturing a ball screw of accuracy grade C7 with clearance GT or G1, the resultant clearance is partially negative.

GO 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 \$\phi\$ 14 mm or less) with a G0 clearance.

Table 12: Manufacturing Limit Lengths of Precision Ball Screws with Axial Clearances (ISO Standard-Compliant Ball Screws) Unit: mm

Shaft	GT cle	arance	G1 cle	arance	G2 clearance			
diameter	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	1,000	1,000	1,000	
32	900	800	1,100	900	1,400	1,200	1,200	
40	1,000	800	1,300	1,000	2,000	1,500	1,500	
50, 63	1,200	1,000	1,600	1,300	2,500	2,000	2,000	

Note: When manufacturing a ball screw of accuracy grade C7 (Ct7) with clearance GT or G1, the resultant clearance is partially negative.

Axial Clearance of Rolled Ball Screws

Table 13 shows axial clearance of rolled ball screws.

Table 13: Axial Clearance of Rolled Ball Screws

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 applied in order to eliminate the axial clearance and minimize the displacement under an axial load.

A preload is generally used in applications requiring highly accurate positioning.

Rigidity of the Ball Screw under a Preload

When a preload is applied to a ball screw, the rigidity of the nut is increased.

Fig. 4 shows elastic displacement curves of a ball screw under a preload and without a preload.

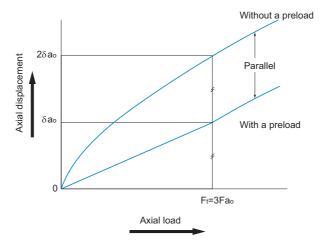
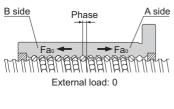
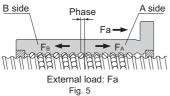


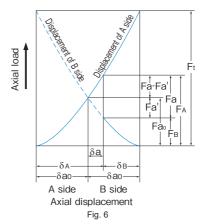
Fig. 4: Elastic Displacement Curve of the Ball Screw

Accuracy of the Ball Screw

Fig. 5 shows a single-nut type of the ball screw.







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.

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

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

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

Therefore, under a preload, the load that the A side receives equals Fa–Fa'. This means that the displacement of the A side is smaller because load Fa', which is applied when the A side receives no preload, is deducted from Fa.

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.

$$\delta \mathbf{a_0} = \mathbf{KFa_0}^{2/3}$$
 (**K**: constant)
 $2\delta \mathbf{a_0} = \mathbf{KF_t}^{2/3}$

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

Thus, the ball screw under a preload is displaced by δa_0 when an axial load (F_1) 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 that an excessive preload adversely affects the service life and heat generation. The maximum preload 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).

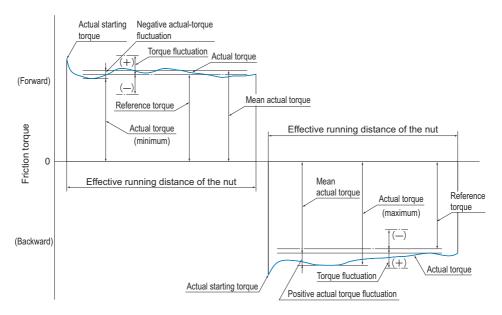


Fig. 7: Preload Torque Terminology

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).

$$T_{P} = 0.05 \left(\tan \beta \right)^{-0.5} \frac{Fa_{0} \cdot Ph}{2\pi} \dots (4)$$

Γ_P : Reference torque (N·mm)

β : Lead angle

Fa₀ : Applied preload (N)
Ph : Lead (mm)

Note: The values listed above and the preload indicated on the delivery specification drawing are without retainers, grease, or seals.

Accuracy of the Ball Screw

Example: 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

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

Fa₀: Applied preload = 3,000 N

Ph: Lead = 10 mm

$$T_p = 0.05 (tan \beta)^{-0.5} \frac{Fa_0 \cdot Ph}{2\pi} = 0.05 (0.0762)^{-0.5} \frac{3,000 \times 10}{2\pi} = 865 \text{ N} \cdot \text{mm}$$

■Calculating the Torque Fluctuation

$$\frac{\text{thread length}}{\text{screw shaft outer diameter}} = \frac{1,300}{40} = 32.5 \le 40$$

Thus, with the reference torque in Table 14 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.

 $865 \times (1\pm0.3) = 606 \text{ N} \cdot \text{mm}$ to 1,125 N·mm

■Result

Reference torque : 865 N·mm

Torque fluctuation : 606 N·mm to 1,125 N·mm

Table 14: Tolerance Range in Torque Fluctuation

		Effective thread length												
Reference torque N·mm		4,000 mm or less								Above 4,000 mm and up to 10,000 mm				
		thread length ≤40					thread length					_		
		screw shaft outer diameter ⁼⁴⁰				screw shaft outer diameter								
		Accuracy grades				Accuracy grades				Accuracy grades				
Above	Up to	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%		_	1	_
600	1,000	±20%	±25%	±30%	±35%	±40%	±30%	±30%	±35%	±40%	±45%	±40%	±45%	±50%
1,000	2,500	±15%	±20%	±25%	±30%	±35%	±25%	±25%	±30%	±35%	±40%	±35%	±40%	±45%
2,500	6,300	±10%	±15%	±20%	±25%	±30%	±20%	±20%	±25%	±30%	±35%	±30%	±35%	±40%
6,300	10,000	_	_	±15%	±20%	±30%	_	_	±20%	±25%	±35%	±25%	±30%	±35%