B-2 Technical Description of Ball Screws

B-2-1 Accuracy

B-2-1.1 Lead Accuracy

The lead accuracy of NSK precision ball screws (C0-C5 grades) conforms to the four characteristics specified in JIS Standards. These characteristics are expressed by codes *ep*, υ_u, υ_{300}, and $\upsilon_{2\pi}$.
Fig. 1.1 explains the definition of each characteristic, and shows allowable value of each. Leads are classified into two categories: C system for positioning; Ct system for transportation. Table 1.2, 1.3 and 1.4 show tolerance of each characteristic.
JIS B1192 sets C type and Cp type standards for positioning ball screws. NSK uses the specification of C type only. JIS B1192 specifies Ct1, 3, and 5 grade. NSK standards are integrated by C type only. Refer to Table 1.2 for C type standard tolerance.

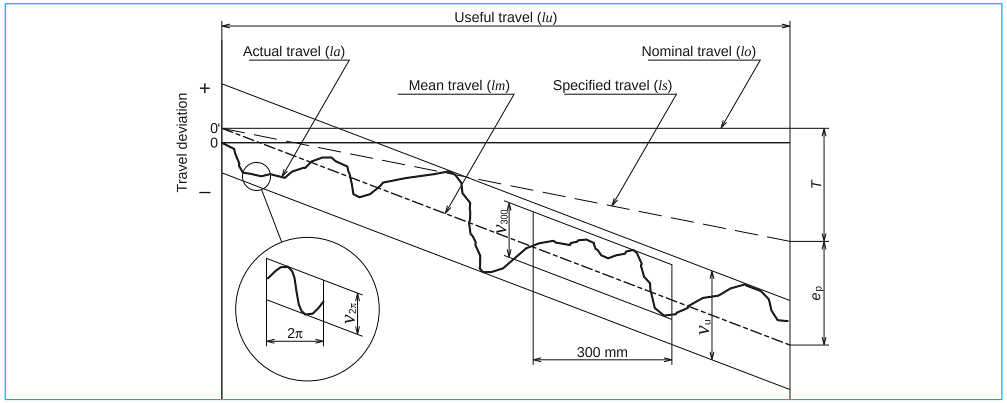

Fig. 1.1 Definition of lead accuracy

Table 1.1 Terminology in lead accuracy

Term	Code	Description	Tolerance
Specified travel	*ls*	The travel compensates the nominal travel for an elongation caused by an increase of temperature or load.	
Travel compensation	*T*	Value obtained by subtracting the specified travel from the nominal travel based on the useful travel. The value is to compensate for the errors caused by thermal deformation or deformation by load.This value is determined by tests and experience (See Page B43).	
Actual travel	*la*	Actually measured travel	
Actual mean travel	*lm*	A straight line that demonstrates the direction of actual travel. This straight line is obtained from the curve that shows actual travel volume by least-squares method or by resembling approximation.	
Tolerance on specified travel	*ep*	Obtained by subtracting the specified travel from the actual mean travel.	Table 1.2
Travel variation	υ_u υ_{300} $\upsilon_{2\pi}$	Maximum range of the actual travel which is between the two straight lines drawn parallel to the actual mean travel. There are three categories as shown below. • Maximum range relative to the effective length of thread. • Maximum range relative to the length of 300 mm anywhere within the effective length of thread. • Maximum range which corresponds to any single rotation (2π*rad*.) within the effective length of thread.	Table 1.2 Table 1.3, 1.4 Table 1.3

Table 1.2 Tolerance on specified travel (±*ep*) and travel variation (υ_u) of the positioning (*C* type) ball screws

Unit: µm

Effective thread length mm		C0		C1		C2		C3		C5	
over	or less	±*ep*	υ_u	±*ep*	υ_u	±*ep*	υ_u	±*ep*	υ_u	±*ep*	υ_u
–	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
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
10000	12500									320	170

Table 1.3 Tolerance of travel variation relative to 300 mm (υ_{300}) and one revolution ($\upsilon_{2\pi}$) of the positioning (*C* type) ball screws

Unit: µm

Accuracy grade	C0	C1	C2	C3	C5
υ_{300}	3.5	5	7	8	18
$\upsilon_{2\pi}$	2.5	4	5	6	8

Remark [shaded] to JIS B1192 standards. Values in other areas are NSK standards.

Table 1.4 Travel variation (υ_{300}) relative to 300 mm of the transportation (*Ct* type) ball screws

Unit: µm

Accuracy grade	Ct7	Ct10
υ_{300}	52	210

Remark Tolerance on specified travel (*ep*) of the transportation (*Ct* type) ball screws is calculated as follows.

$$ep = \frac{2 \cdot lu}{300} \cdot \upsilon_{300}$$

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Example of specifying lead accuracy

<Use Conditions>

Nut model: DFT4010-5

Stroke: 1000 mm

Positioning accuracy: ±0.035 mm/1000 mm

<Calculation>

Obtain required lead accuracy of a ball screw under these conditions.

①Calculate the length of the thread

Stroke + nut length + margin =1000 + 193 + 100

=1293 (mm)···→1300 mm

②Calculate lead accuracy

From Table 1.2, obtain the tolerance on specified travel relative to the length of thread (1300 mm).

C5 ··· ±0.054/1250 – 1600

C3 ··· ±0.029/1250 – 1600

③Determine lead accuracy

Positioning accuracy is: ±ep ＜±0.035/1000 mm

Accuracy grade: C3 grade ±*ep* = 0.029/length of thread (1300 mm)
υ_u = 0.018

B-2-1.2 Thermal Expansion and Target Value of Specified Travel

(1) Thermal expansion

Thermal expansion of screw shaft induces the degradation of positioning accuracy of the ball screws. Thermal expansion of a screw shaft is calculated as follows.

$\Delta L_\theta = \rho \cdot \theta \cdot L$(mm) -- (Ⅱ-1)

In this formula:

- ΔL_θ : Thermal expansion (mm)
- ρ : Thermal expansion coefficient (12.0x10^{-6} °C^{-1})
- θ : Average temperature rise of screw shaft (Celsius)
- L : Length of screw shaft (mm)

The above formula indicates that when the temperature rises one degree Celsius, the screw shaft stretches 12 µm per meter. Ball screw generates more heat when it is used at high speed. This causes elongation of the screw shaft. Although the ball screw lead is ground into high precision, an elongated screw shaft due to high temperature rise may not satisfy required highly accurate positioning.

(2) Countermeasures against temperature rise

Countermeasures against temperature rise of the ball screw are:

Hollow shaft cooling is recommended to operate high-speed and high-precision conditions.

① Suppress heat generation
- Do not apply excessive preload to the ball screw and support bearing.
- Select correct lubricant and use it appropriately.
- Use higher helix ball screw lead to lower rotational speed.

② Use forced cooling.
- Use hollow screw shaft, and flow liquid coolant through it. - Refer to hollow ball screws in the section for application-oriented ball screws (Page B144).
- Cool screw shaft surface with lubricant oil or air.

③ Avoid effects of temperature rise on positioning
- Warm up the machine by high speed until temperature rise saturate, then maintain a stable temperature of ball screw shaft.
- Set pre-tension. (Fig. 1.2)
- Set the negative (minus) target value of specified travel.
- Employ the closed loop control system.

(3) How to determine specified travel

In general, the specified travel of ball screw is the same as the nominal travel . However, the specified lead of ball screw is sometimes set to negative (minus) or positive (plus) to adjust expansion by temperature rise during operation, or the elongation/contraction of the screw shaft by external load. For such occasion, specify travel compensation (T) when ordering the ball screw.

As an example, Table 1.5 shows the travel compensation (T) for typical NC machine tools.

Table 1.5 Travel compensation (T) of specified travel for typical NC machine tools

Unit: mm

Type of machine	Axis	Travel compensation (per 1 m)
NC lathe	X	– 0.02 — – 0.05
	Z	– 0.02 — – 0.03
Machining center	X, Y	– 0.03 — – 0.04
	Z	Differs by structure

(4) How to determine pre-tension force

In order to absorb thermal expansion, pre-tension can be provided to the screw shaft at the time of installation. In this case, the pre-tension is usually equivalent to the expansion brought about by the temperature rise of 2 to 3°C.

Fig. 1.2 shows the bearing support structure in such occasion.

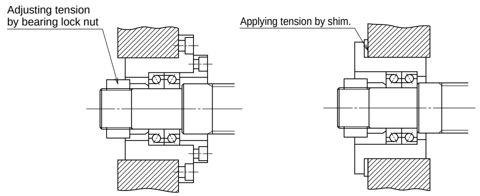

Fig. 1.2 Bearing structure to provide pre-tension

B-2-1.3 Mounting Accuracy and Tolerance of Ball Screws

The accuracy related to mount the ball screws is specified in the following seven characteristics (Fig. 1.3).

The tolerance is indicated in the specification drawing.

Detailed tolerances are specified by JIS B1192. For reference, Table 1.6 shows standard values of "(7) Total run-out of the screw shaft axis (straightness of the screw shaft)". NSK sets stricter tolerance standards than JIS standards. For accuracy of the ball screw installation, refer to "Installation of Ball Screw (1) Centering of the units" (Page B77).

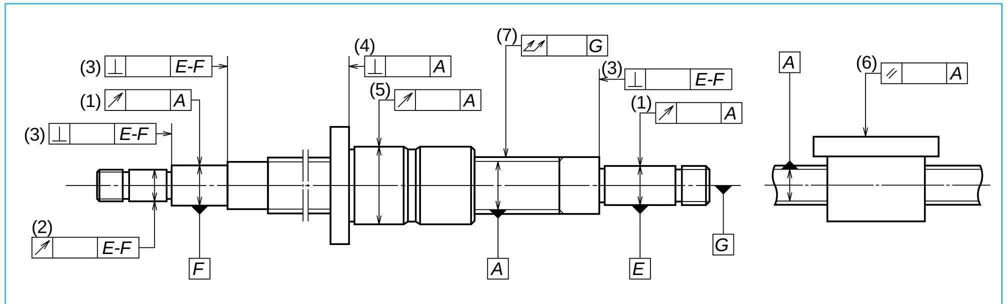

Fig. 1.3 Mounting accuracy of ball screw

(1) Radial run-out of the support bearing seat relative to the axis of the ball thread of screw shaft.
(2) Radial run-out of the other shaft ends section relative to the axis of the support bearing seat.
(3) Perpendicularity of the shoulder of support bearing seat relative to the axis of support bearing seat.
(4) Perpendicularity of the nut flange face, or of the nut end datum face, relative to the axis of screw shaft.
(5) Eccentricity of the nut outside surface (cylindrical shape) to the axis of screw shaft.
(6) Parallelism of the nut mounting surface to the screw shaft axis. (in case of flat mounting surface)
(7) Total run-out of the screw shaft axis.

Table 1.6 Total run-out of the screw shaft axis

Unit: µm

Accuracy grade		C0						C1						
Nominal diameter (mm) over		–	8	12	20	32	50	–	8	12	20	32	50	80
or less		8	12	20	32	50	80	8	12	20	32	50	80	125
Overall length of screw shaft (mm) over	or less													
–	125	15	15	15				20	20	15				
125	200	25	20	20	15			30	25	20				
200	315	35	25	20	20			40	30	25	20			
315	400		35	25	20	15		45	40	30	25	20		
400	500		45	35	25	20			50	40	30	25		
500	630		50	40	30	20	15		60	45	35	25	20	
630	800			50	35	25	20			60	40	30	25	
800	1000			65	45	30	25			75	55	40	30	25
1000	1250			85	55	40	30			95	65	45	35	30
1250	1600			110	70	50	40			130	85	60	45	35
1600	2000				95	65	45				120	80	55	40
2000	2500											100	70	50
2500	3150												130	90
3150	4000													120

Unit: µm

Accuracy grade		C3							C5						
Nominal diameter (mm) over		–	8	12	20	32	50	80	–	8	12	20	32	50	80
or less		8	12	20	32	50	80	125	8	12	20	32	50	80	125
Overall length of screw shaft (mm) over	or less														
–	125	25	25	20					35	35	35				
125	200	35	35	25	20				50	40	40	35			
200	315	50	40	30	30				65	55	45	40			
315	400	60	50	40	35	25			75	65	55	45	35		
400	500		65	50	40	30				80	60	50	45		
500	630		70	55	45	35	30			90	75	60	50	40	
630	800			70	55	40	35				90	70	55	45	
800	1000			95	65	50	40	30			120	85	65	50	45
1000	1250			120	85	60	45	35			150	100	75	60	50
1250	1600			160	110	75	55	40			190	130	95	70	55
1600	2000				140	95	70	50				170	120	85	65
2000	2500					120	85	60					150	110	80
2500	3150					160	110	75					200	140	95
3150	4000					220	150	100					260	180	120
4000	5000						200	130						240	160
5000	6300													310	210
6300	8000														280
8000	10000														370

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B-2-1.4 Automatic lead accuracy measuring system of NSK

In response to the demand for high precision in production technology, NSK is the first in the world that developed and uses "Lead Accuracy Measuring System (LAMS)." Lead accuracy is measured by the system that employs a laser interferometer measuring instrument and a personal computer.

Fig. 1.4 shows the lead accuracy measuring system. The inspection date of the ball screw is shown in Fig. 1.5. The laser interferometer measures either ball nut travel accuracy or lead accuracy of the ball thread. The data which are input into a computer are processed into four characteristics readings regarding lead accuracy. (See Page B41.)

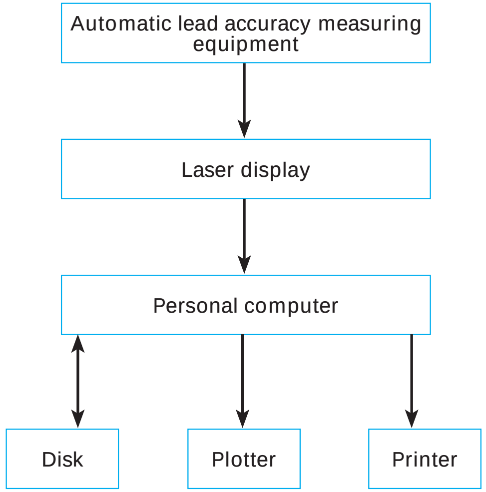

Fig. 1.4 Lead accuracy measuring system

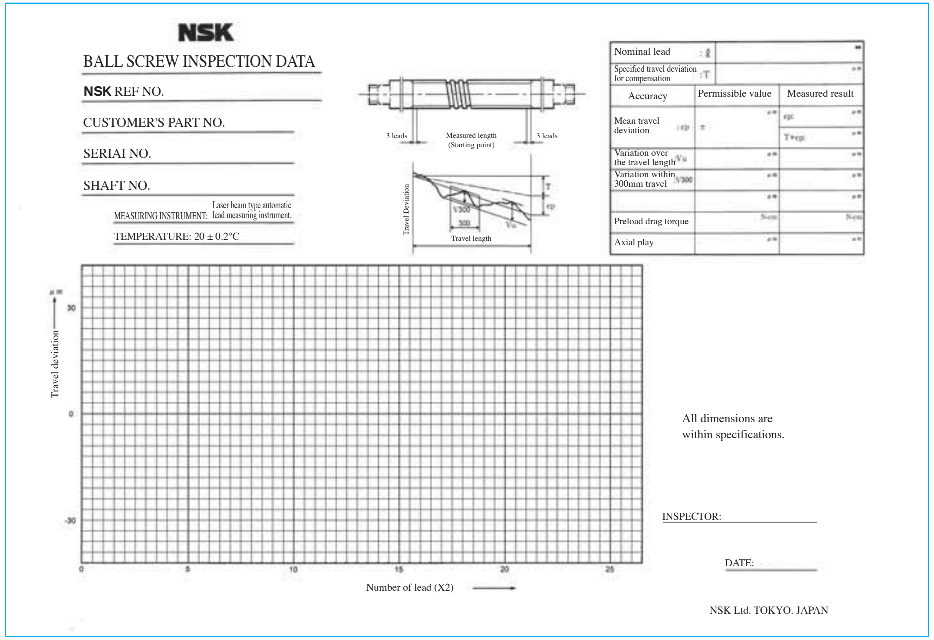

Fig. 1.5 Ball screw Inspection data

B-2-2 Static Load Limitation

Ball screw, based on its function, will generally receive axial load only. Ball screw shaft in general is long, so it is necessary to consider 3 items below:

- Buckling load of the screw shaft
- Yielding of the screw shaft by tensional or compressive stress
- Permanent deformation at the ball contact points

B-2-2.1 Buckling Load

It is necessary to calculate whether the ball screw shaft is safe against buckling.

Buckling load, i.e. permissible compressive load "P" to axial direction, is calculated as follows.

$$P = \alpha = \frac{N \cdot \pi^2 \cdot E \cdot I}{L^2} = m\frac{d_r^{\,4}}{L^2} \times 10^4 \quad \text{(N)} \cdots\cdots (\text{II-2})$$

In this formula:

α : Safety factor (α = 0.5)

E : Elastic modulus (E = 2.06 x 10^5 MPa)

I : Moment of inertia

$$I = \frac{\pi}{64} d_r^{\,4} \quad (\text{mm}^4) \cdots\cdots (\text{II-3})$$

d_r : Screw shaft root diameter (mm) [See the dimension table.]

L : Unsupported length (mm) [See Fig. 4.1 and 4.2 'Supporting conditions of screw shaft and nut' in Page B55.)

m, N : Factors determined by the supporting condition of the ball screw shaft

Table 2.1 Factors of bucking load

Supporting condition	m	N
Fixed - Fixed support	19.9	4
Fixed - Simple support	10.0	2
Fixed support - Free	1.2	0.25
Simple - Simple support	5.0	1

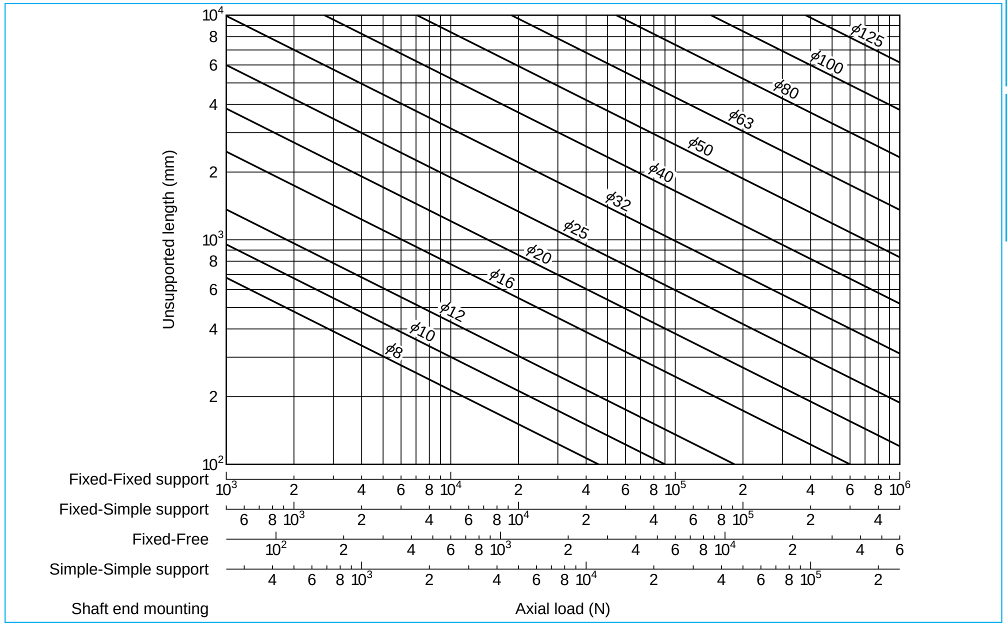

Fig. 2.1 Buckling load