Selection of Ball Screws 1

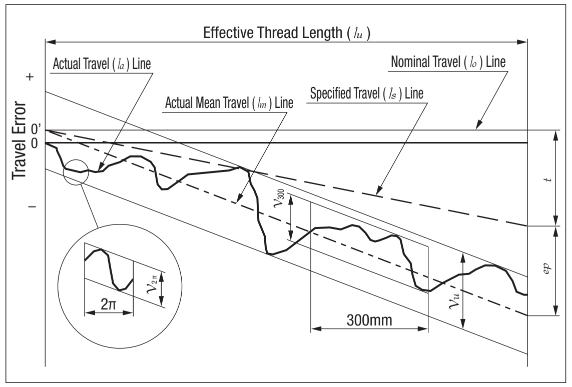
1. Ball Screw Selection Procedure

Basic ball screw selection procedure and required evaluation items are shown below.

Determine the application parameters	Moving mass, feed speed, motion pattern, screw shaft rotational speed, stroke, mounting orientation (horizontal or vertical), life, positioning accuracy
Interim selection of ball screw specifications	Temporary selection of ball screw lead accuracy grade (C3~C10), shaft diameter, lead, and length. P.3483 · 3484
Evaluation of various basic safety factors (NG → return)	•Axial Load Capacity Confirm that the applied axial load is within the ball screw's axial load capacity rating. P.3485
	•Allowable Rotational Speed Confirm that the intended shaft rotational speed is within the ball screw's allowable rotational speed rating. P.3486
	• Life Confirm that the ball screw satisfies the life requirement. P.3487
Evaluations based on required performances (NG → return)	If higher positioning accuracy and/or improved responsiveness is needed, below parameters need to be evaluated. •Screw shaft rigidity P.3488 •Effects of temperature variation on life P.3488

2. Ball Screw Lead Accuracy

Ball screw lead accuracy is defined by JIS Standards property parameters (ep, vu, v300, v2π).
Parameter definitions and allowable values are shown below.
In general, a ball screw lead accuracy grade is selected by evaluating if the Actual Mean Travel Error of a candidate is within the allowable positioning error.



Terms	Symbols	Meaning
Actual Mean Travel Error	ep	A value that is Specified Travel subtracted from Actual Mean Travel.
Variation		The maximum difference of the actual travel contained between two lines drawn parallel to the actual mean travel, and is defined by three parameters below.
	Vu	Variation for the effective thread length of screw shaft.
	V300	Variation for an arbitrarily taken length of 300mm within the effective thread length of screw shaft.
	V2π	Variation for an arbitrary one revolution (2πrad) taken within the effective thread length of screw shaft.
Specified Travel	ls	Axial travel compensated for temperature rise and loading conditions, in relation to the Nominal Travel (Lead).
Specified Travel Target Value	t	A value that is Nominal Travel subtracted from Specified Travel, over the effective thread length. This value is set to compensate for possible screw shaft expansion and contraction due to temperature changes and applied loads. The value is to be determined based on experiments or experiences.
Actual Travel	la	Actually measured travel distance
Actual Mean Travel	lm	A straight line representing the actual travel trend. A straight line obtained by the least-squares method or other approximation methods from the curve representing the actual travel.

■Table 1. Positioning Screw (C Class) Actual Mean Travel Error (±ep) and Variation (u) allowances Unit : μm

Thread Effective Length (mm)		Accuracy Grade			
		C3		C5	
over	or less	Actual Mean Travel Error	Variation	Actual Mean Travel Error	Variation
	315	12	8	23	18
315	400	13	10	25	20
400	500	15	10	27	20
500	630	16	12	30	23
630	800	18	13	35	25
800	1000	21	15	40	27
1000	1250	24	16	46	30
1250	1600	29	18	54	35

■Table 2. Positioning Screws (C Class) variation per 300mm (300) Variation per rotation (2π) standard values Unit : μm

Accuracy Grade	C3		C5	
Parameters	V300	V2π	V300	V2π
Standard Values	8	6	18	8

■Table 3. Transfer Screw (Ct Class) variation per 300mm (300) Standards Unit : μm

Accuracy Grade	Ct7	Ct10
V300	52	210

Actual Mean Travel Error (ep) for Transfer Screws (Ct Class) is calculated as ep=2·Lu/300·V300

3. Axial Clearances of Ball Screws

Axial clearance does not affect positioning accuracy if the feed is unidirectional, but will generate backlash and negatively affect on positioning accuracy if the direction or the axial load is reversed.

■Table 4. Axial Clearances of Rolled Ball Screws

Types	Prod. Example	Screw Shaft Dia.	Lead	Axial Clearance (mm)
Standard Nut Accuracy Grade C7	BSST	8	2	0.03 or less
		10	4	
		12	4	
		15	5	
			10	
			20	
		20	5	
			10	0.05 or less
			20	0.03 or less
		25	5	
			10	0.07 or less
Standard Nut Accuracy Grade C10	BSSZ BSSR	8	2	0.05 or less
			4	
		10	2	
			4	
			10	
		12	4	
			10	0.10 or less
		14	5	
		15	5	
			10	
			20	
		20	5	
			10	0.15 or less
			20	0.10 or less
		25	5	
			10	0.20 or less
			25	0.12 or less
		28	6	0.10 or less
		32	10	0.20 or less
			32	0.15 or less
Compact Nut Accuracy Grade C10	BSSC	8	2	0.05 or less
		10	2	
		12	4	
		15	5	0.10 or less
			10	
		20	5	
			10	
		25	5	
Block Nut Accuracy Grade C10	BSBR	15	5	0.10 or less
		20		
		25		
		15	10	
		20		
		25		

■Table 5. Axial Clearances of Precision Ball Screws

Types	Prod. Example	Screw Shaft Dia.	Lead	Axial Clearance (mm)
Standard Nut Accuracy Grade C3	BSX	6	1	0 (Preloaded)
		8	1	
			2	
		10	2	
		12	2	
			5	
		15	5	
Standard Nut Accuracy Grade C5	BSS (BSL)	8	2	0.005 or less
		10	2	
			4	
			10	
		12	2	
			4	
			5	
			10	
		15	5	
			10	
			20	
			40	0.010 or less
		20	5	0.005 or less
			10	
			20	
			40	
		25	5	
			10	
			20	
Standard Nut Accuracy Grade C7	BSSE	8	2	0.030 or less
		10	2	
			4	
		12	2	
			5	
			10	
		15	5	
			10	
			20	
		20	5	
			10	
			20	
		25	10	
			20	

Selection Example of Lead Accuracy

<Requirements>
· Ball screw diameter Ø15, lead 20.
· Stroke 720mm
· Positioning accuracy ±0.05mm/720mm

<Selection Details>
Select an appropriate lead accuracy grade based on the application requirements.

(1) Evaluating the screw thread length
Stroke+Nut Length+Margin=720+62+60=842
*The Margin shown above is an overrun buffer, and normally determined as 1.5~2 times the screw lead.
Lead 20x1.5x2 (both ends)=60

(2) Evaluating the lead accuracy
P.1893 Table 1. is referenced and an Actual Mean Travel Error ±ep for 842mm ball screw thread.
C3 · · · ±0.021mm/800~1000mm
C5 · · · ±0.040mm/800~1000mm

(3) Determining the lead accuracy
It can be determined that a C5 grade (±0.040/800~1000mm) ball screw can satisfy the required positioning accuracy of ±0.05/720mm.

Selection Example of Axial Clearance

<Requirements>
· Ball screw diameter Ø15, lead 5.
· Allowable backlash ±0.01mm

<Selection Details>
From Table 5., it can be determined that C5 grade with 0.005mm or less axial clearance satisfies the allowable backlash amount of 0.01mm for the Ø15 group.

4. Allowable Axial Load

Allowable Axial Load is a load with a safety margin built-in against a shaft bucking load.
Axial load that applies to a ball screw needs to be less than Allowable Maximum Axial Load.
Allowable Axial Load can be obtained by the following formula.
Additionally, approximate Allowable Axial Load can be obtained from Table 1. Allowable Axial Load Graph.

•Allowable Axial Load (P)

$$P= \frac{n\pi^2 EI}{\ell^2}\alpha = m\frac{d^4}{\ell^2}\times 10^4 (N)$$

Where:
P: Allowable Axial Load (N)
ℓ: Distance between Points of Buckling Load (mm)
E: Young's Modulus ($2.06\times 10^5 N/mm^2$)
I: Min. Geometrical Moment of Inertia of Across Root Thread Area (mm^4)

$$I= \frac{\pi}{64}d^4$$

d : Thread Root Diameter (mm)
n, m : Coefficient Determined by Method of Screw Support

Method of Screw Support	n	m
Support - Support	1	5
Fixed - Support	2	10
Fixed - Fixed	4	19.9
Fixed- Free	0.25	1.2

α : Safety Factor = 0.5
For higher safety, a higher safety factor should be required.

Allowable Axial Load Calculation Example

Find the Allowable Axial Load for Fig.1

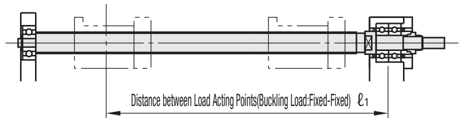
<How to use>
· Thread shaft diameter Ø15, Lead 5
· Mounting method Fixed - Support
· Distance between Points of Buckling Load ℓ_1 820mm
· Screw Shaft Root Diameter d 12.5

<Calculations>
g=15.1 since the mounting method is Fixed-Supported,
the Allowable Rotational Speed (Nc) is,

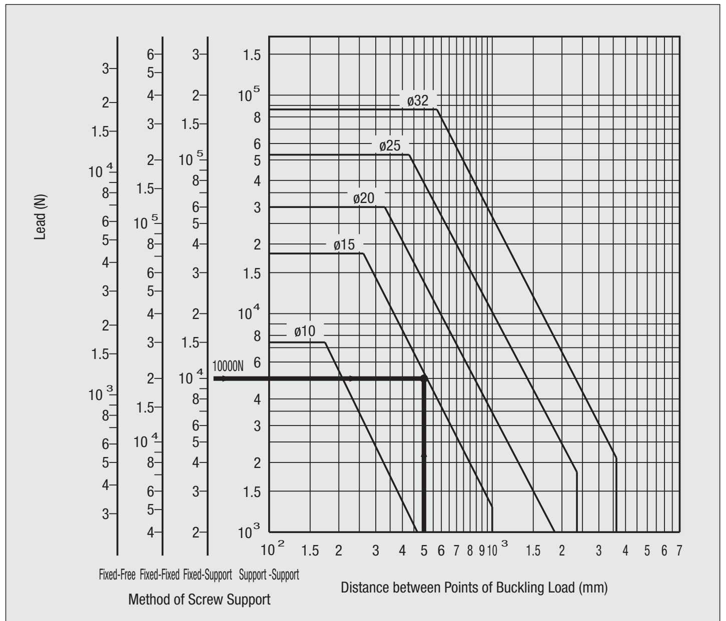
$$P= m\frac{d^4}{\ell^2}\times 10^4 = 10\times\frac{12.5^4}{820^2}\times 10^4 = 3630(N)$$

Therefore, the rotational speed will need to be 3024min^{-1} or less.

Table.1



•Figure1. Allowable Axial Load Curve



Screw Shaft Dia. Calculation Example

<Requirements>
· Distance between Points of Buckling Load 500mm
· Mounting method Fixed - Support
· the max. axial load 10000N

<Calculations>
(1) Find the intersection between a distance of 500mm between load acting points and the axial load of 10000daN(from the fixed-support graduation).[Figure 1]

(2) Read the shaft diameter of the diagonal line nearest to the intersection on the outside. The shaft diameter can be a min. 15mm.

5. Allowable Rotational Speed

Ball screw rotational speed is determined by required feed speed and the given screw lead, and needs to be less than the Allowable Maximum Rotational Speed.
Ball screw rotational speed is evaluated based on the shaft's critical speed and ball recirculation speed limitation DmN value.

5-1. Critical Speed

Allowable rotational speed is defined as a speed 80% or less of the Critical Speed where the rotational speed coincides with a natural resonant frequency of the screw shaft.
The Allowable Rotational Speed can be obtained by the following formula.
Additionally, approximate Allowable Rotational Speeds can be obtained from Table 2. Allowable Maximum Rotational Speed Graph.

•Allowable Rotational Speed (min^{-1})

$$N_C = fa\frac{60\lambda^2}{2\pi\ell^2}\sqrt{\frac{EI\times 10^3}{\gamma}} = g\frac{d}{\ell^2}10^7 (min^{-1})$$

Where:
ℓ: Distance of Supports (mm)
fa: Safety Factor (0.8)
E: Young's Modulus ($2.06\times 10^5 N/mm^2$)
I: Min. Geometrical Moment of Inertia of Across Root Thread Area (mm^4)

$$I= \frac{\pi}{64}d^4$$

d: Thread Root Diameter (mm)
γ: Specific Gravity ($7.8\times 10^{-6} kg/mm^3$)
A: Root Thread Section Area (mm^2)

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

g, λ: Coefficient Determined by Method of Screw Support

Method of Screw Support	g	λ
Support - Support	9.7	π
Fixed - Support	15.1	3.927
Fixed - Fixed	21.9	4.73
Fixed- Free	3.4	1.875

Allowable Rotational Speed Calculation Example

Find the Allowable Maximum Rotational Speed for Fig.2

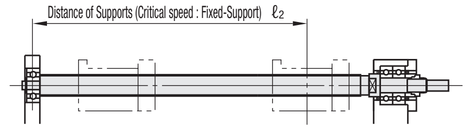
<How to use>
· Thread shaft diameter ø15, Lead 5
· Mounting method Fixed - Support
· Distance between Points of Buckling Load ℓ_1 790mm

<Calculations>
g=15.1 since the mounting method is Fixed-Supported,
the Allowable Rotational Speed (Nc) is,

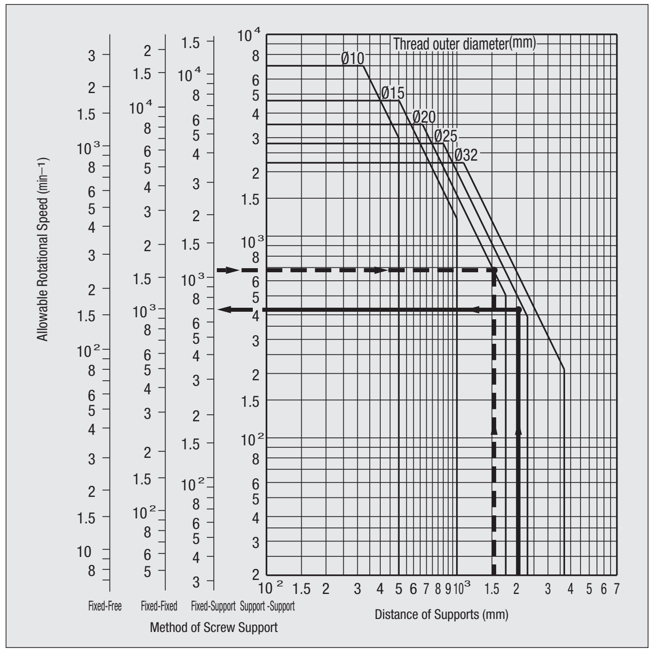
$$Nc= g\frac{d}{l^2}10^7(min^{-1}) = 15.1\times\frac{12.5}{790^2}\times 10^7(min^{-1}) = 3024(min^{-1})$$

Therefore, the rotational speed will need to be 3024min^{-1} or less.

Table.2



•Figure2. Allowable Rotational Speed Graph



Allowable Rotational Speed Calculation Example

<Requirements>
· Thread outer diameter 20
· Distance of Supports 1500mm
· Mounting method Fixed - Support

<Calculations>
(1) From Table 2., find a intersection of a vertical line from Supported Span Distance 1500mm and Screw Shaft O.D. Ø20 line.

(2) The value 1076min-1 on the Fixed-Supported scale (Y-Axis) that corresponds to the intersection of (1) above is the Allowable Maximum Speed.

Screw Shaft Dia. Calculation Example

<Requirements>
· Distance of Supports 2000mm
· Maximum Revolution Frequency 1000min^{-1}
· the max. axial load Fixed - Fixed

<Calculations>
(1) From Table 2., find a intersection of a vertical line from Supported Span Distance 2000mm and a horizontal line from Fixed-Fixed max. speed scale (Y-Axis) at 1000min^{-1}.

(2) A line that reaches down to the intersection in (1) is the Ø25 ball screw that satisfies the required speed of 1000min^{-1}.

5-2. DmN Value

The DmN value represents a ball recirculation (orbit) speed limit within a ball nut.
If this vale is exceeded, the recirculation components will be damaged.

•Allowable Rotational Speed (min^{-1})

$D_m N \leqq 70000$ (Precision Ball Screws)
$D_m N \leqq 50000$ (Rolled Ball Screws)

Where:
D_m: Thread outer diameter(mm)+A Value
N: Maximum Revolution Frequency(min^{-1})

Ball Dia.	A Value
1.5875	0.3
2.3812	0.6
3.175	0.8
4.7625	1.0
6.35	1.8

Selection of Ball Screws 3

6. Life Span

Ball screw's life is defined as: Total number of rotations, time, or distance where either the ball rolling surfaces or the balls begin to exhibit repetitive stress caused flaking. Ball screw's life can be calculated based on Basic Dynamic Load Rating with the following formula.

6-1. Life Hours (Lh)

$$L_h=\frac{10^6}{60N_m}\left(\frac{C}{P_m f_w}\right)^3 \text{(hrs)}$$

Where:
L_h: Life Span Hours (hrs)
C: Basic Dynamic Load Rating (N)
P_m: Mean Axial Load (N)
N_m: Mean Revolution Frequency (min^{-1})
f_w: Work Factor

Impactless Run	f_w = 1.0~1.2
Normal Run	f_w = 1.2~1.5
Run with Impact	f_w = 1.5~2.0

•Basic Dynamic Load Rating : C
Basic Dynamic Load Rating (C) is defined as: An axial load which a group of same ball screws are subjected and 90% of the specimen will reach 1 million rotations (10^6) without experiencing any flaking of the rolling surfaces. See product catalog pages for the Basic Dynamic Load Ratings.

*Setting life span hours longer than what is actually necessary not only requires a larger ball screw, but also increases the price.
In general, the following standards are used for life span hours:

Machine Tools:20,000hrs	Automatic Control Equipment:15,000hrs
Industrial Machinery:10,000hrs	Measuring Instruments:15,000hrs

*The basic dynamic load rating that satisfies the set life span hours is expressed by the following formula.

$$C=\left(\frac{60L_hN_m}{10^6}\right)^{\frac{1}{3}}P_m f_w \text{(N)}$$

Life Calculation Example

<Requirements>

· Ball Screw Model	BSS1520(Ø15 Lead 5)
· Mean Axial Load Pm	250N
· Mean Revolution Frequency Nm	2118 (min^{-1})
· Work Factor fw	1.2

<Calculations>
Since Basic Dynamic Load Rating C for BSS1520 is 4400N,

$$L_h=\frac{10^6}{60\times2118}\left(\frac{4400}{250\times1.2}\right)^3=24824\text{(hr)}$$

Therefore, Life will be 24824 hours.

6-2. Axial Load

Axial loads that apply on the screw shafts will vary depending on applicable motion profile such as acceleration, constant velocity, and deceleration phases. Following formula can be used.

-Axial Load Formula-
Constant Velocity · · · Axial Load (Pb)=μWg
Acceleration · · · Axial Load (Pa)=Wα+μWg
Deceleration · · · Axial Load (Pc)=Wα-μWg

* Omit the "μ" for vertical applications.

μ: Linear bearing friction coefficient (0.02 or Linear Guides)
W: Load Mass N
g: Gravitational Acceleration 9.8m/s^2
α: Acceleration (*)

(*) Acceleration (α)=(Vmax/t)x10^{-3}
Vmax: Rapid Feed Rate mm/s
t: Acceleration/Deceleration Time s

6-3. Formulae for Average Axial Load and Average Rotational Speed

Average Axial Load and Average Rotational Speed are calculated based on proportions of motion profiles.
Average Axial Load and Average Rotational Speed for Motion profiles in Table 1. can be calculated with the formula 2.

[Table 1. Motion Profile] ($t_1+t_2+t_3$=100%)

Motion Profile	Axial Load	Rotational Speed	Hours Ratio
A	P_1N	N_1min-1	t_1%
B	P_2N	N_2min-1	t_2%
C	P_3N	N_3min-1	t_3%

[Formula 2. Average Axial Load Calculation]

$$P_m=\left(\frac{P_1^3N_1t_1+P_2^3N_2t_2+P_3^3N_3t_3}{N_1t_1+N_2t_2+N_3t_3}\right)^{\frac{1}{3}}\text{(N)}$$

$$N_m=\frac{N_1t_1+N_2t_2+N_3t_3}{t_1+t_2+t_3}\ (min^{-1})$$

For case of a machine tool application, Max. Load (P1) would be for the heaviest cutting cycles, Regular Load (P2) is for the general cutting conditions, and Minimum Load (P3) is for the non-cutting rapid feeds during positioning moves.

Average Axial Load and Average Rotational Seed Calculation Example

<Requirements>

Motion Profile	Axial Load	Rotational Speed	Hours Ratio
A	343N	1500min	29.4%
B	10N	3000min	41.2%
C	324N	1500min	29.4%

<Calculations>

(1) Average Axial Load

$$Pm=\left(\frac{343^3\times1500\times0.294+10^3\times3000\times0.412+324^3\times1500\times0.294}{1500\times0.294+3000\times0.412+1500\times0.294}\right)^{\frac{1}{3}}=250\text{(N)}$$

Therefore, the Average Axial Load Pm will be 250N.

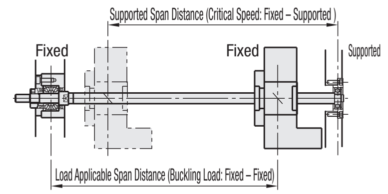
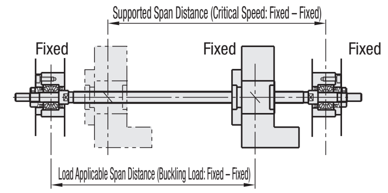
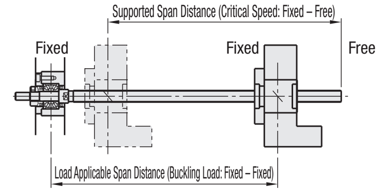
(2) Average Rotational Speed

$$Nm=\left(\frac{1500\times0.294+3000\times0.412+1500\times0.294}{0.294+0.412+0.294}\right)=2118(min^{-1})$$

Therefore, the Average Rotational Speed Nm will be 2118min.

7. Screw Shaft Mounting Arrangements

Representative ball screw mounting arrangements are shown below.

Mounting Methods	Application Example
	· Typical method · Medium ~ High Speeds · Medium ~High Accuracy · For Support Units, Standard Type BRW / BUR is selected.
	· Medium Speeds · High Accuracy · For Support Units, Standard Type BRW is selected.
	· Low Speeds · For Short Screw Shafts · Medium Accuracy · For Support Units, Economy Type BRWE is selected

8. Temperature and Life

When ball screws are continuously used at 100°C or higher, or used momentarily at very high temperatures, Basic Dynamic/Static Load Ratings will be reduced according to the temperature rise due to changes in material compositions.
However, there will be no effects up to 100°C. Basic Dynamic Load Rating C" and Basic Static Load Rating Co" at 100°C or higher with the temperature factors ft and ft' can be expressed with the following formula.

C"=ftC(N)
Co"=ft'Co(N)

Temperature °C	100 or less	125	150	175	200	225	250	350
ft	1.0	0.95	0.90	0.85	0.75	0.65	0.60	0.50
ft'	1.0	0.93	0.85	0.78	0.65	0.52	0.46	0.35

Normal usage range is -20~80°C. For application in high temperature, use of heat resistant grease as well as heat resistivity of other components should be evaluated.

9. Rigidity

In order to improve accuracies and system response of precision machinery and equipment, feed screw related component rigidity must be evaluated. Rigidity of feed screw system can be expressed with the following formula.

$$K=\frac{P}{\delta}\ (N/\mu m)$$

Where:
P: Axial Loads Applied on Feed Screw System (daN)
δ: Elastic Deformation of Feed Screw System (μm)
Additionally, the following relationship exists between the feed screw system rigidity and other various construction element rigidity.

$$\frac{1}{K}=\frac{1}{K_\ell}+\frac{1}{K_n}+\frac{1}{K_b}+\frac{1}{K_h}$$

Where:
K_ℓ: Screw Shaft Compressive/Tensile Rigidity
K_n: Nut Rigidity
K_b: Support Bearing Rigidity
K_h: Nut and Bearing Mount Rigidity

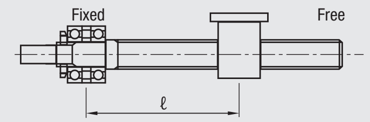
•Screw Shaft Compressive/Tensile Rigidity : Kℓ

$$K_\ell=\frac{P}{\delta_\ell}\ (N/\mu m)$$

Where:
P: Axial Load (N)
δ_ℓ: Screw Shaft Expansion/Contraction (μm)

The expansion and contraction are expressed in the following formula. The expansion and contraction will directly appear as ball screw backlash.

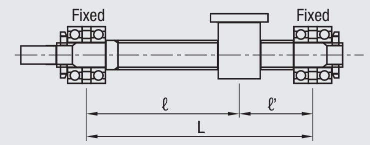
(1) Fixed-Free Arrangement



$$\delta_\ell=\frac{4P\ell}{E\pi d^2}\times10^3(\mu m)$$

Where:
P: Axial Load (N)
E: Young's Modulus (2.06x10^5N/mm^2)
d: Screw Shaft Root Diameter (mm)
ℓ: Load Applicable Span Distance (mm)

(2) Fixed-Fixed Arrangement



$$\delta_\ell=\frac{4P\ell\ell'}{E\pi d^2L}\times10^3(\mu m)$$

Where:
P: Axial Load(N)
E: Young's Modulus (2.06x10^5N/mm^2)
d: Screw Shaft Root Diameter (mm)
ℓ,ℓ': Load Applicable Span Distance (mm)
L: Mounting Span Distance (mm)

The formula produces the max. value when $\ell=\ell'=\frac{L}{2}$

$$\left(\delta_\ell=\frac{PL}{E\pi d^2}\times10^3\right)$$

Therefore, the max. shaft expansion and contraction will be 1/4 of Fixed-Free arrangement.

Selection of Ball Screws 4

10. Driving Torque

This selection provides a guide for selecting ball screw frictional properties and the driving motor.

10-1. Friction and Efficiency

Ball screw efficiency can be expressed in the following formulas; wherein μ is the coefficient of friction and β is the screw's lead angle. Variables are determined through analysis of a dynamic model.

When rotational force is converted into axial force (Forward Action)

$$\eta=\frac{1-\mu\ \tan\beta}{1+\mu/\tan\beta}$$

When axial force is converted into rotational force (Reverse Action)

$$\eta'=\frac{1-\mu/\tan\beta}{1+\mu\ \tan\beta}$$

10-2. Load Torque

The load torque(constant speed driving torque) required in drive source design(motors,etc.)is calculated as follows.

(1) Forward Action

Torque required when converting rotational force into axial force

$$T=\frac{PL}{2\pi\eta}\ (N\cdot cm)$$

Where:

T: Load Torque (N·cm)

P: External Axial Load (N)

L: Ball Screw Lead (cm)

η: Ball Screw Efficiency (0.9)

(2) Reverse Action

External axial load when converting axial force into rotational

$$P=\frac{2\pi\ T}{\eta' L}\ (N)$$

Where:

P: External Axial Load (N)

T: Load Torque (N·cm)

L: Ball Screw Lead (cm)

η': Ball Screw Efficiency (0.9)

(3) Friction Torque Caused by Preloading

This is a torque generated by preloading. As external loads increase, the preload of the nut is released and therefore the friction torque by preloading also decreases.

Under No load

$$T_P=K\frac{P_L L}{2\pi}\ (N\cdot cm)$$

$K=0.05(\tan\beta)^{-\frac{1}{2}}$

Where:

P_L: Preload (N)

L: Ball Screw Lead (cm)

K: Coefficient of Internal Friction

β: Lead Angle $\beta \fallingdotseq \tan^{-1}\left(\frac{L}{\pi D}\right)$

D: Thread Outer Diameter

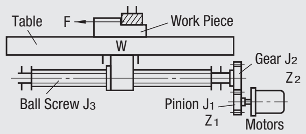
11. Selecting the Driving Motors

When selecting a driving motor, it is necessary to satisfy the following conditions:

1.Ensure a marginal force sufficient to counter the load torque exerted on the motor's output thread.

2.Enable starting, stopping at prescribed pulse speeds, sufficiently powered to counter the moment of inertia exerted on the motor's output thread.

3.Obtain the prescribed acceleration and deceleration constants, sufficient to counter the moment of inertia exerted on the motor's output thread.



(1) Constant Speed Torque Exerted on the Motor Output Thread

This is the amount of torque required to drive the output thread against the applied external load, at a constant speed.

$$T_1=\left(\frac{PL}{2\pi\eta}+T_P\frac{(3P_L-P)}{3P_L}\right)\frac{Z_1}{Z_2}\ (N\cdot cm)$$

Where: $P\leqq 3P_L$

T_1: Driving Torque at Constant Speed (N·cm)

P: External Axial Load (N)

$P=F+\mu Mg$

F: Thrust Reaction Produced in Cutting Force (N)

M: Masses of Table and Work Piece (kg)

μ: Coefficient of Friction on Sliding Surfaces

g: Gravitational Acceleration (9.8m/s²)

L: Ball Screw Lead (cm)

η: Mechanical Efficiency of Ball Screw or Gear

T_P: Friction Torque Caused by Preloading (N·cm) Referto Formula 10-2-(3)

P_L: Preload (N)

Z_1: Number of Pinion's Teeth

Z_2: No. of Gear's Teeth

(2) Acceleration Torque Exerted on the Motor Output Thread

This is the amount of torque required to drive the output shaft against the external load during acceleration.

$$T_2=J_M\omega=J_M\frac{2\pi N}{60t}\times10^{-3}\ (N\cdot cm)$$

$$J_M=J_1+J_4+\left(\frac{Z_1}{Z_2}\right)^2\left\{J_2+J_3+J_5+J_6\right\}\ (kg\cdot cm^2)$$

Where:

T_2: Driving Torque in Acceleration (N·cm)

ω: Motor Thread Angular Acceleration (rad/s²)

N: Motor Thread Revolutions (min⁻¹)

t: Acceleration (s)

J_M: Moment of Inertia Exerted on the Motor (kg·cm²)

J_1: Moment of Inertia Exerted on Pinion (kg·cm²)

J_2: Moment of Inertia Exerted on Gear (kg·cm²)

J_3: Moment of Inertia Exerted on Ball Screw (kg·cm²)

J_4: Moment of Inertia Exerted on Motor's Rotor (kg·cm²)

J_5: Moment of Inertia of Moving Body (kg·cm²)

J_6: Moment of Inertia of Coupling (kg·cm²)

M: Masses of Table and Work Piece (kg)

L: Ball Screw Lead (cm)

Moment of inertia exerted on cylinders as screws and cylinders such as Gears (Calculation of J_1~J_4, J_6)

$$J=\frac{\pi\gamma}{32}D^4\ell\ (kg\cdot cm^2)$$

Where:

D: Cylinder Outer Diameter (cm)

ℓ: Cylinder Length (cm)

γ: Material Specific Gravity

$\gamma=7.8\times10^{-3}$ (kg/cm³)

$$J_5=M\left(\frac{L}{2\pi}\right)^2\ (kg\cdot cm^2)$$

(3) Total Torque Exerted on the Motor Output Thread

Overall torque can be obtained by adding results from formulas (1) and (2).

$$T_M=T_1+T_2=\left(\frac{PL}{2\pi\eta}+T_P\frac{(3P_L-P)}{3P_L}\right)\frac{Z_1}{Z_2}+J_M\frac{2\pi\ N}{60t}\times10^{-3}(N\cdot cm)$$

Where:

T_M: Total Torque Exerted on the Motor Output Thread (N·cm)

T_1: Driving Torque at Constant Speed (N·cm)

T_2: Driving Torque at In Acceleration (N·cm)

Once you have temporarily found the type of motor you need, check

1. effective torque,

2. acceleration constant and

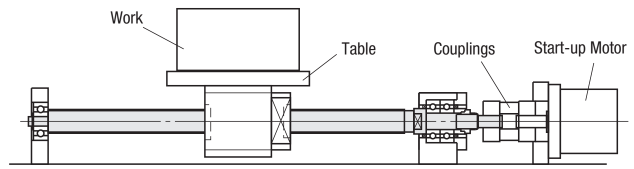
3. motor overload properties and heat tolerance during repeated starting, stopping.

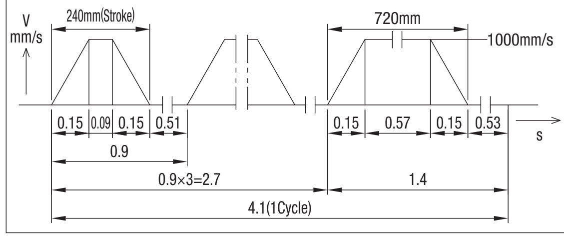
It is necessary to ensure a sufficient margin for these parameters.

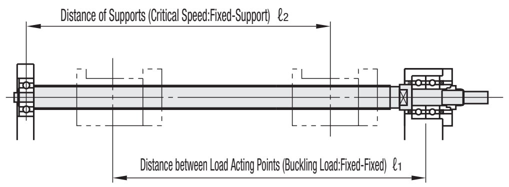
12. Example of Selection of Ball Screws

Condition of Use

•Work & Table Mass	W=50(kg)
•Maximum Strokes	Smax.=720(mm)
•Threading Speed	Vmax.=1000(mm/s)
•Acceleration Constant	t=0.15(s)
•Positioning Precision	±0.1/720(mm)
•Repeat Accuracy	±0.01(mm)
•Life Span	Lh=30000Hours
•Direct Acting Guide Coefficient of Friction	μ=0.02
•Driving Motor	Nmax.=3000(min⁻¹)
•Duty Cycle Model Diagram	







1. Setting Lead (L)

Set lead based on maximum motor revolutions and threading speed. Use the following formula.

$$L\geqq\frac{Vmax\times60}{Nmax}=\frac{1000\times60}{3000}=20$$

Required lead is 20mm or higher.

2. Nut selection

(1) Calculating Axial Load

P.3487, 6-2. Axial Load calculation formula is used to obtain the axial loads for each segment of a motion profile.

· At Constant Speed

Axial Load (Pb) =μWg=0.02×50×9.8≒10 (N)

· In Acceleration

Acceleration(α) = (Vmax/t)×10⁻³ = (100/0.15)×10⁻³=6.67 (m/s²)

Axial Load (Pa) =Wα+μWg=50×6.67+0.02×50×9.3≒343 (N)

· In Deceleration

Axial Load (Pc) Wα-μWg=50×6.67-0.02×50×9.8≒324 (N)

(2) Actual moving time during each segment in a motion profile

Below derived from Duty Cycle Model Diagram.

Operating Pattern	In Acceleration	At Constant Speed	In Deceleration	Total Operating Time
Operating Time	0.60	0.84	0.60	2.04

(3) Summary of Axial Loads, Rotational Speeds, and Operation Time for Each Motion Profile

Operating Pattern	In Acceleration	At Constant Speed	In Deceleration
Axial Load	343N	10N	324N
Revolutions Frequency	1500min⁻¹	3000min⁻¹	1500min⁻¹
Operating Time Ratio	29.4%	41.2%	29.4%

(4) Calculating the Average Axial Load with a formula in **P.3487**, 6-3.

$$\text{Mean Axial Load(Pm)}=\left(\frac{P_1^3N_1t_1+P_2^3N_2t_2+P_3^3N_3t_3}{N_1t_1+N_2t_2+N_3t_3}\right)^{\frac{1}{3}}=250(N)$$

(5) Calculating the mean turns

$$\text{Mean Turns (Nm)}=\frac{N_1t_1+N_2t_2+N_3t_3}{t_1+t_2+t_3}=2118(min^{-1})$$

(6) Calculation of the required basic dynamic load rating

(1) Calculating Continuous Operational Life (Lho)

A Continuous Operational Life which is derived by subtracting Resting time from Desired Life while a motion profile of 4.01s with a moving time of 2.04s can be calculated as follows.

$$Lho=\text{Desired Life (Lh)}\times\left(\frac{2.04}{4.1}\right)=14927\ (Hours)$$

(2) Calculating Required Basic Dynamic Load Rating

P.3487 6-1. contains a formula for calculating a Basic Dynamic Load Rating for continuous operational life.

$$C=\left(\frac{60L_{ho}N_m}{10^6}\right)^{\frac{1}{3}}\times P_m\times f_w=\left(\frac{60\times14927\times2118}{10^6}\right)^{\frac{1}{3}}\times250\times1.2=3700(N)$$

(7) Tentative Ball Screw Selection

A ball screw to satisfy the requirements of Lead 20 and Basic Dynamic Load Rating of 3700N, BSS1520 is tentatively selected.

3. Accuracy Evaluation

(1) Evaluating Accuracy Grades and Axial Clearances

P.3483 2. "Ball Screw Lead Accuracy" section shows a table for accuracy values of various Accuracy Grades.

From the lead accuracy value table, it can be confirmed that the C5 Grade with Actual Mean Travel Error ±ep 0.040/800~1000mm will satisfy the requirement of ±0.1/720mm, and a BSS1520 is suitable.

Additionally, the Precision Screws axial clearance table on shows that axial clearance of BSS1520 is 0.005 or less.

The required positioning repeatability is ±0.01mm, and it can be confirmed that BSS1520 satisfies the requirement.

4. Screw Shaft Selection

(1) Determining the Overall Length

Screw Shaft O.A.L. (L)=

Max. Stroke+Nut Length+Margin+Shaft End Terminations (both sides). Therefore,

Max Stroke:	720mm
Nut Length:	62mm
Margin:	Lead×1.5=60mm
Shaft End Termination Dims.:	72

Screw Shaft O.A.L. (L)=720+62+60+72=914mm

* The Margin is provided as a countermeasure in case overruns, and the amount is typically set as 1.5~2 times the screw lead.

Lead 20×1.5×2(Ends)=60

(2) Evaluating the Allowable Axial Load

Load Applicable Span Distance l1 is 820mm, and the Axial Load can be obtained by the formula on **P.3485**, "4. Allowable Axial Load" as below.

$$P=m\frac{d^4}{\ell^2}10^4=10\times\frac{12.5^4}{820^2}\times10^4=3660N$$

The above formula produces an Axial Load value of 343N which is well within the Allowable Max. Axial Load 3660N, and suitability is confirmed.

(3) Evaluating the Allowable Max. Rotational Speed

Shaft supported span is 790mm, and the formula in "5-1. Critical Speed" on produces a value for the Critical Speed Nc as **P.3486**

$$Nc=g\frac{d}{\ell^2}10^7=15.1\times\frac{12.5}{790^2}\times10^7=3024min^{-1}$$

The max. speed requirement of 3000min⁻¹ is within the Critical Speed of 3024min⁻¹, and the suitability is confirmed.

Additionally, the DmN value can be evaluated with the formula in **P.3486**, "5-2. DmN Value" as...

DmN=(Shaft O.D.+A value)×Max Rotational Speed=15.8×3000=47400≤70000

and the suitability is confirmed.

5. Selection Result

From the above, it is determined that a suitable ball screw model is BSS1520-914.