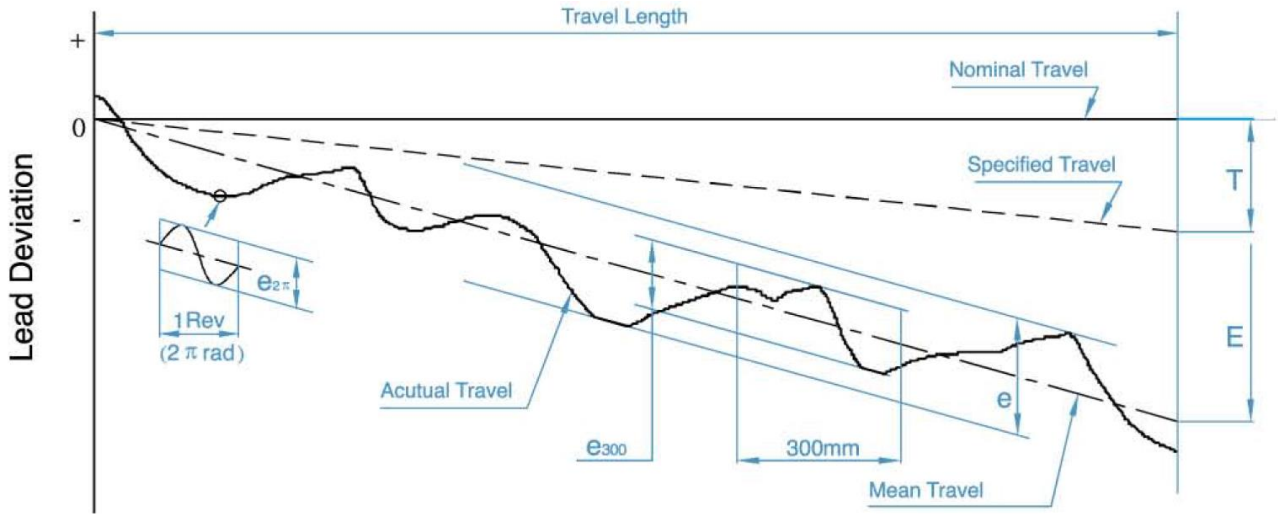
MIT-Ball Screw

LEAD/TRAVEL ACCURACY

1 · Lead accuracy of ball screws (grade C0 ~ C5) is specified in 4 basic terms (E,e,es00, e2,). There are defined in Fig. 2.1 Tolerance of deviation (±E) and variation (e) of accumulated reference travel are shown in Table 2.2 and 2.3.

2 · Accumulated travel deviations for grade C7 and C10 are specified only by the allowable value per 300mm measured within any portion of the thread length. They are 0.05mm for C7 and 0.21 mm for C10.



Definition of terms for lead accuracy.

Terms	Reference	Definition	Allowable
Travel Compensation	T	Travel compensation is the difference between specified and nominal travel within the useful travel. A slightly smaller value compared to the nominal travel is often selected by the customer to compensate for an expected elongation caused by temperature rise or external load. Therefore "T" is usually a negative value. Note : if no compensation is needed, specified travel is the same as nominal travel.	
Actual Travel		Actual travel is the axial displacement of the nut relative to the screw shaft.	
Mean Travel		Mean travel is the linear best fit line of actual. This could be obtained by the least quares method. This line represents the tendency of actual travel.	
Mean Travel Deviation	E	Mean travel deviation is the difference between mean travel and specified travel within travel length.	Table2.2
Travel Variations	e e_{300} $e_{2\pi}$	Travel variations is the band of 2 lines drawn parallel to the mean travel, on the plus and minus side. Maximum width of variation over the travel length. Actual width of variation for the length of 300mm taken anywhere within the travel length. Wobble error, actual width of variation for one revolution (2π radian)	Table2.2 Table2.3 Table2.3

MIT-Ball Screw

LEAD/TRAVEL ACCURACY

Mean travel deviation (±E) and travel variation (e) (JIS B 1192)

Grade			C0		C1		C2		C3		C5		C7	C8	C10
	Over	Incl.	±E	e	±E	e	±E	e	±E	e	±E	e	e	e	e
Travel Length (mm)	---	100	3	3	3.5	5	5	7	8	8	18	18	±50 / 300mm	±50 / 300mm	±210 / 300mm
	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	9393			
	6300	8000	---	---	---	---	---	---	110	60	210	115			
	8000	10000	---	---	---	---	---	---	---	---	260	140			
	10000	12500	---	---	---	---	---	---	---	---	320	170			

Variation per 300mm (e_{300}) and Wobble Error ($e_{2\pi}$) (JIS B 1192)

Unit : μm

Grade	C0	C1	C2	C3	C5	C7	C10
e_{300}	3.5	5	7	8	18	50	210
$e_{2\pi}$	3	4	5	6	8	---	---

MIT-Ball Screw

AXIAL PLAY

1 · Clearance in the axial direction of ball screw (P0).

Screw Shaft OD	Rolled Ball Screw Clearance in the axial direction (max.)	Ground Ball Screw Clearance in the axial direction (max.)
4mm~14mm	0.05	0.015
15mm~14mm	0.08	0.025
50mm~80mm	0.12	0.05

2 · Clearance in the axial direction (P1).

Screw Shaft OD	Rolled Ball Screw Clearance in the axial direction (max.)	Ground Ball Screw Clearance in the axial direction (max.)
4mm~80mm	0	0

3 · Spring force of internal circulation (kgf · Cm).

Model No.	P2		P3		P4	
	3%Spring Force	TP Reference Torque	8% Spring Force	TP Spring Force	13% Spring Force	TP Spring Force
1404-4	0.1	0.13	0.2	0.34	0.3	0.56
1604-3	0.1	0.17	0.3	0.45	0.5	0.73
1604-4	0.1	0.21	0.3	0.57	0.5	0.93
1605-3	0.2	0.29	0.4	0.79	0.7	1.28
1605-4	0.2	0.30	0.4	0.80	0.7	1.30
1610-3	0.2	0.39	0.5	1.04	0.9	1.69
2005-4	0.2	0.47	0.5	1.26	0.9	2.05
2504-4	0.1	0.33	0.3	0.88	0.6	1.43
2505-4	0.2	0.60	0.6	1.60	1.0	2.59
2510-3	0.4	1.11	1.2	2.95	1.9	4.79
2510-4	0.6	1.47	1.2	3.93	2.5	6.38
3205-4	0.2	0.76	0.6	2.02	1.0	3.28
3206-4	0.3	1.14	0.8	3.03	1.3	4.93
3210-3	0.6	2.02	1.7	5.37	2.7	8.73
3210-4	0.8	2.62	2.2	6.99	3.5	11.36
4005-4	0.2	0.95	0.6	2.53	1.1	4.11
4006-4	0.3	1.25	0.9	3.32	1.4	5.40
4010-3	0.8	2.59	2.2	6.91	3.6	11.23
4010-4	0.8	3.31	2.3	8.84	3.7	14.36
5010-3	0.9	3.29	2.3	8.77	3.8	14.26
5010-4	0.9	4.21	2.4	11.23	3.9	18.25
6310-4	1.0	5.42	2.7	14.46	4.4	23.49
6320-4	2.3	13.08	6.1	34.87	9.9	56.66
8010-4	1.1	6.68	2.9	17.82	4.6	28.96
8020-3	2.3	16.87	6.2	44.98	10.1	73.10

MIT-Ball Screw

AXIAL PLAY

4 · Spring force of plastic circulation (kgf · Cm).

Model No.	P2		P3		P4	
	2%Spring Force	TP Reference Torque	5% Spring Force	TP Spring Force	8% Spring Force	TP Spring Force
1210-2	0.1	0.12	0.1	0.20	0.2	0.32
1605-4	0.2	0.32	0.4	0.81	0.7	1.29
1610-3	0.1	0.26	0.3	0.65	0.5	1.04
1610-4	0.1	0.33	0.4	0.83	0.6	1.33
1616-3	0.2	0.44	0.6	1.09	0.9	1.75
2005-4	0.2	0.42	0.4	1.04	0.7	1.67
2505-4	0.2	0.52	0.5	1.29	0.8	2.07
2510-4	0.3	0.84	0.8	2.09	1.3	3.34
3205-4	0.2	0.79	0.6	1.98	1.0	3.17
3220-3	0.4	1.45	1.1	3.62	1.8	5.80
4005-4	0.3	1.19	0.8	2.98	1.2	4.77
4020-3	0.8	3.14	2.0	7.85	3.2	12.55
5010-4	0.7	3.47	1.9	8.66	3.0	13.86
5020-5	1.5	6.98	3.8	17.46	6.0	27.93
1616-2	0.2	0.33	0.4	0.83	0.7	1.30
2020-2	0.2	0.45	0.4	1.12	0.7	1.79
2525-2	0.3	0.88	0.7	2.20	1.2	3.52
3232-2	0.4	1.61	1.1	4.04	1.7	6.46
4040-2	0.7	3.30	1.8	8.24	2.8	13.18
5050-2	1.3	7.35	3.3	18.38	5.3	29.41

5 · Spring force of external circulation (kgf · Cm).

Model No.	P2		P3		P4	
	3%Spring Force	TP Reference Torque	8% Spring Force	TP Spring Force	13% Spring Force	TP Spring Force
082.5-2.5	0.1	0.05	0.1	0.08	0.1	0.13
1003-2.5	0.1	0.06	0.1	0.15	0.2	0.24
1204-3.5	0.1	0.13	0.3	0.34	0.4	0.55
1205-3.5	0.2	0.22	0.5	0.59	0.7	0.95
1605-2.5	0.2	0.28	0.5	0.73	0.7	1.19
1520-1.5	1.5	3.41	4.0	9.08	6.6	14.76
2010-2.5	0.2	0.70	0.6	1.88	1.0	3.05

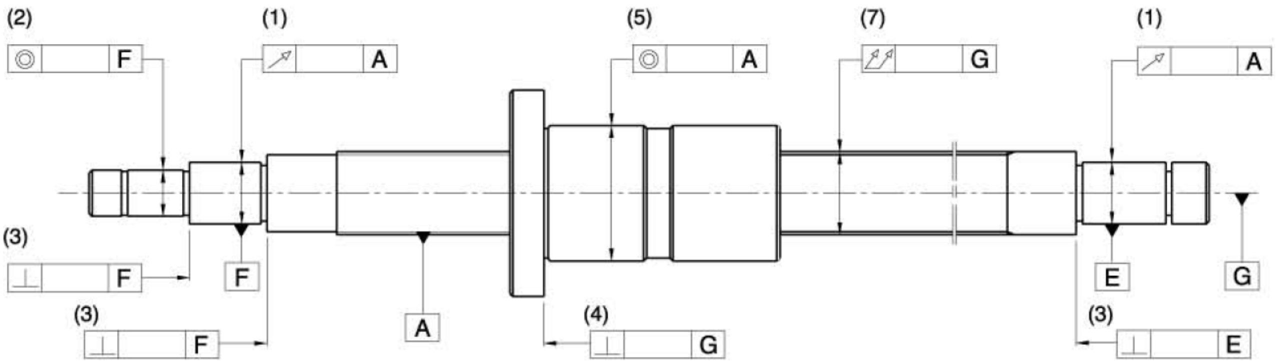
MIT-Ball Screw

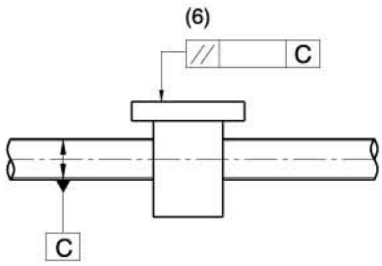
DEFINITION OF MOUNTING ACCURACY AND TOLERANCES ON BALL SCREW

To use a ball screw properly dimensional accuracy and tolerances are most important. We will help you determine the tolerance factors as they are subject to change according to accuracy grade.

1 · Periphery run-out of the supporting part of the screw shaft to the screw groove.
2 · Concentricity of a mounting portion of the shaft to the adjacent ground portion of the screw shaft.
3 · Perpendicularity of the shoulders to the adjacent ground portion of the screw shaft.
4 · Perpendicularity of the nut flange to the axis of the screw shaft.
5 · Concentricity of the ball nut diameter to the screw groove.
6 · Parallelism of the mounting surface of a ball nut to the screw groove.
7 · Total run-out of the screw shaft to the axis of the screw shaft.

Our ball screws are manufactured, inspected and guaranteed to be within specifications.



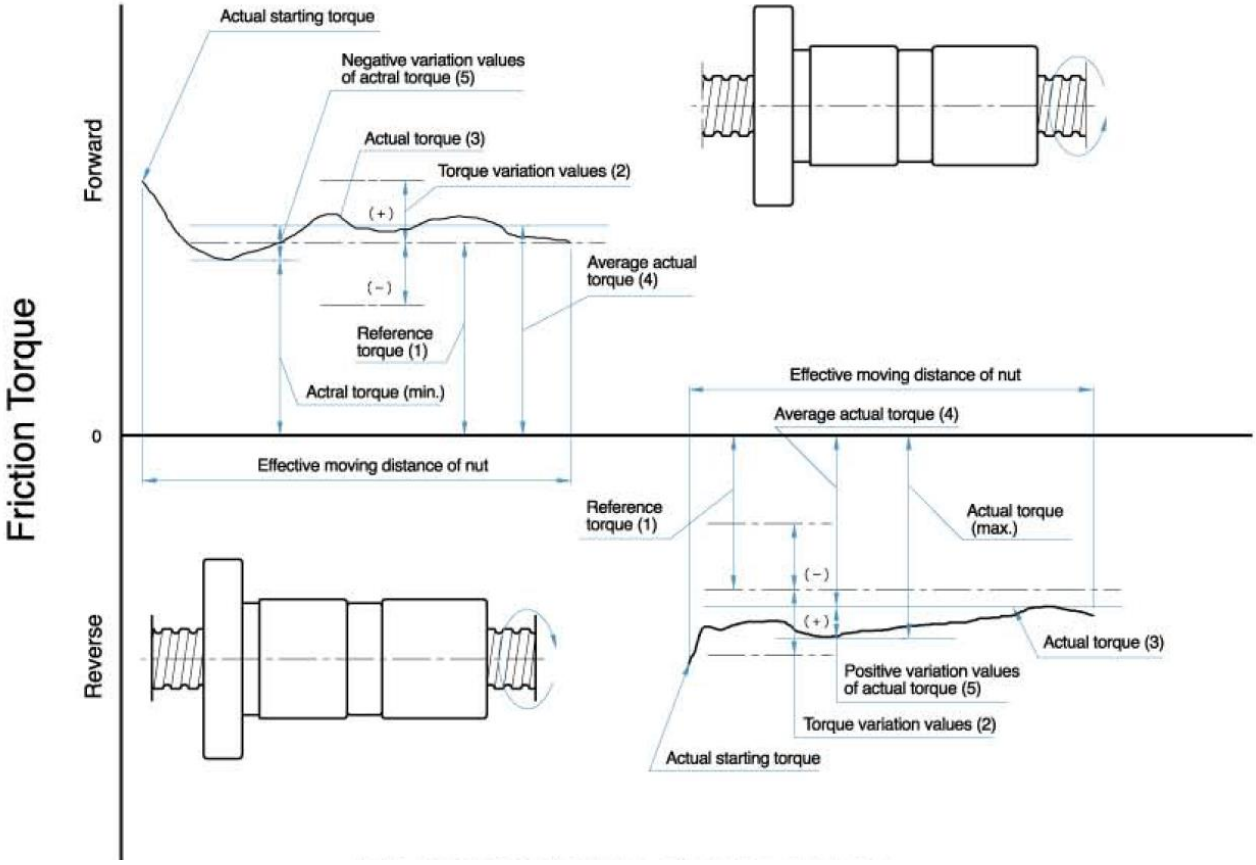


MIT-Ball Screw

PRELOAD TORQUE

1 · Terms in relation to the preload torque generated during the rotation of the preload ball screws are shown in Fig. 2.3.

2 · Permissible ranges of torque variation rates is shown in Table 2.6.



3 · Glossary

- Preload : The stress generated inside the screws when inserting a set of steel balls of one gage (approximately 2μ) larger into the nut or using them on the 2 nuts which exercise mutual displacements along the screws axis in order to eliminate the gaps of the screw or upgrade the rigidity of the screw.
- Preload dynamic torque : The dynamic torque required for continuously rotating the screws shaft or the nuts under unload condition after the specified preload has been applied upon the ball screws.
- Reference : The targeted preload dynamic torque (Fig.2.2-1).
- Torque variation values : The variation values of the targeted preload torque variation rates are specified generally based on JIS Standards as indicated in Table 3.5.
- Torque variation rate : The rate of variation values in relation to the reference torque.
- Actual torque : The actually measured preload dynamic torque of the ball screws.
- Average actual torque : The arithmetic average of the maximal and minimal actual torque values measured when the nuts are exercising reciprocating movements.
- Actual torque variation values : The maximal variation values measured within the effective length of the threads when the nuts are exercising reciprocating movements, the positive or negative values relative to the actual torque are adopted.
- Actual torque variation rate : The rate of actual torque variation values in relation to the average actual torque.

PRELOAD TORQUE

Permissible ranges of torque variation rates Unit : mm

Reference torque Kgf . cm		Below 4000								4000 ~ 10000		
		Slenderness 1:below 40				Slenderness 1:40~1:60				-		
		Grade				Grade				Grade		
Over	Incl.	C0	C1	C2,C3	C5	C0	C1	C2,C3	C5	C1	C2,C3	C5
2	4	± 35%	± 40%	± 45%	± 55%	± 45%	± 45%	± 55%	± 65%	-	-	-
4	6	± 25%	± 30%	± 35%	± 40%	± 38%	± 38%	± 45%	± 50%	-	-	-
6	10	± 20%	± 25%	± 30%	± 35%	± 30%	± 30%	± 35%	± 40%	-	± 40%	± 45%
10	25	± 15%	± 20%	± 25%	± 30%	± 25%	± 25%	± 30%	± 35%	-	± 35%	± 40%
25	63	± 10%	± 15%	± 20%	± 25%	± 20%	± 20%	± 25%	± 30%	-	± 30%	± 35%
63	100	-	-	± 15%	± 20%	-	-	± 20%	± 25%	-	± 25%	± 30%

Remarks : 1 . Slenderness is the value of dividing the screws shaft outside diameter with the screws shaft threading length.

2 . For reference torque less than 2 kgf . cm, the specifications we will apply.

4 · Calculation of reference torque Tp : The formula for computing reference torque of the ball screws is given in following.

$$Tp=0.05(\tan\beta)^{-0.05} \cdot \frac{Fao \cdot \ell}{2\pi}$$

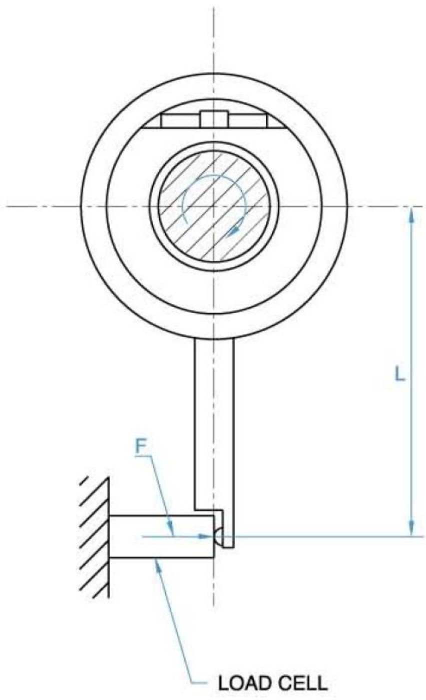
Where . Fao : Preload (kgf).

β : Lead angle.

ℓ : Lead (cm).

5 · Measurement conditions

The preload dynamic torque Tp is determined first by adopting the following measurement conditions together with the method illustrated in Diagram 34 for measuring the force F needed to rotate the screws shaft without bringing the nuts to rotate along with the shaft after the screws shaft has started rotating, then multiplying the measured value of F with the arm of force L, the product is Tp.



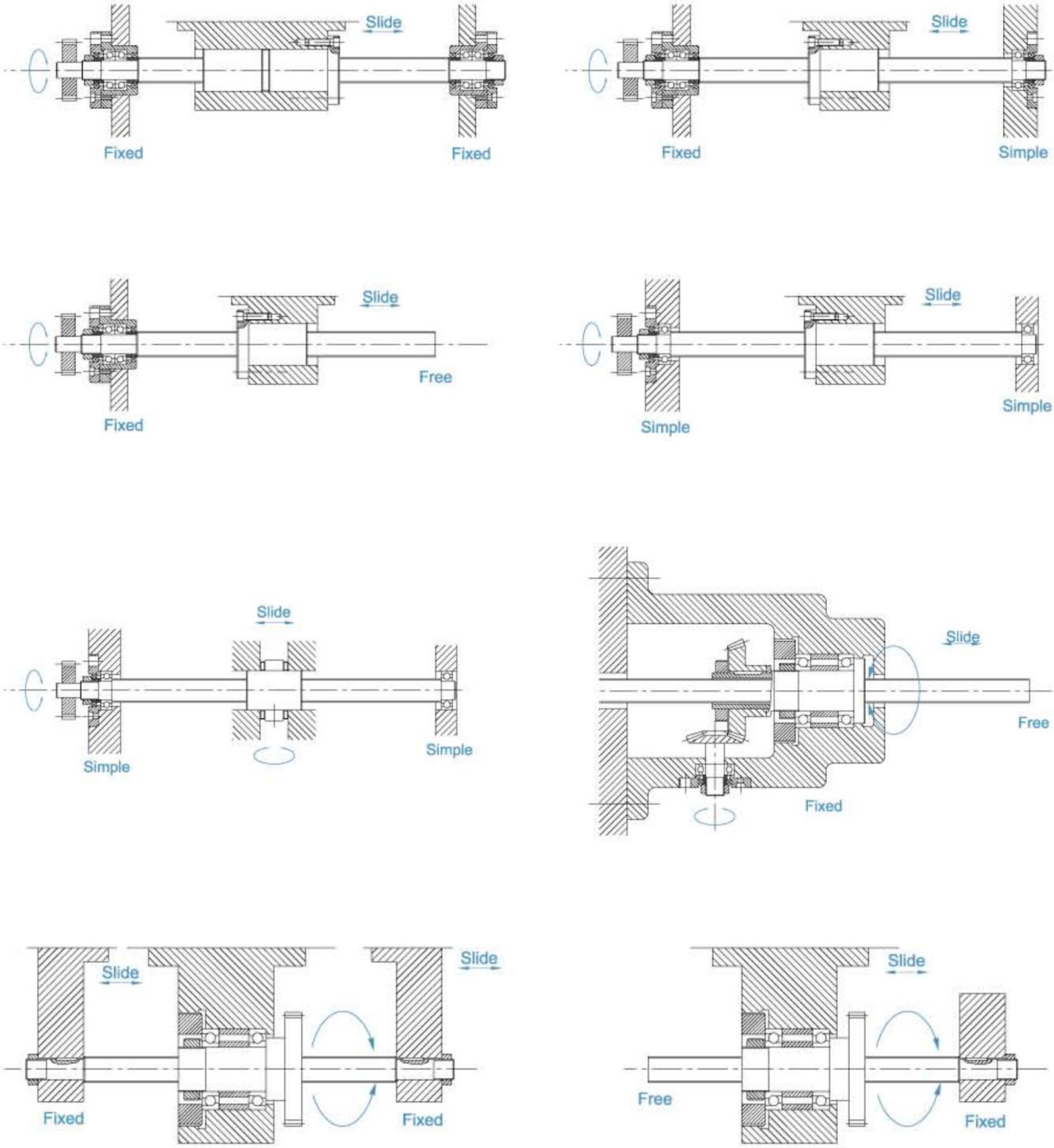
Tp=F . L

Measure conditions :

- Measurement is executed under the condition of not attaching with scraper.
- The rotating speed during measurement maintains at 100rpm.
- According to JSK 2001 (industrial lubrication oil viscosity classification standards), the lubrication oil used should be in compliance with ISO VG68.

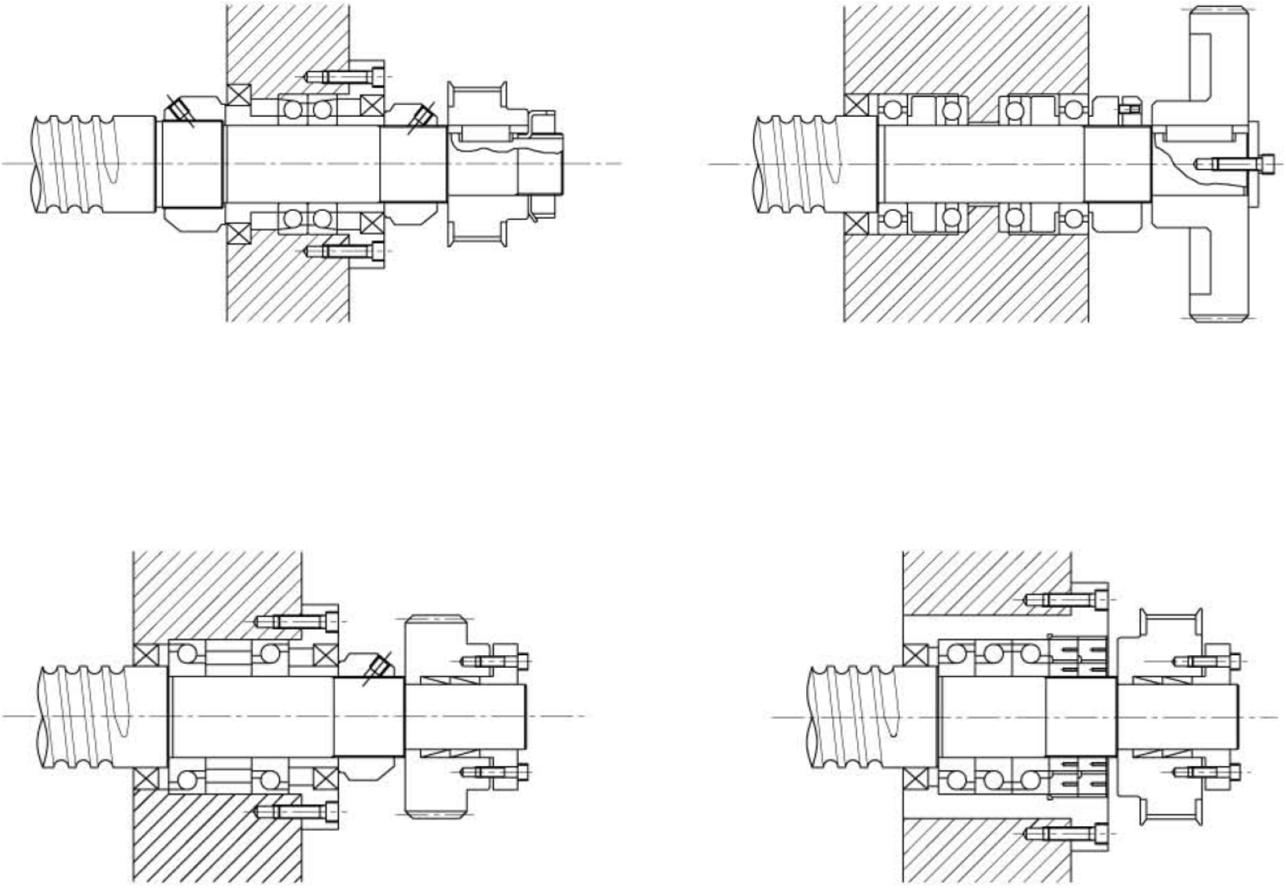
MOUNTING METHODS

Both the critical speed and column bucking load depend upon the method of mounting and the unsupported length of the shaft, the most common mounting methods for ball screws are shown in Fig. 3.1-3.15.

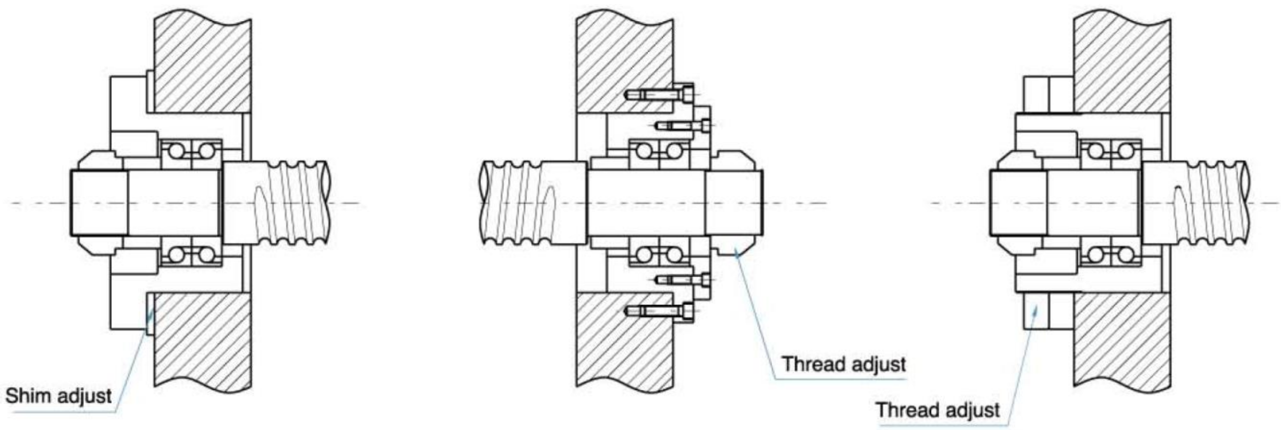


Most common mounting methods for ball screws.

MOUNTING METHODS



Most machines mounting methods for ball screws.



Most common mounting methods for ball screws.

BUCKLING LOAD

The safety of the screw shaft against buckling needs to be checked when the shaft is expected to receive buckling loads. Fig. 3.16 shows a diagram which summarizes the allowable compressive load for buckling for each nominal outside diameter of screw shaft. (Calculate with the equation shown right when the nominal outside diameter of the screw shaft exceeds 125mm.) Select the graduation of allowable axial load according to the method of ball screw support.

Remark :

1 · Allowable tensile / buckling load.

2 · Check the allowable tensile / buckling load (the formula shown below) and allowable load of the ball groove regardless of the mounting method when the mounting distance is short.

$$P=\sigma A=11.8dr^2(kgf)$$

Where, σ : Allowable tensile compressive stress (kgf/mm^2).

A : Sectional area (mm^2) of screw shaft root bottom diameter.

dr : Screw shaft root diameter (mm).

$$P=\alpha\times\frac{N\pi^2E}{L^2}=m\frac{dr^4}{L^2}\times10^3$$

α : Safety Factor (α=0.5).

E : Vertical elastic modules ($E = 2.1\times10^{-4}$ kgf/mm^2).

I : Min. secondary moment of screw shaft sectional area.

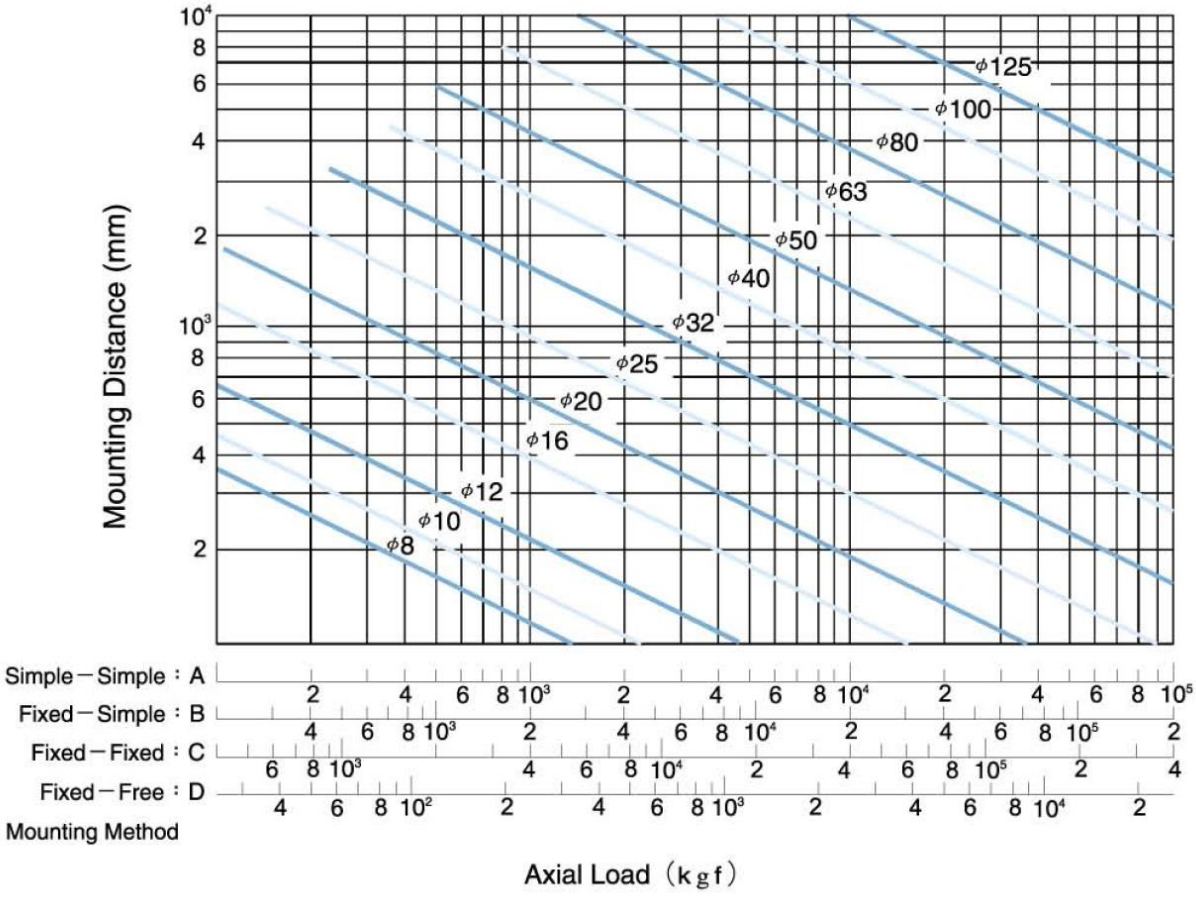
$$I=\frac{\pi}{64}dr^4(mm^4)$$

dr : Screw shaft root diameter (mm).

L : Mounting distance (mm).

m . N : Coefficient determined from mounting method of ball screw.

Simple — Simple	m = 5.1 (N=1)
Fixed — Simple	m = 10.2 (N=2)
Fixed — Fixed	m = 20.3 (N=4)
Fixed — Free	m = 1.3 (N=1/4)



CRITICAL SPEED

It is necessary to check if the ball screw rotation speed is resonant with the natural frequency of the screw shaft. It has determined 80% or less of this critical speed as an allowable rotation speed, Fig. 3,17 shows a diagram which summarizes the allowable rotation speed for shaft nominal diameters up to outside diameter of the screw shaft exceeds125mm.) Select the graduation of allowable rotation speed according to the method of supporting the ball screw.

Where the working rotation speed presents a problem in terms of critical speed, it would be best to provide an intermediate support to increase the natural frequency of the screw shaft. The allowable rotation speed is regulated also by the dm . n value (dm : Diameter of central circle of steel ball ; n : Revolution speed, rpm) which expresses the peripheral speed. Generally;

For precision (accuracy grade C7 to C0)	For general industry (C10)
dm . n≤70000	dm . n≤50000

Product exceeding the above limits can be produced, contact us.

$$n=\alpha \times \frac{60\lambda^2}{2\pi L^2}\sqrt{\frac{EIg}{\gamma A}}=f\frac{dr}{L^2}\times 10^7 \text{(rpm)}$$

α : Safety factor (α=0.8).

E : Vertical elastic modules (E = 2.1×10^{-4} kgf/mm²).

I : Min. secondary moment of screw shaft sectional area.

$$I=\frac{\pi}{64}dr^4 (mm^4)$$

dr : Screw shaft root diameter (mm).

g : Acceleration of gravity (g=9.8×10^3 mm/s²).

γ : Density (γ=7.8×10^{-6} kgf/mm³).

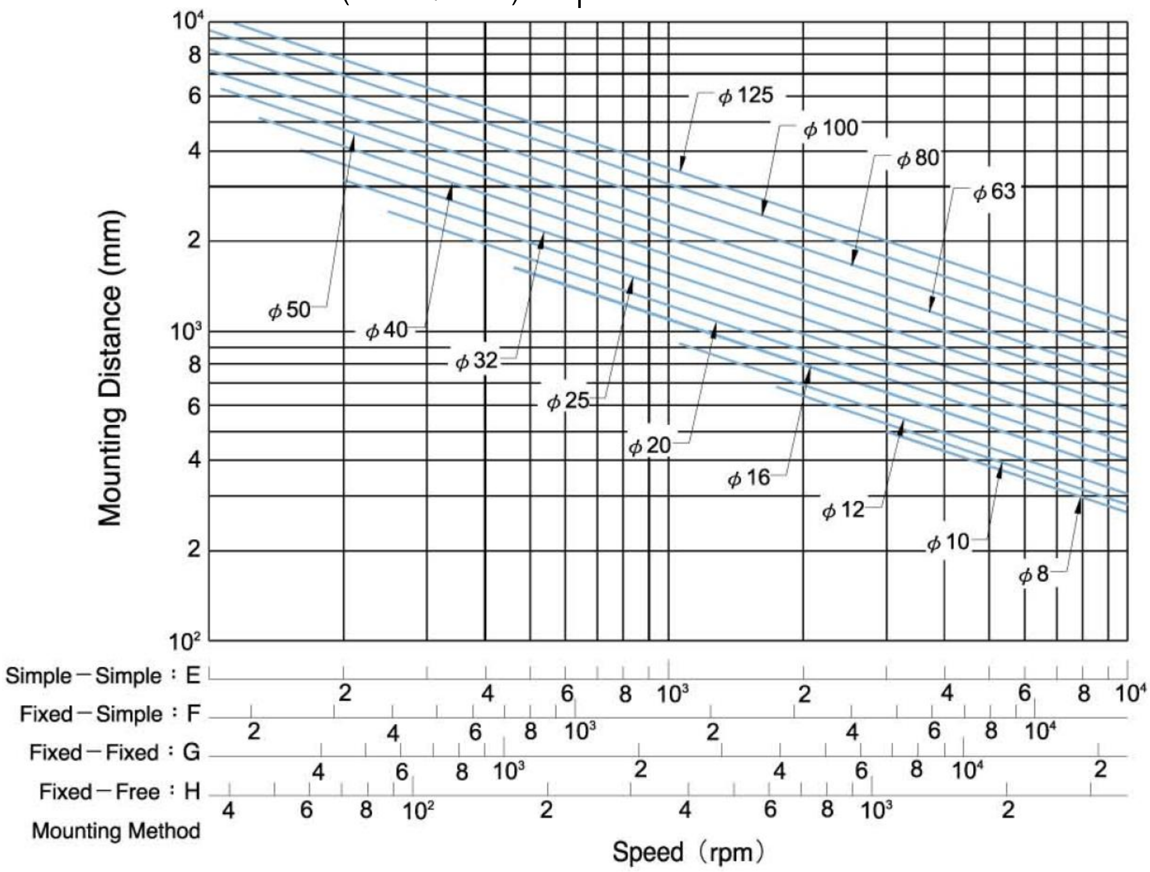
A : Screw shaft sectional area (A=πdr²/4mm²).

L : Mounting distance (mm).

ƒ、γ : Coefficient determined from the ball screw.

Simple ─ Simple	γ= 9.7	(λ=π)
Fixed ─ Simple	γ= 15.1	(π=3.927)
Fixed ─ Fixed	γ= 21.9	(π=4.730)
Fixed ─ Free	γ = 3.4	(π=1.875)

(Particular consideration is necessary for manufacturing when the screw length/shaft dia. Ratio is ε >70. In such an event, contact us)



MIT-Ball Screw

SELECTION OF NUT

1．Series

When making selection of series, please take into consideration of demanded accuracy, intended delivery time, dimensions(the outside diameter of the screw, ratio of lead / the outside diameter of the screw), preload load, etc.

2．Circulation type

Selection of circulation type：Please focus on the economy of space for the nut installation portion.

- External circulation type：
  Economy.
  Suitable for mass production.
  Applicable to those with larger lead / the outside diameter of the screw.
- Internal circulation type：
  With nuts of finely crafted outside diameter (occupying small space).
  Applicable to those with smaller lead / the outside diameter of the screw.
- End-caps circulation type：Suitable for high speed positioning.

3．Number of loop circuits.

Performance and life of service should be considered when selecting number of loop circuits.

4．Shape of flanges (FLANGE).

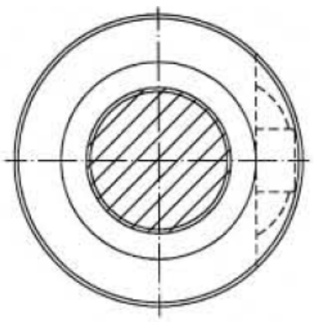
Please make selection based on the available space for the installation of nuts.

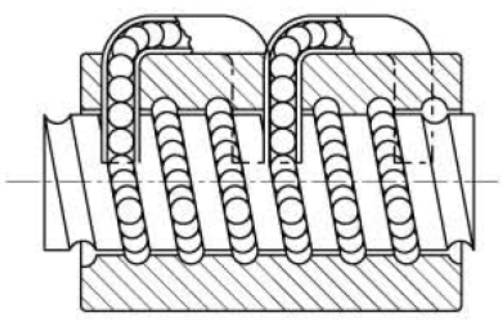
5．Oil hole

Oil holes are provided for the precision ballscrews, please use them during machine assembling and regular furnishing.

EXTERNAL BALL CIRCULATION NUTS

Features：1 . Offers smoother ball running.
2 . Offers better solution and quality for long lead or large diameter ballscrews.



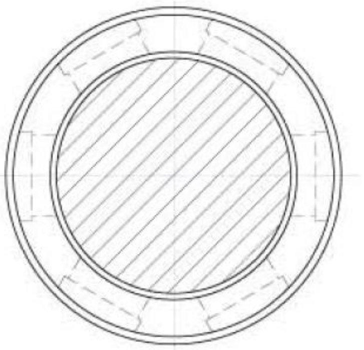


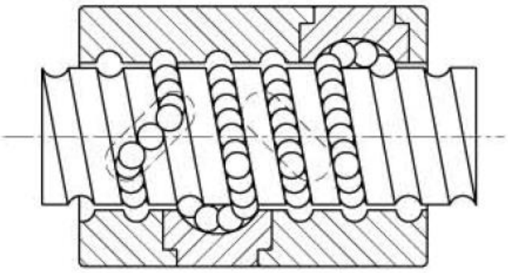
MIT-Ball Screw

INTERNAL BALL CIRCULATION NUTS

Features : The advantage of internal ball circulation nut is that the outer diameter is smaller than that of external ball circulation nut. Hence it is suitable for the machine with limit space for Ballscrew installation.

It is strictly required that there is at least one end of screw shaft with complete threads. Also the rest area next to this complete thread must be with smaller diameter than the nominal diameter of the screw shaft. Above are required for easy assembling the ballnut onto the screw shaft.





HIGH LEAD BALLSCREWS

Features : It is important for a High-lead Ballscrew to be with characteristics of high rigidity, low noise and thermal control. Our designs and treatments are taken for following :

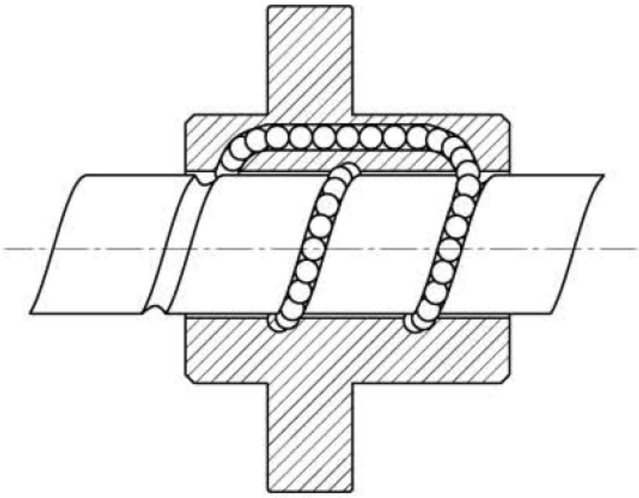
1 · High DN value : The DN value can be 130,000 in normal case. For some special cases, for example in a fixed ends case, the DN value can be as high as 140,000. Please contact our engineers for this special application.

2 · High speed : Our High-speed Ballscrews provide 100 m/rain and even higher traverse speed for machine tools for high performance cutting.

3 · High rigidity : Both the screw and ballnut are surface hardened to a specific hardness and case depth to maintain high rigidity and durability. Multiple thread starts are available to make more steel balls loaded in the ballnut for higher rigidity and durability.

4 · Low noise

- Special design of ball circulation tubes (patent pending) offer smooth ball circulation inside the ballnut. It also makes safe ball fast running into the tubes without damaging the tubes.
- Accurate ball circle diameter (BCD) through whole threads for consistent drag torque and low noise.



AXIAL RIGIDITY

Excessively weak rigidity of the screw's peripheral structure is one of the primary causes that result in lost motion. Therefore in order to achieve excellent positioning accuracy for the precision machines such as NC working machines, etc., axial rigidity balance as well as torsional rigidity for the parts at various portions of the transmission screw have to be taken into consideration at time of designing.

1 · Static rigidity K : The axial elastic deformation and rigidity of the transmission screw system can be determined from the formula below.

$$K=\frac{P}{e}\text{(kgf/mm)}$$

P : Axial load (kgf) borne by the transmission screw system (kgf).

e : Axial flexural displacement (mm).

$$\frac{1}{K}=\frac{1}{K_S}+\frac{1}{K_N}+\frac{1}{K_B}+\frac{1}{K_H}\text{(mm/kgf)}$$

K_S : Axial rigidity of screw shaft..........2

K_N : Axial rigidity of nut....................3

K_B : Axial rigidity of bracing shaft.........4

K_H : Axial rigidity of installation portions of nuts and bearings (4) 5

2 · Axial rigidity K_S and displacement δ_S of screw shaft.

$$K_S=\frac{P}{\delta_S}\text{(kgf/mm)}$$

P : Axial load (kgf).

- For places of Fixed - Fixed installation.

$$\delta_{SF}=\frac{PL}{4AE}\text{(mm)}$$

- For places other than Fixed - Fixed installation.

$$\delta_{SS}=\frac{PL_0}{AE}\text{(mm)}$$

$$\delta_{SS}=4\delta_{SF}$$

δ_{SF} : Directional displacement at places of fixed-fixed installation.

δ_{SS} : Directional displacement at places other than fixed-fixed installation.

A : Cross-sectional area of the screw shaft tooth root diameter (mm^2).

E : Longitudinal elastic modulus (2.1×10^4kgf/mm).

L : Distance between installations (mm).

L_0 : Distance between load applying points (mm).

3·Axial rigidity K_N and displacement δ_N of nut.

$$K_N=\frac{P}{\delta_s}\text{(kgf/mm)}$$

- In case of single nut.

$$\delta_{NS}=\frac{K}{\sin\beta}\left(\frac{Q^2}{d}\right)^{\frac{1}{3}}\times\frac{1}{\zeta}(mm)$$

$$Q=\frac{P}{n\cdot\sin\beta}(kgf)$$

$$n=\frac{Do\pi m}{d}(\text{each})$$

Q : Load of one steel ball (kgf).

n : Number of steel ball.

k : Constant determined based on material, shape, dimensions. $k≒5.7\times10^{-4}$

β : Angle of contact (45°).

P : Axial load (kgf).

d : Steel ball diameter (mm).

ζ : Accuracy, internal structure coefficient.

m : Effective number of bails.

Do : Steel ball center diameter (mm).

$$Do=\frac{\ell}{\tan\alpha\cdot\pi}$$

ℓ : Lead (mm).

α : Lead angle.

AXIAL RIGIDITY

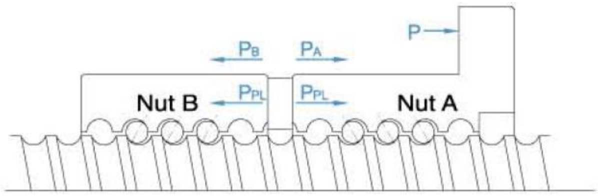
3．Axial rigidity K_N and displacement δ_N of nut.

● In case of double nuts.

When an axial load P of approximately 3 times of the preload load P_{PL} is exerted, for the purpose of eliminating the preload P_{PL} on nut B, please set the preload load P_{PL} at no more than 1/3 of the maximal axial load (0.25Ca should be taken as the standard maximal preload load).

With respect to the displacement value, it should be of 1/2 of the single nut displacement when axial load is 3 times of the preload.

$$K_N=\frac{P}{\delta_{NW}}=\frac{3P_{PL}}{\delta_{NS}/2}=\frac{6P_{PL}}{\delta_{NS}}(kgf/mm)$$



δ_{NS} : Displacement of single nut (mm).

δ_{NW} : Displacement of double nuts (mm).

(Explanation of the rigidity of double nuts)

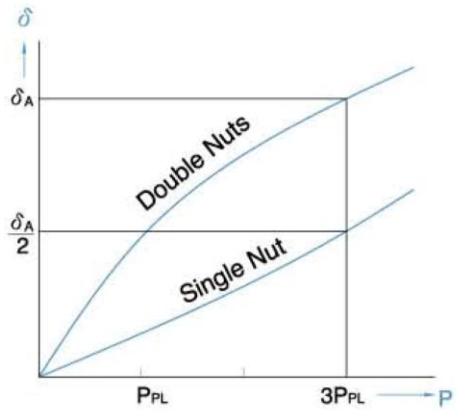
As shown in Diagram 5.1 and 5.2, when a preload P_{PL} is applied on the 2 nuts A, B, both nuts A & B would produce flexural deformations that will reach point X. If an external force P is exerted from here, nut A would move from point X to point XI, while nut B would move from X to X2.

Then, based on the computing formula for displacement δ_{NS} the single nut, we can obtain :

$$\delta o=aP_{PL}^{2/3}$$

While displacements of nuts A & B are $\delta_A= aP_{PL}^{2/3}$

Since displacements of nuts A & B generated due to exertion of external force P are equal, therefore $\delta_A-\delta o=\delta o-\delta_B$



Or if P is the only external force P that exerts on nuts A,B, if P_A increases $P_A-P_B=P$, $\delta_B=0$,

For preventing the external force applied on nut B being absorbed by nut A thus decreasing, so

When $\delta_B=0$,

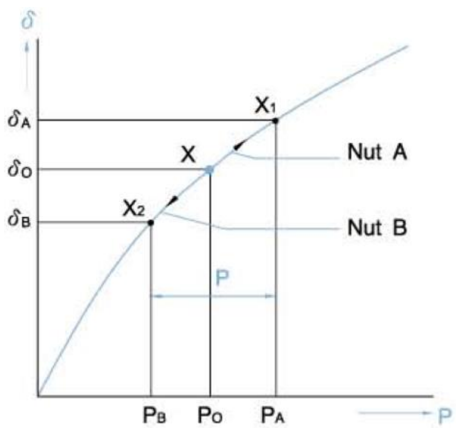
$$aP_A^{2/3}-aP_{PL}^{2/3}=aP_{PL}^{2/3}$$

$$P_A^{2/3}=2P_{PL}^{2/3}$$

$$P_A=\sqrt{8}P_{PL}\fallingdotseq 3P_{PL}$$

Or based on $\delta_A-\delta o=\delta o$

$$\delta o=\frac{\delta_A}{2}$$



thus it can also be judged from Fig. 5.3 that, when axial load is 3 times of preload load, for a single nut with 1/2 displacement, the rigidity is 2 times as high.

AXIAL RIGIDITY

4．Axial rigidity K_B and displacement δ_B of bracing shaft.

$$K_B=\frac{P}{\delta_B}(kgf/mm)$$

The rigidity of the assembled diagonal thrust ball bearing that is used as the bracing bearing for the ball screw and is widely utilized in the field of precision machines can be found from the following formula.

$$\delta_B=\frac{2}{\sin\beta}\left(\frac{Q^2}{d}\right)^{\frac{1}{3}}$$

$$Q=\frac{P}{n\cdot\sin\beta}(kgf)$$

Q：Load of one steel ball (kgf).

β：Angle of contact (45°).

d：Steel ball diameter (mm).

P：Axial load (kgf).

n：Number of steel balls.

5．Axial rigidity K_H and displacement δ_H of installation portions of nuts and bearings. In early stage of machine development, special attentions should be paid to the requirement of high rigidity for the installation portion.

$$K_H=\frac{P}{\delta_H}(kgf/mm)$$

MIT-Ball Screw

HORIZONTAL RECIPROCATING MOVING MECHANISM

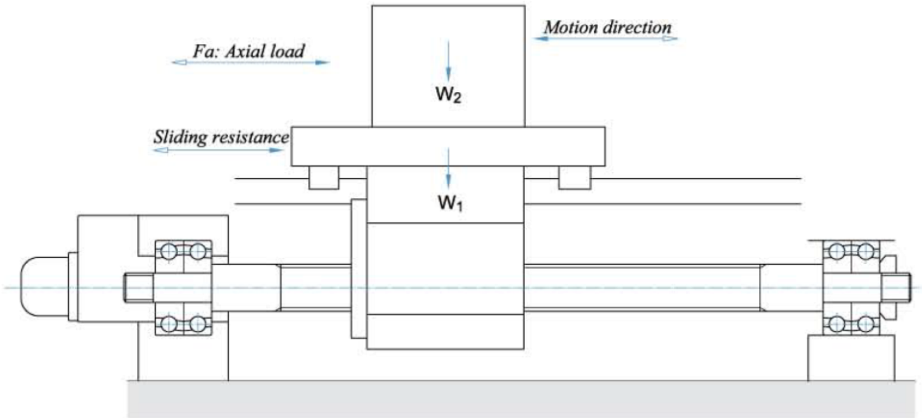
For reciprocal operation to move work horizontally (back and forth) in an conveyance system, the axial load (Fa) can be gotten using the following equations :

Acceleration (leftward) $Fa_1=\mu\times mg+f+ma$
Constant speed (leftward) $Fa_2=\mu\times mg+f$
Deceleration (leftward) $Fa_3=\mu\times mg+f-ma$
Acceleration (rightward) $Fa_4=-\mu\times mg-f-ma$
Constant speed (rightward) $Fa_5=-\mu\times mg-f$
Deceleration (rightward) $Fa_6=-\mu\times mg-f+ma$

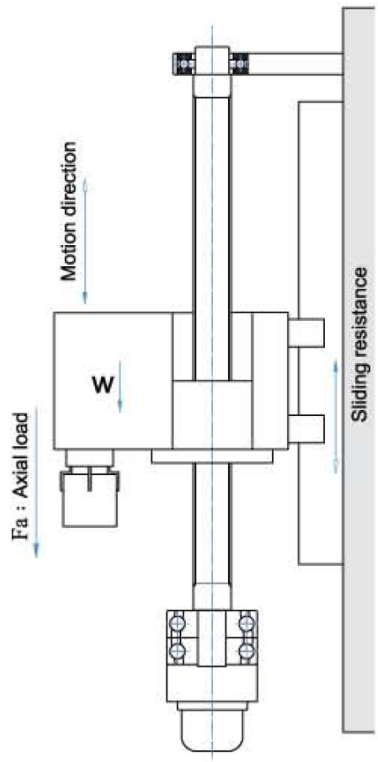
Here, α : Acceleration.

$\alpha=\frac{V\max}{t}$ (Vmax : Rapid feed speed ; t : time)

m : Total weight (table weight + work piece weight).
μ : Sliding surface friction coefficient.
ƒ : Non-load resistance.



VERTICAL RECIPROCATING MOVING MECHANISM



MIT-Ball Screw

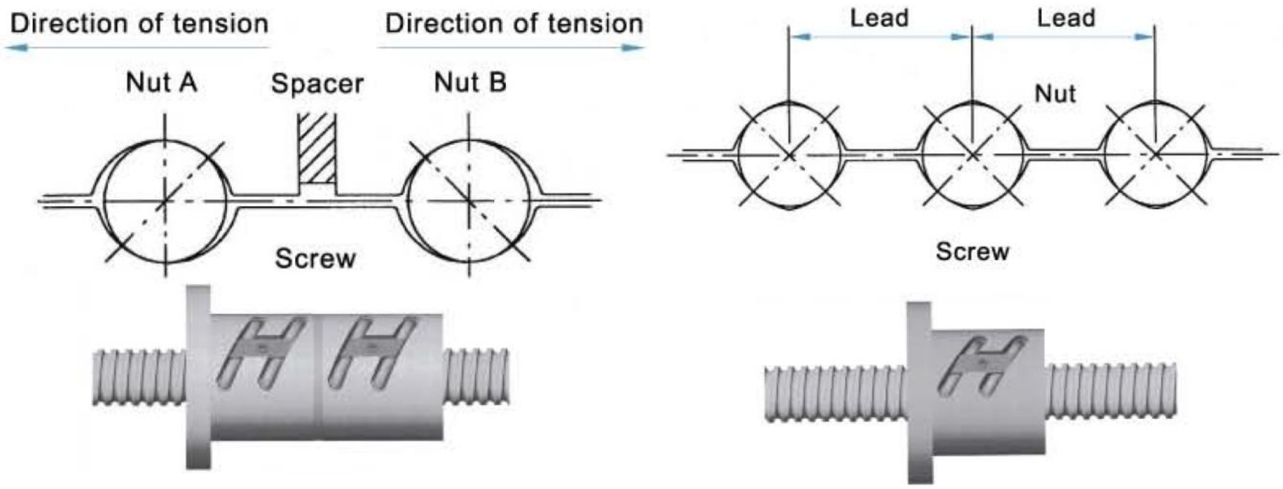
BALL SCREW'S PRELOAD AND EFFECT

In order to get high positioning accuracy, there are two ways to reach it. One is commonly known as to clear axial play to zero. The other one is to increase Ballscrew rigidity to reduce elastic deformation while taking axial load. Both two ways are done by preloading.

1．Methods of preloading.

● Double-nut method : A spacer inserted between two nuts exerts a preload. There are two ways for it. One is illustrated in Fig.5.1 that is to use a spacer with thickness complies with required magnitude of preload. The spacer makes the gap between Nut A and B to be bigger, hence to produce a tension force on Nut A and B. It is.

● Single-nut method : As that illustrated on Fig. 5.2 using oversize balls onto the space between Ballnut and screw to get required preload. The balls shall make four-point contact with grooves of Ballnut and screw.



2．Relation between preload force and elastic deformation.

Fig 5.3 nuts A and B are assembled with preloading spacer. The preload forces on nut A and B are Fa_0, but with reversed direction. The elastic in fig.5.4 deformation on both nuts are δa_0.

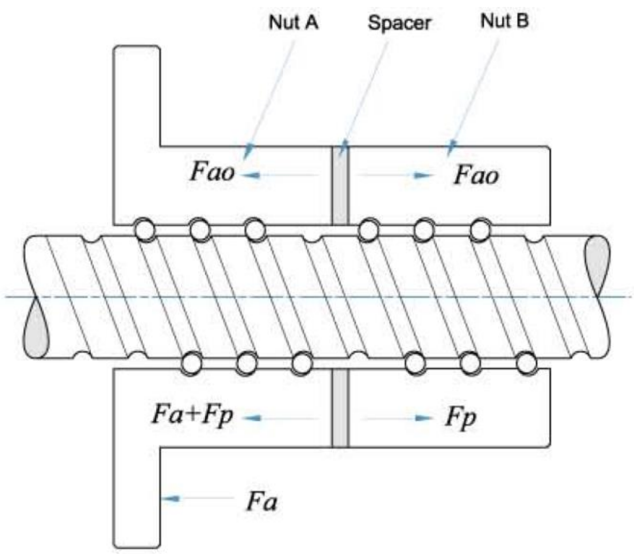
$\delta_A = \delta a_0 + \delta a_1$

$\delta_B = \delta a_0 - \delta a_1$

The load in nut A and nut B are

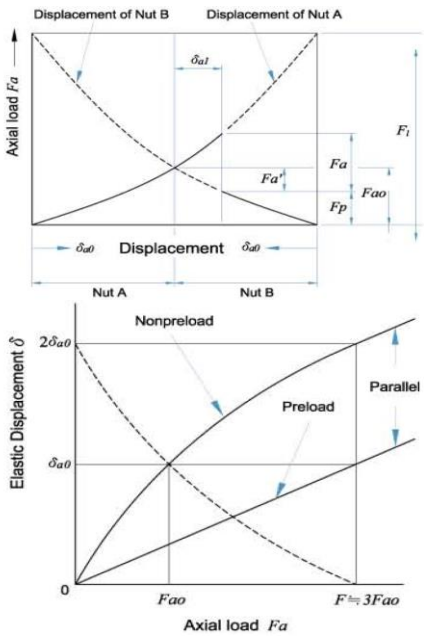
$F_A = Fa_0 + Fa - Fa = Fa + F_P$

$F_B = Fa_0 - Fa = F_P$



MIT-Ball Screw

BALL SCREW'S PRELOAD AND EFFECT



1 · It means Fa is offset with an amount Fa' because of the deformation of nut B decreases. As a result, the elastic deformation of nut A is reduced. This effect shall be continued until the deformation of nut B becomes zero, that is, until the elastic deformation δa_1 caused by the external axial force equals δa_0, and the preload force applied to nut B is completely released. The formula related the external axial force and elastic deformation is shown as below :

$\delta a_0 = K \times Fa_0^{2/3}$ and $2\delta a_0 = K \times F_1^{2/3}$

$(F_1/Fa_0)^{2/3} = (2\delta a_0/\delta a_0) = 2$

$F_1 = 2.8Fa_0 \fallingdotseq 3Fa_0$

Therefore, the preload amount of a ballscrew is recommended to set as 1/3 of its axial load. Too much preload for a Ballscrew shall cause temperature raise and badly affect its life. However, taking the life and efficiency into consideration, the maximum preload amount of a ballscrew is commonly set to be 10% of its rated basic dynamic load. Shown on Fig 5.5 with the axial load to be three times as the preload, the elastic displacement for the non-preloaded ball nut is two times as that of the preloaded nut.

POSITIONING ACCURACY

1 · Causes of error in positioning accuracy : Lead error and rigidity of feed system are common causes of feed accuracy error. Other causes like thermal deformation and feed system assembly are also playing important roles in feed accuracy.

2 · Considering thermal displacement : If the screw-shaft temperature increases during operation, the heat elongates the screw shaft, thereby reducing the positioning accuracy. Expansion and shrinkage of a screw shaft due to heat can be calculated using equation (5.6).

$$\Delta L_\theta = \rho \, . \, \theta \, . \, L$$

ΔL_θ : Thermal displacement.	θ : Screw-shaft temperature change.
ρ : Thermal-expansion coefficient.	L : Ballscrew length.

That is to say, an increase in the screw shaft temperature of 1 expands the shaft by 12μm per meter. The higher the ballscrew speed, the greater the heat generation. Thus, temperature increases reduce positioning accuracy. Where high accuracy is required, anti-temperature elevation measures must be provided as follows:

- To control temperature :
  - a . Selecting appropriate preload.
  - b . Selecting appropriate preload.
  - c . Selecting larger lead for the ballscrew and decrease the rotation speed.
- Compulsory cooling :
  - a . Ballscrew with hollow cooling.
  - b . Lubrication liquid or cooling air can be used to cool down external surface of ballscrew.
- To keep off effect upon temperature raise :
  - a . Set a negative cumulative lead target value for the ballscrew.
  - b . Warm up the machine to stable machine's operating temperature.
  - c . Pretension by using on ballscrew while installing onto the machine.

LIFE OF THE BALLSCREW

Even though the ballscrew has been used with correct manner, it shall naturally be worn out and can no longer be used for a specified period. Its life is defined by the period from starting use to ending use caused by nature fail.

1 · Fatigue life : Time period for surface flaking off happened either on balls or on thread grooves.

2 · Accuracy life : Time period for serious loosing of accuracy caused by wearing happened on thread groove surface, hence to make ballscrew can no longer be used.

FATIGUE LIFE

The basic dynamic rate load (Ca) of the ballscrew is used to calculate its fatigue life.

1 · Basic dynamic rate load Ca.

The basic dynamic rate load (Ca) is the revolution of 10^6 that 90% of identical ballscrew units in a group, when operated independently of one another under the same conditions, can achieve without developing flaking.

2 · Fatigue life.

- Calculating life : There are three ways to show fatigue life.
  - a . Total operating time.
  - b . Total operating time.
  - c . Total travel.

$$L=\left(\frac{Ca}{Fa\times f_W}\right)^3\times 10^6$$

$$Lt=\frac{L}{60\times n}$$

$$Ls=\frac{L\times l}{10^6}$$

L : Fatigue life (total number of revolutions)
Lt : Fatigue life (total operating time)
Ls : Fatigue life (total travel)
Ca : Basic dynamic rate load.

Fa : Axial load.
n : Rotation speed.
l : Lead.
fw : Load factor (refer to Table 6.1).

Load factor fw

Vibration and impact	Velocity (V)	fw
Light	V < 15(m/min)	1.0~1.2
Medium	15 < V < 60(m/min)	1.2~1.5
Heavy	V > 60	1.5~3.0

Too long or too short fatigue life are not suitable for ballscrew selection. Using longer life make the ballscrew's dimensions too large. It's an uneconomical result. Following table is a reference of the ballscrew's fatigue life.

a · Machine center 20,000 hrs.
b · Production machine 10,000 hrs.
c · Automatic controller 15,000 hrs.
d · Surveying instruments 15,000 hrs.

FATIGUE LIFE

● Mean load：When axial load changed constantly.　It is required to calculate the mean axial load (Fm) and the mean rotational speed (Nm) for fatigue life.　Setting axial load (Fa) as Y-axis ; rotational number (n.t) as X-axis.　Getting three kind curves or lines.

a · Gradational variation curve (Fig.6.1), mean load can be calculated by using equation：

$$Fm=\left(\frac{F_1^{3}\cdot n_1\cdot t_1+F_2^{3}\cdot n_2\cdot t_2+\ldots+F_n^{3}\cdot n_n\cdot t_n}{n_1\cdot t_1+n_2\cdot t_2+\ldots n_n\cdot t_n}\right)^{\frac{1}{3}}$$

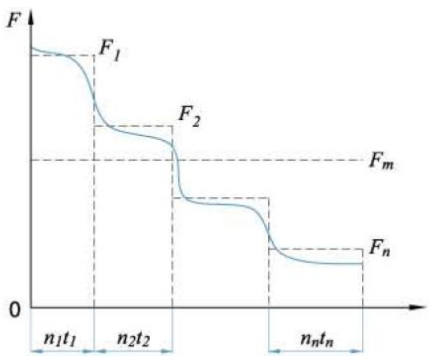
Mean rotational speed can be calculated by using equation：

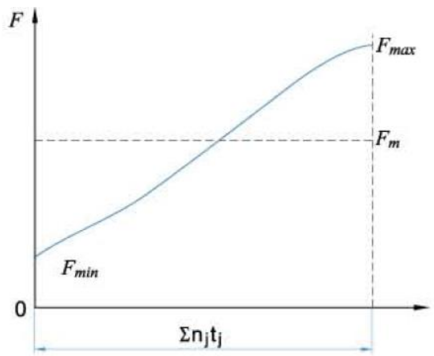
$$Nm=\frac{n_1\cdot t_1+n_2\cdot t_2+\ldots+n_n\cdot t_n}{t_1+t_2+\ldots+t_n}$$

Axial load (kgf)	Rotation speed (rpm)	Time ratio (Sec)
F_1	n_1	t_1
F_2	n_2	t_2
.	.	.
.	.	.
.	.	.
F_n	n_n	t_n

b · Similar straight line (Fig.6.2), when mean load variation curve like similar straight line.　Mean rotational speed can be calculated using equation (6.6)

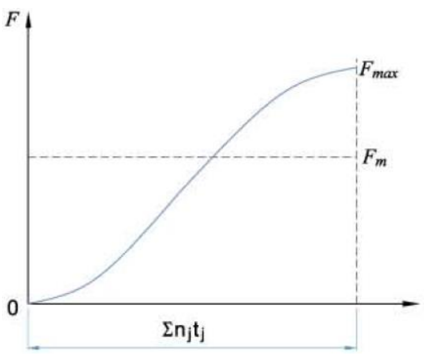
Fm=1/3(Fmin+Fmax)

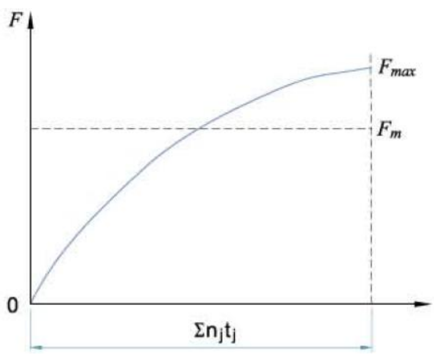




c · Sine curve there are two cases (Fig.6.3)：

- When mean load variation curve shown as the diagram below.　Mean rotational speed can be calculated by using equation (6.3.1)：Fm=0.65Fmax.
- When mean load variation curve shown as the diagram below.　Mean rotational speed can be calculated by using equation (6.3.2)：Fm=0.75Fmax.





MIT-Ball Screw

MATERIAL AND HARDNESS

Material and hardness of our ballscrews

Denomination	Material	Heat treatng	Hardness (HRC)
Precision ground	50CrMo4 QT	Induction hardening	58~62
Rolled	S55C	Induction hardening	58~62
Nut	SCM415H	Carburized hardening	58~62

LUBRICATION

Lithium base lubricants are used for ballscrew lubrication. Their viscosity are 30~40 cst (40℃) and ISO grades of 32~100. Selecting：

1．Low temperature application：Using the lower viscosity lubricant.

2 · High temperature, high load and low speed application : Using the higher viscosity lubricant.

Checking and supply interval of lubricant

Manner	Checking interval	Checking item	Supply or replacing interval
Automatic interval oil supply	Every week	Oil volume and purity	To supply on each check, its volume depends on oil tank capacity.
Lubricating grease	Within 2~3months after starting operation of machine	Foreign matter	Normally supply once a year as per the result of check.
Oil bath	Everyday before operation of machine	Oil surface	To supply as per wasting condition.

DUSTPROOF

Same as the rolling bearings, if there is the particles such as chips or water get into the ballscrew, the wearing problem shall be deteriorated. In some serious cases, ballscrew shall then be damaged. In order to prevent these problems from happening, there are wipers assembled at both ends of ball nut to scrape chips and dust. There is also the "O-Ring" at the wipers to seal the lubrication oil from leaking from ball nut.