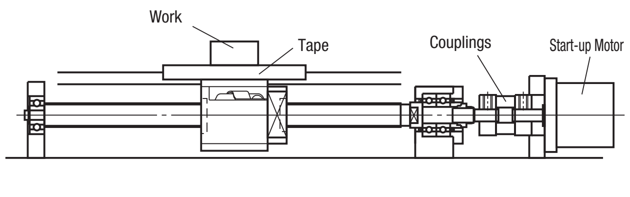
Selection of Ball Screws 1

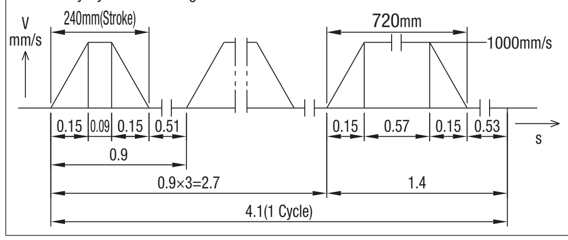
⦿ Technical calculation software is available at http://efa.misumi.jp/ for easy calculation of complex formulas.(Free of charge)

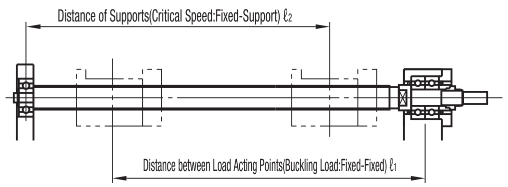
Example of Selection of Ball Screws (For X-Axis of Orthogonal Robot)

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=30000hrs
•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.

$$L \geq \frac{Vmax \times 60}{Nmax} = 20(mm)$$

2.Calculating Basic Dynamic Load Rating

Examines the required basic dynamic load rating and the allowable revolution frequency(D_mN Value)

(A) In Acceleration

$$\text{Acceleration}(\alpha) = \frac{Vmax}{t} \times 10^{-3} = 6.7(m/s^2)$$

Axial Load(P_a)=Wα+μWg≈343(N)

(g:Gravitational Acceleration9.8m/s^2)

(B) At Constant Speed

Axial Load(Pb)=μWg≈10(N)

(C) In Deceleration

Axial Load(Pc)=Wα-μWg≈324(N)

Operating Hour(s)Per 1 Cycle for Each Operating

Operating Pattern	(A)	(B)	(C)	Total Operating Time
Operating Time	0.60	0.84	0.60	2.04

Load Conditions for a Lead of 20

Operating Pattern	(A)	(B)	(C)
Axial Load	343N	10N	324N
Revolutions Frequency	1500min^{-1}	3000min^{-1}	1500min^{-1}
Operating Time Ratio	29.4%	41.2%	29.4%

Calculating the mean axial load(P_m), and the mean turns(N_m) by load conditions(P.2800(1),(2))

P_m=250(N) N_m=2118(min^{-1})

Calculation of the required basic dynamic load rating(C)

The actual life span in running(L_{ho}), which excludes downtime, is as follows:

$$L_{ho} = 30000\left(\frac{2.04}{4.1}\right) = 14927(\text{Time})$$

Insert the work factor f_w=1.2 into the formula of deformation given on P.2800 to select a suitable ball screw from P.554

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

The suitable ball screw should be BSS1520.

Next, look at the DmN values(P.2800(4)) as the allowable revolution frequency.

For DmN≤70000, DmN=15.8×3000=47400. This is within the allowable range.

Therefore, proceed to the following investigation using this size of ball screw.

3.Allowable Buckling Load Critical Speed

Investigation of full length of thread shaft(L), critical speed(N_c), and buckling load(P_k)

L=Maximum Strokes+Nut length+Margin+Dimensions of Both Ends

=720+62+60+78=920(mm)

Check allowable axial load in terms of buckling load. Assuming the distance between load acting points

ℓ_1=820, the following is obtained from formulas (6) and (7) on P.2800.

P_k=7220(N)

This satisfies the conditions of use.

To calculate critical speed, assuming the distance of supports ℓ_2=790 the following is obtained from the formula (5)(Fixed-Support)on P.2800.

N_c=3024(min^{-1})

This satisfies the conditions of use.

4.Design Precision

Investigation of Precision Class and Axial Play

According to the tolerance values for lead accuracy(P.535), the class of positioning precision ±0.1/720mm is C5(Accumulative typical lead errors=0.035 Fluctuation=0.025)

Axial play is max. 0.005 less than the repeated positioning precision of ±0.01.

5.Results of the Selection of Ball Screws and Support Units

From the previous calculations, the best selection of the ball screw is Part No.

BSS1520-950

The best support unit is Part No. BSW 12.

Reference Formulas

(1)Mean Axial Load(P_m) (2)Mean Revolution Frequency(N_m)

(t_1+t_2+t_3=100%)

Axial Load	Revolutions Frequency	Operating Time Ratio
P_1N(Max.)	N_1 min^{-1}	t_1%
P_2N(Normal)	N_2 min^{-1}	t_2%
P_3N(Min.)	N_3 min^{-1}	t_3%

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

$$N_m = \frac{N_1t_1+N_2t_2+N_3t_3}{t_1+t_2+t_3}(min^{-1}) \quad \text{(2)}$$

If little difference is obtained between the maximum(P_1)and minimum(P_3)axial loads, or if the load change is almost linear, an approximated value can be obtained with the following formula.

$$P_m \approx \frac{2P_1+P_3}{3}(N)$$

(3) Life Span Hours

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

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

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

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

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:10,000hr Measuring Instruments:15,000hrs

(4) Allowable Revolution Frequency(D_mN)

D_mN≤70000(Precision Ball Screws) (4)

D_mN≤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

(5) Critical Speed(N_c)

$$N_c = fa\,\frac{60}{2\pi}\frac{\lambda^2}{\ell^2}\sqrt{\frac{EI}{\gamma A}} \times 10^3 (min^{-1}) \quad \text{(5)}$$

Where:

ℓ : Distance of Supports(mm)

fa : Safety Factor(0.8)

E : Young's Modulus(2.06×10^{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(7.8×10^{-6}kg/mm^3)

A : Root Thread Section Area(mm^2)

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

λ : Coefficient Determined by Method of Screw Support

Support-Support	λ=π
Fixed-Support	λ=3.927
Fixed-Fixed	λ=4.730
Fixed-Free	λ=1.875

(6) Buckling Load(P_k)Derived with Euler's Equations of Motion

$$P_k = \frac{n\pi^2EI}{\ell^2}(N) \quad \text{(6)}$$

Where:

P_k: Load at Buckling Moment(N)

ℓ : Distance between Points of Buckling Load(mm)

E : Young's Modulus(2.06×10^{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 : Coefficient Determined by Method of Screw Support

Support-Support	n=1
Fixed-Support	n=2
Fixed-Fixed	n=4
Fixed-Free	n=0.25

(7) Allowable Axial Load(P)for Buckling Load

$$P = \alpha P_k(N) \quad \text{(7)}$$

Where:

P_k: :Buckling Load(N)

α : Safety Factor(α=0.5)

For higher safety, a higher safety factor should be required.

Driving Torque

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

Friction and Efficiency

Ball screw efficiency can be expressed in the following formulas; wherein η is the coefficient of friction and μ 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)

$$\eta = \frac{1-\mu\ \tan\beta}{1+\mu/\tan\beta} \quad \text{(1)}$$

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

$$\eta' = \frac{1-\mu/\tan\beta}{1+\mu\ \tan\beta} \quad \text{(2)}$$

Load Torque

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

•Forward Action

Torque required when converting rotational force into axial force

$$T = \frac{PL}{2\pi\eta}(N\cdot cm) \quad \text{(3)}$$

Where:

T : Load Torque(N·cm)

P : External Axial Load(N)

L : Ball Screw Lead(cm)

η : Ball Screw Efficiency(0.9)

•Reverse Action

External axial load when converting axial force into rotational

$$P = \frac{2\pi T}{\eta' L}(N) \quad \text{(4)}$$

Where:

P : External Axial Load(N)

T : Load Torque(N·cm)

L : Ball Screw Lead(cm)

η' : Ball Screw Efficiency(0.9)

•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.