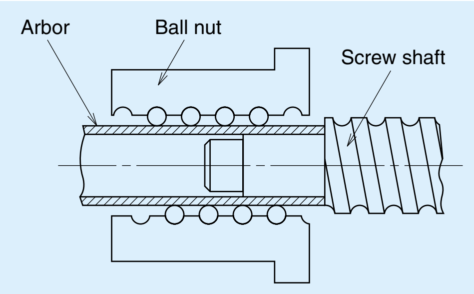

Fig. Ⅱ-14•4 Arbor to install and remove nut

(4) Centering of the ball nut when installing

When installing the nut as shown in Fig. Ⅱ-14•5, provide a space between the housing and the nut body diameter, allowing the centering to be performed.

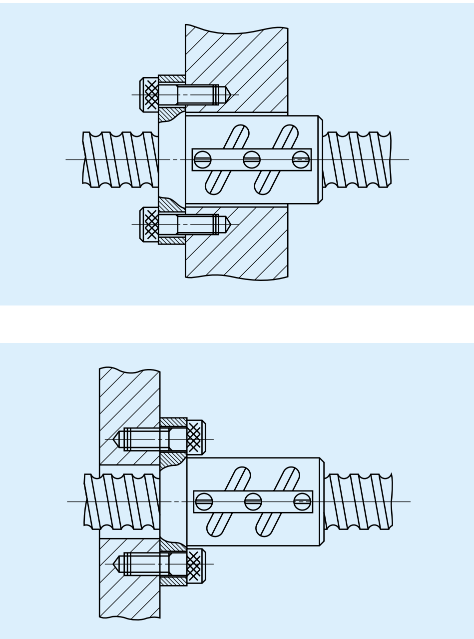

Fig. Ⅱ-14•5 Fixing a ball nut by flange

(5) Preventing the thread screw of nut from loosening

When installing and securing the nut to the housing at the thread screw section, as in the case for RNCT Series rolled ball screw, apply an agent which prevents the nut from loosening.

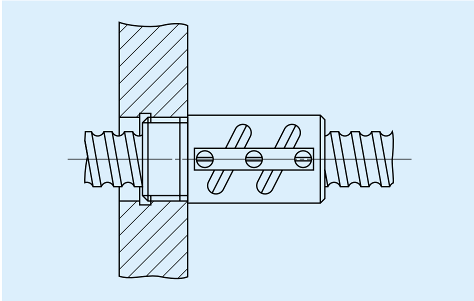

Fig. Ⅱ-14•6 Fixing a ball nut with thread screw

(6) Installation of brush-seal to the nut

If the brush-seal is installed at the thread screw side of the nut which comes with a thread screw, the brush-seal should be designed to be secured as shown in Fig. Ⅱ-14•7.

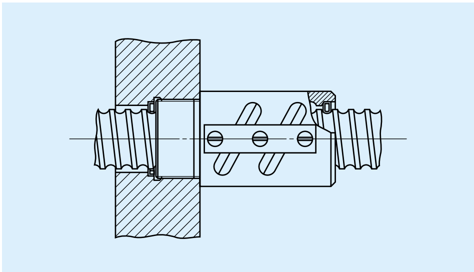

Fig. Ⅱ-14•7 Installation of brush-seal to a ball nut with thread screw

B-Ⅱ-14.3 Effective Stroke of Ball Screw

Rigidity of a ball screw which is hardened by the induction hardening may be slightly low at both ends of the screw section. Consider this low hardness prior to determining the length of effective stroke. Please consult NSK for details.

B-Ⅱ-14.4 Matching after Delivery

Please inform NSK on the position and size if it is necessary to machine the screw shaft end, or if a knock pin at the nut installation section is needed after delivery.

NSK takes a measure and protects designated spots from heat treatment prior to delivery to make subsequent machining easy.

B-Ⅱ-15 Ball Screw Selection Exercise

[Drill 1] High-speed transporting system

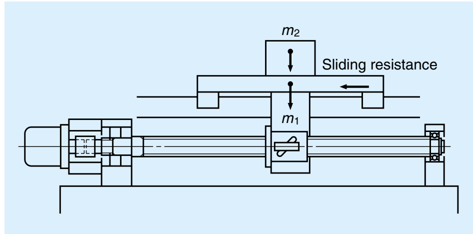

Fig. Ⅱ-15•1

* Design conditions

① Table design specifications

Table mass :	m_1=40kg
Mass of the transporting item :	m_2=20kg
Maximum stroke :	S_{max}=700mm
Rapid traverse speed :	Vmax=1000mm/sec(60m/min)
Positioning accuracy :	±0.05/700mm(0.005 mm/pulse)
Repeatability :	±0.005mm
Required life :	Lt=25000 h(5 years)
Guide way (rolling) :	μ=0.005(friction coefficient)
Drive motor :	AC servo motor (Nmax=3000min^{-1})

② Operating conditions

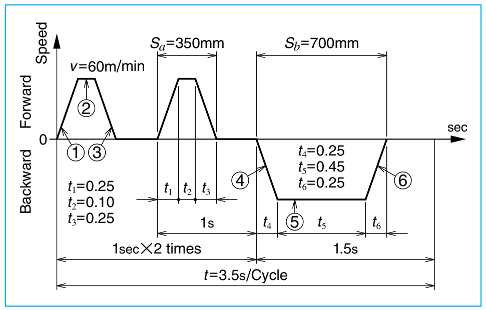

Fig. Ⅱ-15•2

1 Selection of basic factors

(1) Selection of accuracy grade

Accuracy grade should be in the range of C5 to Ct10 according to "Table Ⅰ-4•1 Accuracy grades of ball screw and their application" on Page B17.

From the following conditions in design, the axial play should be 0.005 mm or less.

Repeatability : ±0.005 (mm)

Resolution : 0.005 mm/pulse

From "Table Ⅰ-4•2 Combinations of accuracy grades and axial play" on Page B18, select C5 accuracy grade, and axial play Z code (0 : preloaded).

(2) Selection of lead

From the maximum rotational speed of AC servo motor:

$$l \geqq \frac{V_{max}}{N_{max}} = \frac{1000\times60}{3000} = 20(\text{mm})$$

Select a lead of 20 mm or larger.

(3) Selection of screw shaft diameter

According to "Table Ⅰ-4•5 Standard stock ball screw: Combinations of screw shaft diameter and leads" on Page B19, the diameter of the shaft which has a lead larger than 20 mm should be in the range of 15 mm to 32 mm. Select the smallest 15 mm.

(4) Selection of stroke

From "Table Ⅰ-4•6 Maximum stroke of standard ball screw A&S Series" on Page B20, the shaft diameter 15 mm and lead 22 mm satisfy maximum stroke 700 mm.

Primary selection:

Shaft diameter :	15 mm
Lead :	22 mm
Stroke :	700 mm
Accuracy grade :	C5
Axial play :	Z

② Find out if the required item is in standard stock

In consideration of delivery time and price, select from the standard A Series (finished shaft end).

Primary candidate: W1507FA-3PG-C5Z20

③ Checking basic safety

(1) Checking allowable axial load

① Calculation of allowable axial load (See Fig. Ⅱ-15•2.)

Acceleration at accelerating/decelerating is:

$$\alpha_1 = \frac{V_{max}}{t_1} = \frac{1000}{0.25} = 4000\,(mm/s^2) = 4\,(m/s^2)$$

(At time of acceleration ①, ④)

$$F_1 = \mu(m_1 + m_2) \times g + (m_1 + m_2) \times \alpha 1$$
$$= 0.01 \times (40 + 20) \times 9.80665 + (40 + 20) \times 4 = 246(N)$$

(At time of constant speed ②, ⑤)

$$F_2 = \mu(m_1 + m_2) \times g = 0.01 \times (40 + 20) \times 9.80665 = 6(N)$$

(At time of deceleration ③, ⑥)

$$F_3 = -\mu(m_1 + m_2) \times g + (m_1 + m_2) \times \alpha_1 = 234(N)$$

② Buckling load

Calculate using the dimension table on Page B71. Bearing structure is a common Fixed -- Simple support type.

From Formula (Ⅱ-2) on Page B505:

$$dr \geqq \left[\frac{P \cdot L^2}{m} \times 10^{-4}\right]^{1/4} = \left[\frac{246 \times 804^2}{19.9} \times 10^{-4}\right]^{1/4}$$
$$= 5.3(mm)$$

Dimension table does not list dr. But "Dimensions and Model Numbers of Ball Nut" on Page B401 has a listing of those with the same nut models. According to this table, *dr* is 12.2 mm, and satisfies the requirement.

<u>Result: Acceptable</u>

(2) Checking allowable value of rotational speed

P = 246 (N), L = 804 (mm)

The permissible rotational speed listed in the dimension table is 3000 min^{-1}. Since the motor maximum rotational speed is 3000 min^{-1}, the operation is in the range of permissible rotational speed.

<u>Result: Acceptable</u>

(3) Checking life expectation (See Fig. Ⅱ-15•2.)

(At time of acceleration ①, ④)

From calculation of axial load:

$$F_1 = 246(N)$$

$$N_1 = \frac{n}{2} = \frac{3000}{2} = 1500\,(min^{-1})$$

$$t_a = 2 \times t_1 + t_4 = 0.75(s)$$

(At time of constant speed ②, ⑤)

$$F_2 = 6(N)$$
$$N_2 = 3000(min^{-1})$$
$$t_b = 2 \times t_2 + t_5 = 0.65(s)$$

(At time of deceleration ③, ⑥)

$$F_3 = 234(N)$$
$$N_3 = 1500(min^{-1})$$
$$t_c = 2 \times t_3 + t_6 = 0.75(s)$$

Table Ⅱ-15•1

Operating condition	Axial load (N)	Rotational speed (mean) (min^{-1})	Operating time (s)
① ④	$F_1 = 246$	$N_1 = 1500$	$t_a = 0.75$
② ⑤	$F_2 = 6$	$N_2 = 3000$	$t_b = 0.65$
③ ⑥	$F_3 = 234$	$N_3 = 1500$	$t_c = 0.75$

① Mean load F_m, mean rotational speed N_m

From Formulas (Ⅱ-11) and (Ⅱ-12) on Page B515:

$$F_m = \left[\frac{F_1^3 \cdot N_1 \cdot t_a + F_2^3 \cdot N_2 \cdot t_b + F_3^3 \cdot N_3 \cdot t_c}{N_1 \cdot t_a + N_2 \cdot t_b + N_3 \cdot t_c}\right]^{1/3}$$
$$= 195(N)$$

$$N_m = \frac{N_1 \cdot t_a + N_2 \cdot t_b + N_3 \cdot t_c}{t}$$
$$= 1200(min^{-1})$$

② Calculation of life expectation

From Formulas (Ⅱ-8) and (Ⅱ-9) on Page B515:

(T axial play C_a = 5070N)

$$L_t = \left[\frac{C_a}{F_m \cdot f_w}\right]^3 \times \frac{1}{60N_m} \times 10^6$$
$$= \left[\frac{3870}{195 \times 1.2}\right]^3 \times \frac{1}{60 \times 1200} \times 10^6$$
$$\fallingdotseq 62800 \geqq 25000\ (h)$$

<u>Result: Acceptable</u>

④ Check whether the following figures meet requirements

(1) Checking accuracy and axial play

Positioning accuracy

From the dimension table and the permissible value of lead accuracy on Page B500:

According to Table Ⅱ-1•2:

Accuracy grade: C5

$$e_p = \pm 0.035/800(mm)$$
$$\upsilon_u = 0.025(mm)$$

This grade satisfies the required function.

Checking axial play is omitted here since it is explained in "①Selection of basic factors."

(2) Checking drive torque

Required specifications

Motor rotational sped : 3000 min^{-1}

Time to reach maximum speed : Under 0.25 sec

① Load (converted to motor axis)

From Formulas (Ⅱ-31) and (Ⅱ-32) on Page B524:

Screw shaft

$$J_B = \frac{\pi \cdot \gamma}{32} D^4 \cdot L = \frac{\pi \times 7.8 \times 10^{-3}}{32} \times 1.5^4 \times 80$$

Moving part

$$J_w = m \times \left[\frac{l}{2\pi}\right]^2 = 60 \times \left[\frac{2}{2\pi}\right]^2$$
$$= 6.1(kg \cdot cm^2)$$

Coupling

J_c = 0.25 (kg. cm^2) -- Temporary

Total

$$J_L = 6.7(kg \cdot cm^2) \rightarrow 6.7 \times 10^{-4}(kg \cdot m^2)$$

② Driving torque

From Formulas (Ⅱ-27) and (Ⅱ-29) on Page B524:

At time of constant speed

$$T_1 = \frac{F_2 \cdot l}{2\pi \cdot \eta_1} + T_{pmax} + T_U = \frac{6 \times 2}{2\pi \times 0.9} + 7.8 + 2.1$$
$$= 12(N \cdot cm) \rightarrow 0.12(N \cdot m)$$

Use WBK12-01, a light load support unit for small equipment T_u : Refer to Page B279.

At time of acceleration:

$$T_2 = T_1 + J \cdot \frac{2\pi \cdot n}{60t_1} = T_1 + \frac{(J_L + J_M) \cdot \pi \cdot n}{30t_1}$$
$$= 0.12 + \frac{(6.7 \times 10^{-4} + 3.1 \times 10^{-4}) \times \pi \times 3000}{30 \times 0.25}$$
$$= 1.35(N \cdot m)$$

* Assuming that J_M of the motor is: J_M = 3.1(kg・cm^2) = 3.1 x 10^{-4} (kg・m^2).

At time of deceleration

$$T_3 = T_1 - J \cdot \frac{2\pi \cdot n}{60t_3} = T_1 + \frac{(J_L + J_M) \cdot \pi \cdot n}{30t_3}$$
$$= 0.12 - \frac{(6.7 \times 10^{-4} + 3.1 \times 10^{-4}) \times \pi \times 3000}{30 \times 0.25}$$
$$= -1.11(N \cdot m)$$

③ Selection of motor

[Selection conditions]

Maximum rotational speed: $N_M \geqq 3000(min^{-1})$

Motor rating torque: $T_M \geqq T_{rms}(N \cdot m)$

(T_{rms}: Effective torque)

Motor's rotor inertia -- $J_M > J_L/3$ or more, select an AC servo motor with the following specifications.

Motor specifications:	
Rating power output:	$W_M = 300(W)$
Maximum rotational speed:	$N_M = 3000(min^{-1})$
Rating torque:	$T_M = 1(N \cdot m) = 1 \times 10^2(N \cdot cm)$
Rotor inertia:	$J_M = 3.1 \times 10^{-4}(kg \cdot m^2) = 3.1(kg \cdot cm^2)$

(4) Checking effective torque

$$Trms = \sqrt{\frac{T_2^2 \times t_a + T_1^2 \times t_b + T_3^2 \times t_c}{t}}$$
$$= \sqrt{\frac{1.35^2 \times 0.75 + 0.12^2 \times 0.55 + 1.11^2 \times 0.75}{3.5}}$$
$$= 0.81 \leqq 1(N \cdot m)$$

(5) Checking time to reach maximum speed:

$$t_a = \frac{(J_L + J_M) \times 2\pi \times n}{(T_M - T_1)} \times 1.4$$
$$= \frac{(6.7 \times 10^{-4} + 3.1 \times 10^{-4}) \times 2\pi \times 3000}{(2 \times 1 - 0.12) \times 60} \times 1.4$$
$$= 0.23 \leqq 0.25(sec)$$

In this formula: $T_M = 2 \times T_M$

<u>From above: Use W1507FA-3PG-C5Z20</u>

B 542

[Drill 2] Processing table for special machines

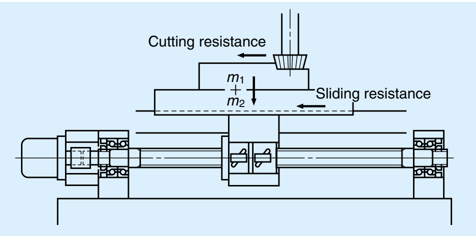

Fig. Ⅱ-15•3

* Design conditions

① Table design specifications

Table mass: $m_2 = 1000$kg

Mass of the moving item: $m_1 = 600$kg

Maximum stroke: $S_{max} = 1000$mm

Maximum speed: $V_{max} = 15000$mm/min

Positioning accuracy: ±0.035/1000 mm (no load)

※ Attitude accuracy of the table and thermal displacement are not included in the accuracy requirement of the ball screw.

Repeatability: ±0.005 mm (no load)

Lost motion: 0.020mm (no load)

Required life expectancy: $L_t = 20000$ h

($16^{h} \times 250^{days} \times 10^{years} \times 0.5^{\text{rate of operation}}$)

Guide way (sliding) : $\mu = 0.15$ (friction coefficient)

Processing: Milling and drilling

Drive motor: AC servo motor (N max$=2000\text{min}^{-1}$)

(2) Operating conditions

Table Ⅱ-15•2

Operation	Axial load (N) Cutting resistance	Axial load (N) Sliding resistance	Feed speed (mm/min)	Use time ratio (%)
Rapid traverse	0	2354	15000	30
Light/medium cutting	4000	2354	500	50
Heavy cutting	8000	2354	100	20

※ Sliding resistance: $F_r = (1000+600) \times 0.15 \times 9.80665 = 2354$(N)

※ Ignore inertia at time of acceleration/deceleration because their time ratios are small.

1 Selection of basic factors

(1) Selection of accuracy grade

Accuracy grade should be in the range from C1 to Ct5 according to "Table Ⅰ-4•1 Precision grades of ball screw and their applications" on Page B17.

Assuming that the screw length Ls is:

L_s = Maximum stroke + nut length + margin

= 1000 = (200) + (100) = 1300

From "Table Ⅱ-1•2 Permissible lead accuracy" on Page B500, the accuracy that satisfies required function is possibly:

Accuracy C3 grade

$e_p = \pm 0.029/1600$(mm)

$\upsilon_u = 0.018$(mm) Therefore select C3 Grade.

Considering importance on the volume of lost motion, select Z code (axial play 0 and less) for axial play.

(2) Selection of lead

From the maximum rotational speed of AC servo motor:

$$l \geqq \frac{V_{max}}{N_{max}} = \frac{15000}{2000} = 7.5\text{(mm)}$$

Larger lead would be beneficial for feed speed. But from the view of the control system (resolution), limit the lead to 8 mm or 10 mm.

(3) Selection of screw shaft diameter

According to "Table Ⅰ-4•5 Standard stock ball screws: Combinations of shaft diameter and lead" on Page B19, shafts whose lead is 8 mm or 10 mm are in the range of 12 mm to 50 mm. Placing more importance on rigidity than to the volume of lost motion, select a relatively large size in the range of 32 mm to 50 mm.

(4) Selection of stroke

Select 1000 mm, the maximum stroke in request.

Primary selection:

Standard ball screw in stock
Shaft diameter: 32, 36, 40, 45, 50 mm
Lead: 8, 10 mm
Stroke: 1000 mm
grade: C3
Axial play code: Z

2 Determining if the required item is in standard stock

Giving consideration to delivery time and price, select from the standard series.

C3 grade chosen in the Primary selection was not found in the standard series. Let us check whether there is a C3 grade among ball screws to order.

3 Finding out whether C3 grade is among the custom made ball screws.

Since C3 grade was the only missing item in step 2, select a custom made ball screw with accuracy grade C3.

Second selection:

Custom made ball screw
Shaft diameter : 32, 36, 40, 45, 50 mm
Lead : 8, 10 mm
Stroke : 1000 mm
Accuracy grade : C3
Axial play : Z

4 Selection of screw shaft diameter, lead, and nut

(1) Checking dynamic load rating

Obtain required load carrying capacity of each lead through load conditions.

Table Ⅱ-15•3

Operating condition	Axial load (N)	Rotations per minute (min^{-1}) $l = 8$	Rotations per minute (min^{-1}) $l = 10$	Use time ratio (%)
Rapid traverse	F_1=2354	N_1=1875	N_1=1500	t_1=30
Light/medium cutting	F_2=6354	N_2=62.5	N_2=50	t_2=50
Heavy cutting	F_3=10354	N_3=12.5	N_3=10	t_3=20

Obtain mean load F_m, and mean rotational speed N_m from Formulas (Ⅱ-11) and (Ⅱ-12) on Page B515:

Table Ⅱ-15•4

Lead (mm)	8	10
Mean load F_m (N)	3122	3122
Mean rotational speed N_m (min^{-1})	596	477

Required load carrying capacity is:

From Formulas (Ⅱ-8) and (Ⅱ-9) on Page B515:

$C_a \geqq (60 N_m \cdot L_t)^{1/3} \cdot F_m \cdot f_w \times 10^{-2}$(N)

Therefore: $L_t = 20000$(h)

$f_w = 1.2$

Therefore:

$l = 8$(mm) ········$C_a \geqq 33500$(N)

$l = 10$(mm) ········$C_a \geqq 31100$(N)

(2) Selection of the nut

Assuming that the design requires more importance on rigidity than on lost motion :

* T Type (Tube recirculation system standard ball screw)

* Model: DFT (Pages B335-B344)

* Number of turns of balls : Select from 2.5 turns 2 circuits or 2.5 turns 3 circuits

Table Ⅱ-15•5

Screw shaft diameter (mm)	Dynamic load rating Ca: (N) Lead 8 mm 2.5 turns 2 circuits	Lead 8 mm 2.5 turns 3 circuits	Lead 10 mm 2.5 turns 2 circuits	Lead 10 mm 2.5 turns 3 circuits
32	31700		46300	
36			49300	
40	34900		52000	
45			54200	76800
50	38700	54900	57700	81800

Third selection: In the range surrounded by the dotted lines in Table Ⅱ-15•5

(3) Checking permissible rotational speed

① Critical speed

Calculate based on rapid traverse speed. Ball screw rotational speed at each lead is:

$l = 8$(mm) ······1875(min^{-1})

$l = 10$(mm) ···1500(min^{-1})

From Formula (Ⅱ-7) on Page B500:

$$dr \geqq \frac{n \cdot L_2}{f} \times 10^{-7}\text{(mm)}$$

In this formula:

L = Maximum stroke + nut length/2 + shaft end extra length

$= 1000 + 100 + 200 = 1300$(mm)

$f = 21.9$ (Fixed -- Fixed)

Therefore:

$l = 8$(mm) ······ $d_r \geqq 14.5$(mm)

$l = 10$(mm) ····· $d_r \geqq 11.6$(mm)

② d・n value

From Formula Table Ⅱ-3.1 on Page B512:

$$d \geqq \frac{70000}{n}$$

Therefore: l =8(mm) ······· $d \leqq 37.8$(mm)

l =10(mm) ······· $d \leqq 46.7$(mm)

※ Please consult NSK if it is necessary to use at d・n >70000.

Fourth selection: In the range surrounded by the solid-lines in Table Ⅱ-15•5

(4) Checking rigidity of the ball screw system

Set the lost motion of the ball screw system (screw shaft, nut and support bearing) at 80% of the specified value. Then calculate the system rigidity.

20(μm)×0.8=16(μm)

At this time, the single-direction elastic deformation of the major factors of ball screw system becomes half.

$\Delta L \leqq 8(\mu m)$

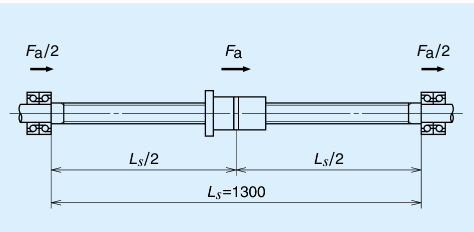

Fig. Ⅱ-15•4

① Rigidity of the screw shaft: Ks (Elastic deformation: ΔLs)

Calculate at the screw shaft center where axial deformation becomes the largest.

From Formula (Ⅱ-20) on Page B519:

$$Ks = \frac{\pi \cdot dr^2 \cdot E}{Ls} \times 10^{3}\ (\text{N}/\mu\text{m}) \quad (\text{Fixed -- Fixed})$$

$$\Delta Ls = \frac{Fa}{Ks} = \frac{Fa \cdot Ls}{\pi \cdot dr^2 \cdot E} \times 103(\mu\text{m})$$

In this formula:

Fa: Sliding resistance (Fa = 2354N)

Calculation result is shown in Table Ⅱ-15•7

② Rigidity of the nut: K_N (Elastic deformation: ΔL_N)

Set about 1/3 of the maximum axial load as the preload value.

$$F_{a0} = \frac{F_{max}}{3} = \frac{10354}{3} \fallingdotseq 3452 \rightarrow 3500(\text{N})$$

From Formula (Ⅱ-23) on Page B521:

Rigidity at this time:

$$K_N = 0.8 \times K\left[\frac{F_{a0}}{\varepsilon \cdot C_a}\right]^{1/3} = 0.8 \times K\left[\frac{3500}{0.1C_a}\right]^{1/3} (\text{N}/\mu\text{m})$$

$$\Delta L_N = \frac{F_a}{K_N}$$

In this formula:

C_a, K: Values listed in the dimension table

F_a: Sliding resistance (Fa = 2354N)

Calculation result is shown in Table Ⅱ-15•7.

③ Rigidity of the support bearing: K_B (Elastic deformation: ΔL_B)

The bearing is thrust angular contact ball bearing for ball screw support (TAC Series). Assume each shaft diameter is as shown in Table Ⅱ-15•6 (Refer to Page B299).

Table Ⅱ-15•6

Screw shaft diameter (mm)	Bearing code
32	25TAC62BDF
36	25TAC62BDF
40	30TAC62BDF
45	35TAC72BDF

Refer to Page B303 for rigidity K_B of each bearing (axial spring modulus).

$$\Delta L_B = \frac{Fa}{2K_B}$$

Calculation result is shown in Table Ⅱ-15•7.

Table Ⅱ-15•7

Unit : N/μm, μm

Nut model number	Screw shaft K_s	Screw shaft ΔL_s	Nut K_N	Nut ΔL_N	Support bearing K_B	Support bearing ΔL_B	Total ΔL
DFT3210-5	347	6.8	839	2.8	1000	1.2	10.8
DFT3610-5	460	5.1	907	2.6			8.9
DFT4010-5	589	4.0	973	2.4	1030	1.1	7.5
DFT4510-5	772	3.0	1050	2.2	1180	1.0	6.2
DFT4510-7.5			1375	1.7			5.7

In consideration of expense, the following is selected.

Nut model code of the selected ball screw: DFT4010-5

Shaft diameter : 40 mm

Lead : 10 mm

5 Decision of screw shaft length

Screw shaft length

L_s = Maximum stroke + nut length + margin

=1000+193+100=1293 → 1300mm

6 Checking basic safety

(1) Permissible axial load

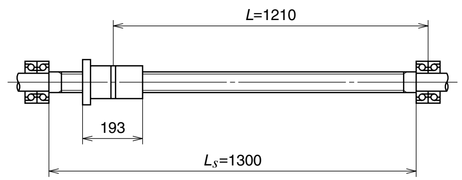

Fig. Ⅱ-15•5

Bucking load

Calculate at: P = 10354(N), L = 1210 (mm)

Bearing supporting condition: Fixed - Fixed support

$$dr \geqq \left[\frac{P \cdot L^2}{m} \times 10^{-4}\right]^{1/4} = \left[\frac{10354 \times 1210^2}{19.9} \times 10^{-4}\right]^{1/4}$$

=16.6(mm)

Result: Acceptable

(2) Checking permissible rotational speed

a) Critical speed

$$n = f \cdot \frac{dr}{L^2} \times 10^7 = 21.9 \times \frac{34.4}{1210^2} \times 10^7$$

$\fallingdotseq 5140 \geqq 1500(\text{min}^{-1})$

b) d・n value

d・n=40×1500=60000≦70000

Result: Acceptable

(3) Checking life

$$L_t = \left[\frac{C_a}{f_w \cdot F_m}\right]^3 \times 10^6 \times \frac{1}{60 \cdot N_m}$$

≒95000≧20000(h)

Result: Acceptable

7 Check whether the following factors satisfy requirements

(1) Checking accuracy

• Positioning accuracy ±0.035/1000 mm stroke

From "Table Ⅱ-1•2 Tolerance of specified travel and travel variation" on Page B500:

Accuracy grade : C3

e_p = ±0.029/1600(mm)

υ_u = 0.018(mm)

• Measures against thermal expansion

Provide pre-tension force equivalent to the elongation of 3℃ temperature rise, taking in consideration of the load carrying capacity of bearing. Also, adjust the travel compensation for the specified travel by a volume equivalent to 3℃ temperature rise.

① Thermal elongation : ΔL_θ

From Formula (Ⅱ-1) on Page B501:

$\Delta L_\theta = \rho \cdot \theta \cdot L = 12.0 \times 10^{-6} \times 3 \times 1300 = 0.047$(mm)

② Pre-tension force : F_θ

$$F_\theta = \Delta L_\theta \cdot Ks = \frac{\Delta L_\theta \cdot E \cdot \pi \cdot dr^2}{4L}$$

$$= \frac{0.047 \times 2.06 \times 10^5 \times \pi \times 34.4^2}{4 \times 1300}$$

≒6922 → 6900(N)

Travel compensation :	–0.047/1300(mm)
Pre-tension force :	6900(N)
Tension (elongation) volume :	0.047(mm)

• Selection of support bearing

Assuming that the ratio of basic dynamic load rating of support bearing (Ca) and pre-tension force (F_θ) is ε, select a bearing which generally satisfies:

$\varepsilon = F_\theta / C_B < 0.20$

Design the bearing supporting configuration to which pre-tension force is applied in such way that the axial load is received by the duplex combination or more. Please consult to NSK when one bearing must sustain the pre-tension load.

Table Ⅱ-15•7

Bearing reference number	C_B(N)	ε
30TAC62BDF	29200	0.23
30TAC62BDFD	47500	0.14

Selected support bearing: 30TAC62BDFD

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(2) Checking drive torque

Selection of driving motor

《Required specifications》

Motor rotational speed : 1500min^{-1}

Time to reach maximum speed : Under 0.16 sec

(At time of rapid traverse)

① Load (converted to the motor load)

From Formula (Ⅱ-31) and (Ⅱ-32) on Page B524:

Screw shaft

$$J_B = \frac{\pi \cdot \gamma}{32} D^4 \cdot L = \frac{\pi \times 7.8 \times 10^{-3}}{32} \times 4^4 \times 155$$

$$= 30(\text{kg} \cdot \text{cm}^2)$$

Moving part

$$J_w = m \times \left[\frac{l}{2\pi}\right]^2 = 1600 \times \left[\frac{1}{2\pi}\right]^2$$

$$= 40(\text{kg} \cdot \text{cm}^2)$$

Coupling

$J_c = 10(\text{kg} \cdot \text{cm}^2)$ … assumed

Total

$J_L = 80(\text{kg} \cdot \text{cm}^2) \rightarrow 80 \times 10^{-4}(\text{kg} \cdot \text{m}^2)$

② Driving torque

Driving torque at time of constant speed is:

From Formula (Ⅱ-29) on Page B524:

$T_1 = T_A + T_P + T_U$

In this formula:

$$T_A = \frac{Fa \cdot l}{2\pi \eta_1}$$

$$T_P = 0.014 F_{a0} \sqrt{\text{dm} \cdot l}$$

$$\eta_1 = 0.9$$

Refer to the starting torque value on Page B303:

$$T_U = 33 + 33 = 66 \ (\text{N} \cdot \text{cm})$$

At time of rapid traverse

$$T_{11} = \frac{2354 \times 1}{2\pi \times 0.9} + 0.014 \times 3500 \sqrt{4.1 \times 1} + 66$$

$$= 580(\text{N} \cdot \text{cm}) \rightarrow 580 \times 10^{-2}(\text{N} \cdot \text{m})$$

At time of heavy cutting

$$T_{12} = \frac{10354 \times 1}{2\pi \times 0.9} + 0.014 \times 3500 \sqrt{4.1 \times 1} + 66$$

$$= 1995(\text{N} \cdot \text{cm}) \rightarrow 1995 \times 10^{-2}(\text{N} \cdot \text{m})$$

③ Selection of the motor

《Selection conditions》

Maximum rotational speed : $N_M \geqq 1500(\text{min}^{-1})$

Motor rating torque : $T_M > T_1(\text{N} \cdot \text{m})$

Motor's rotor inertia : $J_M > J_L / 3(\text{kg} \cdot \text{m}^2)$

Based on this, select AC servo motor as below.

Motor specifications		
Rating power output:	W_M	$= 1.8(\text{kW})$
Maximum rotational speed:		
	N_M	$= 1500(\text{min}^{-1})$
Rating torque:	T_M	$= 22.5(\text{N} \cdot \text{m})$
		$= 22.5 \times 10^2(\text{N} \cdot \text{cm})$
Rotor inertia:	J_M	$= 190 \times 10^{-4}(\text{kg} \cdot \text{m}^2)$
		$= 190(\text{kg} \cdot \text{cm}^2)$

④ Checking time to reach maximum speed:

$$t_a = \frac{(J_L + J_M) \times 2\pi \times N}{(T_M' - T_1) \times 60} \times 1.4$$

$$= \frac{(80 \times 10^{-4} + 190 \times 10^{-4}) \times 2\pi \times 1500}{(2 \times 22.5 - 580 \times 10^{-2}) \times 60} \times 1.4$$

$$= 0.15 \leqq 0.16(\text{sec})$$

In the above, $T_M' = 2 \times T_M$

[Drill 3] Cartesian type robot Z axis (vertical axis)

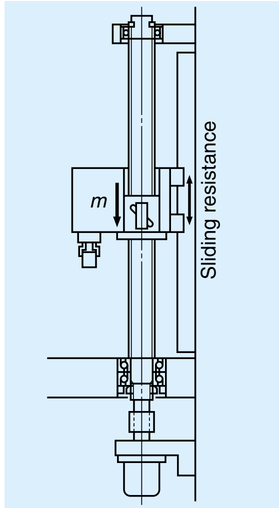

Fig. Ⅱ-15•6

Design conditions

① Design specifications

Mass of the traveling item : $m = 300\text{kg}$

Maximum travel : $S_{max} = 1500\text{mm}$

Rapid traverse speed : $V_{max} = 10000\text{mm/min}$

Repeatability : 0.3mm

Required life : $L_t = 24000\text{h}$ (16 hours x 300 days x 5 years)

Screw shaft supporting condition : Fixed -- Simple support

Nut: Flanged single nut

Guide way (rolling) : $\mu = 0.01$ (friction coefficient)

Drive motor : AC servo motor (Nmax = 1000min^{-1})

Environment : Slightly dusty

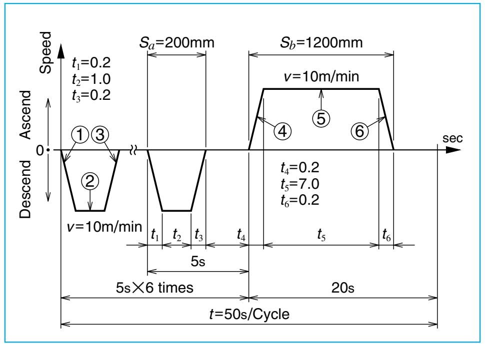

Fig. Ⅱ-15•7

1 Selection of basic factors

(1) Selection of accuracy grade

There is no listing concerning this system in "Table Ⅰ-4•1 Precision grades of ball screw and their applications" on Page B17.

A rolled ball screws in R Series, which is standard in stock, can be a candidate according to "repeatability 0.3 mm" and "Mass of the traveling item 2940 (N)."

(2) Selection of lead

From the maximum rotational speed of AC motor:

$$l \geqq \frac{V_{max}}{N_{max}} = \frac{10000}{1000} = 10(\text{mm})$$

Select a lead 10 mm or over.

(3) Selection of screw shaft diameter

According to "Table Ⅰ-4•8 Rolled ball screw: Combinations of screw shaft diameter and leads" on Page B21, the shaft diameters whose lead is more than 10 mm are in the range of 12 mm to 50 mm.

(4) Selection of stroke

According to "Table Ⅰ-4•10 Maximum stroke range of standard stock rolled ball screws" on Page B22, the shaft diameter which satisfies maximum stroke is between 15 mm and 50 mm.

Primary selection: Rolled ball screw, standard in stock	
Screw shaft diameter :	15～50(mm)
Lead :	10(mm)
Stroke :	1500(mm)

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2 Find out if the required item is standard stock.
In consideration of delivery time and price, select from the standard R Series (rolled ball screws). Select from Flanged single nuts.

Second selection :	Rolled ball screw, standard in stock
Screw shaft diameter :	15、16、20、25、32、36、40、45、50(mm)
Lead :	10(mm)
Stroke :	1500(mm)

3 Checking basic safety
(1) Checking allowable axial load
① Calculation of allowable axial load (see Fig. Ⅱ-15•7.)
Acceleration at accelerating/decelerating time is:

$$\alpha_1=\frac{V}{60t_1}=\frac{10\times10^3}{60\times0.2}=833(mm/s^2)=0.833(m/s^2)$$

①、⑥ ……$F_1=mg-ma=2690(N)$

②、⑤ ……$F_2=mg=2940(N)$

③、④ ……$F_1=mg+ma=3190(N)$

(2) Bucking load
Use values below.

$P=3190$(N), $L=1600$ (mm)

Bearing supporting condition is common Fixed -- Simple support.
From Formula (Ⅱ-2) on Page B505:

$$d_r\geqq\left[\frac{P\cdot L^2}{m}\times10^{-4}\right]^{1/4}=\left[\frac{3190\times1600^2}{10.0}\times10^{-4}\right]^{1/4}$$

$=16.8$(mm)

(2) Checking permissible rotational speed
① Critical speed
Use values below.

$n=1000$ min^{-1}, $L=1600$ mm.

From Formula (Ⅱ-7) on Page B509:

$$d_r\geqq\frac{n\cdot L^2}{f}\times10^{-7}=\frac{1000\times1600^2}{15.1}\times10^{-7}$$

$=17$(mm)

② d・n value
From Table Ⅱ-3.1 on Page B512:

$$d\leqq\frac{50000}{n}=\frac{50000}{1000}$$

$=50$(mm)

* Please consult NSK if d・n >50000 is required.

(3) Decision of screw length

L_s = Stroke + nut length + margin + shaft end length
(Stroke + nut length + margin = Screw section length)

$=1500+100+100+200=1900\leqq2000$(mm)

Normally, Ls/d (screw length/shaft diameter) ≦70 is recommended.

$$d\geqq\frac{L_s}{70}=\frac{1900}{70}=27.1$$

Third selection:	Rolled ball screw, standard in stock
Shaft diameter:	32、36、40、45、50 (mm)
Lead:	10 (mm)
Stroke:	1500 (mm)

(4) Checking life (dynamic load rating)
Determine required load carrying capacity from load conditions.

Table Ⅱ-15•8

Operating condition	Axial load (N)	Rotational speed (mean)(min^{-1})	Use time (s)
① ⑥	F_1=2690	N_1=500	t_a=1.4
② ⑤	F_2=2940	N_2=1000	t_b=13.0
③ ④	F_3=3190	N_3=500	t_c=1.4

Calculate mean load F_m and mean rotational speed N_m from Formulas (Ⅱ-11) and (Ⅱ-12) on Page B515:
Required load carrying capacity is:

$$F_m=\left[\frac{F_1^3\cdot N_1\cdot t_a+F_2^3\cdot N_2\cdot t_b+F_3^3\cdot N_3\cdot t_c}{N_1\cdot t_a+N_2\cdot t_b+N_3\cdot t_c}\right]^{1/3}$$

$=2940$(N)

$$N_m=\frac{N_1\cdot t_a+N_2\cdot t_b+N_3\cdot t_c}{t}$$

$=288$(min^{-1})

From Formulas (Ⅱ-8) and (Ⅱ-9) on Page B515:

$C_a\geqq(60N_m\cdot L_t)^{1/3}\cdot F_m\cdot f_w\times10^{-2}$(N)

$=(60\times288\times24000)^{1/3}\times2940\times1.2\times10^{-2}$

$=26300$(N)

Checking static load rating

$C_{0a}=Fmax\times f_s=3190\times2$

$=6380$(N)

In consideration of expense:

Fourth selection :	
Rolled ball screw, standard in stock	
Shaft diameter :	32(mm)
Lead :	10(mm)
Stroke :	
Turns of balls and circuit number :	2.5x2
Screw length :	2000(mm)
Basic dynamic load rating :	35700(N)

4 Selection of nut
Select a "standard nut with a flange and a seal (Brush-seals contained inside)" based on the necessity as well as on the environmental conditions.

Selected ball screw:Nut assembly RNFTL3210A5S
Screw shaft RS3210A20

B-Ⅱ-16 Reference

"NSK Motion & Control (technical journal)" was compiled to introduce NSK products and its technologies. You will find data summaries which are imperative in selecting ball screws in this catalogue. If you need detailed technical data, other than described in this catalogue, please refer to "NSK Motion & Control" technical journal.
For inquiries and orders, please contact NSK branch offices, sales offices, and representatives assigned at various locations.

Table Ⅱ-16•1 NSK Motion & Control (technical journal) : Issues relating to ball screws (1980-)

No.	Issued Date	Title
No.4	Jun. 1998	Recent Technical Trends in Ball Screws
No.8	May. 2000	Ball Screw with Rotating Nut and Vibration Damper
No.9	Oct. 2000	WFA Standard-Stock Ball Screws
No.10	Apr. 2001	High Performance Seals for Ball Screws
No.11	Oct. 2001	Development of NSK S1 Series Ball Screws and Linear Guides
No.11	Oct. 2001	Low Inertia Series of Nut Rotatable Ball Screws
No.13	Oct. 2002	Development of HTF Series Ball Screws for High Load Drive Application
No.13	Oct. 2002	High Lead Precision Rolled Ball Screws
No.14	May. 2003	High Speed and Low Noise Ball Screws HMC-B02 Series
No.15	Dec. 2003	Clean Support Units for Ball Screws
No.16	Aug. 2004	Development of High Speed and Low Noise Ball Screws
No.18	Aug. 2005	S3 Ball Screws: Super Low Noise Ball Screws for Automation Equipment