KALATEC AUTOMAÇÃO

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Ball Screw

1-9-1 Service Life of Ball Screws

Even the ball screw is used under correct conditions, it would still fail after a period time of usage. From the beginning to the unusable condition of ball screw, this period of time is called service life of ball screw, which is generally classified into the fatigue life when delamination phenomenon occurs and the accuracy deterioration life caused by wear-out, etc.

1-9-2 Basic Static Load Rating C_{oa}

The basic load rating is an axial static load which will produce a permanent deformation at contact points of the steel balls to ball grooves equal to 0.01% of ball diameter.

1-9-3 Basic Dynamic Load Rating C_a

The basic dynamic load rating is an axial load which allow 90% of a group of identical ball screws (rotated under the same condition) to rotate without flaking for 10^6 revolutions. This basic dynamic load rating is shown in the table of dimensions.

Relation between load and service life $L_\alpha = \left(\frac{1}{P}\right)^3$ L : Service life P : Load

1-9-4 Fatigue Life

Average load P_e

(1) When axial load keeps changing, please calcuate in order the average load for the equivalent fatigue life under different load condition changes. (see Table 1.9.1)

$$\left(P_e = \frac{P_1^3 n_1 t_1 + P_2^3 n_2 t_2 + \ldots + P_n^3 n_n t_n}{n_1 t_1 + n_2 t_2 + \ldots + n_n t_n}\right)^{\frac{1}{3}} \text{(kgf)}$$

Axial Load (kgf)	Rotating Speed (min^{-1})	Time(%)
P1	n1	t1
P2	n2	t2
.	.	.
.	.	.
.	.	.
Pn	nn	tn

But, $t_1 + t_2 + t_3 + \ldots + t_n = 100$

Table 1.9.1 Service Life in Different Application.

Usage	Life in hours (h)
Working machines	20000
General industrial machines	10000
Automatic control machines	15000
Measurement machines	15000

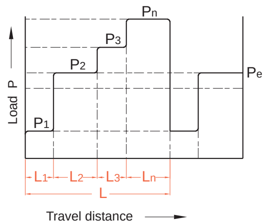


Fig 1.9.1

$$P_e = \frac{2P_{max} + P_{min}}{3} \text{ (kgf)}$$

P_{max} : Maximal axial load (kgf)
P_{min} : Minimal axial load (kgf)

(2) When load changes according to sine curve (see Fig 1.9.2)

$P_e \fallingdotseq 0.65\ P_{max}$ ..... (Fig A)
$P_e \fallingdotseq 0.75\ P_{max}$ ..... (Fig B)

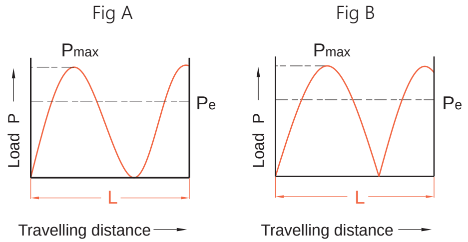


Fig 1.9.2

■ 1-9-5 Calculation of Service Life

The fatigue life is generally expressed by the total number of revolutions. The total rotation hours or total travel distance may also be used to express service life. The fatigue life is calculated as follow :

$$L = \left(\frac{C_a}{P_a \cdot f_w}\right)^3 \cdot 10^6 \qquad L_t = \frac{L}{60_n} \qquad L_s = \frac{L \cdot \ell}{10^6}$$

Where
L : Rated fatigue life (rev)
L_s : Life in travel distance (km)
P_a : Axial load (kgf)

fw : Load Coefficient
(Required coefficient to operate)
L_t : Life in hours (h)
C_a : Basic dynamic load rating (kgf)

n : Rotating speed (rpm)
ℓ : Lead (mm)

Table 1.9.2 Load Factor (fw)

Vibration and impact	Velocity (V)	fw
Minor	V ≦ 0.25 m/sVery Low	1~1.2
Little	0.25 < V ≦ 1m/s Low	1.2~1.5
Moderate	1 < V ≦ 2 m/sMedium	1.5~2
Heavy	V > 2 m/sHigh	2~3.5

Table 1.9.3 Factor of Safety (fs)

Usage	Operation	f s
Machine tool	Normal operation	1.0 ~ 1.3
	Operation with impact and vibration	2.0 ~ 3.0
Industrial machine	Normal operation	1.0 ~ 1.5
	Operation with impact and vibration	2.5 ~ 7.0

Basic Dynamic Load Rating C_a
$C_a = P_e \cdot f_s$
Basic Static Load Rating C_{oa}
$C_{oa} = P_{max} \cdot f_s$

1-9 Life Design

Key Points for Ball Screws Selection

To choose a perfect fit ball screw, users need to understand operating requirement, which is the fundamental principal of deciding the design. Besides, the main factors of selection include load weight, stroke, torque, positioning accuracy in a single time and repeatedly, rigidity, lead and nut's inner diameter. Among all the factors, any single factor's change will cause the change of other factors. Therefore, the balance between all factors is a must to pay attention to.

1. Setting of operation conditions

(a) Machine service life time reckoning of H (hr)

H= ______ · ______ · ______ · ______

hours/day · days/year · life years · running rate

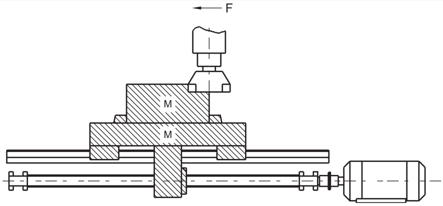
(b) Mechanical conditions

Calculation Items / Different Operations	Speed/ rotations	Cutting resistance	Sliding resistance	Time used
Fast feed	m/min/min^{-1}	kgf	kgf	%
Light cutting	/			
Medium cutting	/			
Heavy cutting	/			

(c) Position determination accuracy

Feed accuracy error factor includes load accuracy and system rigidity. Other factors which caused by temperature rise such as heat deformation and mounting accuracy of surface are needed to be considered.

Calculation for Ball Screws Selection



Design conditions

1. Working table weight 300 Kg
2. Working object weight 400 Kg
3. Max Stroke 700 mm
4. Feeding speed 10 m/min
5. Minimal disassembly ability 10μm/stroke
6. Driving motor DC motor (MAX 1000 min)
7. Guiding surface friction coefficient (μ= 0.05~0.1)
8. Running rate 60 %
9. Accuracy review items
10. Inertia generated during acceleration/deceleration can be neglected because the time periods involved are comparatively small.

1. Setting of operation conditions

(a) Machine service life time reckoning of H (hr)

H = 12 hr · 250 days · 10 years · 0.6 Running rate
= 18000 hr

(b) Mechanical conditions

Calculation Items / Different Operations	Speed/ rotations	Cutting resistance	Sliding resistance	Time used
Fast feed	10m/min/1000min^{-1}	0 kgf	70 kgf	10 %
Light cutting	6/600	100	70	50
Medium cutting	2/200	200	70	30
Heavy cutting	1/100	300	70	10

Sliding resistance = (300 + 400) · 0.1 = 70 kgf

Key Points for Ball Screws Selection	Calculation for Ball Screws Selection
2. Ball screw lead ℓ (mm) $\ell = \frac{\text{Feeding speed (m/min)} \cdot 1000}{\text{Max. Rotating speed (min}^{-1}\text{) of motor}}$ (mm)	2. Ball screw lead ℓ (mm) $\ell = \frac{10000}{1000} = 10\text{(mm)}$ Minimal disassembly = $\frac{10\text{mm}}{1000\text{ stroke}}$ = 0.01 mm/stroke
3. Computation of average load P_e (kgf) $P_e = \left(\frac{P_1^3 n_1 t_1 + P_2^3 n_2 t_2 + \dots + P_n^3 n_n t_n}{n_1 t_1 + n_2 t_2 + \dots + n_n t_n} \right)^{\frac{1}{3}}$ $P_e = \frac{2P_{max} + P_{min}}{3}$ $P_e \fallingdotseq 0.65\ P_{max}$ $P_e \fallingdotseq 0.75\ P_{max}$	3. Computation of average load P_e (kgf) $P_e = \left[\frac{70^3 \cdot 1000 \cdot 10 + 170^3 \cdot 600 \cdot 50 + 270^3 \cdot 200 \cdot 30 + 370^3 \cdot 100 \cdot 10}{1000 \cdot 10 + 600 \cdot 50 + 200 \cdot 30 + 100 \cdot 10} \right]^{\frac{1}{3}}$ $= \left(\frac{31.7 \cdot 10^{10}}{4.7 \cdot 10^4} \right)^{\frac{1}{3}}$ $\fallingdotseq 189$ kgf
4. Average number of rotations n_m $n_m = \frac{n_1 t_1 + n_2 t_2 + \dots + n_n t_n}{100}$	4. Average number of rotations n_m $n_m = \frac{1000 \cdot 10 + 600 \cdot 50 + 200 \cdot 30 + 100 \cdot 10}{100}$ $= \frac{4.7 \cdot 10^4}{100} = 470\ \text{min}^{-1}$
5. Calculation of required dynamic rated load C_a $C_a = P_e \cdot f_s$	5. Calculation of required dynamic rated load C_a $C_a = 189 \cdot 5 = 945$ (kgf)
6. Calculation of required static rated load C_{oa} $C_{oa} = P_{max} \cdot fs$	6. Calculation of required static rated load C_{oa} $C_{oa} = 369 \cdot 5 = 1845$ (kgf)
7. Selection of nut type $C_a > 945$ $C_{oa} > 1845$ Select the nut types with basic dynamic rated load and and basic static rated load as specified above.	7. Selection of nut type Choose SFNI 2510 on the catalogue $C_a = 2954$ (kgf) $C_{oa} = 7295$ (kgf)

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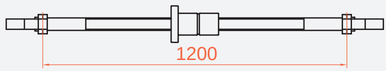
Ball Screw

Key Points for Ball Screws Selection	Calculation for Ball Screws Selection
8. Calculation of service life L_t (h) $L_t = \frac{L}{60_n} = (\frac{C_a}{P_e \cdot f_w})^3 \cdot 10^6 \cdot \frac{1}{60_n}$	8. Calculation of service life Lt (h) $Lt = (\frac{2954}{189 \cdot 2})^3 \cdot 10^6 \cdot \frac{1}{60 \cdot 470} = 42544(h)$
9. Mounting distance between supporting bearings	9. Mounting distance between supporting bearings 
10. Determination of screw length Screw length = Maximal stroke + Nut length + Two reserved length at shaft end	10. Determination of screw length Screw length = 700 + 85 + 76 + 76 = 937 mm 937 mm<1200 mm
11. Permissible axial load	11. Permissible axial load Omitted because of F-F support
12. Permissible revolution speed n and DN $n = \alpha \cdot \frac{60\lambda^2}{2\pi L^2}\sqrt{\frac{Elg}{\gamma A}} = f\ \frac{dr}{L^2} \cdot 10^7(rpm)$ DN = Shaft dia · Maximal speed	12. Permissible revolution speed n and DN $n = \frac{21.9 \cdot 21.86 \cdot 10^7}{1200^2} = 3324\ min^{-1} < n_{max}$ DN = 25 · 1000 = 25000 < 50000
13. Countermeasure against thermal displacement $\triangle \ell = \alpha \cdot \triangle t \cdot L$ $\triangle \ell$: Thermal displacement α : Coefficient of thermal expansion △t : Temperature rise (deg) at screw shaft L : Effective length of screw thread	13. Countermeasure against thermal displacement It is estimated there would be a temperature rise 2~5°C with the ball screws of the general machinery, take temperature rise of 2°C to compute the extension of ball screw. $\triangle \ell = \alpha \cdot \triangle t \cdot L = 11.7 \cdot 10 \cdot 2 \cdot 700mm$ $\fallingdotseq 0.016mm$ $F_p = \frac{EA\Delta\ell}{L}$ $= \frac{2.06 \cdot 10^4 \frac{\pi \cdot 21.86^2}{4} \cdot 0.016}{700}$ $\fallingdotseq 177(kgf)$

Key Points for Ball Screws Selection	Calculation for Ball Screws Selection
14. Rigidity (1) Axial rigidity Ks and displacement δs of screw shaft $Ks = \frac{P}{\delta s}$ (kgf/mm) P : Axial load (kgf) $\delta_{SF} = \frac{PL}{4AE}$ (mm).......(with reference to page C21) (2) Axial rigidity KN and displacement δs of nut $\delta_{NS} = \frac{K}{\sin\beta}\left[\frac{Q^2}{d}\right]^{\frac{1}{3}} \cdot \frac{1}{\zeta}$ (mm) $Q = \frac{P}{n \cdot \sin\beta}$ (kgf) $n = \frac{D_0 \pi m}{d}$ (each).......(with reference to page C22) (3) Axial rigidity KB and displacement δB of bracing shaft $K_B = \frac{P}{\delta_B}$ (kgf/mm).......(with reference to page C23)	14. Rigidity Deviation can be corrected by estimating the temperature rise per extension of 0.016 mm, and taking into consideration of the pre-tension of 177 kgf. (1) Directional rigidity $\delta_{SF} = \frac{PL}{4AE} = \frac{27 \cdot 1200}{4 \cdot \frac{\pi \cdot 21.86^2}{4} \cdot 2.06 \cdot 10^4}$ = 0.00105 (mm) $Ks = \frac{370}{0.00105} = 3.5 \cdot 10^5$ kgf/mm (2) Rigidity of steel ball and nut groove $n = \frac{26.62 \cdot \pi \cdot 4}{4.762} = 70$ $Q = \frac{370}{70 \sin 45^\circ} = 10$ $\delta_{NS} = \frac{0.00057}{\sin 45^\circ}\left(\frac{10^2}{4.762}\right)^{\frac{1}{3}} \cdot \frac{1}{0.7}$ = 3.2 · 10 mm $K_N = \frac{370}{3.2 \cdot 10^{-3}} = 1.27 \cdot 10^5$ kgf/mm (3) Rigidity of support bearings Where, nut rigidity 50 kgf/μm $\delta_B = \frac{370}{51 \cdot 2} \fallingdotseq 3.6\mu m$ $K_B = \frac{370}{0.0036} = 1 \cdot 10^5$ kgf/mm ● $\delta_{TOTAL} = 1.05 + 3.2 + 3.6 = 7.85\mu m$
15.Confirmation of the ball screw life	15.Confirmation of the ball screw life L = 42544 (h)>18000 (h)

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Ball Screw

1-10 Cautions About Use of Ball Screws

Ball screw assemblies are delicate components. Therefore,extra care must be taken to prevent the ball track from damages that caused by edged component or tools. Meanwhile, to prevent steel ball fall out of the nut through the disassembly of screw and nut or over stroke, please be careful while operating. If the steel ball falls out, please contact with TBI MOTION for further instruction.Do not attempt to reassemble, which might cause permanent damage to the ball screw.)

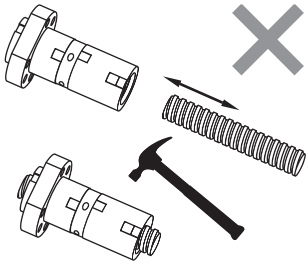

Fig 1.10.1 Error installation

If disassemble is required, please use a transfer pipe which has minor diameter than the screw diameter to transfer the nut to prevent falling out of the steel balls.

■ 1-10-1 Lubrication

Adequate lubrication must be provided when ball screw is used, insufficient lubrication will result in collision of metal, which leads to increase of friction and detrition, thus cause failure or shortening the service life.

Lubricants applied to ball screws can be divided into 2 types, namely lubricating oil and consistent grease. In general speaking, in respect of maintenance, consistent grease will lead to increase of dynamic friction torque linearly along with increase of rotating speed, hence oil lubrication is deemed the better way when speed exceeds 3-5 m/min; however, don't forget the fact that there have been examples that using grease has been capable of achieving speed of 10 m/min, with respect to the equipment.

In terms of equipments, there are some cheaper lubricant that can be used. In general, to fully utilize the function of ball screw, lubricating oil of 5m/minute is the best option to choose.In figure 1.10.1, we provide the standard of lubricating oil inspection and supplement interval. Before replenishing, please clean up the previous grease to continue.

Table 1.10.1 Inspection of lubrication and interval of refill

Method	Interval	Check Item	Replenish or Change Interval
Auto. Periodial oil supply	Weekly	Oil level, contamination	Add at each check, as required depending on tank level
Grease	Initially 2~3 months	Contamination on entry of chip	replenish yearly or according to the inspection result.
Oil bath	Daily	Oil level	To be determined according to consumption