A-3-10 Drills to Select Linear Guide

(1) Single Axis Material Handling System

This section explains linear guide selection, life calculation, and deformation at load acting point for a single axis material handling system equipped with linear guide.

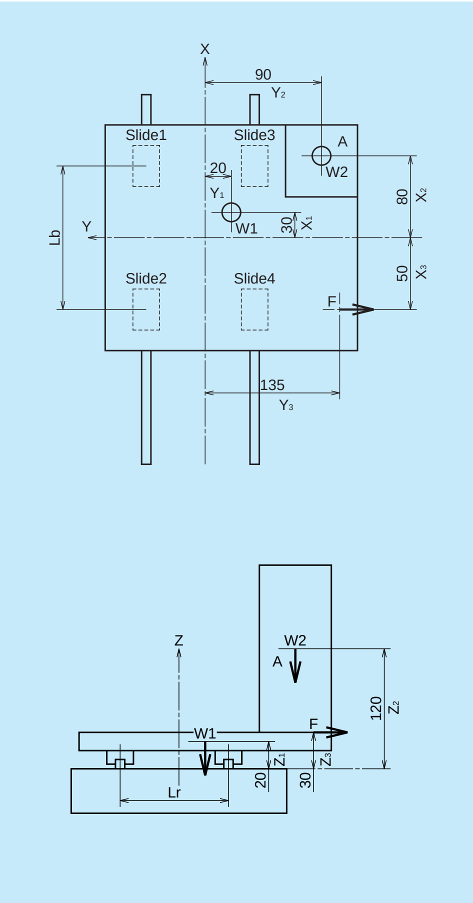


Fig. 10.1 Single axis material handling system

The work load is applied only to one way of stroke. Assume that the load is acting in full stroke as the condition of acting load is unknown.

Specification of single axis material handling system

Table weight	W1 : 150 (N)
Weight of the work	W2 : 200 (N)
Acting load	*F* : 200 (N)
Ball slide span	L_b : 100 (mm)
Rail span	L_r : 90 (mm)

Load point coordinates from the table center (mm)

Load	X coordinate	Y coordinate	Z coordinate
W1	30	−20	20
W2	80	−90	120
F	−50	−135	30

Stroke: 1000 mm
(1 cycle: 2000 mm)

Environment	: 10 – 30 (°C)
Travel speed	: 12 (m/min)
Time to reach travel speed	: 0.25 (sec)
Operating hour	: 16 (hr/day)

(1)-1 Selection of linear guide model

Select a type of linear guide from **"A-1-2 Structure and Characteristics of Linear Guide."** Since this material handling system has 2 rails and 4 ball slides, **LH, LS, and LU Series** are suitable.

Here, we temporary select LU15 because of the dimensions of mounting space.

(1)-2 Calculating life

Calculate life of the selected LU15AL based on **"A-3-2 Rating Life and Basic Load Rating."**

Linear guide LU15AL

Basic dynamic load rating : 5550 (N)
Basic static load rating : 6600 (N)

Load conditions of the linear guide

Table weight	W1 : 150 (N)
Weight of the work	W2 : 200 (N)
Applied load	*F* : 200 (N)
Rail span	L_r : 90 (mm)
Ball slide span	L_b : 100 (mm)

From the time to reach travel speed and the travel speed, the table acceleration is 0.8 m/sec^2. Therefore, it is not necessary to take into account inertial force brought about by table mass.

Calculation of the load applied to ball slide

Calculate two occasions:

1. There is the work mounted on the table.
2. No work mounted on the table.

From **Pattern 4** in Table 2.2 (page A19)

There is a work mounted on the table

Vertical direction loads

$$M1=\sum_{j=1}^{n}(F_{yj}\cdot Z_{yj})+\sum_{k=1}^{n}(F_{zk}\cdot Y_{zk})$$
$$=F\cdot Z_3+W1\cdot Y_1+W2\cdot Y_2$$
$$=-200\times 30+150\times(-20)+200\times(-90)$$
$$=-27000\ (\text{N}\cdot\text{mm})$$

$$M2=\sum_{i=1}^{n}\{F_{xi}\cdot(Z_{xi}-Z_b)\}+\sum_{k=1}^{n}(F_{zk}\cdot X_{zk})$$
$$=W1\cdot X_1+W2\cdot X_2$$
$$=150\times 30+200\times 80$$
$$=20500\ (\text{N}\cdot\text{mm})$$

$$F_{r1}=\frac{\sum_{k=1}^{n}F_{zk}}{4}+\frac{M1}{2\cdot L}+\frac{M2}{2\cdot \ell}$$
$$=\frac{W1+W2}{4}+\frac{M1}{2\cdot L_r}+\frac{M2}{2\cdot L_b}$$
$$=\frac{150+200}{4}+\frac{-27000}{2\times 90}+\frac{20500}{2\times 100}$$
$$=40\ (\text{N})$$

Similarly

F_{r2} = −165(N)
F_{r3} = 340(N)
F_{r4} = 135(N)

Lateral direction loads

$$M3=-\sum_{i=1}^{n}\{F_{xi}\cdot(Y_{xi}-Y_b)\}+\sum_{j=1}^{n}(F_{yj}\cdot X_{yj})$$
$$=F\cdot X_3$$
$$=-200\times(-50)$$
$$=10000\ (\text{N}\cdot\text{mm})$$

$$F_{s1}=F_{s3}=\frac{\sum_{j=1}^{n}F_{yj}}{4}+\frac{M3}{2\cdot\ell}$$
$$=\frac{F}{4}+\frac{M3}{2L_b}$$
$$=\frac{-200}{4}+\frac{10000}{2\times100}$$
$$=0\ (\text{N})$$

Similarly

$F_{s2}=F_{s4}=-100(\text{N})$

No work mounted on the table

Vertical direction load

$$M1=\sum_{j=1}^{n}\left(F_{yj}\cdot Z_{yj}\right)+\sum_{k=1}^{n}\left(F_{zk}\cdot Y_{zk}\right)$$
$$=F\cdot Z_3+W1\cdot Y_1$$
$$=-200\times30+150\times(-20)$$
$$=-9000\ (\text{N}\cdot\text{mm})$$

$$M2=\sum_{i=1}^{n}\left\{F_{xi}\left(Z_{xi}-Z_b\right)\right\}+\sum_{k=1}^{n}\left(F_{zk}\cdot X_{zk}\right)$$
$$=W1\cdot X_1$$
$$=150\times30$$
$$=4500\ (\text{N}\cdot\text{mm})$$

$$F_{r1}=\frac{\sum_{k=1}^{n}F_{zk}}{4}+\frac{M1}{2\cdot L}+\frac{M2}{2\cdot\ell}$$
$$=\frac{W1}{4}+\frac{M1}{2\cdot L_r}+\frac{M2}{2\cdot L_b}$$
$$=\frac{150}{4}+\frac{-9000}{2\times90}+\frac{4500}{2\times100}$$
$$=10\ (\text{N})$$

Similarly

$F_{r2}=-35\ (\text{N})$

$F_{r3}=110\ (\text{N})$

$F_{r4}=\ \ 65\ (\text{N})$

Lateral direction loads

$$M3=-\sum_{i=1}^{n}\left\{F_{xi}\cdot\left(Y_{xi}-Y_b\right)\right\}+\sum_{j=1}^{n}\left(F_{yj}\cdot X_{yj}\right)$$
$$=F\cdot X_3$$
$$=-200\times(-50)$$
$$=10000\ (\text{N}\cdot\text{mm})$$

$$F_{s1}=F_{s3}=\frac{\sum_{j=1}^{n}F_{yj}}{4}+\frac{M3}{2\cdot\ell}$$
$$=\frac{F}{4}+\frac{M3}{2\cdot L_b}$$
$$=\frac{-200}{4}+\frac{10000}{2\times100}$$
$$=0\ (\text{N})$$

Similarly

$F_{s2}=F_{s4}=-100\ (\text{N})$

For calculation, take into consideration the positive or negative signs (+, -) for load point coordinate.

Calculation of dynamic equivalent load

Use **"A-3-2.2 (3) Calculation of dynamic equivalent load."**

It matches Position 4 in **"Table 2.3 Loads in the arrangement of linear guides."** Ball slide loads that must be considered are vertical and lateral direction loads.

In case of LU15AL,

Vertical direction dynamic equivalent load

$F_r = F_r$

Lateral direction dynamic equivalent load

$F_{se} = F_s \cdot \tan\alpha = F_s$

Use the formula for full dynamic equivalent load (Page A23) to calculate F_e.

Results are shown in the table below.

Unit: N

Work mounted	Slide1	Slide2	Slide3	Slide4
F_r ($F_{r1}-F_{r4}$)	40	– 165	340	135
F_{se} ($F_{s1}-F_{s4}$)	0	– 100	0	– 100
F_e	40	215	340	185
No work mounted	Slide1	Slide2	Slide3	Slide4
F_r ($F_{r1}-F_{r4}$)	10	– 35	110	65
F_{se} ($F_{s1}-F_{s4}$)	0	– 100	0	– 100
F_e	10	118	110	133

Based on the results of calculations, a ball slide that bears the maximum dynamic equivalent load shall be taken as the representative of the linear guides for further life calculation. For this case, we take the Slide3.

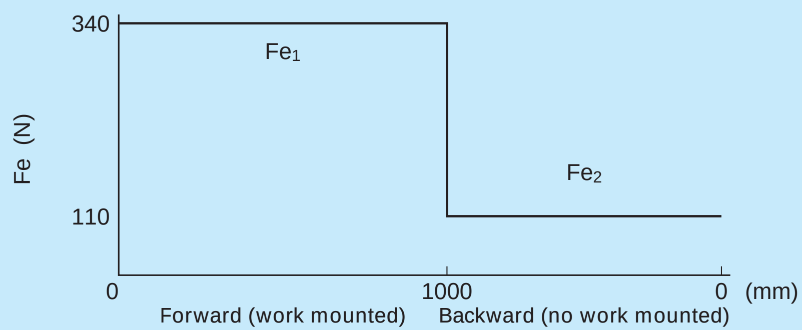
Therefore;

Work mounted $F_{e1}=340$ **(N)**

No work mounted $F_{e2}=110$ **(N)**

Calculation of mean effective load

Based on **"A-3-2.2 (4) Calculation of mean effective load,"** calculate from the largest full dynamic equivalent loads.



Cycle patterns of full dynamic equivalent load

From the cycle pattern, the mean effective load matches **"① When load and running distance vary by phase."** Therefore, use the following formula.

Assuming that L is: $L = L_1 + L_2$.

$$Fm = \sqrt[3]{\frac{1}{L}\left(F_{e1}^3 L_1 + F_{e2}^3 L_2\right)}$$

$$= \sqrt[3]{\frac{1}{2000}\left(340^3 \times 1000 + 110^3 \times 1000\right)}$$

$$= 273 \text{ (N)}$$

Determine various coefficients

Determine applicable coefficients from **"A-3-2.2 (5) Various coefficients."**

Load factors

Use conditions are: Travel speed, 12 m/min; Acceleration, 0.8 m/sec^2 (0.082G). As the load factor f_w is in the range of 1.0 to 1.5, use common value $\boldsymbol{f_w = 1.2}$.

Hardness coefficient

The hardness of NSK linear guides is HRC58 – 62. Use a hardness coefficient $\boldsymbol{f_H = 1}$ and take the value of basic dynamic load rating as it is.

Calculate rating life

Use **"A-3-2.2 (6) Calculation of rating life."**

The basic dynamic load rating (C) of linear guide LU15AL : 5550 (N)

Mean effective load F_m : 273 (N)

Load factor f_w : 1.2

Hardness coefficient f_H : 1

$$\text{Rating fatigue life } L = 50 \times \left(\frac{f_H \cdot C}{f_w \cdot F_m}\right)^3$$

$$= 50 \times \left(\frac{1 \times 5550}{1.2 \times 273}\right)^3$$

$$= \text{approximately } 243110 \text{ (km)}$$

Travel speed, 12 m/min; Operating hours, 16 hr/day.

Convert the above rating fatigue life into hours:

$$\frac{243110 \times 1000}{12 \times 60 \times 16} = \text{approximately } 21100 \text{ (days)}$$

Examine static load

Based on **"A-3-2.2 (7) Examination of static load,"** find out on which ball slide the static equivalent load P_0 becomes largest.

The basic static load rating (C_0) of linear guide LU15AL: 6600 (N)

Ball slide No. 3 bears the largest load.

P_0 at this time:

$P_0 = F_r + F_s = 340$

Therefore, static permissible load coefficient fs is:

$$fs = \frac{C_0}{P_0} = \frac{6600}{340} = 19.4$$

There is no problem at this value.

(1)-3 Selection of accuracy grade and preload

Based on **"A-1-3.4 (2) Application examples of accuracy,"** select accuracy grade PN and preload Z1 for material handling system.

(1)-4 Calculation of deformation

Calculate deformation by the weight of the mounted work W_2. From **"Rigidity of LU series,"** the rigidity of linear guide LU15AL with Z1 preload is:

$\boldsymbol{K_s = K_r = 45}$ **(N/μm) = 45000 (N/mm)**

Deformation by the weight of the mounted work W_2 can be obtained as the difference in deformation when W_2 applies or does not apply.

From Pattern 4 in Table 2.2 (Page A19)

Work mounted:

$$\delta_{x1} = Y_d \cdot \frac{F_{s2} - F_{s1}}{L_b \cdot K_s} + Z_d \cdot \frac{F_{r1} - F_{r2}}{L_b \cdot K_r}$$

$$= -90 \times \frac{-100 - 0}{100 \times 45000} + 120 \times \frac{40 - (-165)}{100 \times 45000}$$

$$= 0.0075 \text{ (mm)} = 7.5 \text{ (μm)}$$

Similarly, δ_{y1} = – 0.0082 (mm) = – 8.2 (μm)

δ_{z1} = 0.0123 (mm) = 12.3 (μm)

No work mounted:

$$\delta_{x2} = Y_d \cdot \frac{F_{s2} - F_{s1}}{L_b \cdot K_s} + Z_d \cdot \frac{F_{r1} - F_{r2}}{L_b \cdot K_r}$$

$$= -90 \times \frac{-100 - 0}{100 \times 45000} + 120 \times \frac{10 - (-35)}{100 \times 45000}$$

$$= 0.0032 \text{ (mm)} = 3.2 \text{ (μm)}$$

Similarly, δ_{y2} = –0.0023 (mm) = –2.3 (μm)

δ_{z2} = 0.0039 (mm) = 3.9 (μm)

Therefore, the difference in deformation by whether there is a mounted work or not is as follows:

$\delta_x = \delta_{x1} - \delta_{x2}$ = 7.5 –3.2 = 4.3 (μm)

$\delta_y = \delta_{y1} - \delta_{y2}$ = –8.2 – (–2.3) = –5.9 (μm)

$\delta_z = \delta_{z1} - \delta_{z2}$ = 12.3 –3.9 = 8.4 (μm)

(2) Machining Center

The following is a case calculation for a horizontal type machining center. Arrangements of each axis are shown in Fig. 10.2 and Fig. 10.3.

Operating conditions

Dimensions and load conditions are:

X axis column's weight	Wx	: 7500 (N)
Y axis spindle head's weight	Wy	: 2500 (N)
Z axis table's weight	Wz	: 5500 (N)
X axis rail span	XL_r	: 450 (mm)
X axis ball slide span	XL_b	: 310 (mm)
Y axis rail span	YL_r	: 410 (mm)
Y axis ball slide span	YL_b	: 308 (mm)
Z axis rail span	ZL_r	: 660 (mm)
Z axis ball slide span	ZL_b	: 420 (mm)

X axis stroke : 400 (mm)

Y axis stroke : 350 (mm)

Z axis stroke : 500 (mm)

Average rapid traverse speed	: 15 (m/min) [Max. 30 (m/min)]
Starting accelerating speed	: 1 (G)
Milling speed	: 2.5 (m/min)
Drilling speed	: 0.8 (m/min)

Cutting load

Milling process $Fx = Fy$ = 1000 (N)

Drilling process Fz = 3000 (N)

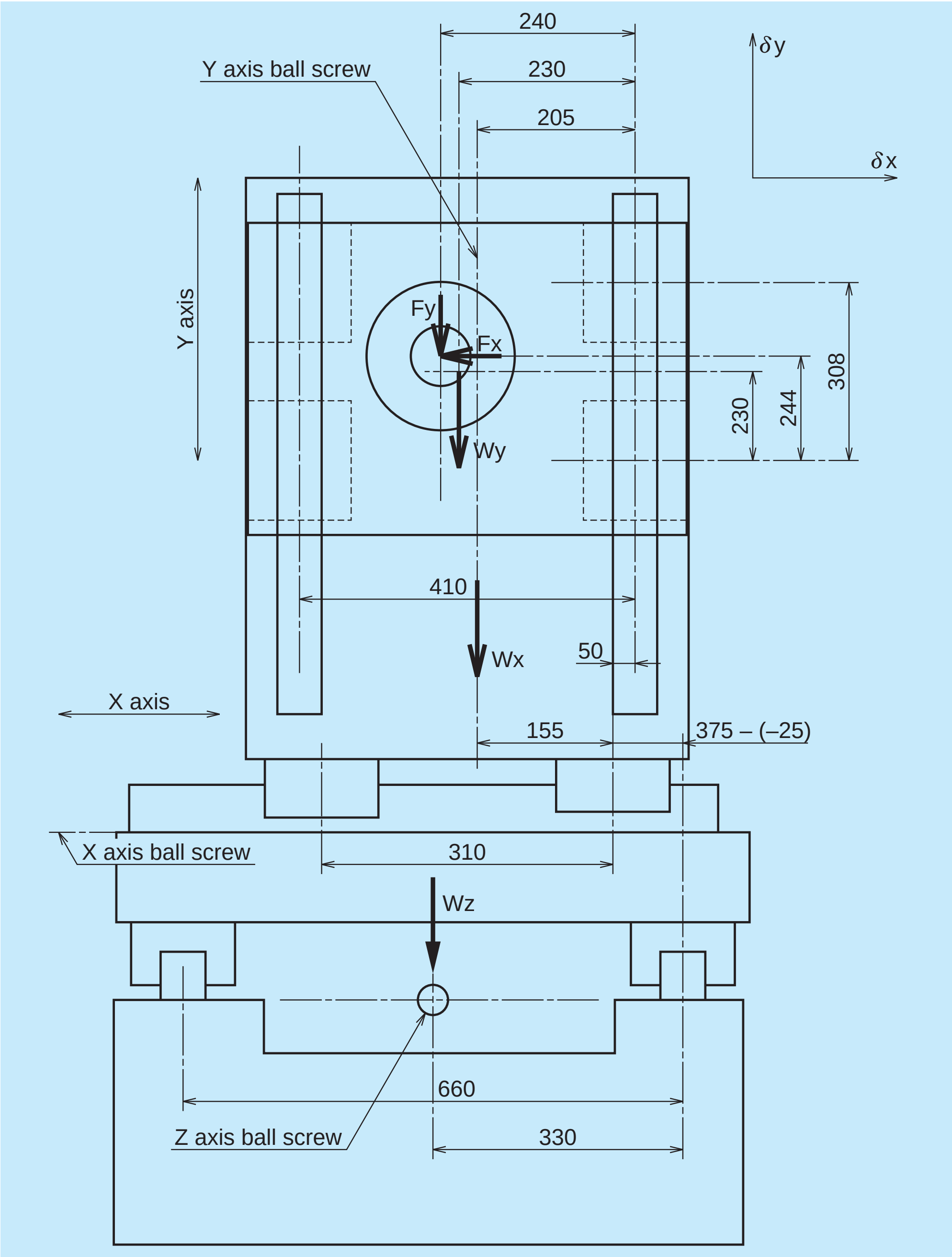


Fig. 10.2 Machining center (front view)

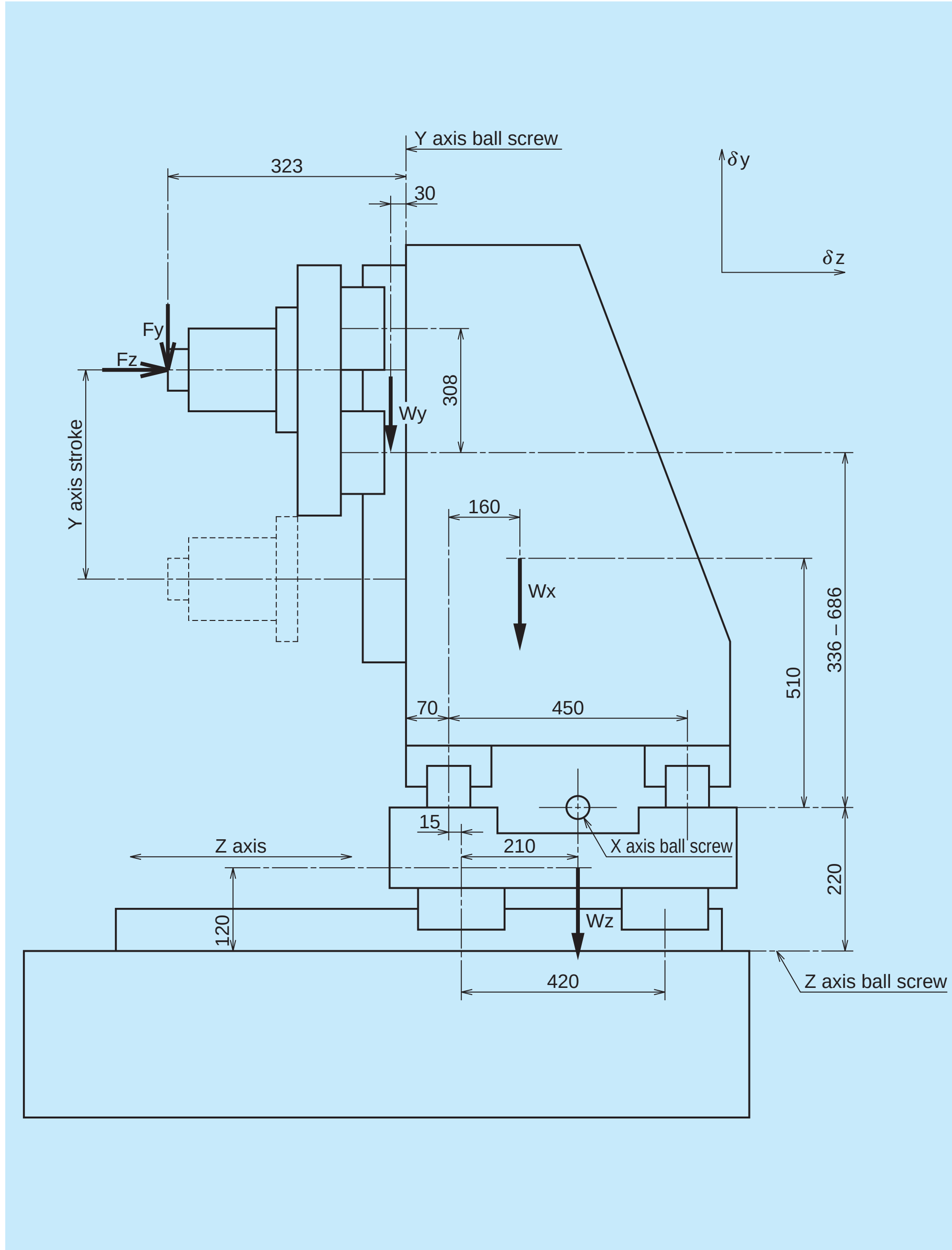


Fig. 10.3 Machining center (side view)

(2)-1 Selection of linear guide model

From the operating conditions, the linear guide should be LA Series which is suitable for the machining center.

Select below temporaly from shaft diameter of ball screw:

X axis LA55
Y axis LA35
Z axis LA65

(2)-2 Calculation of life expectation

Examination shall be done in three cases, no cutting load; milling process; and drilling process.

Inertial force associated with the starting acceleration is not considered in this case. However, it must be calculated for more accurate figures.

Calculation of the loads that apply to the ball slide

In case of no cutting load: $F_x = F_y = F_z = 0$

Calculate load on X, Y, Z axes using **"Table 2.2"** in **"A-3-2.2 (2) Calculating load to a ball slide."**

X axis: Loads to consider Wx and Wy
Y axis: Loads to consider Wy
Z axis: Loads to consider Wx, Wy, and Wz

Unit: N

Axis	Load direction	Slide1	Slide2	Slide3	Slide4
X axis	Vertical direction F_r	1156	955	4045	3844
	Lateral direction F_s	0	0	0	0
Y axis	Vertical direction F_r	122	−122	122	−122
	Lateral direction F_s	102	−102	102	−102
Z axis	Vertical direction F_r	765	3860	3890	6985
	Lateral direction F_s	0	0	0	0

In case of milling process: $F_x = F_y = 1000$ (N)

Similarly,
X axis: Loads to consider W_x, W_y, F_x, and F_y
Y axis: Loads to consider W_y, F_x, and F_y
Z axis: Loads to consider W_x, W_y, W_z, F_x, and F_y

The table below shows calculation of each load coordinates at stroke end which imposes most strict condition.

Unit: N

Axis	Load direction	Slide1	Slide2	Slide3	Slide4
X axis	Vertical direction F_r	2277	−1039	6539	3224
	Lateral direction F_s	997	−997	997	−997
Y axis	Vertical direction F_r	252	−1040	1040	−252
	Lateral direction F_s	54	−554	54	−554
Z axis	Vertical direction F_r	−771	3796	4453	9020
	Lateral direction F_s	486	−986	486	−986

In case of drilling process: $F_z = 3000$ (N)

X axis: Loads to consider W_x, W_y, and F_z
Y axis: Loads to consider W_y and F_z
Z axis: Loads to consider W_x, W_y, W_z, and F_z

The table below shows calculation of each load coordinates at a stroke end which imposes most strict condition.

Unit: N

Axis	Load direction	Slide1	Slide2	Slide3	Slide4
X axis	Vertical direction F_r	4256	4055	945	744
	Lateral direction F_s	919	581	919	581
Y axis	Vertical direction F_r	305	938	561	1195
	Lateral direction F_s	102	−102	102	−102
Z axis	Vertical direction F_r	4872	−247	7997	2878
	Lateral direction F_s	839	−839	839	−839

Calculation of dynamic equivalent load

Next, find dynamic equivalent load under each cutting condition. From **"Table 2.3"** in **"A-3-2.2 (3) Calculation of dynamic equivalent load,"** necessary load F_r and F_{se} are, as the linear guide model is LA Series, obtained as follows.

Vertical dynamic equivalent load

$$F_r = F_r$$

Lateral dynamic equivalent load

$$F_{se} = F_s \cdot \tan\alpha = F_s$$

From above, calculate F_e using formulas for full dynamic equivalent loads shown in Page A23.

From calculation, the largest full dynamic equivalent loads are as follows.

Axis	Largest full dynamic equivalent load Fe (N)		
	No cutting load	For milling process	For drilling process
X axis	4045	7038	4716
Y axis	173	1317	1246
Z axis	6985	9513	8417

Calculation of mean effective load

Calculate the mean effective loads from full dynamic equivalent loads. If duty cycle in the cutting process is not clear, set at 70% of the largest full dynamic equivalent load in all processes.

Therefore,

X axis: 7038 × 0.7 = 4927 (N)
Y axis: 1317 × 0.7 = 922 (N)
Z axis: 9513 × 0.7 = 6659 (N)

Determine various coefficients

Determine based on **"A-3-2.2 (5) Various coefficients."**

In this occasion,

Load coefficient f_w : 1.5

Hardness coefficient f_H : 1

Calculation of rating life

Based on the calculated loads and various coefficients, calculate life from **"A-3-2.2 (6) Calculation of rating life."**

Basic dynamic load rating C

(X axis linear guide LA55): 139000 (N)

Basic dynamic load rating C

(Y axis linear guide LA35): 61500 (N)

Basic dynamic load rating C

(Z axis linear guide LA65): 260000 (N)

Load coefficient f_W: 1.5

Hardness coefficient f_H: 1

Rating fatigue life $L = 50 \times \left(\frac{f_H \cdot C}{f_w \cdot F_m}\right)^3$

From this,

In case of X axis Lx = 332650 (km)

In case of Y axis Ly = 4396720 (km)

In case of Z axis Lz = 881830 (km)

In case of roller, shown in **A-3-2.2 (6) "Calculation of rating life"** (Page A26)

Examination of static loads based on "A-3-2.2 (7)"

Basic static load rating C_0

(X axis linear guide LA55): 215000 (N)

Basic static load rating C_0

(Y axis linear guide LA35): 98000 (N)

Basic static load rating C_0

(Z axis linear guide LA65): 420000 (N)

Examine for milling process with large load.

$$\text{X axis } fs = \frac{C_0}{P_0} = \frac{C_0}{(F_r + F_s)} = \frac{215000}{(6539 + 997)} = 28.5$$

Similarly,

Y axis fs = 61.5

Z axis fs = 42.0

Therefore, there is no problem.

(2)-3 Selection of accuracy grade and preload

For machining center, select accuracy grade P5, and preload Z3.

(2)-4 Calculation of deformation

Calculate deformation at processing points (stroke position is the stroke end positions on Y axis and X axis)

Rigidity of X axis linear guide LA55Z3 : 1400 (N/μm)

Rigidity of Y axis linear guide LA35Z3 : 825 (N/μm)

Rigidity of Z axis linear guide LA65Z3 : 1730 (N/μm)

Calculate using Pattern 4 in Table 2.2.

Load conditions	Deformation direction	Deformation of each axis (μm)			Total deformation (μm)
		X axis	Y axis	Z axis	
Table weight alone	δx	−0.2	−0.1	−3.1	−3.4
	δy	−4.6	−0.3	−4.2	−9.1
	δz	−4.3	−0.1	−4.9	−9.3
Milling process	δx	−9.9	−1.3	−6.7	−17.9
	δy	−6.4	−1.7	−5.2	−13.3
	δz	−6.1	−0.4	−7.7	−14.2
Drilling process	δx	−0.9	−0.3	−4.6	−5.8
	δy	1.4	0.8	2.8	5.0
	δz	5.5	1.2	7.6	14.3

Therefore, deformation at processing points at time of milling is:

δx = −17.9 − (−3.4) = −14.5 (μm)

δy = −13.3 − (−9.1) = −4.2 (μm)

δz = −14.2 − (−9.3) = −4.9 (μm)

Deformation at processing points at time of milling:

δx = −5.8 − (−3.4) = −2.4 (μm)

δy = 5.0 − (−9.1) = 14.1 (μm)

δz = 14.3 − (−9.3) = 23.6 (μm)

If a life of this long period is not required, select a smaller linear guide model, and calculate life again.

To reduce deformation at processing point, select a linear guide model with higher rigidity. Then calculate life again.

A-3-11 Reference

The articles in "Motion & Control (NSK Technical Journals)" which refer to NSK linear guides are listed in the table below for user convenience.

"Motion & Control" is compiled to introduce NSK products and its technologies.

For inquiries and orders of "Motion & Controls," please contact your local NSK sales offices, or representatives.

Table 11.1 Motion & Control (NSK Technical Journal): Articles relating to linear guides (1997 –)

Issue No.	Date of Publication	Articles related to linear guides
No.5	Dec. 1998	Development of the NSK K1 Seal for Linear Guides
No.8	May. 2000	NSK Linear Guides for High-Temperature Environments
No.9	Oct. 2000	Recent Developments in Highly Precise NSK Linear Guides
No.9	Oct. 2000	High-Performance Seals for NSK Linear Guides
No.11	Oct. 2001	Development of the NSK S1 Series™ Ball Screws and Linear Guides High Load Capacity Mini LH Series of NSK Linear Guides
No.12	Apr. 2002	NSK Linear Guides & Ball Screws Equipped with NSK K1™ Lubrication Unit
No.12	Apr. 2002	NSK S1 Series, NSK Linear Guides and Ball Screws
No.13	Oct. 2002	Translide™ -New Rolling Element Linear Motion Bearing-
No.14	May. 2003	New Generation of NSK Linear Guides Miniature PU Series
No.15	Dec. 2003	Ultra-Precision NSK Linear Guides for Machine Tools-the HA Series
No.16	Aug. 2004	Numerical analysis Technology & NSK Linear Guides for Machine Tools
No.16	Aug. 2004	NSK RA Series Roller Guide
No.18	Aug. 2005	New Generation of NSK linear Guides Miniature PU Series/PE Series
No.20	Aug. 2007	V1 Series of Highly Dust-Resistant NSK Linear Guides