

A-II-9.6 Handling Preloaded Assembly

- In case of the preloaded assembly (non interchangeable), do not remove ball slides from the rail as a general rule.
- If it is unavoidable to remove ball slide from the rail, make certain to use a provisional rail (a tool used to insert a ball slide to the rail) as shown in Fig. II-9-27.
- Provisional rail for each model is in stock.
- Pay due attention to the assembly mark when returning the ball slide back to the rail. Follow the cautions described below.

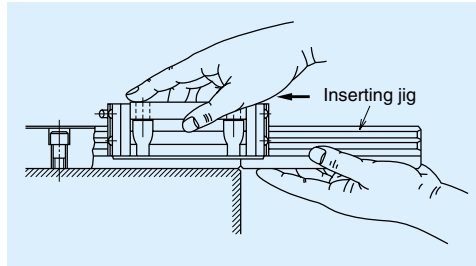


Fig. II-9-27

Mark for assembling ball slide and rail

- Rails of preloaded assembly (not interchangeable) are marked with a reference number and a serial number on the opposite of the datum face.
- Ball slide to be combined are also marked with the same serial number (reference number is not marked).
- Furthermore, ball slides are marked with an arrow. Ball slides should be positioned with their arrows facing each other.
- In case that the ball slides had to be removed from the rail, confirm their serial numbers and the directions of arrows for re-assembly (Fig. II-9-28).
- When two or more rails are used in a single set, serial numbers are in sequence if their reference numbers are the same. The linear guide with smallest serial number has the "KL" mark (Fig. II-9-29).
- When two or more rails of different reference number are used in a single set, the rails and ball slides have the same serial number. In this case, when ball slide is removed from the rail, it is confusing which rail each ball slide was previously installed. When removing ball slides from the rail for an unavoidable reason (Fig. II-9-30), sufficient precaution is required.

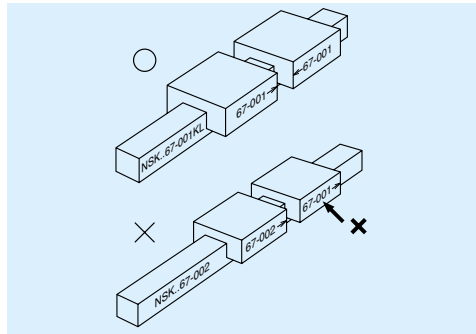


Fig. II-9-28

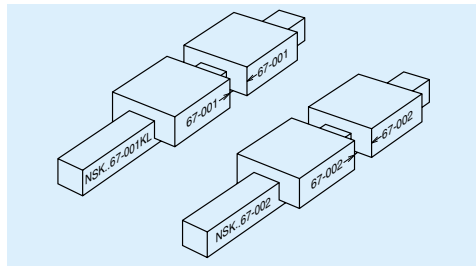


Fig. II-9-29 When two rails have the same reference number

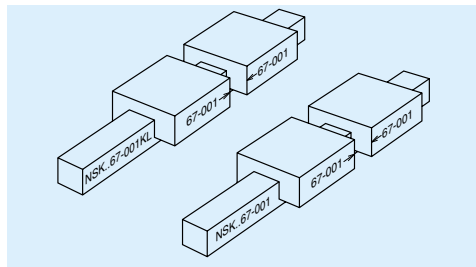


Fig. II-9-30 When two rails have different reference number

A-II-10 Drills to Select Linear Guide

A-II-10.1 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.

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) Selection of linear guide model

Select a type of linear guide from "A-I-2.1 Types and Characteristics of Linear Guide." Since this material handling system has 2 rails and 4 ball slides, LH, LS, and LU Series are suitable.

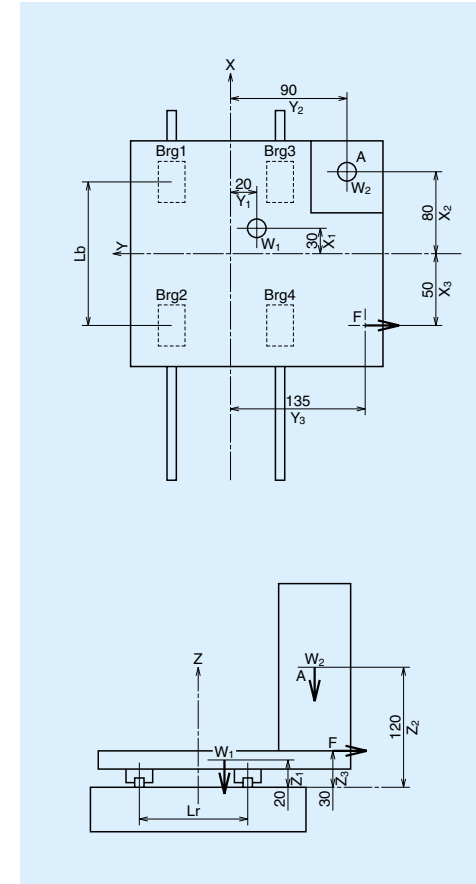


Fig. II-10-1 Single axis material handling system

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.

(2) Selection of size (model number)

Select a size (model number) from "A-II-3.2 Calculation of Life Expectancy (3) Calculating loads to a ball slide."

Calculating load P per ball slide

Find out potential coefficients **Kp1** (for vertical load W1), **Kp2** (for vertical load W2) and **Kp3** (load F right angle direction to the axis).

From load point coefficients, the potential coefficient **Kp1** of vertical direction load **W1** is:

$$Kp1 = \frac{|X_1|}{L_b} + \frac{|Y_1|}{L_r} = \frac{30}{100} + \frac{20}{90} = 0.52$$

From load point coefficients, the potential coefficient **Kp2** of vertical load **W2** is:

$$Kp2 = \frac{|X_2|}{L_b} + \frac{|Y_2|}{L_r} = \frac{80}{100} + \frac{90}{90} = 1.80$$

From load point coefficients, the potential coefficient **F** of lateral load is:

$$Kp3 = \frac{|X_3|}{L_b} + \frac{|Z_3|}{L_r} = \frac{50}{100} + \frac{30}{90} = 0.83$$

Therefore, **load P** per ball slide is:

$$P = \sum \frac{F}{4} + \sum \frac{Kp \cdot F}{2}$$

$$= \frac{W1 + W2 + F}{4} + \frac{Kp1 \cdot W1 + Kp2 \cdot W2 + Kp3 \cdot F}{2}$$

$$= \frac{150 + 200 + 200}{4} + \frac{0.52 \times 150 + 1.8 \times 200 + 0.83 \times 200}{2}$$

$$= 439.5(N)$$

Based on this, select **LU15AL** from "Fig. I-3-4 Selection based on the load "

(3) Calculating life

Calculate life of the selected LU15AL based on "A-II-3.2 Calculation of Life Expectancy."

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 0.8m/sec². 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 II-3-2

There is a work mounted on the table

Vertical direction loads

$$M1 = \sum_{j=1}^n (F_{yj} \cdot Z_{yj}) + \sum_{k=1}^n (F_{zk} \cdot Y_{zk})$$

$$= F \cdot Z_3 + W1 \cdot Y_1 + W2 \cdot Y_2$$

$$= -200 \times 30 + 150 \times (-20) + 200 \times (-90)$$

$$= -27000 (N \cdot mm)$$

$$M2 = \sum_{i=1}^n \{F_{xi} \cdot (Z_{xi} - Z_b)\} + \sum_{k=1}^n (F_{zk} \cdot X_{zk})$$

$$= W1 \cdot X_1 + W2 \cdot X_2$$

$$= 150 \times 30 + 200 \times 80$$

$$= 20500 (N \cdot mm)$$

$$F_{r1} = \frac{\sum_{k=1}^n F_{zk}}{4} + \frac{M1}{2 \cdot L} + \frac{M2}{2 \cdot \ell}$$

$$= \frac{W1 + W2}{4} + \frac{M1}{2 \cdot L_r} + \frac{M2}{2 \cdot L_b}$$

$$= \frac{150 + 200}{4} + \frac{-27000}{2 \times 90} + \frac{20500}{2 \times 100}$$

$$= 40 (N)$$

Similarly

$$F_{r2} = -165 (N)$$

$$F_{r3} = 340 (N)$$

$$F_{r4} = 135 (N)$$

Lateral direction loads

$$M3 = -\sum_{i=1}^n \{F_{xi} \cdot (Y_{xi} - Y_b)\} + \sum_{j=1}^n (F_{yj} \cdot X_{yj})$$

$$= F \cdot X_3$$

$$= -200 \times (-50)$$

$$= 10000 (N \cdot mm)$$

$$F_{s1} = F_{s3} = \frac{\sum_{j=1}^n F_{yj}}{4} + \frac{M3}{2 \cdot \ell}$$

$$= \frac{F}{4} + \frac{M3}{2L_b}$$

$$= \frac{-200}{4} + \frac{10000}{2 \times 100}$$

$$= 0 (N)$$

Similarly

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

No work mounted on the table

Vertical direction load

$$M1 = \sum_{j=1}^n (F_{yj} \cdot Z_{yj}) + \sum_{k=1}^n (F_{zk} \cdot Y_{zk})$$

$$= F \cdot Z_3 + W1 \cdot Y_1$$

$$= -200 \times 30 + 150 \times (-20)$$

$$= -9000 (N \cdot mm)$$

$$M2 = \sum_{i=1}^n \{F_{xi} \cdot (Z_{xi} - Z_b)\} + \sum_{k=1}^n (F_{zk} \cdot X_{zk})$$

$$= W1 \cdot X_1$$

$$= 150 \times 30$$

$$= 4500 (N \cdot mm)$$

$$F_{r1} = \frac{\sum_{k=1}^n F_{zk}}{4} + \frac{M1}{2 \cdot L} + \frac{M2}{2 \cdot \ell}$$

$$= \frac{W1}{4} + \frac{M1}{2 \cdot L_r} + \frac{M2}{2 \cdot L_b}$$

$$= \frac{150}{4} + \frac{-9000}{2 \times 90} + \frac{4500}{2 \times 100}$$

$$= 10 (N)$$

Similarly

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

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

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

Lateral direction loads

$$M3 = -\sum_{i=1}^n \{F_{xi} \cdot (Y_{xi} - Y_b)\} + \sum_{j=1}^n (F_{yj} \cdot X_{yj})$$

$$= F \cdot X_3$$

$$= -200 \times (-50)$$

$$= 10000 (N \cdot mm)$$

$$F_{s1} = F_{s3} = \frac{\sum_{j=1}^n F_{yj}}{4} + \frac{M3}{2 \cdot \ell}$$

$$= \frac{F}{4} + \frac{M3}{2 \cdot L_b}$$

$$= \frac{-200}{4} + \frac{10000}{2 \times 100}$$

$$= 0 (N)$$

Similarly

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

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

Calculation of dynamic equivalent load

Use "A-II-3.2 (4) Calculation of dynamic equivalent load."

It matches Position 4 in "Table II-3-3 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

$$F_v = F$$

Lateral direction dynamic equivalent load

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

Use the formula for full dynamic equivalent load (Page A173) to calculate F_e .

Results are shown in the table below.

Unit: N

Work mounted	Brg1	Brg2	Brg3	Brg4
$F_r (F_{r1} \sim F_{r4})$	40	- 165	340	135
$F_{se} (F_{s1} \sim F_{s4})$	0	- 100	0	- 100
F_e	40	215	340	185
No work mounted	Brg1	Brg2	Brg3	Brg4
$F_r (F_{r1} \sim F_{r4})$	10	- 35	110	65
$F_{se} (F_{s1} \sim F_{s4})$	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 Brg3.

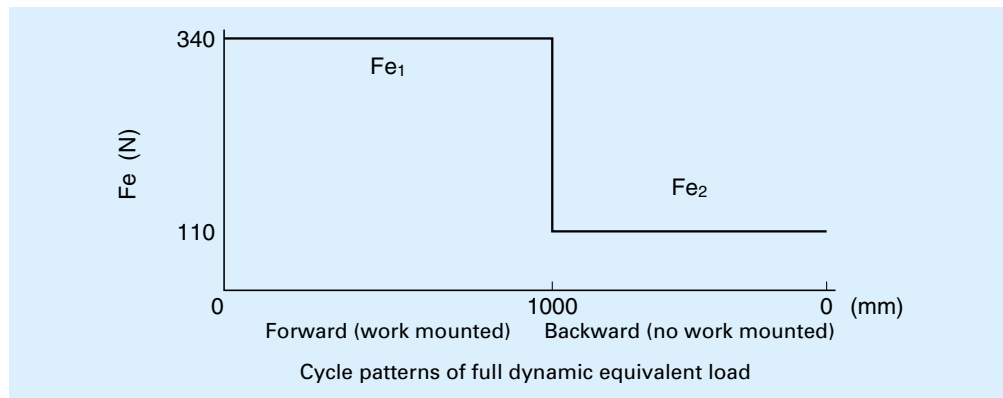
Therefore;

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

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

Calculation of mean effective load

Based on "A-II-3.2 (5) Calculation of mean effective load," calculate from the largest full dynamic equivalent loads.



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: $L = L_1 + L_2$.

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

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

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

Determine various coefficients

Determine applicable coefficients from "A-II-3.2 (6) Various coefficients."

Load factors

Use conditions are: Travel speed -- 12 m/min; Acceleration -- 0.8m/ sec² (0.082G). As the load factor f_w is in the range of 1.0 ~ 1.5, use common value $f_w = 1.2$.

Hardness coefficient

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

Calculate rating life

Use "A-II-3.2 (7) Calculation of rating life."

Linear guide LU15AL's basic dynamic load rating C : 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: 16hr/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-II-3.2 (8) Examination of static load," find out on which ball slide the static equivalent load P_0 becomes largest.

Linear guide LU15AL's basic static load rating C_0 : 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 f_s is:

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

There is no problem at this value.

(4) Selection of accuracy grade and preload

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

(5) Calculation of deformation

Calculate deformation by the weight of the mounted work W_2 . From "Table II-2-11" in "A-II-2 Preload and Rigidity," the rigidity of linear guide LU15AL with Z1 preload is:

$$K_s = K_r = 45 \text{ (N / } \mu\text{m)} = 45000 \text{ (N / mm)}$$

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 II-3-2 (Page A168)

Work mounted:

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

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

$$= 0.0075 \text{ (mm)} = 7.5 \text{ (} \mu\text{m)}$$

Similarly, $\delta_{y1} = -0.0082 \text{ (mm)} = -8.2 \text{ (} \mu\text{m)}$

$$\delta_{z1} = 0.0123 \text{ (mm)} = 12.3 \text{ (} \mu\text{m)}$$

No work mounted:

$$\begin{aligned} \delta_{x2} &= Y_d \cdot \frac{F_{s2} - F_{s1}}{L_b \cdot K_s} + Z_d \cdot \frac{F_{r1} - F_{r2}}{L_b \cdot K_r} \\ &= -90 \times \frac{-100 - 0}{100 \times 45000} + 120 \times \frac{10 - (-35)}{100 \times 45000} \\ &= 0.0032(\text{mm}) = 3.2(\mu\text{m}) \end{aligned}$$

Similarly, $\delta_{y2} = -0.0023(\text{mm}) = -2.3(\mu\text{m})$

$$\delta_{z2} = 0.0039(\text{mm}) = 3.9(\mu\text{m})$$

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

$$\begin{aligned} \delta_x &= \delta_{x1} - \delta_{x2} = 7.5 - 3.2 = 4.3(\mu\text{m}) \\ \delta_y &= \delta_{y1} - \delta_{y2} = -8.2 - (-2.3) = -5.9(\mu\text{m}) \\ \delta_z &= \delta_{z1} - \delta_{z2} = 12.3 - 3.9 = 8.4(\mu\text{m}) \end{aligned}$$

A-II-10.2 Machining Center

The following is a case calculation for a horizontal type machining center. Arrangements of each axis are shown in Fig. II-10*2 and Fig. II-10*3.

Operating conditions

Dimensions and load conditions are:

X axis column's weight	W_x : 7500 (N)
Y axis spindle head's weight	W_y : 2500 (N)
Z axis table's weight	W_z : 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)

Cutting load	
Milling process	$F_x = F_y = 1000$ (N)
Drilling process	$F_z = 3000$ (N)

- 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)

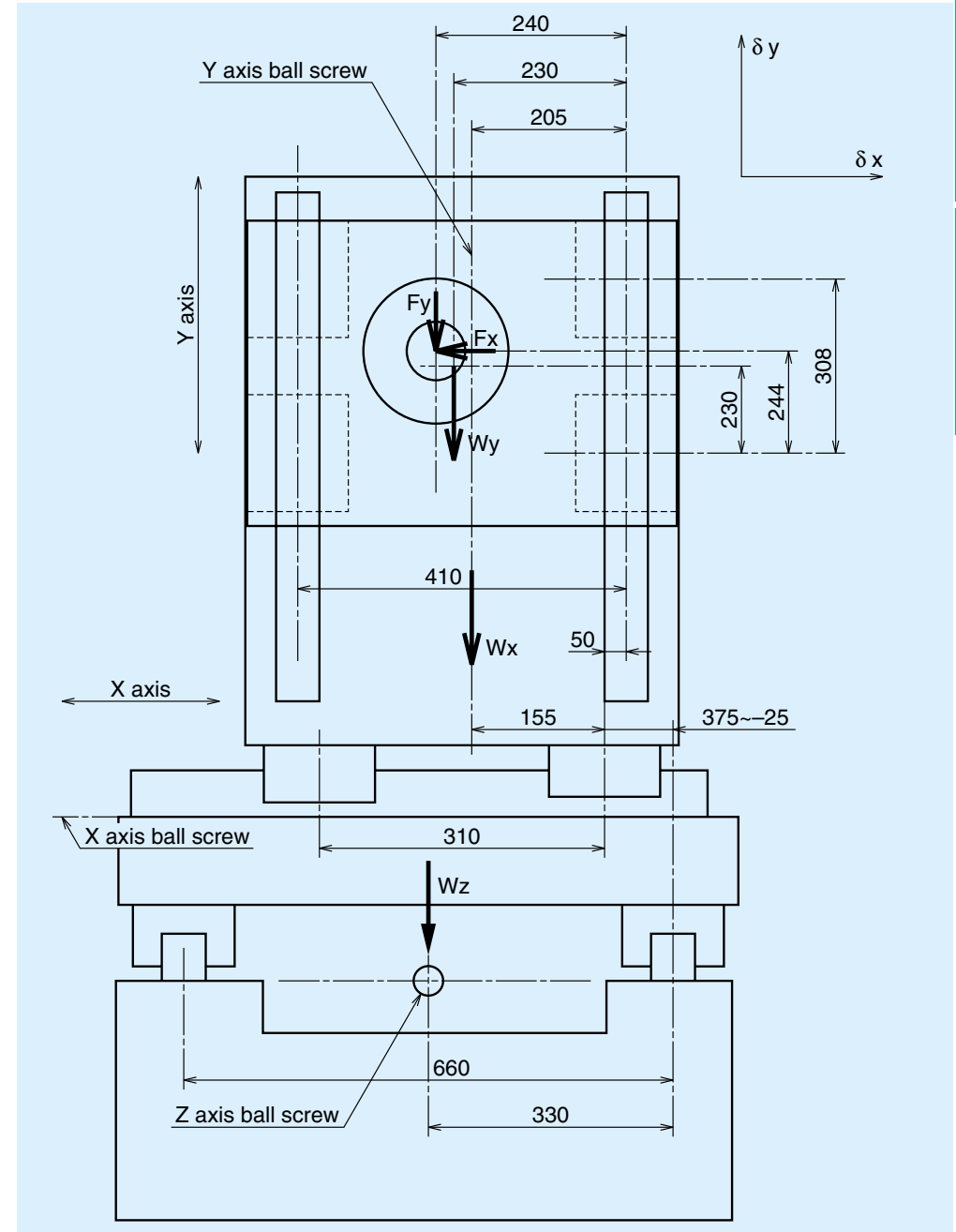


Fig. II-10*2 Machining center (front view)

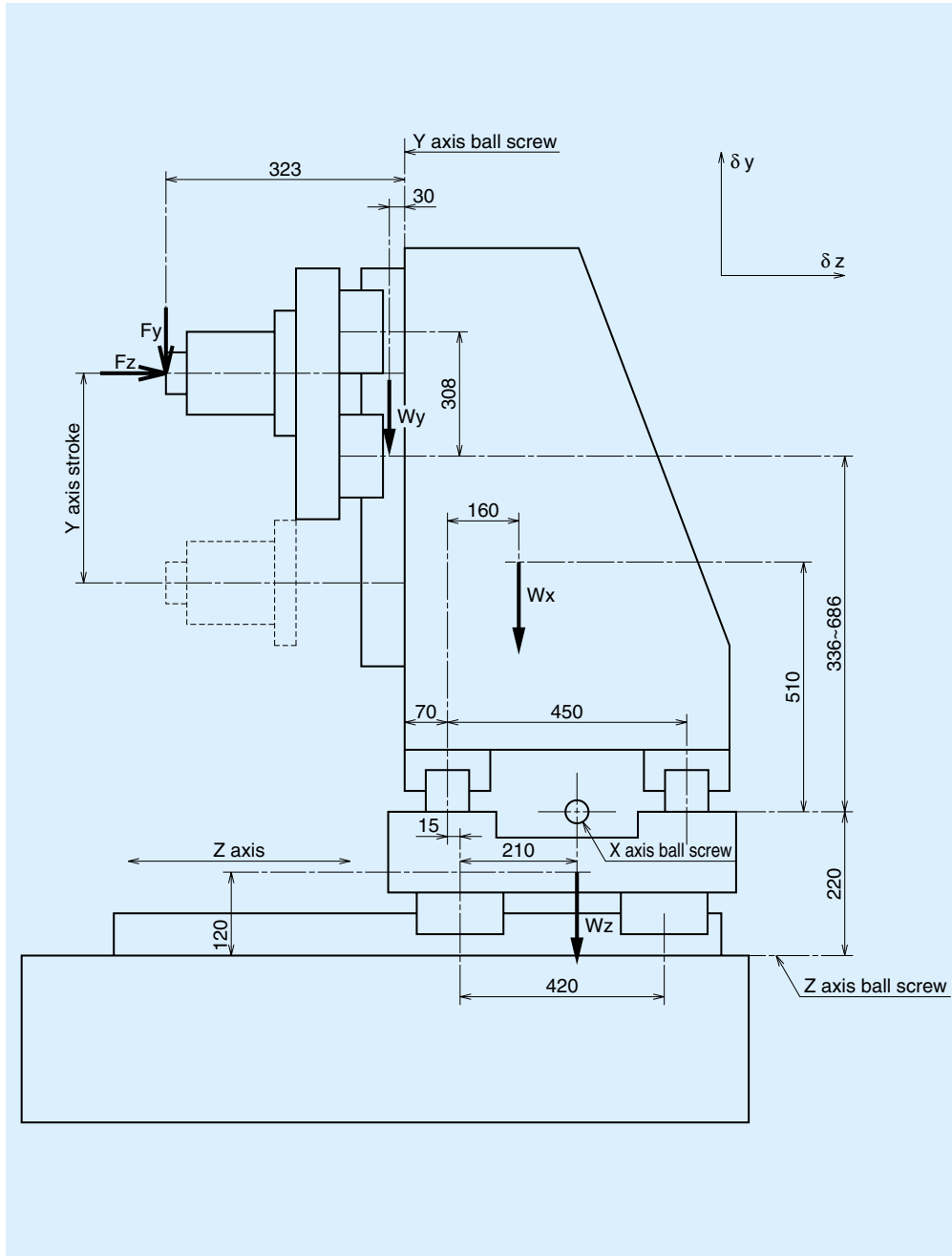


Fig. II -10-3 Machining center (side view)

(1) Selection of linear guide model

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

(2) Selection of linear guide size (model number)

Start selection from Y axis which has fewer acting loads.

Coordinates of load points are as follows.

$W_y (X_{W_y}, Y_{W_y}, Z_{W_y}) = (-25, 76, -30)(mm)$

$F_x (X_{F_x}, Y_{F_x}, Z_{F_x}) = (-35, 90, -323)(mm)$

$F_y (X_{F_y}, Y_{F_y}, Z_{F_y}) = (-35, 90, -323)(mm)$

$F_z (X_{F_z}, Y_{F_z}, Z_{F_z}) = (-35, 90, -323)(mm)$

Ball slide span : $Y_{L_b} = 308 mm$

Rail span : $Y_{L_r} = 410 mm$

First, find out the load volume P per ball slide in milling process (P_{yf}) and drilling process (P_{yd}). Refer to "A-I-3.2 Selection of linear guide size (model code)."

Position coefficients at time of milling process (W_y, F_x and F_y must be considered.)

Regarding W_y : From load application coordinates

$$K_{py1} = \frac{|Z_{W_y}|}{Y_{L_b}} + \frac{|X_{W_y}|}{Y_{L_r}} = \frac{30}{308} + \frac{25}{308} = 0.10 + 0.08 = 0.18$$

Regarding F_x : From load point coordinates

$$K_{py2} = \frac{|Y_{F_x}|}{Y_{L_b}} + \frac{|Z_{F_x}|}{Y_{L_r}} = \frac{90}{308} + \frac{323}{410} = 0.29 + 0.79 = 1.08$$

Regarding F_y : From load point coordinates

$$K_{py3} = \frac{|Z_{F_y}|}{Y_{L_b}} + \frac{|X_{F_y}|}{Y_{L_r}} = \frac{323}{308} + \frac{35}{308} = 1.05 + 0.11 = 1.16$$

Therefore, load volume P_{fy} is:

$$P_{fy} = \sum \frac{F}{4} + \sum \frac{K_p \cdot F}{2} = \frac{W_y + F_x + F_y}{4} + \frac{K_{py1} \cdot W_y + K_{py2} \cdot F_x + K_{py3} \cdot F_y}{2} = \frac{2500 + 1000 + 1000}{4} + \frac{0.18 \times 2500 + 1.08 \times 1000 + 1.16 \times 1000}{2} = 2470 (N)$$

Position coefficients at time of drilling processing (W_y and F_z must be considered.)

Regarding W_y , as in the case for milling process,

$K_{py1} = 0.18$

Regarding F_z : From load point coefficient

$$K_{py4} = \frac{|Y_{F_z}|}{Y_{L_b}} + \frac{|X_{F_z}|}{Y_{L_r}} = \frac{90}{308} + \frac{35}{410} = 0.29 + 0.09 = 0.38$$

Therefore, load volume P_{yd} is:

$$P_{yd} = \sum \frac{F}{4} + \sum \frac{K_p \cdot F}{2} = \frac{W_y + F_z}{4} + \frac{K_{py1} \cdot W_y + K_{py4} \cdot F_z}{2} = \frac{2500 + 3000}{4} + \frac{0.18 \times 2500 + 0.38 \times 3000}{2} = 2170 (N)$$

From the above results, for milling process with large values, select a model LY 35 from Fig. I-3-4. for Y axis.

Next, determine the linear guide size for X axis. As with Y axis, the distance from the center of the table to the loads and their load points are shown. The stroke position on Y axis is the top point which imposes strict condition.

$W_x (X_{W_x}, Y_{W_x}, Z_{W_x}) = (0, 510, -65)(mm)$

$W_y (X_{W_y}, Y_{W_y}, Z_{W_y}) = (-25, 916, -325)(mm)$

$F_x (X_{F_x}, Y_{F_x}, Z_{F_x}) = (-35, 930, -618)(mm)$

$F_y (X_{F_y}, Y_{F_y}, Z_{F_y}) = (-35, 930, -618)(mm)$

$F_z (X_{F_z}, Y_{F_z}, Z_{F_z}) = (-35, 930, -618)(mm)$

Ball slide span : $Y_{L_b} = 310 (mm)$

Rail span : $Y_{L_r} = 450 (mm)$

Also, determine per-ball slide load volume P_{fx} and P_{xd} .

Position coefficients at time of milling process (W_x, W_y, F_x and F_y must be considered)

Regarding W_x : From load point coordinates

$$K_{px1} = \frac{|X_{W_x}|}{X_{L_b}} + \frac{|Z_{W_x}|}{X_{L_r}} = \frac{0}{310} + \frac{65}{450} = 0 + 0.14 = 0.14$$

Regarding W_y : From load point coordinates

$$K_{px2} = \frac{|X_{W_y}|}{X_{L_b}} + \frac{|Z_{W_y}|}{X_{L_r}} = \frac{25}{310} + \frac{325}{450} = 0.08 + 0.72 = 0.8$$

Regarding F_x : From load point coordinates

$$K_{px3} = \frac{|Y_{F_x}|}{X_{L_b}} + \frac{|Z_{F_x}|}{X_{L_r}} = \frac{930}{310} + \frac{618}{310} = 3.00 + 1.99 = 4.99$$

Regarding F_y : From load point coordinates

$$K_{px4} = \frac{|X_{F_y}|}{X_{L_b}} + \frac{|Z_{F_y}|}{X_{L_r}} = \frac{35}{310} + \frac{618}{450} = 0.11 + 1.37 = 1.48$$

Therefore,

$$Pxf = \sum \frac{F}{4} + \sum \frac{Kp \cdot F}{2}$$

$$= \frac{Wx + Wy + Fx + Fy}{4}$$

$$+ \frac{Kpx1 \cdot Wx + Kpx2 \cdot Wy + Kpx3 \cdot Fx + Kpx4 \cdot Fy}{2}$$

$$= \frac{7500 + 2500 + 1000 + 1000}{4}$$

$$+ \frac{0.14 \times 7500 + 0.8 \times 2500 + 4.99 \times 1000 + 1.48 \times 1000}{2}$$

$$= 7760 (N)$$

Position coefficients at time of drilling process (Wx, Wy and Fz must be considered)

Regarding Wx: Kpx1=0.14

(same as milling process)

Regarding Wy: Kpx2=0.80

(same as milling process)

Regarding Fz: From the load point coordinates

$$Kpx5 = \left| \frac{X_{Fz}}{XL_b} \right| + \left| \frac{Y_{Fz}}{XL_r} \right| = \frac{35}{310} + \frac{930}{450} = 0.11 + 2.07 = 2.18$$

Therefore,

$$Pxd = \sum \frac{F}{4} + \sum \frac{Kp \cdot F}{2}$$

$$= \frac{Wx + Wy + Fz}{4}$$

$$+ \frac{Kpx1 \cdot Wx + Kpx2 \cdot Wy + Kpx5 \cdot Fz}{2}$$

$$= \frac{7500 + 2500 + 3000}{4}$$

$$+ \frac{0.14 \times 7500 + 0.8 \times 2500 + 2.18 \times 3000}{2}$$

$$= 8045 (N)$$

From the above results, for drilling process with large values, select a model from Fig. I-3•4. and LY55 is chosen for X axis.

Finally, determine Z axis. Similarly, the distance from the center of the table to the loads and their loading points are shown. The stroke positions on Y and X axes are at stroke end which imposes strict condition.

Wx (X_{Wx}, Y_{Wx}, Z_{Wx}) = (- 200, 730, - 65) (mm)

Wy (X_{Wy}, Y_{Wy}, Z_{Wy}) = (- 225, 1136, - 325) (mm)

Wz (X_{Wz}, Y_{Wz}, Z_{Wz}) = (0, 120, 0) (mm)

Fx (X_{Fx}, Y_{Fx}, Z_{Fx}) = (- 235, 1150, - 618) (mm)

Fy (X_{Fy}, Y_{Fy}, Z_{Fy}) = (- 235, 1150, - 618) (mm)

Fz (X_{Fz}, Y_{Fz}, Z_{Fz}) = (- 235, 1150, - 618) (mm)

Ball slide span : ZL_b = 420 (mm)

Rail span : ZL_r = 660 (mm)

Determine per-ball slide lode volume Pzf, Pzd

Position coefficients at time of milling process (Wx, Wy, Wz, Fx and Fy must be considered)

Regarding Wx: From load point coordinates

$$Kpz1 = \left| \frac{Z_{Wx}}{ZL_b} \right| + \left| \frac{X_{Wx}}{ZL_r} \right| = \frac{65}{420} + \frac{200}{660} = 0.15 + 0.30 = 0.45$$

Regarding Wy: From load point coordinates

$$Kpz2 = \left| \frac{Z_{Wy}}{ZL_b} \right| + \left| \frac{X_{Wy}}{ZL_r} \right| = \frac{325}{420} + \frac{225}{660} = 0.77 + 0.34 = 1.11$$

Regarding Wz: From load point coordinates

$$Kpz3 = \left| \frac{Z_{Wz}}{ZL_b} \right| + \left| \frac{X_{Wz}}{ZL_r} \right| = \frac{0}{420} + \frac{0}{660} = 0 + 0 = 0$$

Regarding Fx: From load point coordinates

$$Kpz4 = \left| \frac{Z_{Fx}}{ZL_b} \right| + \left| \frac{Y_{Fx}}{ZL_r} \right| = \frac{618}{420} + \frac{1150}{660} = 1.47 + 1.74 = 3.21$$

Regarding Fy: From load point coordinates

$$Kpz4 = \left| \frac{Z_{Fy}}{ZL_b} \right| + \left| \frac{X_{Fy}}{ZL_r} \right| = \frac{618}{420} + \frac{235}{660} = 1.47 + 0.36 = 1.83$$

Therefore,

$$Pzf = \sum \frac{F}{4} + \sum \frac{Kp \cdot F}{2}$$

$$= \frac{Wx + Wy + Wz + Fx + Fy}{4}$$

$$+ \frac{Kpz1 \cdot Wx + Kpz2 \cdot Wy + Kpz3 \cdot Wz + Kpz4 \cdot Fx + Kpz5 \cdot Fy}{2}$$

$$= \frac{7500 + 2500 + 5500 + 1000 + 1000}{4}$$

$$+ \frac{0.45 \times 7500 + 1.11 \times 2500 + 0 \times 5500 + 3.21 \times 1000 + 1.83 \times 1000}{2}$$

$$= 9970 (N)$$

Position coefficients at time of drilling process (Wx, Wy, Wz and Fz must be considered)

Regarding Wx: Kpz1 = 0.45

Regarding Wy: Kpz2 = 1.11

Regarding Wz: Kpz3 = 0

Regarding Fz: From the load point coordinates

$$Kp6 = \left| \frac{Y_{Fz}}{ZL_b} \right| + \left| \frac{X_{Fz}}{ZL_b} \right| = \frac{1150}{420} + \frac{235}{420} = 2.74 + 0.56 = 3.30$$

Therefore,

$$Pzd = \sum \frac{F}{4} + \sum \frac{Kp \cdot F}{2}$$

$$= \frac{Wx + Wy + Wz + Fz}{4}$$

$$+ \frac{Kpz1 \cdot Wx + Kpz2 \cdot Wy + Kpz3 \cdot Wz + Kpz6 \cdot Fz}{2}$$

$$= \frac{7500 + 2500 + 5500 + 3000}{4}$$

$$+ \frac{0.45 \times 7500 + 1.11 \times 2500 + 0 \times 5500 + 3.30 \times 3000}{2}$$

$$= 12650 (N)$$

From the above results, for drilling process with large values, select a model LY 65 from Fig. I-3•4. for Z axis.

The selected linear guides are:

X axis LY55

Y axis LY35

Z axis LY65

(3) 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. But it must be calculated for more accurate figures.

Calculation of the loads that apply to the ball slide

In case of no cutting load: Fx = Fy = Fz = 0

Calculate load on X, Y, Z axes using "Table II-3•1" in "A-II-3.2 (3) 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

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

Unit: N

Axis	Load direction	Brg1	Brg2	Brg3	Brg4
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: Fx = Fy = 1000 (N)

Similarly,

X axis: Loads to consider Wx, Wy, Fx, and Fy

Y axis: Loads to consider Wy, Fx, and Fy

Z axis: Loads to consider Wx, Wy, Wz, Fx, and Fy

Unit: N

Axis	Load direction	Brg1	Brg2	Brg3	Brg4
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: Fz = 3000 (N)

X axis: Loads to consider Wx, Wy, and Fz

Y axis: Loads to consider Wy, and Fz

Z axis: Loads to consider Wx, Wy, Wz, and Fz

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

Unit: N

Axis	Load direction	Brg1	Brg2	Brg3	Brg4
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 II-3*2" in "A-II-3.3 (4) Calculation of dynamic equivalent load," necessary load F_r , F_{se} are, as the linear guide model is LY Series, obtained as follows.

Vertical dynamic equivalent load

$$F_r = Fr$$

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 A173. From calculation, the largest full dynamic equivalent loads are as follows.

	Largest full dynamic equivalent load F_e (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 x 0.7 = 4927 (N)

Y axis: 1317 x 0.7 = 922 (N)

Z axis: 9513 x 0.7 = 6659 (N)

Determine various coefficients

Determine based on "A-II-3.2 (6) 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-II-3.2 (7)

Calculation of rating life."

Basic dynamic load rating C

(X axis linear guide LY 55): 103000 (N)

Basic dynamic load rating C

(Y axis linear guide LY 35): 46000 (N)

Basic dynamic load rating C

(Z axis linear guide LY 65): 212000 (N)

Load coefficient f_w : 1.5

Hardness coefficient f_H : 1

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

From this,

In case of X axis $L_x = 135350$ (km)

In case of Y axis $L_y = 1839800$ (km)

In case of Z axis $L_z = 478050$ (km)

Examination of static loads based on "A-II-3.2 (8)"

Basic static load rating C_0

(X axis linear guide LY 55): 165000

Basic static load rating C_0

(Y axis linear guide LY 35): 75000 (N)

Basic static load rating C_0

(Z axis linear guide LY 65): 340000 (N)

Examine for milling process with large load.

$$X \text{ axis } f_s = \frac{C_0}{P_0} = \frac{C_0}{(F_r + F_s)} = \frac{165000}{(6539 + 997)} = 21.9$$

Similarly,

Y axis $f_s = 47.0$

Z axis $f_s = 34.0$

Therefore, there is no problem.

(4) Selection of accuracy grade and preload

For machining center, select accurate grade P5, and Preload Z3.

(5) 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 LY55Z3 : 880 (N/ μ m)

Rigidity of Y axis linear guide LY35Z3 : 580 (N/ μ m)

Rigidity of Z axis linear guide LY65Z3 : 1340 (N/ μ m)

Calculate using Pattern 4 in Table II-3*1.

Load conditions	Deformation direction	Deformation of each axis (μ m)			Total deformation (μ m)
		X axis	Y axis	Z axis	
Table weight alone	δx	-0.7	-0.1	-4.1	-4.9
	δy	-7.4	-0.5	-7.1	-15.0
	δz	-6.8	-0.1	-6.3	-13.2
Milling process	δx	-15.8	-1.8	-8.6	-26.2
	δy	-10.2	-2.5	-9.5	-22.2
	δz	-9.8	-0.5	-8.7	-19.0
Drilling process	δx	-1.5	-0.4	-5.9	-7.8
	δy	2.3	1.1	1.9	5.3
	δz	8.7	1.6	11.2	21.5

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

$$\delta x = -26.2 - (-4.9) = -21.3 (\mu m)$$

$$\delta y = -22.2 - (-15.0) = -7.2 (\mu m)$$

$$\delta z = -19.0 - (-13.2) = -5.8 (\mu m)$$

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.

Deformation at processing points at time of milling:

$$\delta x = -7.8 - (-4.9) = -2.9 (\mu m)$$

$$\delta y = 5.3 - (-15.0) = 20.3 (\mu m)$$

$$\delta z = 21.5 - (-13.2) = 34.7 (\mu m)$$

A-II-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 II -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	May. 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	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