[Technical Data]
Calculation of Life Span of Linear Systems 1

Allowable Load

•Basic Dynamic Load Rating (C)

Basic dynamic load rating is a constant load applied in a constant direction that enables each linear system of the same series to travel 50×10^3m under the same conditions, without 90% of the material suffering damage from rolling contact fatigue.

•Basic Static Load Rating (Co)

Basic static load rating is the static load exerted on contacting parts under maximum stress, at which the sum of the permanent deformation in the rolling element and rolling contact surface equals 0.0001 times the diameter of the rolling element.

•Allowable Static Moment (M_P, M_Y, M_R)

Allowable static moment is a critical static moment load that acts upon a system at the loading moment. It is set in accordance with the permanent deformation as in basic static load rating Co.

•Static Safety Factor (fs)

Static safety factors are given in Table-1. When a linear system is still or moving at low speed, basic static load rating Co must be divided by fs in accordance with the conditions of use.

Table-1 Static Safety Factor(Lower Limit of f_S)

Condition of Use	Lower Limit of f_S
Under Normal Operating Conditions	1~2
When Smooth Travel is Required	2~4
When Subjected to Vibrations, Impacts	3~5

Allowable Load (N) ≤ Co/fs

Allowable Moment (N·m) ≤ (M_P, M_Y, M_R)/fs

f_S:Static Safety Factor Co:Basic Static Load (N)

M_P, M_Y, M_R : Static Allowable Moment (N·m)

Life Span

When a load is applied to a linear system, the system moves back and forth in a linear direction. In the process, repeated stress acts upon rolling elements and rolling contact surfaces, causing damage referred to as flaking from material fatigue. The life span of a linear system is measured in terms of the total travel distance covered by the system up until initial flaking occurs.

•Rated Life Span (L)

Rated life span is the total travel distance that each linear system of the same series can endure under the same conditions, without the occurrence of flaking in 90% of the system.

Rated life span can be obtained as follows from the basic dynamic load rating and various loads exerted on the linear system.

For Ball Bearings $L=\left(\frac{C}{P}\right)^3\cdot50$

For Roller Bearings $L=\left(\frac{C}{P}\right)^{10/3}\cdot50$

L: Rated Life Span (km)

C: Basic Dynamic Load Rating (N)

P: Acting Load (N)

•When actually using a linear system, the first thing you must do is to calculate the load. It is necessary to consider load also in terms of vibration and impact that occur during operation, as well as its distribution across the entire linear system as it moves back and forth in a linear direction. Calculations are not simple. Operating temperature also significantly influences useful life. When these parameters are taken into consideration, the above formula is transformed as follows:

For Ball Bearings $L=\left(\frac{f_H\cdot f_T\cdot f_C}{f_W}\cdot\frac{C}{P}\right)^3\cdot50$

For Roller Bearings $L=\left(\frac{f_H\cdot f_T\cdot f_C}{f_W}\cdot\frac{C}{P}\right)^{10/3}\cdot50$

L: Rated Life Span (km)

f_H: Hardness Coefficient (See Fig.1)

C: Basic Dynamic Load Rating (N)

f_T: Temperature Coefficient (See Fig.2)

P: Acting Load (N)

f_C: Contact Coefficient (See Table 3)

fw: Load Coefficient (See Table 4)

The Life span can be computed as a number of hours by obtaining the travel distance for a unit of time.

It can be obtained by using the following formula, in which stroke length and stroke cycles are assumed to be constant.

$$L_h=\frac{L\cdot10^3}{2\cdot\ell s\cdot n_1\cdot60}$$

L_h: Life Span Hours (hr)

ℓs: Stroke Length (m)

L: Rated Life Span (km)

n_1: Reciprocating Times per Minute (cpm)

Friction Resistance and Required Thrust

Using the following formula, the friction resistance (required thrust) can be obtained from the load and the seal resistance specified by the system.

$$F=\mu\cdot W+f$$

F: Friction Resistance (N)

μ: Dynamic Friction Coefficient

W: Weight Loaded

f: Seal Resistance (2N~5N)

Table-2 Dynamic Friction Coefficient

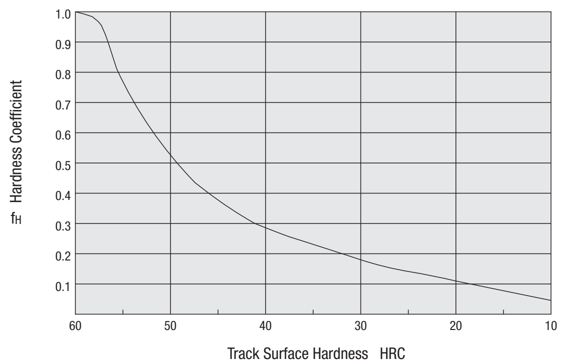
Type	Dynamic Friction Coefficient (μ)
Miniature Slide Guides	0.004~0.006
Medium Load Slide Guides	0.002~0.003
Slide Ways	0.001~0.003
Slide Tables	0.001~0.003
Linear Bushings	0.002~0.003
Linear Ball Bushings	0.0006~0.0012

•Hardness Coefficient(f_H)

In a linear system, the shaft must be hard enough to withstand contact with the ball bearings. Unless sufficient hardness is provided, the allowable load can decrease, resulting in a short useful life.

Compensate the rated life span with the hardness coefficient.

Fig-1. Hardness Coefficient



•Contact Coefficient (fc)

In general, two or more linear systems are used with each shaft. Depending on the machining precision, the load exerted on each of the respective systems can vary. In this case, the load applied on each linear system changes depending on the machining precision, therefore it cannot be uniformly applied. As a result, allowable load per linear system changes depending on the number of linear systems on one axis.

Compensate the rated life span with the contact coefficient in Table-3.

•Load Coefficient (fw)

When calculating the load that acts on a linear system, it is necessary to work with precise figures for material weight, the force of inertia resulting from operating speed, load moment, various changes that occur over time, and so on. However, it is difficult to have accurate calculation for oscillating movement as beside the normal repetition of start and stop, other factors such as vibration and impact also need to be considered. Therefore, the life span calculation needs to be simplified using the load coefficient in Table-3.

Linear Bushings

Rated life span can be obtained as follows from the basic dynamic load rating and the load to the linear bushing.

$$L=\left(\frac{f_H\cdot f_T\cdot f_C}{f_W}\cdot\frac{C}{P}\right)^3\cdot50$$

L: Rated Life Span (km) f_H: Hardness Coefficient (See Fig.1)

C: Basic Dynamic Load Rating (N) f_T: Temperature Coefficient (See Fig.2)

P: Working Load (N) f_C: Contact Coefficient (See Table3)

fw: Load Coefficient (See Table4)

The Life span can be computed as a number of hours by obtaining the travel distance for a unit of time. It can be obtained using the following formula, in which stroke length and stroke cycles are assumed to be constant.

$$L_h=\frac{L\cdot10^3}{2\cdot\ell s\cdot n_1\cdot60}$$

L_h: Life Span Hours (hr) ℓs: Stroke Length (m) L: Rated Life Span (km)

n_1: Reciprocating Times per Minute (cpm)

•Temperature Coefficient (f_T)

When temperature in a linear system exceeds 100˚C, the hardness of the system and the shaft become degraded. This decreases the allowable load to a greater extent than when the system is used at ambient temperature, and can shorten the life span.

Compensate the rated life span with the temperature coefficient.

Fig.-2 Temperature Coefficient

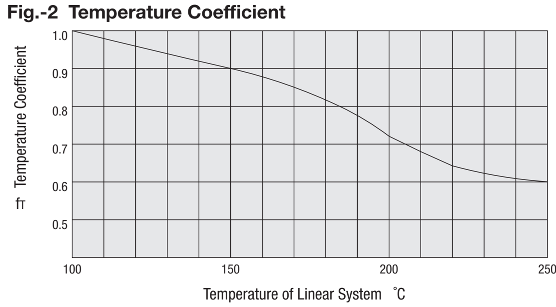


Table-3. Contact Coefficient

Number of Bearings per Shaft	Contact Coefficient fc
1	1.00
2	0.81
3	0.72
4	0.66
5	0.61

Table-4. Load Coefficients

Condition of Use	fw
Low speed with no external vibration or impact (Max. 15m/min)	1.0~1.5
Middle range speed with no exerted vibration or impact of considerable force(Max. 60m/min)	1.5~2.0
High speed with no external vibration or impact (Over 60m/min)	2.0~3.5

Linear Ball Bushings

Rated life span can be obtained as follows from the basic dynamic load rating and the load to the linear ball bushing.

$$L=\left(\frac{f_H\cdot f_T\cdot f_C}{f_W}\cdot\frac{C}{P}\right)^3\cdot50$$

L: Rated Life Span (km) f_H: Hardness Coefficient (See Fig.1)

C: Basic Dynamic Load Rating (N) f_T: Temperature Coefficient (See Fig.2)

P: Working Load (N) f_C: Contact Coefficient (See Table 3)

fw: Load Coefficient (See Table 4)

Life Span Hours

·For revolution and reciprocating motion

$$L_h=\frac{10^6\cdot L}{60\sqrt{(dm\cdot n)^2+(10\cdot S\cdot n_1)^2}/dm}$$

·For reciprocating motion

$$L_h=\frac{10^6\cdot L}{600\cdot S\cdot n_1/(\pi\cdot dm)}$$

L_h:Life Span Hours(hr) S: Stroke Length(mm) n: Revolutions per Minute(rpm)

n_1:Strokes Per Minute(cpm)

dm:Pitch Diameter of Ball(mm)≈1.15dr

·Revolution and reciprocal motion allowable values

$$DN\geq dm\cdot n+10\cdot S\cdot n_1$$

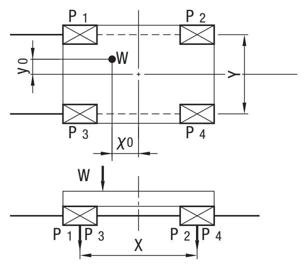
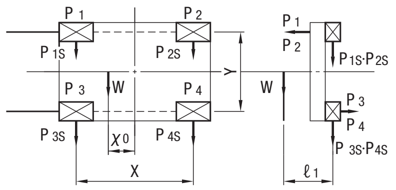
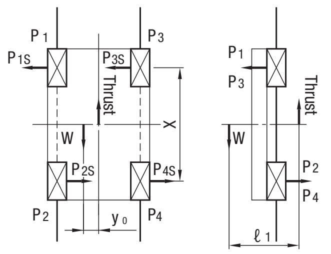
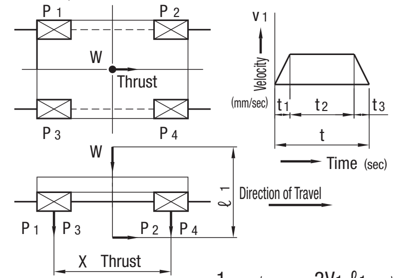
[Technical Data]
Calculation of Life Span of Linear Systems 2

•Load Calculations

Since a linear system bears the weight of the work while it performs a reciprocating linear motion, the load exerted on the system can vary depending on the work's center of gravity, thrust acting position change, and the speed changes by starting, stopping and acceleration, deceleration.

It is necessary to take these conditions into consideration when selecting a linear system.

Table-5. Use Conditions and Load Calculation Formulas

Type	Condition of Use and Load	Type	Condition of Use and Load
1	Horizontal Axis  $P_1=\frac{1}{4}W+\frac{x_0}{2X}W+\frac{y_0}{2Y}W$ $P_2=\frac{1}{4}W-\frac{x_0}{2X}W+\frac{y_0}{2Y}W$ $P_3=\frac{1}{4}W+\frac{x_0}{2X}W-\frac{y_0}{2Y}W$ $P_4=\frac{1}{4}W-\frac{x_0}{2X}W-\frac{y_0}{2Y}W$	3	Perpendicular to Horizontal Axis  $P_1=P_2=P_3=P_4=\frac{\ell_1}{2X}W$ $P_{1S}=P_{3S}=\frac{1}{4}W+\frac{x_0}{2X}W$ $P_{2S}=P_{4S}=\frac{1}{4}W-\frac{x_0}{2X}W$
2	Vertical Axis  $P_1=P_2=P_3=P_4=\frac{\ell_1}{2X}W$ $P_{1S}=P_{2S}=P_{3S}=P_{4S}=\frac{y_0}{2X}W$	4	In Acceleration, Deceleration  •Acceleration at Starting $P_1=P_3=\frac{1}{4}W\left(1+\frac{2V_1\cdot\ell_1}{g\cdot t_1\cdot X}\right)$ $P_2=P_4=\frac{1}{4}W\left(1-\frac{2V_1\cdot\ell_1}{g\cdot t_1\cdot X}\right)$ •Deceleration at Stopping $P_1=P_3=\frac{1}{4}W\left(1-\frac{2V_1\cdot\ell_1}{g\cdot t_3\cdot X}\right)$ $P_2=P_4=\frac{1}{4}W\left(1+\frac{2V_1\cdot\ell_1}{g\cdot t_3\cdot X}\right)$ •Constant Speed $P_1=P_2=P_3=P_4=\frac{1}{4}W$ g:Gravitational Acceleration=9.8×10^3mm/sec^2

W :Acting Load(N)　P_1,P_2,P_3,P_4:Load applied to the Linear System(N)
X,Y: Linear System Span(mm)　V:Moving Speed(mm/sec)
t_1 :Acceleration Time(sec)　t_3:Deceleration Time(sec)

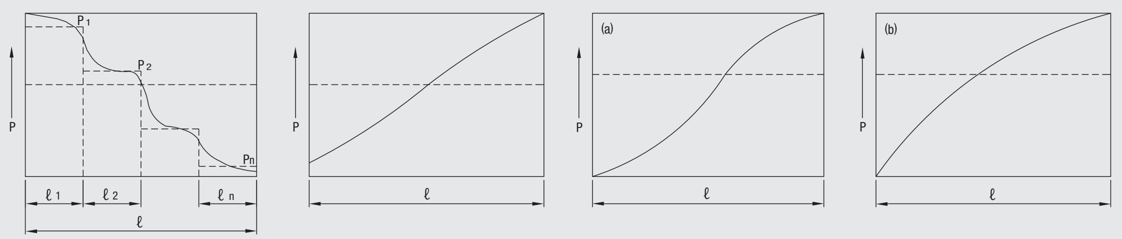


Fig-3. Stepped Load Fluctuation　Fig-4. Flat Fluctuation Load　Fig-5. Sinusoidal Load Fluctuation

•Mean Load Derived from Fluctuating Loads

In general, the load acting upon a linear system can change according to how the system is used.This happens for example when the reciprocating motion is started, stopped as compared to constant speed motion, and whether or not work is present during transfer, etc. Therefore, in order to correctly design the life span under various conditions and fluctuating loads, it is necessary to obtain a mean load and apply it to the life span calculations.

(1) When load changes in steps by a travel distance(Fig-3)

Travel distance ℓ_1 subjected to load P_1
Travel distance ℓ_2 subjected to load P_2
⋮　⋮
Travel distance ℓ_n subjected to load P_n

Mean load Pm can be obtained by using the following formula:

$$P_m=\sqrt[3]{\frac{1}{\ell}(P_1^3\ell_1+P_2^3\ell_2\cdots+P_n^3\ell_n)}$$

P_m : Mean Load Derived from Fluctuating Loads(N)　ℓ : Total Travel Distance(m)

(2) When load changes almost linearly(Fig-4)

Mean load P_m can be approximated by the following formula:

$$P_m\approx\frac{1}{3}(P_{min}+2\cdot P_{max})$$

P_{min}: Min. Fluctuating Load (N)
P_{max}: Max. Fluctuating Load(N)

(3) When the load change resembles a sinusoidal curve as shown in Fig-5 (a), (b), Mean Load Pm can be approximated by the following formula:

Fig-5(a) $P_m\approx0.65P_{max}$
Fig-5(b) $P_m\approx0.75P_{max}$

Slide Guides

Rated life span is the total travel distance each linear guide of the same series can endure under the same conditions, without the occurrence of flaking in 90% of the system.

Rated life span can be obtained as follows from the basic dynamic load rating and the load to the slide guide.

$$L=\left(\frac{f_T}{f_W}\cdot\frac{C}{P}\right)^3\cdot50 \qquad (1)$$

L : Rated Life Span(km)　C : Basic dynamic load rating(N)
f_T : Temperature Coefficient(See Fig-2)　P : Acting Load(N)
fw : Load Coefficient(See Fig-4)

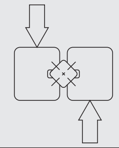
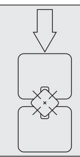
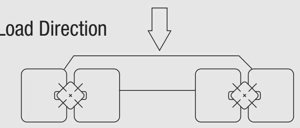
The life span hours can be computed as a number of hours by obtaining the travel distance for a unit of time.It can be obtained by using the following formula, in which stroke length and stroke cycles are assumed to be constant.

$$L_h=\frac{L\cdot10^3}{2\cdot\ell_s\cdot n_1\cdot60} \qquad (2)$$

Lh :Life Span Hours(hr)　ℓ_s:Stroke Length(m)
L :Rated Life Span(km)　n_1:Reciprocating Times per Minute(cpm)

Slide Ways

Rated load for slide ways is determined by the rolling elements(numbers of rollers). It can be calculated by using the following formulas:

One shaft is used	Load Direction	
	Dynamic Load Rating (N)	$C=\left(\frac{Z}{2}\right)^{3/4}\cdot C_1$
	Static Load Rating (N)	$C_0=\left(\frac{Z}{2}\right)\cdot C_{01}$
One shaft is used vertically	Load Direction	
	Dynamic Load Rating (N)	$C=\left(\frac{Z}{2}\right)^{3/4}\cdot C_1\cdot2^{7/9}$
	Static Load Rating (N)	$C_0=\left(\frac{Z}{2}\right)\cdot C_{01}\cdot2$
Two shafts are used in parallel	Load Direction	
	Dynamic Load Rating (N)	$C=\left(\frac{Z}{2}\right)^{3/4}\cdot C_1\cdot2^{7/9}$
	Static Load Rating (N)	$C_0=\left(\frac{Z}{2}\right)\cdot C_{01}\cdot2$

C_1 : Basic Dynamic Load Rating per Roller(N)
C_{01}: Basic Static Load Rating per Roller(N)
Z : Number or Rolling Elements

The life span for slide ways is calculated by using the following formula.

$$L=\left(\frac{f_T\cdot C}{f_W\cdot P}\right)^{10/3}\cdot50$$

L :Life Span Hours(km)　C :Dynamic Load Rating(N)
f_T :Temperature Coefficient(See Fig-2)　P :Acting Load(N)
fw :Load Coefficient(See Fig-4)

Life Span Hours

$$L_h=\frac{L\cdot10^3}{2\cdot\ell_s\cdot n_1\cdot60}$$

L_h :Life Span Hours(hr)　ℓ_s:Stroke Length(m)
L :Life Span Hours(km)　n_1:Reciprocating Times per Minute(cpm)