2 System technology

2.1 Definitions

Service life time
The service life time L is the running distance that a component can handle before the first signs of material fatigue become apparent on the tracks or the rolling elements.

Nominal service life time L_{10}
The nominal service life time L_{10} is the calculated service life time of a single linear guide system or of a group of equivalent linear guide systems operating under equal conditions that can be reached with a probability of 90%, assuming the use of currently common materials of average manufacturing quality and common operating conditions.

Dynamic load rating C
The dynamic load rating C is the in size and direction constant, radial load that a linear roller bearing can theoretically withstand for a nominal service life of $5x10^4$ m travelled distance (according to ISO 14728-1). When the calculation of the dynamic load rating is based on a nominal service life of 10^5 m, the dynamic load rating for a nominal service life of $5x10^4$ m is multiplied by the conversion factor 1.26.

Static load rating C_0
The static load rating C_0 is the static, radial load that corresponds to the middle of the highest-stressed contact area between rolling element and race way of a calculated Hertz-type compression. The Hertz-type compression for the linear guide is, according to ISO 14728-1, between 4200 MPa and 4600 MPa and depends on the ball diameter and the osculation.

This load leads to a permanent, total deformation of the rolling element that corresponds to a 0.0001 part of the rolling element diameter (according to ISO 14728-1).

2.2 Standards

DIN 645-1 Roller bearings - profile rail roller guides – Part 1: Dimensions for Series 1 to 3

DIN 645-2 Roller bearings - profile rail roller guides – Part 2: Dimensions for Series 4

DIN ISO 14728-1 Roller bearings - Linear roller bearings – Part 1: Dynamic load ratings and nominal service life (ISO 14728-1: 2004)

DIN ISO 14728-2 Roller bearings – Linear roller bearings – Part 2: Static load ratings (ISO 14728-2: 2004)

The NTN-SNR linear guides comply with the RoHS Directive (EU Directive 2002/95/EC). NTN-SNR linear guides are not listed in the Machine Directive 2006/42/EC and are therefore not affected by this directive.

2.3 Coordinate system

The linear guides can be stressed by forces or torques. The coordinate system (Figure 2.1) shows the forces acting in the main load directions, the torques as well as the six degrees of freedom.

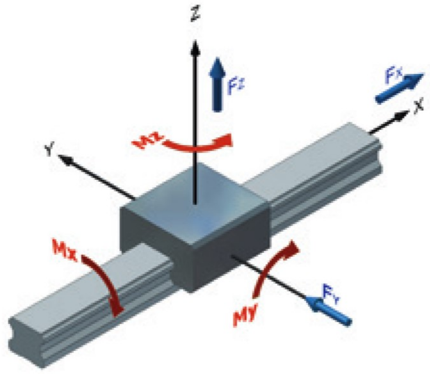


Figure 2.1 Coordinate system

Forces in the main load directions:

F_X Movement force (X-direction)
F_Y Tangential load (Y-direction)
F_Z Radial load (Z-direction)

Torques:

M_X Torque in roll direction (rotation around the X-axis)
M_Y Torque in pitch direction (rotation around the Y-axis)
M_Z Torque in yaw direction (rotation around the Z-axis)

Only five degrees of freedom are relevant for the linear guide. The X-direction is the movement direction of the guide, which defines the following accuracy values:

- > Lateral movement (Y-direction)
- > Height movement (Z-direction)
- > Rolling (rotation around the X-axis)
- > Pitching (rotation around the Y-axis)
- > Yawing (rotation around the Z-axis)

2.4 Static safety

The design of linear guides must consider unexpected and unforeseeable forces and/or torques that are caused by vibration or shocks or short start/stop cycles (short strokes) during operation or standstill as well as overhanging loads. A safety factor is particularly important in such cases. The static structural safety factor f_S is intended to prevent unacceptable, permanent deformation of the tracks and the rolling elements. It is the ratio of the static load rating C_0 to the maximum occurring force F_{0max}. The highest amplitude is relevant, even when it occurs only for a very short time.

$$f_S = \frac{C_0}{F_{0\,max}} * f_H * f_T * f_C \qquad [2.1]$$

f_S static safety factor / static structural safety
C_0 static load rating [N]
F_{0max} maximum static load [N]
f_H Hardness factor
f_T Temperature factor
f_C Contact factor

The static safety factor should be bigger than 2 for normal operating conditions. The recommended values listed below should be used for the factor f_S under special operating conditions.

Table 2.1 Values of the static safety factor

Operating conditions	f_S
Normal operating conditions	≈ 2
With less shock exposure and vibration	≈ 2 ... 4
With moderate shock exposure and vibration	3 ... 5
With strong shock exposure and vibration	4 ... 8
With partially unknown load parameters	> 8

We recommend that you contact our NTN-SNR application engineers when the loads are partially unknown or difficult to estimate.

2.5 Service life time calculation

The nominal service life time of a linear guide in m is calculated with the following equation:

Ball guides

$$L_{10} = \left(\frac{C}{F} * \frac{f_H * f_T * f_C}{f_W} \right)^3 5 * 10^4 \qquad [2.2]$$

Roller guides

$$L_{10} = \left(\frac{C}{F} * \frac{f_H * f_T * f_C}{f_W} \right)^{\frac{10}{3}} * 10^5 \qquad [2.3]$$

L_{10} Nominal service life time [m]
C Dynamic load rating [N]
F Dynamic load [N]
f_H Hardness factor
f_T Temperature factor
f_C Contact factor
f_W Load factor

The service life time in operating hours can be determined when the stroke length and the stroke frequency remain constant during the service life time.

$$L_h = \frac{L_{10}}{2 \cdot S \cdot n \cdot 60} \qquad [2.4]$$

L_{10} Nominal service life time [m]
L_h Service live in hours [h]
S Stroke length [m]
n Stroke frequency (double-strokes per minute) [min^{-1}]

It is very difficult to determine the active load for the service life time calculation. The linear guide systems are usually exposed to oscillations or vibrations resulting from the process or drive forces. Shocks can damage machine elements when the load peaks are higher than the maximum additional load. This applies to the dynamic as well as the static state of the total system. The service life time also depends on parameters such as the surface hardness of the rolling elements, the race ways and the temperature of the system. The modified service life time calculation takes the abovementioned conditions into consideration.

2.5.1 Influencing factors

Hardness factor for shaft hardness f_H

The hardness of the rolling elements and the tracks must be between 58 HRC and 60 HRC. This value ensures optimal running properties and the best possible functional properties of the linear guide.

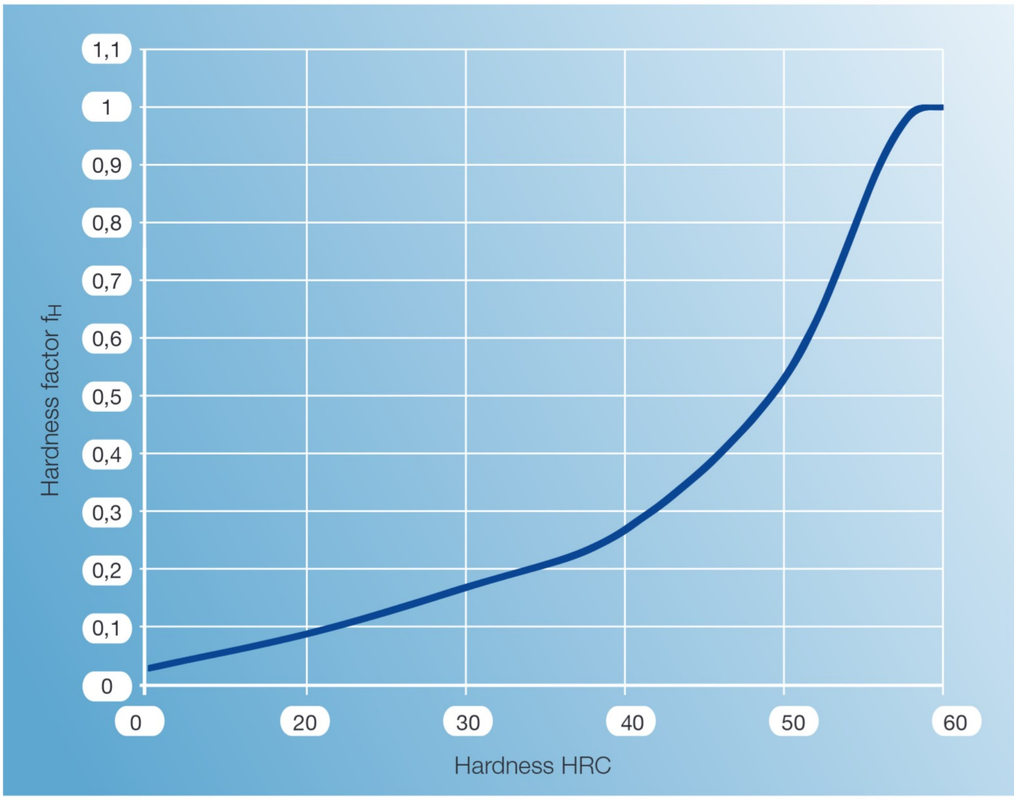


Figure 2.2 Hardness factor f_H

The NTN-SNR linear guides comply with the conditions stipulated above. Therefore, the hardness factor does not need to be considered (f_H=1). The hardness corrections (Figure 2.2) are only required when a special version made of special material with a hardness below 58 HRC is used.

Temperature factor f_T

Corrections to the service life time calculations (Figure 2.3) must be made when the environmental temperature of the linear guide exceeds 100°C during operation.

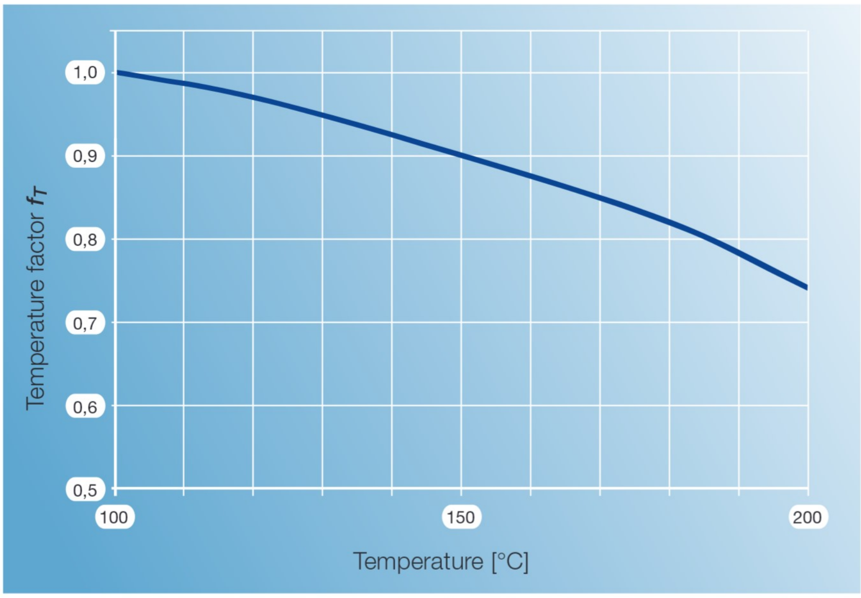


Figure 2.3 Temperature factor f_T

The standard version of the NTN-SNR linear guides can be used up to a maximum temperature of 80°C.

Contact factor f_C

When two or more carriages are installed very close to each other, the running movement is affected by torques, installation accuracy and other factors, so that an even load distribution is hard to achieve. Under such conditions, an appropriate contact factor (Table 2.2) must be taken into account.

Table 2.2 Contact factor

Number of closely spaced carriages	f_C
1	1,00
2	0,81
3	0,72
4	0,66
5	0,61

Load factor f_W

Vibrations and shocks that may occur during operation, for example as a result of high speeds, repeated starting and stopping, process forces or sudden loads, can have a significant effect on the total calculation. It is in some cases very difficult to determine their effects. Empirically determined load factors (Table 2.3) must be used when the actual loads on the linear guide cannot be measured or can be significantly higher than calculated.

Table 2.3 Load factor

Operating conditions, velocity v	f_w
Normal operating conditions without vibrations/shocks $v \le 0{,}25$ m/s	1,0… 1,5
Normal operating conditions with weak vibrations/shocks $0{,}25 < v \le 1{,}0$ m/s	1,5… 2,0
Normal operating conditions with strong vibrations/shocks $v > 1{,}0$ m/s	2,0… 3,5

2.5.2 Active load - equivalence factors

One-axis application

Linear guides are often used with one carriage or several carriages with a small distance between them when the installation space is tight. The service life time of the linear guide can be shortened in such cases, due to the increased wear at the carriage ends. Under such operating conditions, the torques must be multiplied by appropriate equivalence factors (Table 2.4 and Table 2.5).

The equivalent load is determined as follows:

$$F_E = k \cdot M \qquad [2.7]$$

F_E Equivalent load per guide [N]
k Equivalence factors (Table 2.4 and Table 2.5)
M corresponds to the active torque [Nm]

Table 2.4 Equivalence factors (Type LGB..)

Series	Equivalence factor [m^{-1}]				
	k1x	k1y	k2y	k1z	k2z
LGB_15_S	143,5	309,4	38,1	309,4	38,1
LGB_15_N	145,3	165,8	28,8	165,8	28,8
LGB_15_L	144,9	140,6	26,0	140,6	26,0
LGB_20_S	107,6	241,4	32,5	241,4	32,5
LGB_20_N	107,1	138,2	24,5	138,2	24,5
LGB_20_L	106,7	109,6	21,3	109,6	21,3
LGB_20_E	106,9	87,8	18,4	87,8	18,4
LGB_25_S	92,8	207,2	29,2	207,2	29,2
LGB_25_N	93,4	116,6	21,6	116,6	21,6
LGB_25_L	93,1	92,9	18,7	92,9	18,7
LGB_25_E	93,1	77,2	16,5	77,2	16,5
LGB_30_S	77,3	179,8	24,6	179,8	24,6
LGB_30_N	77,2	99,1	18,1	99,1	18,1

Series	Equivalence factor [m^{-1}]				
	k1x	k1y	k2y	k1z	k2z
LGB_30_L	77,2	86,0	16,6	86,0	16,6
LGB_30_E	77,2	64,8	13,7	64,8	13,7
LGB_35_S	63,3	150,7	21,1	150,7	21,1
LGB_35_N	63,2	83,4	15,4	83,4	15,4
LGB_35_L	63,3	72,5	14,2	72,5	14,2
LGB_35_E	63,2	54,8	11,7	54,8	11,7
LGB_45_N	47,3	71,4	13,4	71,4	13,4
LGB_45_L	47,3	61,0	12,1	61,0	12,1
LGB_45_E	47,3	48,3	10,3	48,3	10,3
LGB_55_N	40,4	57,9	11,3	57,9	11,3
LGB_55_L	40,4	43,6	9,3	43,6	9,3
LGB_55_E	40,4	39,2	8,6	39,2	8,6

k1x Equivalence factor for 1 carriage in Mx-direction
k1y Equivalence factor for 1 carriage in My-direction
k2y Equivalence factor for 2 carriages with direct contact in My-direction
k1z Equivalence factor for 1 carriage in Mz-direction
k2z Equivalence factor for 2 carriages with direct contact in Mz-direction

Table 2.5 Equivalence factors (Type LGM..)

Series	Equivalence factor [m^{-1}]				
	k1x	k1y	k2y	k1z	k2z
LGM_07BN	300,8	488,7	64,2	488,7	56,1
LGM_09BN	209,1	255,6	53,0	255,6	53,0
LGM_09BL	220,7	194,7	42,5	194,7	42,5
LGM_09WN	106,8	236,4	43,2	236,4	43,2
LGM_09WL	105,1	153,9	34,5	153,9	34,5
LGM_12BN	152,2	291,7	47,0	291,7	47,0
LGM_12BL	154,7	187,9	36,4	187,9	36,4
LGM_12WN	80,5	204,2	37,9	204,2	37,9
LGM_12WL	80,2	144,1	29,8	144,1	29,8
LGM_15BN	142,8	219,6	38,2	219,6	38,2
LGM_15BL	143,2	145,8	28,8	145,8	28,8
LGM_15WN	48,9	167,8	30,5	167,8	30,5
LGM_15WL	48,0	110,3	23,7	110,3	23,7

k1x Equivalence factor for 1 carriage in Mx-direction
k1y Equivalence factor for 1 carriage in My-direction
k2y Equivalence factor for 2 carriages with direct contact in My-direction
k1z Equivalence factor for 1 carriage in Mz-direction
k2z Equivalence factor for 2 carriages with direct contact in Mz-direction

Two-axis application

The following requirements and operating conditions (Figure 2.4) must be defined for calculating the service life time:

> Stroke length s [mm]
> Velocity diagram (Figure 2.5)
> Velocity v [m/s]
> Acceleration/deceleration a [m/s^2]
> Movement cycles, number of double-strokes per minute n [min^{-1}]
> Arrangement of the linear guide (number of rails and runner blocks l_0, l_1, [mm]
> Installation position (horizontal, vertical, diagonal, wall installation, tilted by 180°)
> Mass m [kg]
> Direction of the outer forces
> Positions of the centres of gravity l_2, l_3, l_4, [mm]
> Position of the drive l_5, l_6, [mm]
> Required service life L [km] or [h]

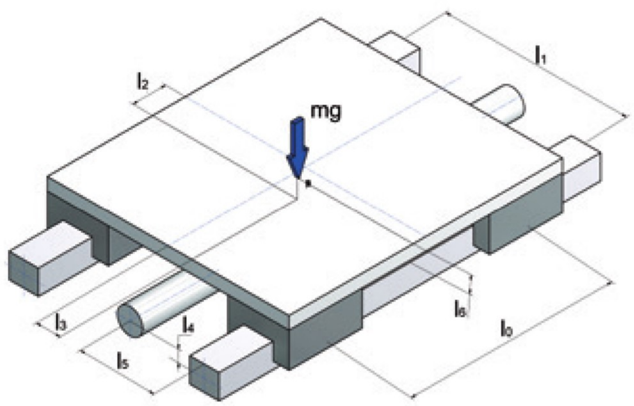


Figure 2.4 Definition of the conditions

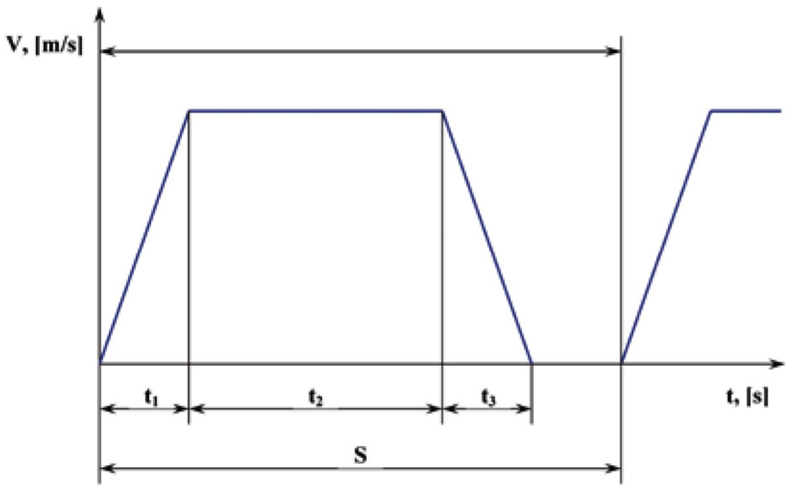


Figure 2.5 Velocity/time diagram

2.5.3 Equivalent loads

The (radial and tangential) loads as well as torque loads may act on the profile rail guide from different directions at the same time (Figure 2.6). In this case, the service life is calculated by using the equivalent load, which includes the radial, tangential and other loads.

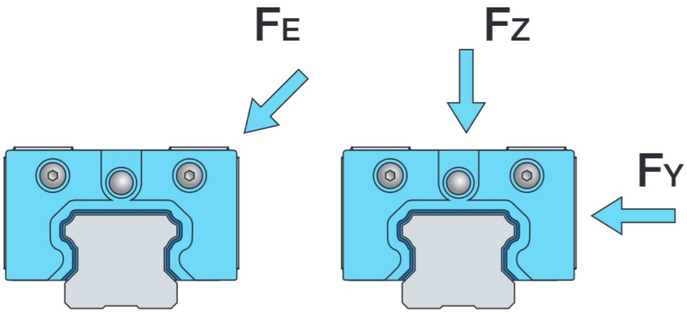


Figure 2.6 Equivalent load F_E

$$F_E = |F_Y| + |F_Z| \quad [2.8]$$

F_E - Equivalent load [N]
F_Y - Tangential load [N]
F_Z - Radial load [N]

The calculation of the equivalent load F_E considers that the NTN-SNR linear guides have the same load-rating capacity in all main directions.

Dynamic equivalent load

It is common that different, varying process forces affect the total system during operation. The guides are, for example, exposed to changing loads during upward and downward movements for picking and placing applications. Where such varying loads occur, they must be considered in the service life time calculations. The calculation of the dynamically equivalent load determines the load on a carriage for each individual movement phase n1, n2...nn (see Chapter 2.4.2) and is summarised in a resulting load for the total cycle. The load change can take place in various ways:

> Stepwise (Figure 2.7)
> Linear (Figure 2.8)
> Sinusoidal (Figure 2.9 and 2.10)

Stepwise load change

$$F_m = \sqrt[3]{\frac{1}{S}\left(F_1^3 \cdot S_1 + F_2^3 \cdot S_2 + \ldots + F_n^3 \cdot S_n\right)} \qquad [2\text{-}9]$$

F_m	Dynamic equivalent load [N]
F_n	Load change [N]
S	Total travel [mm]
S_n	Travel during load change Fn [mm]

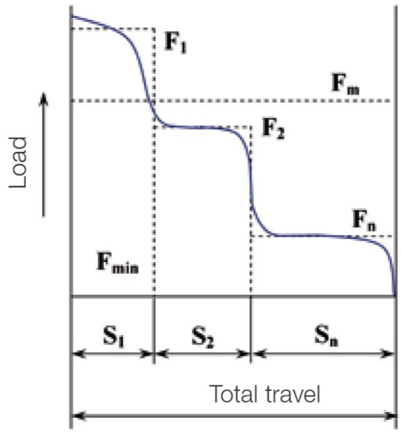


Figure 2.7 Stepwise load change

Linear load change

$$F_m \cong \frac{1}{3}(F_{MIN} + 2 \cdot F_{MAX}) \qquad [2\text{-}10]$$

F_{MIN}	Minimum load [N]
F_{MAX}	Maximum load [N]

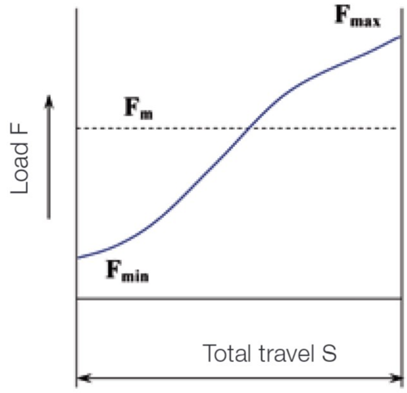


Figure 2.8 Linear load change

Sinusoidal load change

$$F_m \cong 0,65 * F_{MAX}$$ [2.11]

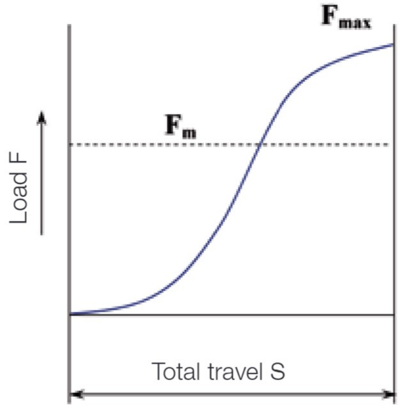


Figure 2.9 Sinusoidal load change (a)

Sinusoidal load change

$$F_m \cong 0,75 * F_{MAX}$$ 2.12]

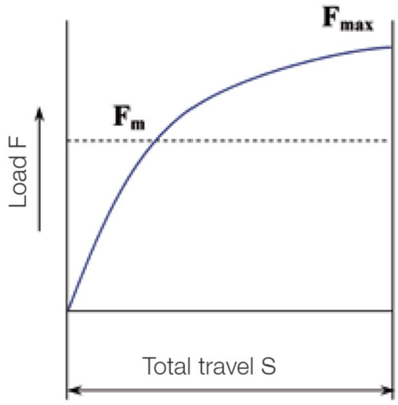


Figure 2.10 Sinusoidal load change (b)

2.5.4 Calculation examples

Example 1
Horizontal installation position with overhanging load
One carriage
LGBCH20FN
Gravity constant g=9.8 m/s²
Mass m=10 kg
l_2=200 mm, l_3=100 mm
C=17,71 kN
C_0=30,50 kN
Normal operating conditions without vibrations $f_W = 1{,}5$

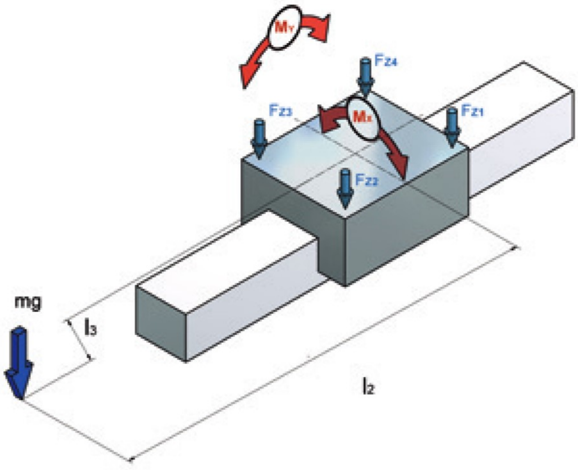


Figure 2.11 Calculation example 1

Calculation:
The equivalent load for the linear guide is calculated, taking the formula [2.7] and the equivalence factors (Table 2.5) into account.

$$Fz_1 = mg - k_x * mg * l_3 - k_y * mg * l_2 = 10*9{,}8 - 107*10*9{,}8*0{,}1 - 138*10*9{,}8*0{,}2 = -3.655{,}4\ N$$

$$Fz_2 = mg - k_x * mg * l_3 + k_y * mg * l_2 = 10*9{,}8 - 107*10*9{,}8*0{,}1 + 138*10*9{,}8*0{,}2 = 1.754{,}2\ N$$

$$Fz_3 = mg + k_x * mg * l_3 + k_y * mg * l_2 = 10*9{,}8 + 107*10*9{,}8*0{,}1 + 138*10*9{,}8*0{,}2 = 3.851{,}4\ N$$

$$Fz_4 = mg + k_x * mg * l_3 - k_y * mg * l_2 = 10*9{,}8 + 107*10*9{,}8*0{,}1 - 138*10*9{,}8*0{,}2 = -1.558{,}2\ N$$

The static safety factor for the maximum load of 3,547.6 N is calculated according to [2.1].

$$f_S = \frac{C_0}{F_{0MAX}} = \frac{30.500}{3.851{,}4} = 7{,}9$$

The nominal service life time for the maximum load 3,547.6 N is calculated according to [Chapter 2.5].

$$L_{10} = \left(\frac{C}{F} * \frac{f_H * f_T * f_C}{f_W}\right)^3 * 5*10^4 = \left(\frac{17.710}{3.851{,}4} * \frac{1}{1{,}5}\right)^3 * 5*10^4 = 1.440.443\ m = 14.440\ km$$

Example 2
Horizontal installation position with overhanging load and 2 rails arranged in parallel. Two carriages per rail, arrangement with mobile table
LGBCH30FN
Gravity constant g=9.8 m/s^2
Mass m=400 kg
l_0=600 mm, l_1=450 mm, l_2=400 mm, l_3=350 mm
C=36,71 kN
C_0=54,570 kN
Normal operating conditions without vibrations f_W=1,5

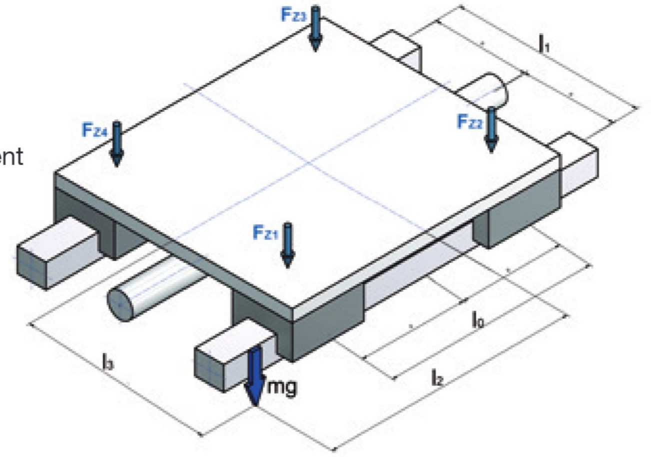


Figure 2.12 Calculation example 2

Calculation:
a) The active radial load per carriage at constant velocity is calculated as follows:

$$F_{Z1} = \frac{mg}{4} + \frac{mg*l_2}{2*l_0} + \frac{mg*l_3}{2*l_1} = \frac{400*9{,}8}{4} + \frac{400*9{,}8*400}{2*600} + \frac{400*9{,}8*350}{2*450} = 3.811{,}11\ N$$

$$F_{Z2} = \frac{mg}{4} - \frac{mg*l_2}{2*l_0} + \frac{mg*l_3}{2*l_1} = \frac{400*9{,}8}{4} - \frac{400*9{,}8*400}{2*600} + \frac{400*9{,}8*350}{2*450} = 1.197{,}77\ N$$

$$F_{Z3} = \frac{mg}{4} - \frac{mg*l_2}{2*l_0} - \frac{mg*l_3}{2*l_1} = \frac{400*9{,}8}{4} - \frac{400*9{,}8*400}{2*600} - \frac{400*9{,}8*350}{2*450} = -1.851{,}11\ N$$

$$F_{Z4} = \frac{mg}{4} + \frac{mg*l_2}{2*l_0} - \frac{mg*l_3}{2*l_1} = \frac{400*9{,}8}{4} + \frac{400*9{,}8*400}{2*600} - \frac{400*9{,}8*350}{2*450} = 762{,}23\ N$$

b) The statistical safety factor is calculated for carriage 1 according to [2.1] for a maximum load of 3,811.11 N.

$$f_S = \frac{C_0}{F_{0MAX}} = \frac{54.570}{3.811{,}11} = 14{,}3$$

c) The service life time of the four runner blocks is calculated according to [2.5]

$$L_1 = \left(\frac{C}{F_{Z1}} * \frac{f_H * f_T * f_C}{f_W}\right)^3 * 5*10^4 = \left(\frac{36.710}{3.811{,}11} * \frac{1}{1{,}5}\right)^3 * 5*10^4 = 13.240.211\ m = 13.240\ km$$

$$L_2 = \left(\frac{C}{F_{Z2}} * \frac{f_H * f_T * f_C}{f_W}\right)^3 * 5*10^4 = \left(\frac{36.710}{1.197{,}77} * \frac{1}{1{,}5}\right)^3 * 5*10^4 = 426.509.871\ m = 426.510\ km$$

$$L_3 = \left(\frac{C}{F_{Z3}} * \frac{f_H * f_T * f_C}{f_W}\right)^3 * 5*10^4 = \left(\frac{36.710}{1.851{,}11} * \frac{1}{1{,}5}\right)^3 * 5*10^4 = 115.545.411\ m = 115.545\ km$$

$$L_4 = \left(\frac{C}{F_{Z4}} * \frac{f_H * f_T * f_C}{f_W}\right)^3 * 5*10^4 = \left(\frac{36.710}{762{,}23} * \frac{1}{1{,}5}\right)^3 * 5*10^4 = 1.654.974.350\ m = 1.654.974\ km$$

The nominal service life time for the most highly stressed carriage 1 corresponds to the service life time of the total system for the application described above and is 13,240 km.

Example 3

Vertical installation position (e.g. transport lift, Z-axis of a lifting device) with inertia forces, 2 rails arranged in parallel,
2 carriages per rail, LGBCH20FN
$v=1$ m/s
$a=0,5$ m/s^2
$s_1=1000$ mm
$s_2=2000$ mm
$s_3=1000$ mm
Mass $m=100$ kg

Gravity constant $g=9.8$ m/s^2
$l_0=300$ mm, $l_1=500$ mm, $l_5=250$ mm, $l_6=280$ mm
$C=17,71$ kN
$C_0=30,50$ kN
$f_w=2,0$ (T able 2.3)

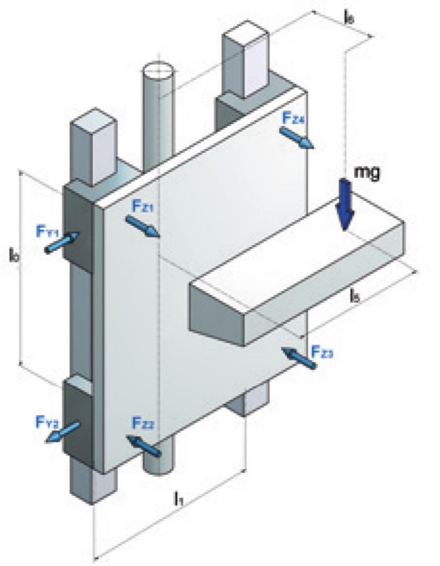
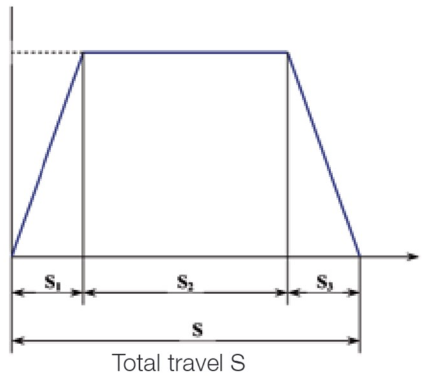


Figure 2.13 Calculation example 3



Total travel S
Figure 2.14 Velocity/distance diagram

Calculation:
a) The active loads are calculated per carriage

During the acceleration phase
Radial loads

$$F_{BeschZ1} = \frac{m(g+a)*l_6}{2*l_0} = \frac{100*(9,8+0,5)*280}{2*300} = 480,67\ N$$

$$F_{BeschZ2} = -\frac{m(g+a)*l_6}{2*l_0} = -\frac{100*(9,8+0,5)*280}{2*300} = -480,67\ N$$

$$F_{BeschZ3} = -\frac{m(g+a)*l_6}{2*l_0} = -\frac{100*(9,8+0,5)*280}{2*300} = -480,67\ N$$

$$F_{BeschZ4} = \frac{m(g+a)*l_6}{2*l_0} = \frac{100*(9,8+0,5)*280}{2*300} = 480,67\ N$$

Tangential loads

$$F_{BeschY1} = \frac{m(g+a)*l_5}{2*l_0} = \frac{100*(9{,}8+0{,}5)*250}{2*300} = 429{,}17\ N$$

$$F_{BeschY2} = -\frac{m(g+a)*l_5}{2*l_0} = -\frac{100*(9{,}8+0{,}5)*250}{2*300} = -429{,}17\ N$$

$$F_{BeschY3} = -\frac{m(g+a)*l_5}{2*l_0} = -\frac{100*(9{,}8+0{,}5)*250}{2*300} = -429{,}17\ N$$

$$F_{BeschY4} = \frac{m(g+a)*l_5}{2*l_0} = \frac{100*(9{,}8+0{,}5)*250}{2*300} = 429{,}17\ N$$

At constant velocyit
Radial loads

$$F_{KonstZ1} = \frac{mg*l_6}{2*l_0} = \frac{100*9{,}8*280}{2*300} = 457{,}33\ N$$

$$F_{KonstZ2} = -\frac{mg*l_6}{2*l_0} = -\frac{100*9{,}8*280}{2*300} = -457{,}33\ N$$

$$F_{KonstZ3} = -\frac{mg*l_6}{2*l_0} = -\frac{100*9{,}8*280}{2*300} = -457{,}33\ N$$

$$F_{KonstZ4} = \frac{mg*l_6}{2*l_0} = \frac{100*9{,}8*280}{2*300} = 457{,}33\ N$$

Tangential loads

$$F_{KonstY1} = \frac{mg*l_5}{2*l_0} = \frac{100*9{,}8*250}{2*300} = 408{,}33\ N$$

$$F_{KonstY2} = -\frac{mg*l_5}{2*l_0} = -\frac{100*9{,}8*250}{2*300} = -408{,}33\ N$$

$$F_{KonstY3} = -\frac{mg*l_5}{2*l_0} = -\frac{100*9{,}8*250}{2*300} = -408{,}33\ N$$

$$F_{KonstY4} = \frac{mg*l_5}{2*l_0} = \frac{100*9{,}8*250}{2*300} = 408{,}33\ N$$

During the deceleration phase

Radial loads

$$F_{VerzZ1} = \frac{m(g-a)*l_6}{2*l_0} = \frac{100*(9,8-0,5)*280}{2*300} = 434\ N$$

$$F_{VerzZ2} = -\frac{m(g-a)*l_6}{2*l_0} = -\frac{100*(9,8-0,5)*280}{2*300} = -434\ N$$

$$F_{VerzZ3} = -\frac{m(g-a)*l_6}{2*l_0} = -\frac{100*(9,8-0,5)*280}{2*300} = -434\ N$$

$$F_{VerzZ4} = \frac{m(g-a)*l_6}{2*l_0} = \frac{100*(9,8-0,5)*280}{2*300} = 434\ N$$

Tangential loads

$$F_{VerzY1} = \frac{m(g-a)*l_5}{2*l_0} = \frac{100*(9,8-0,5)*250}{2*300} = 387,50\ N$$

$$F_{VerzY2} = -\frac{m(g-a)*l_5}{2*l_0} = -\frac{100*(9,8-0,5)*250}{2*300} = -387,50\ N$$

$$F_{VerzY3} = -\frac{m(g-a)*l_5}{2*l_0} = -\frac{100*(9,8-0,5)*250}{2*300} = -387,50\ N$$

$$F_{VerzY4} = \frac{m(g-a)*l_5}{2*l_0} = \frac{100*(9,8-0,5)*250}{2*300} = 387,50\ N$$

b) The combined radial and tangential loads are calculated per carriage according to [2.8].

During the acceleration phase

$$F_{BeschE1} = |F_{BeschZ1}| + |F_{BeschY1}| = 909,84\ N$$

$$F_{BeschE2} = |F_{BeschZ2}| + |F_{BeschY2}| = 909,84\ N$$

$$F_{BeschE3} = |F_{BeschZ3}| + |F_{BeschY3}| = 909,84\ N$$

$$F_{BeschE4} = |F_{BeschZ4}| + |F_{BeschY4}| = 909,84\ N$$

At constant velocity

$$F_{KonstE1} = |F_{KonstZ1}| + |F_{KonstY1}| = 865{,}67\ N$$

$$F_{KonstE2} = |F_{KonstZ2}| + |F_{KonstY2}| = 865{,}67\ N$$

$$F_{KonstE3} = |F_{KonstZ3}| + |F_{KonstY3}| = 865{,}67\ N$$

$$F_{KonstE4} = |F_{KonstZ4}| + |F_{KonstY4}| = 865{,}67\ N$$

During the deceleration phase

$$F_{VerzE1} = |F_{VerzZ1}| + |F_{VerzY1}| = 821{,}50\ N$$

$$F_{VerzE2} = |F_{VerzZ2}| + |F_{VerzY2}| = 821{,}50\ N$$

$$F_{VerzE3} = |F_{VerzZ3}| + |F_{VerzY3}| = 821{,}50\ N$$

$$F_{VerzE4} = |F_{VerzZ4}| + |F_{VerzY4}| = 821{,}50\ N$$

c) The static safety factor for the maximum load on the linear guide during the acceleration phase is calculated according to [2.1].

$$f_S = \frac{C_0}{F_{0MAX}} = \frac{30.500}{909{,}84} = 33{,}5$$

d) The active, dynamic, equivalent load is calculated according to [2.9]

$$S = S_1 + S_2 + S_3 = 4.000\ mm$$

$$F_{m1} = \sqrt[3]{\frac{1}{S}\left(F^3_{BeschE1} * S_1 + F^3_{KonstE1} * S_2 + F^3_{VerzE1} * S_3\right)} =$$

$$= \sqrt[3]{\frac{1}{4.000} * \left(909{,}84^3 * 1.000 + 865{,}67^3 * 2.000 + 821{,}50^3 * 1.000\right)} = 866{,}79\ N$$

$$F_{m2} = \sqrt[3]{\frac{1}{S}\left(F^3_{BeschE2} * S_1 + F^3_{KonstE2} * S_2 + F^3_{VerzE2} * S_3\right)} =$$

$$= \sqrt[3]{\frac{1}{4.000} * \left(909{,}84^3 * 1.000 + 865{,}67^3 * 2.000 + 821{,}50^3 * 1.000\right)} = 866{,}79\ N$$

$$F_{m3} = \sqrt[3]{\frac{1}{S}\left(F^3_{BeschE3} * S_1 + F^3_{KonstE3} * S_2 + F^3_{VerzE3} * S_3\right)} =$$

$$= \sqrt[3]{\frac{1}{4.000} * \left(909{,}84^3 * 1.000 + 865{,}67^3 * 2.000 + 821{,}50^3 * 1.000\right)} = 866{,}79\ N$$

$$F_{m4} = \sqrt[3]{\frac{1}{S}\left(F^3_{BeschE4} * S_1 + F^3_{KonstE4} * S_2 + F^3_{VerzE4} * S_3\right)} =$$

$$= \sqrt[3]{\frac{1}{4.000} * \left(909{,}84^3 * 1.000 + 865{,}67^3 * 2.000 + 821{,}50^3 * 1.000\right)} = 866{,}79\ N$$

e) The nominal service life time is calculated according to [2.5].

$$L_1 = \left(\frac{C}{F_{m1}} * \frac{f_H * f_T * f_C}{f_W}\right)^3 * 5 * 10^4 = \left(\frac{17.710}{866{,}79} * \frac{1}{2{,}0}\right)^3 * 5 * 10^4 = 53.515.380\ m = 53.515\ km$$

Example 4

Horizontal installation position (e.g. transport frame) with inertial forces, 2 rails arranged in parallel, 2 carriages per rail, LGBCH25FN

v=1 m/s

t_1=1 s

t_2=2 s

t_3=1 s

s=4 000 mm

Mass m=150 kg

Gravity constant=9,8 m/s²

l_0=600 mm, l_1=400 mm, l_5=150 mm, l_6=500mm

C=24,85 kN

C_0=47,07 kN

f_W=2,0 (according Table 2.3)

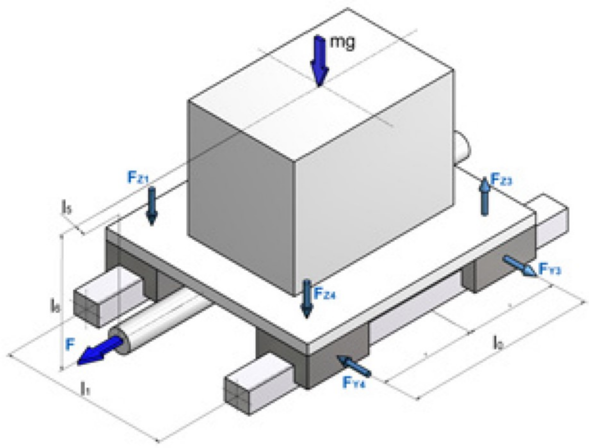


Figure 2.15 Calculation example 4

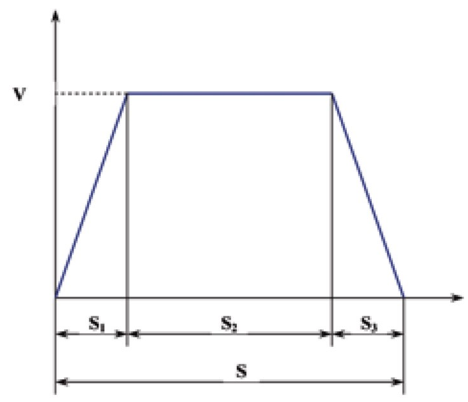


Figure 2.16 Velocity/distance diagram

Calculation:

a) Distance and acceleration calculation

Acceleration phase: $a_1 = \frac{V}{t_1} = \frac{1}{1} = 1 m/s^2$

Deceleration phase $a_3 = \frac{V}{t_3} = \frac{1}{1} = 1 m/s^2$

b) The active loads are calculated per carriage

During the acceleration phase

Radial loads

$$F_{BeschZ1} = F_{BeschZ4} = \frac{mg}{4} - \frac{m * a_1 * l_6}{2 * l_0} = \frac{150 * 9,8}{4} - \frac{150 * 1 * 500}{2 * 600} = 305\ N$$

$$F_{BeschZ3} = F_{BeschZ2} = \frac{mg}{4} + \frac{m * a_1 * l_6}{2 * l_0} = \frac{150 * 9,8}{4} + \frac{150 * 1 * 500}{2 * 600} = 430\ N$$

Tangential loads

$$F_{BeschY1} = F_{BeschY2} = F_{BeschY3} = F_{BeschY4} = \frac{m * a_1 * l_5}{2 * l_0} = \frac{150 * 1 * 150}{2 * 600} = 18,75\ N$$

At constant velocity

Radial loads

$$F_{KonstZ1} = F_{KonstZ2} = F_{KonstZ3} = F_{KonstZ4} = \frac{mg}{4} = \frac{150 * 9,8}{4} = 367,5\ N$$

During the deceleration phase

Radial loads

$$F_{VerzZ1} = F_{VerzZ4} = \frac{mg}{4} + \frac{m * a_3 * l_6}{2 * l_0} = \frac{150 * 9,8}{4} + \frac{150 * 1 * 500}{2 * 600} = 430\ N$$

$$F_{VerzZ2} = F_{VerzZ3} = \frac{mg}{4} - \frac{m * a_3 * l_6}{2 * l_0} = \frac{150 * 9,8}{4} - \frac{150 * 1 * 500}{2 * 600} = 305\ N$$

Tangential loads

$$F_{VerzY1} = F_{VerzY2} = F_{VerzY3} = F_{VerzY4} = \frac{m * a_3 * l_5}{2 * l_0} = \frac{150 * 1 * 150}{2 * 600} = 18,75\ N$$

c) The equivalent radial and tangential loads are calculated per carriage according to [2.8].

During the acceleration phase

$$F_{BeschE1} = F_{BeschE4} = \left|F_{BeschZ1}\right| + \left|F_{BeschY1}\right| = 323{,}75\ N$$

$$F_{BeschE2} = F_{BeschE3} = \left|F_{BeschZ2}\right| + \left|F_{BeschY2}\right| = 448{,}75\ N$$

At constant velocity

$$F_{KonstE1} = F_{KonstE2} = F_{KonstE3} = F_{KonstE4} = 367{,}5\ N$$

During the deceleration phase

$$F_{VerzE1} = F_{verzE4} = \left|F_{VerzZ1}\right| + \left|F_{VerzY1}\right| = 448{,}75\ N$$

$$F_{VerzE2} = F_{verzE3} = \left|F_{VerzZ2}\right| + \left|F_{VerzY2}\right| = 323{,}75\ N$$

d) The static safety factor for the maximum load on the linear guide during the acceleration and deceleration phase is calculated according to [2.1].

$$f_S = \frac{C_0}{F_{0MAX}} = \frac{41.070}{448{,}75} = 91{,}5$$

e) The active, dynamic, equivalent load is calculated according to [2.9].

$$F_{m1} = F_{m4} = \sqrt[3]{\frac{1}{S}\left(F^3_{BeschE1} * S_1 + F^3_{KonstE1} * S_2 + F^3_{VerzE1} * S_3\right)} =$$

$$= \sqrt[3]{\frac{1}{4.000} * \left(323{,}75^3 * 1.000 + 367{,}5^3 * 2.000 + 448{,}75^3 * 1.000\right)} = 382{,}3\ N$$

$$F_{m2} = F_{m3} = \sqrt[3]{\frac{1}{S}\left(F^3_{BeschE2} * S_1 + F^3_{KonstE2} * S_2 + F^3_{VerzE2} * S_3\right)} =$$

$$= \sqrt[3]{\frac{1}{4.000} * \left(448{,}75^3 * 1.000 + 367{,}5^3 * 2.000 + 323{,}75^3 * 1.000\right)} = 382{,}3\ N$$

f) The service life time of the four carriages is calculated according to [2.5].

$$L = \left(\frac{C}{F_{m1}} * \frac{f_H * f_T * f_C}{f_W}\right)^3 * 5 * 10^4 = \left(\frac{24.850}{382{,}3} * \frac{1}{2{,}0}\right)^3 * 5 * 10^4 = 1.716.509.860\ m = 1.716.510\ km$$

10. Guide to queries

Date ______________________________

Offer valid until ______________________

Company ______________________________

City ______________________________ Address ______________________________

Contact person ______________________________

Phone ______________________________ Fax ______________________________

Mail ______________________________

Project description

☐ Once-off requirement Number of items ____ Preferred date ______________________

☐ Series requirement Items/year ________ Preferred date for number of items ______CW

☐ New design ☐ Technical upgrade ☐ Cost reduction

System description

Number of parallel rails ______________________

Distance of the (outer) rails: ______________________ from 4 rails onwards,
distance of the inner rails: ______________

Number of carriages: ______________________

Distance of the (outer) carriages: ______________ from 4 carriages: onwards,
distance of the inner carriages: ____________

Position of the drive: ____________ horizontal (y) [mm] ______________________ vertical (z) [mm]

Installation position: __________ Longitudinal incline [°] ______________________ Cross incline [°]

Installation surface: machined __________ unmachined ______________________

For permanent temperature ________________ °C

Stroke [mm]: ______________________________

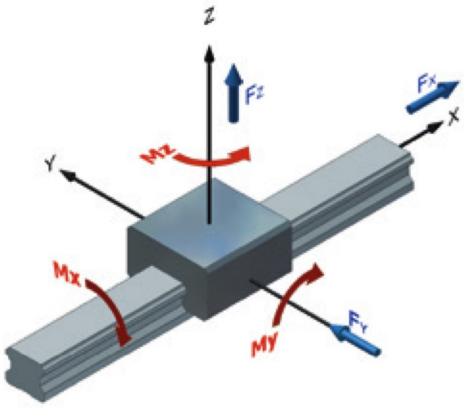
Cycle time [s]: ______________________________

Movement velocity [m/min]: ______________________ Optional movement time [s]: ____________

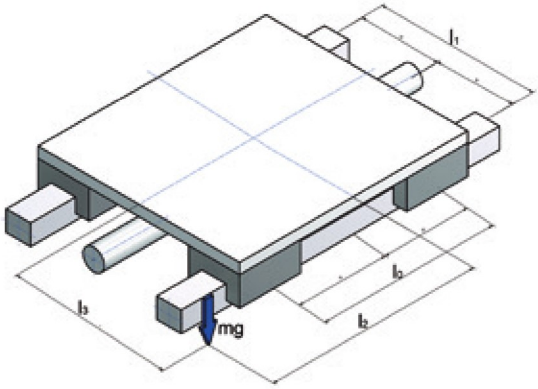
Acceleration [m/s²]: ______________________ Acceleration at emergency stop [m/s²] ______

Desired service life time: ______________________ Cycles or ________ km or ________ hours

Coordinate system



Position of the loads



Loads

Load		longitudinal [mm]		horizontal [mm]	vertical [mm]	Travel percentage	Comments
Centre of gravity	[kg]	x_{max}	x_{min}	y	z	[%]	
m1							
m2							
m3							
m4							
m5							
External force		longitudinal [mm]		horizontal [mm]	vertical [mm]	Travel percentage	Comments
Point of action	[N]	x_{max}	x_{min}	y	z	[%]	
Fx		not applicable					
Fy				not applicable			
Fz					not applicable		

Drawing: