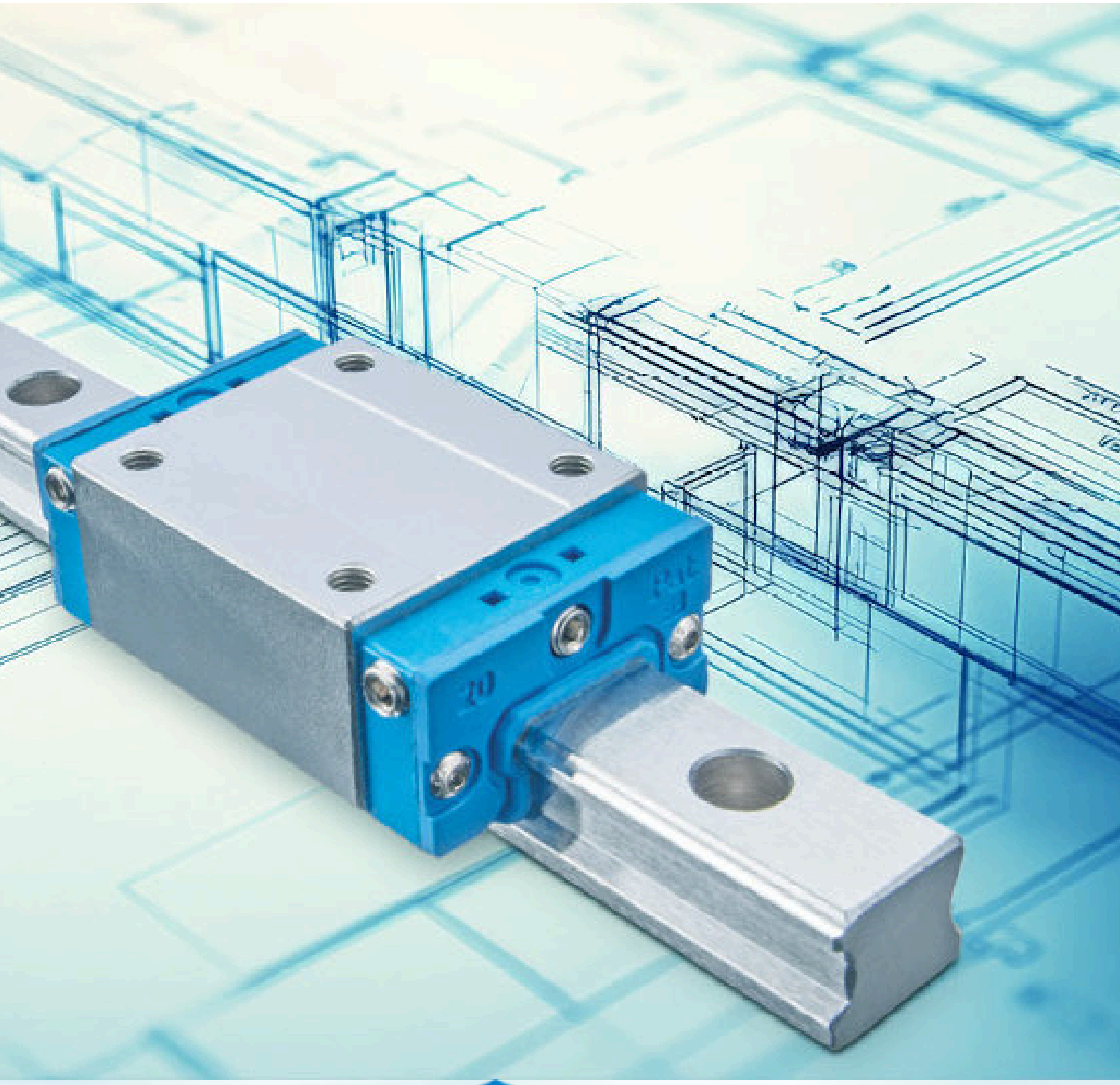
NTN

ALL ABOUT LINEAR MOTION



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Calculation principles (linear guides)

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As with rolling bearings, certain calculation principles must also be mastered in linear motion in order not to expose the linear guides to excessive loads and to prevent failures, a shortened service life and as well the oversizing of linear guides. It is therefore essential, for example, to calculate the service life of linear guides. Other calculations relate to the static safety factor or stiffness.

The nominal service life L_{10}

The servie life L refers to the mileage that a component can cover before the first signs of material fatigue, which are usually visible on the raceways or the rolling elements, appear.
You may already be familiar with the nominal service life L_{10} from the service life calculation of rolling bearings. It is based on a statistical calculation. L_{10} describes the calculated service life; it refers to a single linear guide system or a group of identical linear guide systems that run under the same operating conditions and can achieve the calculated service life with a 90 % probability of failure. If you want to reduce the failure probability of 10 %, you can achieve this goal through different dimensioning. However, this can easily lead to overdimensioning of the linear guide systems. To avoid such overdimensioning and design errors, it is advisable to consult the manufacturer in the event of uncertainties.
The nominal service life L_{10} of linear guides is specified in kilometres. The service life of ball guides is calculated slightly differently to that of roller guides; depending on the type of linear guide, one of the two formulas must always be used.

Formula 1

for ball guides:

$$L = \left(\frac{f_h \times f_c \times f_t}{f_w} \times \frac{C_{50}}{F_m} \right)^3 \times 5 \times 10^4$$

or

$$L = \left(\frac{f_h \times f_c \times f_t}{f_w} \times \frac{C_{100}}{F_m} \right)^3 \times 10^5$$

$$C_{100} = 1,26 \times C_{50}$$

for roller guides:

$$L = \left(\frac{f_h \times f_c \times f_t}{f_w} \times \frac{C_{100}}{F_m} \right)^{10/3} \times 10^5$$

L	Nominal service life (m)
C_{50}	Dynamic load rating based on 50 km (kN)
C_{100}	Dynamic load rating based on 100 km (kN)

f_h	Hardness factor
f_c	Contact factor
f_t	Temperature factor
f_w	Load factor
F_m	Average equivalent load

When calculating the service life, different formulae must be used depending on the type of linear guide.
As indicated above, the operating conditions are a factor that should not be neglected when calculating the service life. The intensity of vibrations and shocks is of particular importance, and a distinction is made between five levels.

Operating conditions	Speed (m/s)	Load factor f_w
No or very low vibrations and shocks	≤0.25	1.0...1.2
Low vibrations and shocks	0.25...≤1.0	1.2...1.5
Medium vibrations and shocks	1.0...≤2.0	1.5...2.0
Strong vibrations and shocks	>2.0	2.0...3.5
Short-stroke applications		3.5...5.0

As in the rotative area, oscillations and vibrations can have negative effects on the contact surface between the rolling element and the raceway.
Depending on the requirements, the nominal service life L_{10} can also be specified in units other than kilometres. It is possible to convert the unit into hours L_h or cycles $L_\#$.
Formula 2

$L_h = \frac{L \times 10^3}{2 \times s \times n \times 60}$		$L_\# = \frac{L}{2 \times s}$	
L_h	Nominal service life (h)	$L_\#$	Nominal service life (cycles)
s	Stroke (m)	s	Stroke (m)
n	Number of Strokes (min^{-1})		

In contrast to $L_\#$, the number of double strokes or cycles (min^{-1}) must be considered when converting to L_h.

The dynamic load rating *C*

According to DIN ISO 14728-1, the dynamic load rating *C* describes a radial load that is not variable in size and direction and that a linear guide can theoretically absorb for a nominal service life of 5×10^{10} m travelled distance. The following applies: If a nominal service life of 10^6 is assumed, the dynamic load rating for a nominal service life of 5×10^{10} m is multiplied by a conversion factor *1,26*. This conversion factor is also used to compare the load ratings. The formula for calculating the dynamic load rating is based on DIN ISO 14728-2.

The static load rating C_0

The static load rating C_0 is the static radial load in the centre of the most heavily loaded contact surface between the rolling element and the raceway. The static load rating C_0 corresponds to a calculated Hertz-type compression. According to DIN ISO 14728-1, this Hertz-type compression for linear guides is between 4 200 MPa and 4 600 MPa. This load results in a permanent overall deformation of the raceway. This deformation corresponds to approximately 0.0001 times the diameter of the rolling element (therefore the static safety factor f_s has to be always *> 1*). The formula for calculating the static load rating C_0 is also defined in accordance with DIN ISO.

The static safety factor f_s

Another factor that needs to be calculated is the static safety factor f_s. This must be considered, as unexpected or unforeseen loads and/or torques can act on the linear guide system when designing linear guides. These can be due to various causes, primarily vibrations, shocks, short start-stop cycles (strokes) or overhanging loads.
The static safety factor f_s is the ratio of the static load rating C_0 to the maximum occurring load F_{omax}. This refers to the highest amplitude; even very short-term amplitudes are taken into account. The function of the static safety factor f_s is to prevent impermissible plastic deformation of the raceways and rolling elements. This factor also prevents cracks and fractures in the raceways.
Formula 3

$$f_s = \frac{f_H \times f_T \times f_C \times C_0}{F_{\max}}$$

f_s	Static safety factor
f_c	Contact factor
f_H	Hardness factor
f_T	Temperature factor
C_0	Static load rating [kN]
F_{max}	Maximum equivalent load [kN]

The static safety factor f_s must not be less than 1 but in practice is usually greater than 2 under normal operating conditions. The formula for the static safety factor f_s is also used for ball bushings.
Finally, a brief explanation of the three influencing factors, the contact factor, hardness factor and temperature factor, follows. The contact factor f_c considers the fact that the full load-capacity cannot be utilised if the carriages are arranged very close together or on block due to tolerances. From a distance between the carriages of two carriage lengths, the contact factor no longer has any influence and is 1.
The hardness factor f_H is always 1 at NTN. However, if a guide is not made from carbon steel like 100Cr6, but from a material with a lower hardness, a different value would have to be calculated.

The fact that the rail hardness is reduced in a temperature range of over 100 °C is considered with the temperature factor f_T . For applications with the corresponding temperature ranges, the temperature factor must therefore always be included in the calculation of the static safety factor f_s.

You may also be interested in

Types of linear axis

Alongside linear guides, screw drives and ball bushings linear axis are an important product in the field of linear motion. Although the first linear axis came onto the market in the early 1990s, they only became established as a standard component for industrial applications at the beginning of the current century. It should be emphasized that there is no uniform
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Types of screw drives

You may have heard of ball screws before. These are certainly the best known of the screw drives, but they are not the only ones, as trapezoidal screw drives are a second type. This article will focus on the former, but you will still find everything you need to know about both types here. Design, mode of operation and areas
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Types of linear guides

Linear guides are presented below as one type of linear system. Linear guides are among the most important guide systems on the market, mainly because they can be used universally. Types of linear guides A distinction is mainly made between two types of linear guides: Shaft guides and rail guides. Both can be subdivided into different types. Types of shaft
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Materials

This article is the right address for you if you want to find out more about the materials used in linear systems. First of all, all components that need to be robust are made of steel, including the rolling elements, the guide rails and the carriages. General information on the materials In addition to steel, various other materials are used
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Point, surface and line contact

If you have already dealt with the point and linear contact of rolling bearings, you will recognise a few things. As with rolling bearings, the rolling elements of linear guide systems have either a ball or roller shape. The contact with a raceway (rolling contact) is different for balls and rollers due to their round or elongated shape. With rolling
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History of linear motion

Linear motion has been around for a very long time – its history even stretches back to ancient times! In ancient Egypt, it was necessary to transport heavy loads from one place to another to build palaces and pyramids.

Creative ideas were already being put into practice back then, as it was of course not possible to simply pull the
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NTN Europe - 1 Rue des Usines, 74010 Annecy
www.ntn-snr.com

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