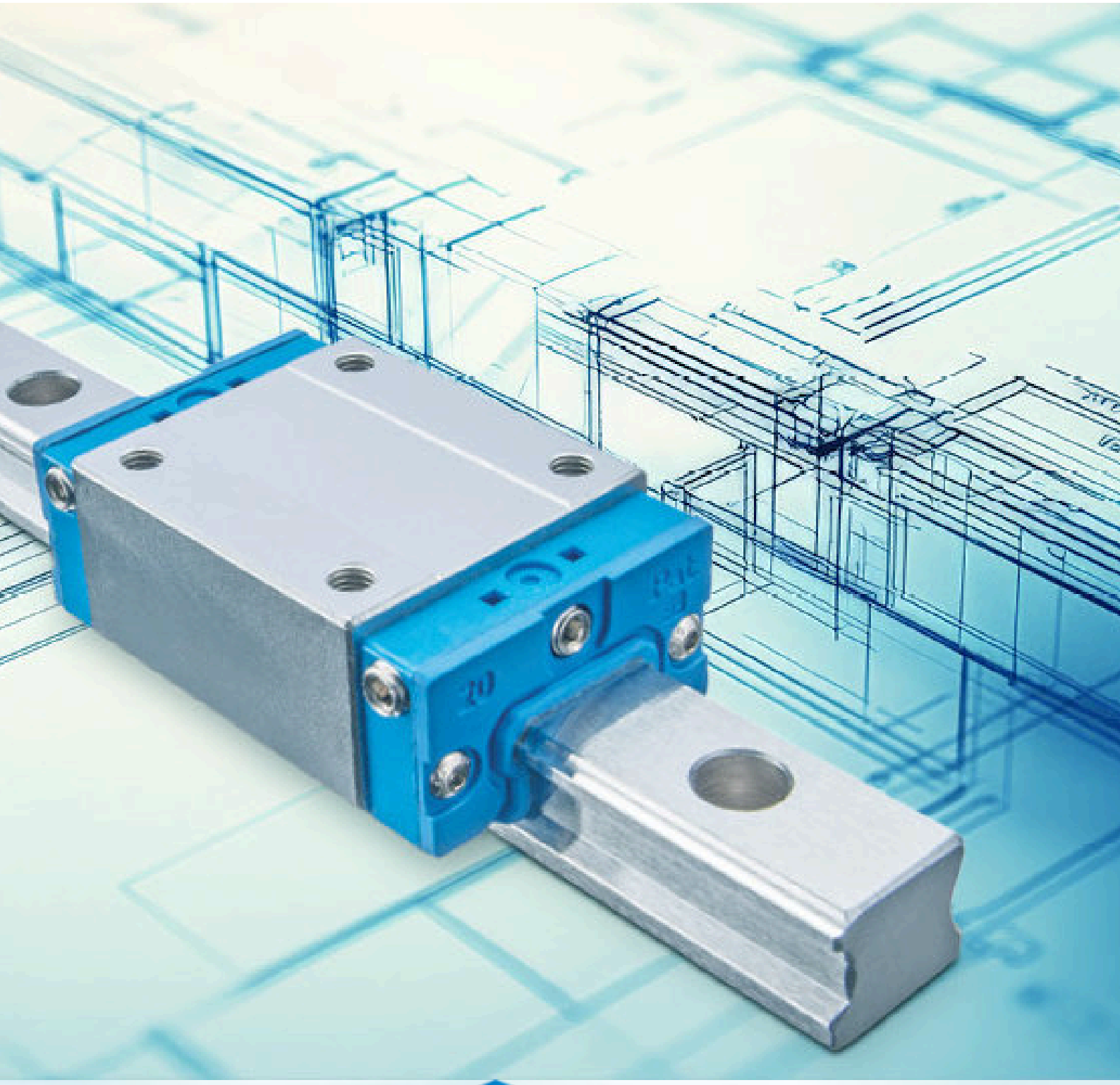
NTN

ALL ABOUT LINEAR MOTION



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Calculation principles (screw drives)

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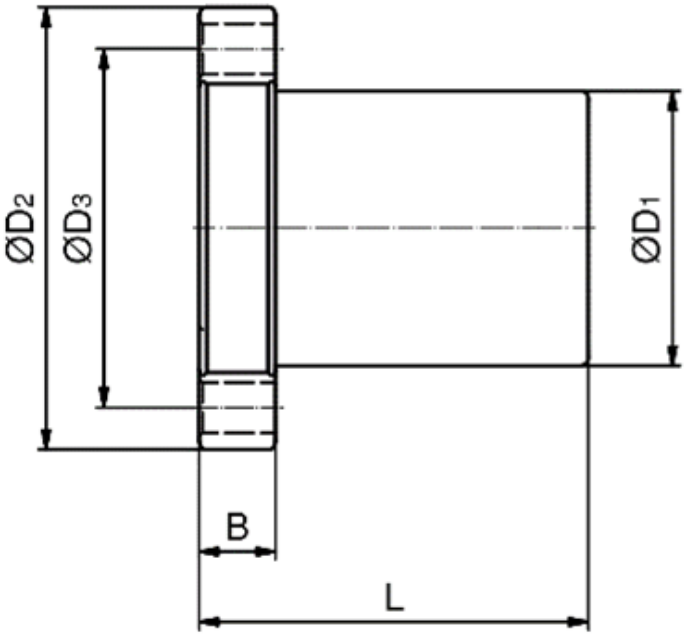
The calculation bases for screw drives are extensive and range from the calculation of the static safety factor to the critical speed, the buckling load and the nominal service life. All of this awaits you below. If you are looking for further calculation bases, you will find them in our catalogue.

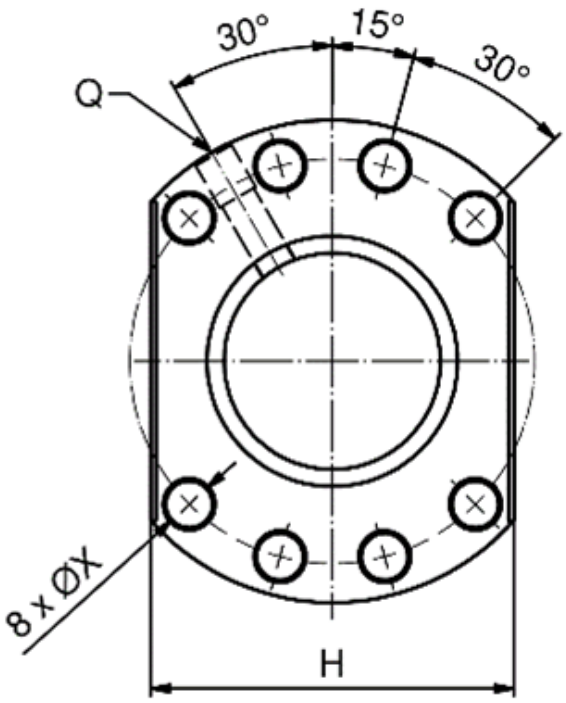
Definition of screw drives

From a mathematical point of view, several factors must be taken into account when defining screw drives. Screw drives have a nominal diameter d_0, which is a round value and cannot be measured directly for every product. What can be measured, however, is the outer diameter of the screw d_1, which in many cases – but not always – deviates from d_0. The spindle core diameter d_2 and the ball centre-to-centre diameter D_{pw} are used to calculate certain dynamic parameters. The latter diameter is measured from the center of the ball on one side to the center of the ball on the other side. The pitch P is also of essential importance, while the use of the pitch angle $ß$ is rarely necessary.
There are three main values to consider for the nut: the outer diameter of the nut body D_1, the flange diameter D_2 and the pitch circle diameter of the flange D_3. Further parameters are the nominal ball diameter D_w, the static axial load rating C_{0a} and the dynamic axial load rating C_a. The nut length must also be taken into account.

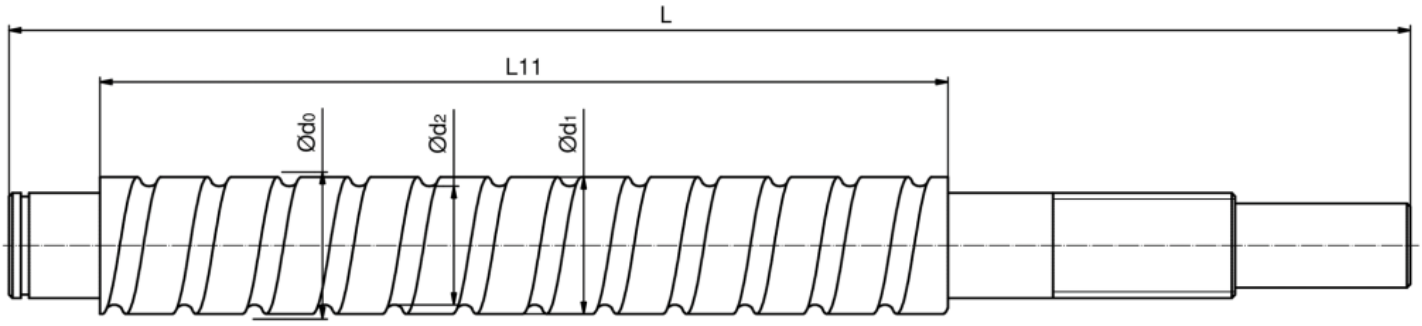
Ball screw drive	Mother
	$øD_1$ = Outer diameter of the nut body
$ød_0$ = Nominal diameter	$øD_2$ = Flange diameter
$ød_1$ = Outer spindle diameter	$øD_3$ = Pitch circle diameter of the flange
$ød_2$ = Spindle core diameter	Ball
$øD_{pw}$ = Ball centre-to-centre diameter	$øD_w$ = Nominal diameter of the ball
P = Pitch	C_{0a} = Static axial load rating
$ß$ = Pitch angle	C_a = Dynamic axial load rating

In this overview you will find all the mathematical definition criteria for ball screws, nuts and balls at a glance.





You can use these measurement sheets to check the values D_1 , D_2, D_3...



...as well as d_0 , d_1 and d_2.

Calculation of the drive torque

The efficiency is the percentage of the applied energy that is converted into active power. The formulas and parameters required for this are as follows.

Formula 4: Calculation of the drive torque T $T = \frac{F_a \times P}{2 \times \pi \times \eta}$		Formula 5: Calculation of the axial force F_a $F_a = m \times a \times \mu$	
T	Drive torque	m	Mass
F_a	Axial force	a	Acceleration

P	Pitch	μ	Coefficient of friction of the drive system
□	Efficiency from conversion from rotation into linear movement		

Both the efficiency □ and the axial force F_a are important for determining the drive torque T.

Load ratings: the axial static load rating C_{0a} and axial dynamic load rating C_a

The axial static load rating C_{0a} describes the constant axial load that generates a total plastic deformation of 0.00001 times the ball diameter. According to DIN, the axial load ratings – both axial static and axial dynamic – based on tolerance class 5. The axial static load rating C_{0a} is calculated on the basis of DIN 69051-4.
The calculation of the axial static load rating C_{0a} is also relevant in addition to the calculation of the axial dynamic load rating C_a. The axial dynamic load rating C_a is defined as the axial load that is unchanging in size and direction and under which a ball screw drive theoretically achieves a service life of 10^6 revolutions. The axial dynamic load rating C_a for ball screws is also determined in accordance with DIN 69051-4.
With regard to the axial load ratings, it is important to note that the relevant information in the NTN catalogue refers to an optimum load distribution on all loaded balls for ball screws of tolerance class 5. For tolerance classes deviating from tolerance class 5, a correction factor f_{ac} must be taken into account, which can be read from the table.
The greater the pitch error of a screw, the less guarantee there is that all balls will bear equally. Consequently, if not all balls loaded evenly, the axial load rating decreases. It is therefore necessary to correct the axial load rating by taking the tolerance class into account.

	Tolerance class		
	0, 1, 3, 5	7	10
Correction factor f_{ac}	1.0	0.9	0.7

Correction factors for the different tolerance classes according to DIN ISO 3408-5 .

The static safety factor f_s

The static safety factor f_s must also be taken into account. This takes into account the fact that ball screw drives can be exposed to unforeseen loads. These can have various causes, such as vibrations, shocks or short start-stop cycles. The static safety factor f_s is used to prevent impermissible, permanent plastic deformation of both raceways and rolling elements of the ball screw. It is essential that this factor is appropriately observed to ensure the stability and functionality of the respective application with ball screws and to guarantee reliable operation under various load conditions. The static safety factor f_s must always be ≥ 1. If the assumed loads fluctuate greatly and tend to be unpredictable, a higher safety factor f_s should be used.
Although the calculation of the static safety factor for ball screws is not the same, it is similar to that for linear guides. For ball screws, the two influence factors (the hardness factor f_H and the temperature factor

f_T) are multiplied by the basic static load rating C_{0a} and divided by the maximum axial load F_{max}.

Formula 6

$$f_s = \frac{f_H \times f_T \times C_{0a}}{F_{\max}}$$

f_s	Static safety factor
f_H	Hardness factor
f_T	Temperature factor
C_{0a}	Axial static load rating [kN]
F_{max}	Maximum axial load [kN]

As with linear guides checking the static safety factor is also important for ball screw drives.

Even if there is no clear rule, there are certain guide values or recommendations as to how high this factor should be as a minimum. The factor depends on the movement speeds acting on the ball screw drive and how heavy the loads and how intense the vibrations and shocks are.

Operating conditions	Static safety factor f_s
• Slow movements • Low loads • No vibrations and shocks	1.0 ... 1.3
• Slow movements • Low loads • Light vibrations and shocks	1.2 ... 1.7
• Slow movements • Medium loads • Vibrations and shocks	1.5 ... 2.5
• Fast movements • High loads • Vibrations and shocks	2.0 ...4.0
• Fast movements • High loads • Strong vibrations and shocks	3.0 ... 8.0

Ideally, you need a low static safety factor f_s, but in extreme conditions or highly loaded applications this can (far) exceed 3.0.

The nominal service life L_{10}

The nominal service life L_{10} is the calculated service life that can be achieved with a 90 % probability of survival for ball screws under normal operating conditions. Several influencing factors are required to calculate the nominal service life of ball screws. These include the load factor f_w, the hardness factor f_H

and the temperature factor f_T. Furthermore, the axial dynamic load rating C_a and the average axial load F_m are required.

Formula 7

$$L = \left(\frac{f_T \times f_H}{f_W} \times \frac{C_a}{F_m} \right)^3 \times 10^6$$

L	Nominal service life [min^{-1}]
C_a	Axial dynamic load rating [kN]
f_w	Load factor
f_H	Hardness factor
f_T	Temperature factor
F_m	Average axial load [kN]

On linearwizard.com you will also find information on calculating the service life of linear guides and ball bushings.

With regard to the load factor f_w, there are recommendations that depend on the operating conditions, more precisely on the strength of the vibrations and shocks that act on the screw drives in the individual application. If the conditions cannot be precisely predicted in advance, the load factor should be taken into account with a certain degree of certainty or based on experience with comparable applications.

Operating conditions	Speed [m/s]	Load factor f_w
No or very low vibrations and shocks	≤0.25	1.0 ... 1.2
Light 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

The load factor results from the operating conditions.

The nominal service life L_{10} can also be specified in units other than revolutions. Depending on the requirement, it can be specified in kilometers L_s, in hours L_h or in cycles $L_\#$.

Formula 8

Formel 12

$$L_s = \frac{L \times P}{10^6}$$

L	nominelle Lebens-dauer [min^{-1}]
L_s	nominelle Lebens-dauer [km]

$$L_h = \frac{L}{n_m \times 60 \times ED}$$

L	nominelle Lebens-dauer [min^{-1}]
L_h	nominelle Lebens-dauer [h]

$$L_\# = \frac{L \times P}{2 \times s}$$

L	nominelle Lebensdauer [min^{-1}]
$L_\#$	nominelle Lebensdauer [Zyklen]

P	Spindelsteigung [mm]	n_m	Mittlere Betriebsdreh-zahl [min^{-1}]	*P*	Spindelsteigung [mm]
		ED	Einschaltdauer [%]	*s*	Verfahrweg

$$L_s = \frac{L \times P}{10^6}$$

L
Nominal service life [min^{-1}]
L_s
Nominal service life [km]
P
Pitch [mm]

$$L_h = \frac{L}{n_m \times 60 \times ED}$$

L
Nominal service life [min^{-1}]
L_h
Nominal service life [h]
n_m
Average operating speed [min^{-1}]
ED
Duty cycle [%]

$$L_\# = \frac{L \times P}{2 \times s}$$

L
Nominal service life [min^{-1}]
$L_\#$
Nominal service life [cycles]
P
Pitch [mm]
s
Stroke
Here you will find the formulas for converting the service life into kilometers, hours or cycles.
Further calculation principles can be found in NTN catalogue for ball screws. Information on mounting screw drives can be found in the corresponding article.

You may also be interested in

Types of ball bushings

Ball bushings, which are also known as “linear ball bearings“, are an important product in linear motion. This article deals with the different variants of ball bushings and their properties but first provides you with basic information regarding their history, characteristics and design.
Read more »

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
Read more »

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
Read more »

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
Read more »

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
Read more »

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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