Ball screw drives
Sizing and selection

Lifetime

The (nominal) lifetime of a ball screw drive can be calculated analogue to that of a ball bearing.

Note that vibration and shocks reduce the lifetime of the ball screw drive.

Average speed

$$n_m = \frac{n_1 \cdot q_1 + n_2 \cdot q_2 + \ldots + n_i \cdot q_i}{100} \qquad \text{(I)}$$

$n_1, n_2, \ldots$ Speeds [rpm] during $q_1, q_2, \ldots$

n_m Average speed [rpm]

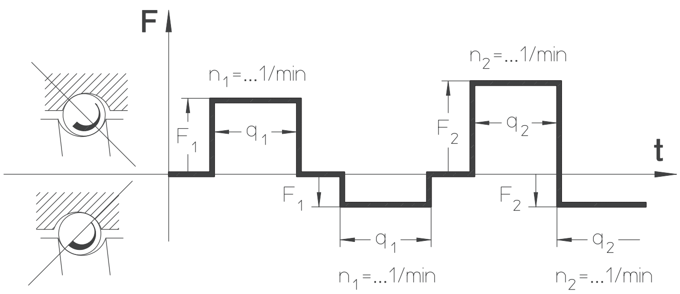
$q_1, q_2, \ldots$ Components of the duration of a load in one load direction in [%]

Dynamic equivalent bearing load

$$F_m = \sqrt[3]{F_1^3 \cdot \frac{n_1 \cdot q_1}{n_m \cdot 100} + F_2^3 \cdot \frac{n_2 \cdot q_2}{n_m \cdot 100} + \ldots + F_i^3 \cdot \frac{n_i \cdot q_i}{n_m \cdot 100}} \qquad \text{(II)}$$

$F_1, F_2, \ldots$ Axial loads [N] in one load direction during $q_1, q_2, \ldots$

F_m Dynamic equivalent bearing load [N]
Since loads can act on a ball screw drive in two directions, F_m should first be determined for each of two load directions; the larger value should then be included in the calculation of L. It is in general useful to draw a schematic diagram like the one below:



It should be noted that any pre-loading represents a continuous load.

Lifetime of a ball screw

$$L_{10} = \left(\frac{C}{F_m}\right)^3 \cdot 10^6 \qquad \text{(III)}$$

C Axial, dynamic load rating [N]
Centrally applied load [N] of constant force direction at which an appropriately large number of identical ball screw drives achieve a nominal lifetime of 10^6 revolutions.

➲ Technical data KGM/KGF see page 14 – 17

L_{10} Lifetime of the ball screw drive. Expressed as the number of revolutions achieved or exceeded by 90 % (L_{10}) of a sufficiently large sample of obviously identical ball screw drives before the first signs of material fatigue occur.

Ball screw drives
Sizing and selection

Example calculation lifetime of a ball screw drive

Given:

$F_1 = 30000$ N	at	$n_1 = 150$ 1/min	for	$q_1 = 21$ %	of the duration of operation
$F_2 = 18000$ N	at	$n_2 = 1000$ 1/min	for	$q_2 = 13$ %	of the duration of operation
$F_3 = 42000$ N	at	$n_3 = 75$ 1/min	for	$q_3 = 52$ %	of the duration of operation
$F_4 = 1800$ N	at	$n_4 = 2500$ 1/min	for	$q_4 = 14$ %	of the duration of operation
				$\Sigma = 100$ %	

Ball screw drive KGT 5010

Required: Maximum achievable lifetime under the given operating conditions.

Average speed n_m

from (I)

$$n_m = \frac{n_1 \cdot q_1 + n_2 \cdot q_2 + n_3 \cdot q_3 + n_4 \cdot q_4}{100}$$

$$n_m = \frac{150 \cdot 21 + 1000 \cdot 13 + 75 \cdot 52 + 2500 \cdot 14}{100} \; 1/\text{min}$$

$$\Rightarrow n_m = 550.5 \; 1/\text{min}$$

Dynamic equivalent bearing load F_m

from (II)

$$F_m = \sqrt[3]{F_1^3 \cdot \frac{n_1 \cdot q_1}{n_m \cdot 100} + F_2^3 \cdot \frac{n_2 \cdot q_2}{n_m \cdot 100} + F_3^3 \cdot \frac{n_3 \cdot q_3}{n_m \cdot 100} + F_4^3 \cdot \frac{n_4 \cdot q_4}{n_m \cdot 100}}$$

$$F_m = \sqrt[3]{{}^3 \cdot \frac{150 \cdot}{550.5 \cdot 100} + 18000^3 \cdot \frac{1000 \cdot 13}{550.5 \cdot 100} + 42000^3 \cdot \frac{75 \cdot 52}{550.5 \cdot 100} + 1800^3 \cdot \frac{2500 \cdot 14}{550.5 \cdot 100}} \; \text{N}$$

$$F_m = 20144 \text{ N}$$

Lifetime of a ball screw drive L_{10}

from (III)

$$L_{10} = \left(\frac{C}{F_m}\right)^3 \cdot 10^6$$

Axial, dynamic load rating C = 68700 N
➲ Technical data KGM/KGF see page 14 – 17

$$L_{10} = \left(\frac{68700}{20144}\right)^3 \cdot 10^6$$

$$L_{10} = 3.966 \cdot 10^7$$

Number of revolutions L_{10}

$$L_h = \frac{L_{10}}{n_m \cdot 60} = \frac{3.966 \cdot 10^7}{550.5 \cdot 60} = 1201 \text{ h}$$

Lifetime in hours L_h

Result:

Under the given load conditions, the selected screw drive has a total lifetime of $3.966 \cdot 10^7$ revolutions, which represents a time of 1201 hours.

Ball screw drives
Sizing and selection

Lifetime of a ball screw drive with pre-loaded nut system
The pre-loading force of the nut unit has the effect of a permanent load on the ball screw drive

Calculation of the dynamic equivalent bearing load F_m
Analog to the single nut (see page 25 equations (I) and (II))

Lifetime L

$$L = \left(F_{m1}^{\frac{10}{3}} + F_{m2}^{\frac{10}{3}} \right)^{-0.9} \cdot C^3 \cdot 10^6 \qquad \text{(IV)}$$

F_{m1}, F_{m2}, …	Dynamic equivalent bearing load of the first or second nut [N]
C	Axial, dynamic load rating [N] Centrally applied load [N] of constant force direction at which an appropriately large number of identical ball screw drives achieve a nominal lifetime of 10^6 revolutions.

➲ Technical data KGM/KGF see page 14 – 17

The calculation methods above are valid only under correct lubrication conditions. Dirt or lack of lubricant may significantly reduce the lifetime. Reduced lifetime must also be expected in the case of very short strokes – please contact us in these cases.

! **Ball screw drives cannot absorb radial forces or tilting moments**

Ball screw drives
Sizing and selection

Critical speed of ball screws

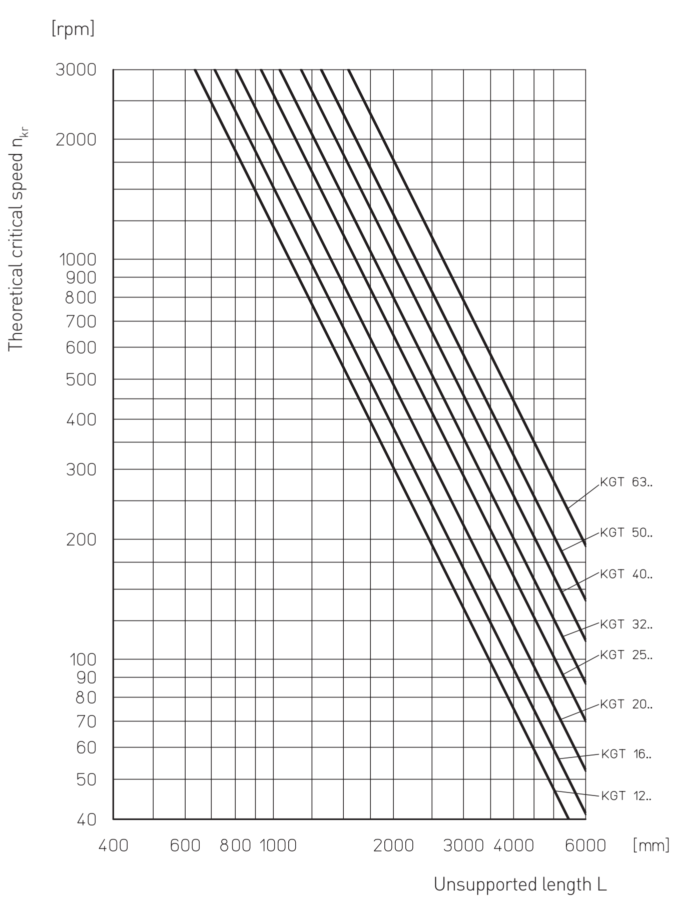
With thin, fast-rotating screws, there is a danger of "whipping". The method described below allows the resonant frequency to be estimated assuming a sufficiently rigid assembly. Furthermore, speeds in the vicinity of the critical speed considerably increase the risk of lateral buckling. The critical speed is therefore included in the calculation of the critical buckling force.

Maximum permissible speed

$$n_{zul} = 0.8 \cdot n_{kr} \cdot f_{kr} \qquad \text{(V)}$$

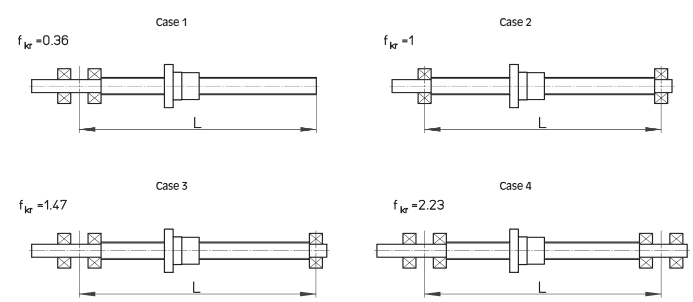
n_{zul}	Maximum permissible speed [rpm]
n_{kr}	Theoretical critical speed [rpm], that can lead to resonance effects ➲ see diagram
f_{kr}	Correction factor, considering the bearing support of the screw. ➲ see table
!	The operating speed must not exceed 80 % of the maximum speed

Theoretical critical speed n_{kr}



Bearing support

Typical values of correction factor f_{kr} corresponding to the usual cases of installation for standard screw bearings.



Ball screw drives
Sizing and selection

Critical buckling force of ball screws

With thin, fast-rotating screws under compressive load, there is a danger of lateral buckling. The procedure described below can be used to calculate the permissible axial force according to Euler.

Before the permissible compressive force is defined, allowance must be made for safety factors appropriate to the installation.

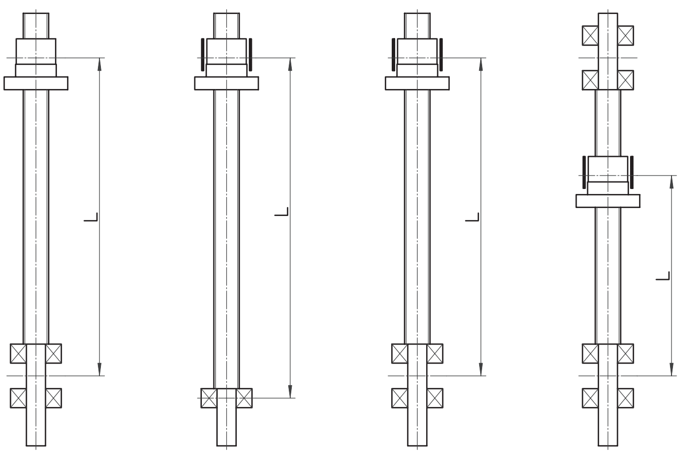
Maximum permissible axial force

$$F_{zul} = 0.8 \cdot F_k \cdot f_k \quad \text{(VI)}$$

F_{zul}	Maximum permissible axial force [kN]
F_k	Theoretical critical buckling force [kN] ➲ see diagram
f_k	Correction factor, considering the bearing support of the screw. ➲ see table
!	The operating force must not exceed 80 % of the maximum permissible axial force

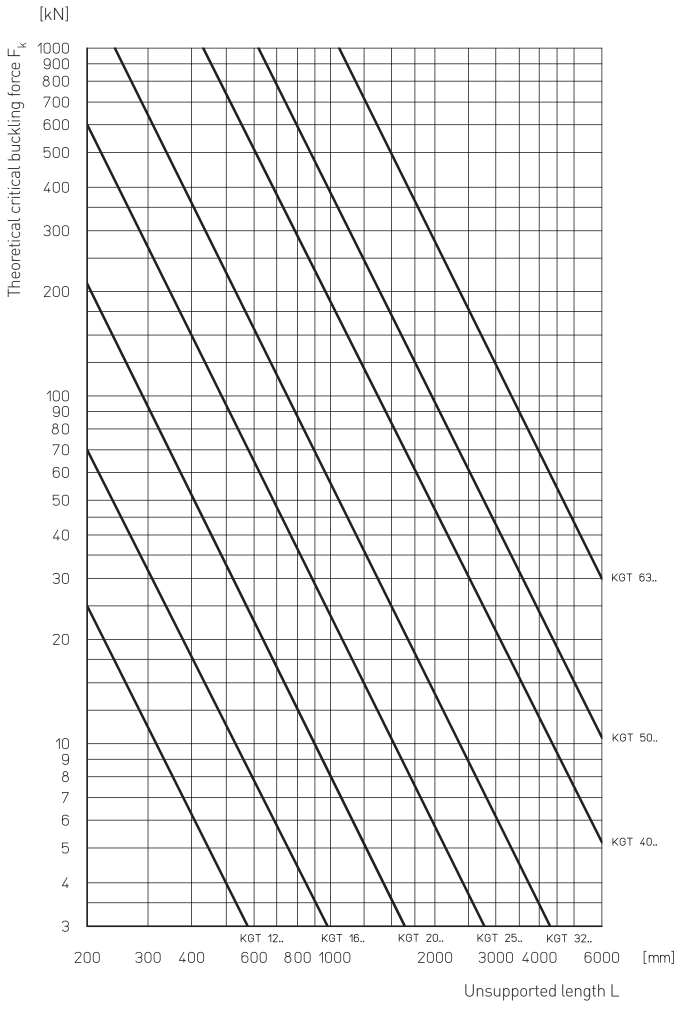
Bearing support

Typical values of correction factor f_k corresponding to the usual cases of installation for standard screw bearings.



Theoretical critical buckling force F_k

! The permissible maximum load is limited by the load rating.



Ball screw drives
Sizing and selection

Deflection of the screw under its own weight

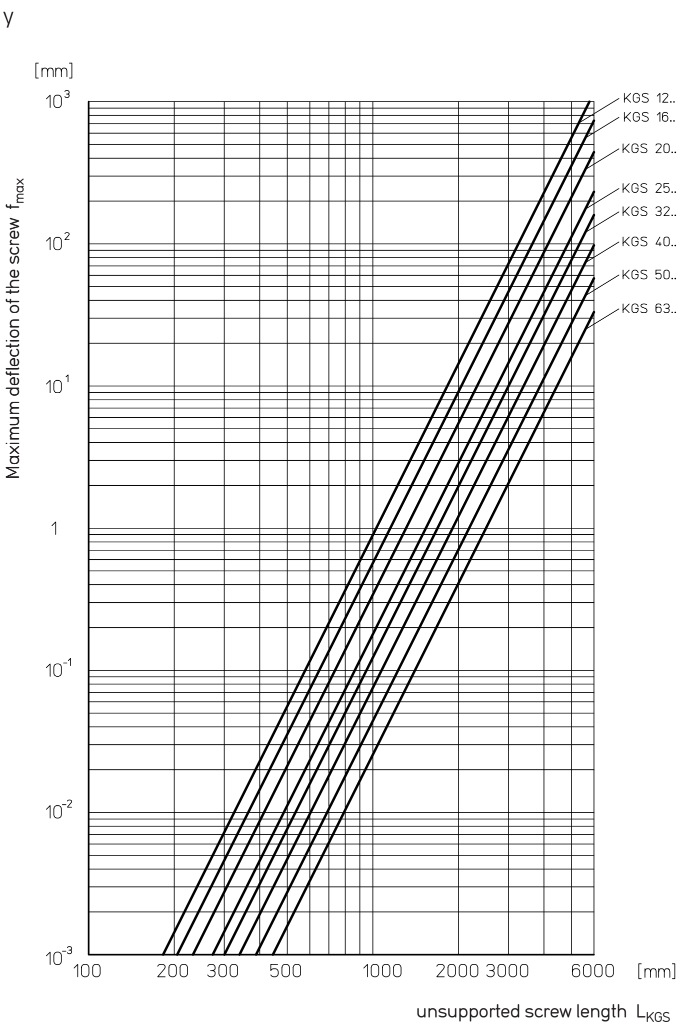
Even in the case of correctly installed screw drives where the resulting radial forces are absorbed by external guides, the weight of the unsupported screw itself may lead to deflection. The formula below allows you to calculate the maximum deflection of the screw.

Maximum deflection of screw

$$f_{max} = f_B \cdot 0.061 \cdot \frac{m'_{KGS} \cdot L_{KGS}{}^4}{I_Y} \qquad \text{(VII)}$$

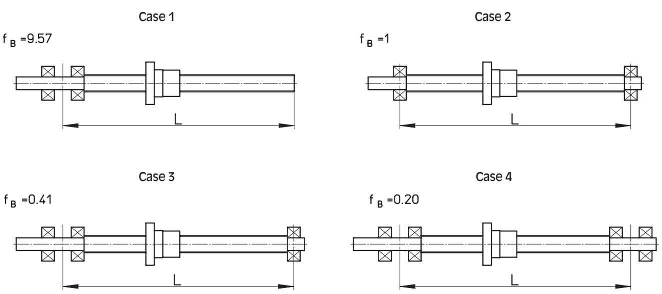
f_{max}	Maximum deflection of the screw [mm]
f_B	Correction factor considering the bearing support of the screw ➲ see table
I_Y	Planar moment of inertia [10^4 mm^4] ➲ see table page 11
L_{KGS}	Unsupported screw length [mm]
m'_{KGS}	Weight [kg/m]

Theoretical maximum deflection of screw



Bearing support

Typical values of correction factor f_B corresponding to the usual cases of installation for standard screw bearings.



Ball screw drives
Sizing and selection

Example calculation for a ball screw drive

Given:
!
Ball screw drive KGT 5010,
Length L = 2000 mm
Installation case 3
Maximum operating speed: n_{max} = 3000 [1/min]

Required:
?
Is the operating speed uncritical?
What is the permissible axial force?
What is the maximum deflection?

Maximum permissible speed n_{zul}

from (V)

$$n_{zul} = 0.8 \cdot n_{kr} \cdot f_{kr} = 0.8 \cdot 1290 \ \ 1/min \cdot 1.47 = 1517 \ \ 1/min$$

$$\Rightarrow n_{zul} \equiv 1517 \ \ 1/min \quad (< \text{limit speed!})$$

Theoretical critical speed n_{kr} = 1290 rpm
➲ from diagram "Theoretical critical speed"

from (VI)

$$F_{zul} = 0.8 \cdot F_k \cdot f_k = 0.8 \cdot 95 kN \cdot 2.05 = 156 kN$$

$$\Rightarrow F_{zul} = 153 \ \ kN \ (\text{max. static load rating } C_0\,!)$$

Theoretical critical buckling force F_K = 95 kN
➲ from diagram "Theoretical critical buckling force"

from (VII)

$$f_{max} = f_B \cdot 0.061 \cdot \frac{m'_{KGS} \cdot L_{KGS}}{I_Y} = 0.41 \cdot 0.061 \cdot \frac{13.50\, kg/m \cdot 2m}{18.566\, cm^4}$$

$$f_{max} = 0.036\ mm$$

Weight m'_{KGS} = 13.50 kg/m
Planar moment of inertia I_Y = 18.566 cm^4
➲ from table page 11

Result:

The selected screw drive may be operated only at n_{max} = 1517 rpm.
It can be statically loaded with a maximum axial force of 150 kN,
and when installed horizontally has a maximum deflection of 0.036 mm

Note the dynamic load rating!