Calculation

On request, we can perform all calculations to your specifications.

See “Design Calculation Service Form” on page 191

Average speed and average load

Where the operating conditions vary (fluctuating speed and load), the service life must be calculated using the average values F_m and n_m.

– Where the speed fluctuates, the average speed n_m is calculated as follows:

$$n_m = \frac{|n_1| \cdot q_{t1} + |n_2| \cdot q_{t2} + \ldots + |n_n| \cdot q_{tn}}{100\%} \quad (1)$$

$n_1, n_2, \ldots n_n$	=	speeds in phases 1 … n	(rpm)
n_m	=	average speed	(rpm)
$q_{t1}, q_{t2}, \ldots q_{tn}$	=	discrete time step in phases 1 … n	(%)

The following applies to the effective equivalent bearing load:

$$F > 2.8 \cdot F_{pr} \qquad F_{eff\,n} = |F_n|$$

$$F \leq 2.8 \cdot F_{pr} \qquad F_{eff\,n} = \left(\frac{|F_n|}{2.8 \cdot F_{pr}} + 1\right)^{\frac{3}{2}} \cdot F_{pr}$$

C	=	dynamic load rating	(N)
$F_{eff\,n}$	=	effective equivalent axial load during phase n	(N)
F_n	=	axial load during phase n	(N)
F_{pr}	=	pre-tensioning force (see tables on pages 148/151)	(N)

– Where the load fluctuates and the speed is constant, the average load F_m is calculated as follows:

$$F_m = \sqrt[3]{|F_{eff\,1}|^3 \cdot \frac{q_{t1}}{100\%} + |F_{eff\,2}|^3 \cdot \frac{q_{t2}}{100\%} + \ldots + |F_{eff\,n}|^3 \cdot \frac{q_{tn}}{100\%}} \quad (2)$$

$F_{eff\,1}, F_{eff\,2}, \ldots F_{eff\,n}$	=	effective equivalent axial load during phases 1 … n	(N)
F_m	=	equivalent dynamic axial load	(N)
$q_{t1}, q_{t2}, \ldots q_{tn}$	=	discrete time step for $F_{eff\,1}, \ldots F_{eff\,n}$	(%)

– Where both the load and the speed fluctuate, the average load F_m is calculated as follows:

$$F_m = \sqrt[3]{|F_{eff\,1}|^3 \cdot \frac{|n_1|}{n_m} \cdot \frac{q_{t1}}{100\%} + |F_{eff\,2}|^3 \cdot \frac{|n_2|}{n_m} \cdot \frac{q_{t2}}{100\%} + \ldots + |F_{eff\,n}|^3 \cdot \frac{|n_n|}{n_m} \cdot \frac{q_{tn}}{100\%}} \quad (3)$$

$F_{eff\,1}, F_{eff\,2}, \ldots F_{eff\,n}$	=	effective equivalent axial load during phases 1 … n	(N)
F_m	=	equivalent dynamic axial load	(N)
$n_1, n_2, \ldots n_n$	=	speeds in phases 1 … n	(rpm)
n_m	=	average speed	(rpm)
$q_{t1}, q_{t2}, \ldots q_{tn}$	=	discrete time step for $F_{eff\,1}, \ldots F_{eff\,n}$	(%)

Nominal service life

Service life in revolutions L

$$L = \left(\frac{f_{ac} \cdot C}{F_m}\right)^3 \cdot 10^6 \quad (4) \Rightarrow C = \frac{F_m}{f_{ac}} \cdot \sqrt[3]{\frac{L}{10^6}} \quad (5) \Rightarrow F_m = \frac{f_{ac} \cdot C}{\sqrt[3]{\frac{L}{10^6}}} \quad (6)$$

C	=	dynamic load rating	(N)
F_m	=	equivalent dynamic axial load	(N)
L	=	nominal service life in revolutions	(–)
f_{ac}	=	Correction factor for tolerance grades (see page 141)	

Service life in hours L_h

$$L_h = \frac{L}{n_m \cdot 60} \quad (7)$$

L_h	=	Service life	(hrs)
L	=	service life in revolutions	(–)
n_m	=	average speed	(rpm)

$$L_{h\ machine} = L_h \cdot \frac{DC_{machine}}{DC_{BASA}} \quad (8)$$

$DC_{machine}$	=	duty cycle of the machine	(%)
DC_{BASA}	=	duty cycle of the BASA	(%)
$L_{h\ machine}$	=	nominal service life of the machine	(h)
L_h	=	nominal service life of the Ball Screw Assembly	(h)

Drive torque and drive power

You must check end machining for the maximum permissible torque

Drive torque M_{ta}
For conversion of rotary motion to linear motion

$$M_{ta} = \frac{F_L \cdot P}{2000 \cdot \pi \cdot \eta} \quad (9)$$

$$M_{ta} \leq M_p$$

F_L	=	thrust force	(N)
M_p	=	maximum permissible drive torque	(Nm)
M_{ta}	=	drive torque	(Nm)
P	=	lead	(mm)
η	=	mech. efficiency ($\eta \approx 0.9$)	(–)

Transmitted torque M_{te}
for conversion of linear motion into rotary motion:

$$M_{te} = \frac{F_L \cdot P \cdot \eta'}{2000 \cdot \pi} \quad (10)$$

$$M_{te} \leq M_p$$

F_L	=	thrust force	(N)
M_p	=	maximum permissible drive torque	(Nm)
M_{te}	=	transmitted torque	(Nm)
P	=	lead	(mm)
η'	=	mech. efficiency ($\eta' \approx 0.8$)	(–)

The dynamic drag torque must be taken into account for preloaded nut units.

Drive power P_a

$$P_a = \frac{M_{ta} \cdot n}{9\,550} \quad (11)$$

M_{ta}	=	drive torque	(Nm)
n	=	speed	(rpm)
P_a	=	drive power	(kW)

⚠ **With critical applications, you must pay attention to the information below.**

Static load safety factor S_0
You must verify mathematically any structural design involving rolling contact with regard to the static load safety factor.

In this connection, $F_{0\ max}$ represents the maximum load amplitude that can occur, which can affect the screw drive.
It does not matter whether this load is exerted only for a short period.
It may represent the peak amplitude of an overall dynamic loading.
For design purposes, the data shown in the table applies.

$$S_0 = C_0 / (F_{0\ max}) \quad (12)$$

C_0	=	Static load rating	(N)
$F_{0\ max}$	=	Maximum static load	(N)
S_0	=	Static load safety factor	(-)

Design of the static load safety factor in relation to the operating conditions

Operating conditions	Static load safety factor S_0
Overhead arrangements and applications representing a high hazard potential	≥ 12
High dynamic load when at standstill, contamination.	8 - 12
Normal design of machinery and plant without full knowledge of the load parameters or connection details.	5 - 8
Full knowledge of all the load data. Vibration-free operation is ensured.	3 - 5

If there are health and safety hazards, protection against falling loads must be provided (see the chapter entitled “Arrestor nut”)

Ball screw assemblies BASA

Calculation

Calculation example Service life

Operating conditions
The service life of the machine should be 40,000 operating hours with the BASA operating 60% of the time.

Proposed BASA: 63 x 10

F_1	=	50 000 N	at	n_1 =	10 rpm	for	q_1 =	6%	of the duty cycle
F_2	=	25 000 N	at	n_2 =	30 rpm	for	q_2 =	22%	of the duty cycle
F_3	=	8 000 N	at	n_3 =	100 rpm	for	q_3 =	47%	of the duty cycle
F_4	=	2 000 N	at	n_4 =	1000 rpm	for	q_4 =	25%	of the duty cycle
								100%	

Calculation procedure

Average torque $\mathbf{n_m}$

$$n_m = \frac{6}{100} \cdot |10| + \frac{22}{100} \cdot |30| + \frac{47}{100} \cdot |100| + \frac{25}{100} \cdot |1000| \quad (1)$$

$$n_m = 304 \text{ rpm}$$

Average load $\mathbf{F_m}$ for variable load and variable speed

$$F_m = \sqrt[3]{|50000|^3 \cdot \frac{|10|}{304} \cdot \frac{6}{100} + |25000|^3 \cdot \frac{|30|}{304} \cdot \frac{22}{100} + |8000|^3 \cdot \frac{|100|}{304} \cdot \frac{47}{100} + |2000|^3 \cdot \frac{|1000|}{304} \cdot \frac{25}{100}} \quad (3)$$

$$F_m = 8\,757 \text{ N}$$

Required service life **L**
(revolutions)
The service life **L** can be calculated by transposing formulas (7) and (8):

$$L = L_h \cdot n_m \cdot 60$$

$$L_h = L_{h\ machine} \cdot \frac{DC_{BASA}}{DC_{machine}}$$

$$L_h = 40\,000 \cdot \frac{60}{100} = 24000 \text{ h}$$

$$L = 24\,000 \cdot 304 \cdot 60$$

$$L = 437{,}760{,}000 \text{ revolutions}$$

Basic dynamic load rating **C**

$$C = 8\,757 \cdot \sqrt[3]{\frac{437\,760\,000}{10^6}} \quad (5) \qquad C \approx 66\,492 \text{ N}$$

Result and selection
Now a selection can be made from the dimension tables:

e.g. Ball Screw Assembly,
size 63 x 10 R x 6-6, with preloaded
FEM-E-S single flange nut,
dyn. load capacity C = 106,600 N,
part no. R1512 640 13,
with screw tolerance grade 7.

Take into account correction factor f_{ac} of the tolerance grade! See page 141.

Attention:
Take into account the dynamic load rating of the screw end bearing used!

Cross-check
Now the following can be selected from the product tables:

Size 63 x 10 R x 6-6

Backlash (C0)

FEM-E-S, with standard backlash
Load rating $C_{dyn} = 106{,}560$ N
correction factor $f_{ac} = 0.9$
Cross-check
Service life of the selected ball screw drive in revolutions

$$L = \left(\frac{0{,}9 \cdot 106\,560}{8\,757}\right)^3 \cdot 10^6$$

$L \approx 1314 \cdot 10^6$ revolutions

Service life in hours L_h

$$L_h = \frac{1\,314 \cdot 10^6}{304 \cdot 60}$$

$L_h \approx 72{,}039$ hours

Preload (preload class C3)

FEM-E-S, with preload class C3
Load rating $C_{dyn} = 106{,}560$ N
Correction factor $f_{ac} = 0.9$
Pre-tensioning force = 4400 N
Cross-check
The following applies to the effective equivalent bearing load:

$$F > 2.8 \cdot F_{pr} \qquad F_{eff\,n} = |F_n|$$

$$F \leq 2.8 \cdot F_{pr} \qquad F_{eff\,n} = \left(\frac{|F_n|}{2.8 \cdot F_{pr}} + 1\right)^{\frac{3}{2}} \cdot F_{pr}$$

C	=	dynamic load rating	(N)
$F_{eff\,n}$	=	effective equivalent axial load during phase n	(N)
F_n	=	axial load during phase n	(N)
F_{pr}	=	pre-tensioning force (see tables on pages 148/151)	(N)

$2{,}8 \times F_{pr} = 2.8 \times 4\,440\text{ N} = 12\,432$ N

- $F_1 = 50\,000\text{ N} > 12\,432\text{ N} \Rightarrow F_{eff1} = 50\,000$ N
- $F_2 = 25\,000\text{ N} > 12\,432\text{ N} \Rightarrow F_{eff2} = 25\,000$ N
- $F_3 = 8\,000\text{ N} < 12\,432\text{ N} \Rightarrow F_{eff3} = \left(\frac{8\,000}{12\,432} + 1\right)^{1{,}5} \cdot 4440\text{ N} = 9\,355$ N
- $F_4 = 2\,000\text{ N} < 12\,432\text{ N} \Rightarrow F_{eff4} = \left(\frac{2\,000}{12\,432} + 1\right)^{1{,}5} \cdot 4\,440\text{ N} = 5\,553$ N

$$F_m = \sqrt[3]{|50000|^3 \cdot \frac{|10|}{304} \cdot \frac{6}{100} + |25000|^3 \cdot \frac{|30|}{304} \cdot \frac{22}{100} + |9355|^3 \cdot \frac{|100|}{304} \cdot \frac{47}{100} + |5553|^3 \cdot \frac{|1000|}{304} \cdot \frac{25}{100}}$$

$F_m = 9\,485$ N

$$L = \left(\frac{0{,}9 \cdot 106\,560}{9\,485}\right)^3 \cdot 10^6 = 1034 \cdot 10^6 \text{ revolutions}$$

$$L_h = \frac{1\,034 \cdot 10^6}{304 \cdot 60} = 56{,}689 \text{ hours}$$

The service life of both BASAs (with standard backlash C0/with preload class C3) exceeds the required service life of 40,000 x 60% = 24,000 hours. This means that it is possible to choose a smaller BASA, subject to a review of it being undertaken.

Critical speed n_{cr}

The critical speed n_{cr} depends on the diameter of the screw, the type of end fixity, and the free length l_{cr}. No allowance must be made for guidance by a nut with backlash. The operating speed should not be more than 80% of the critical speed.

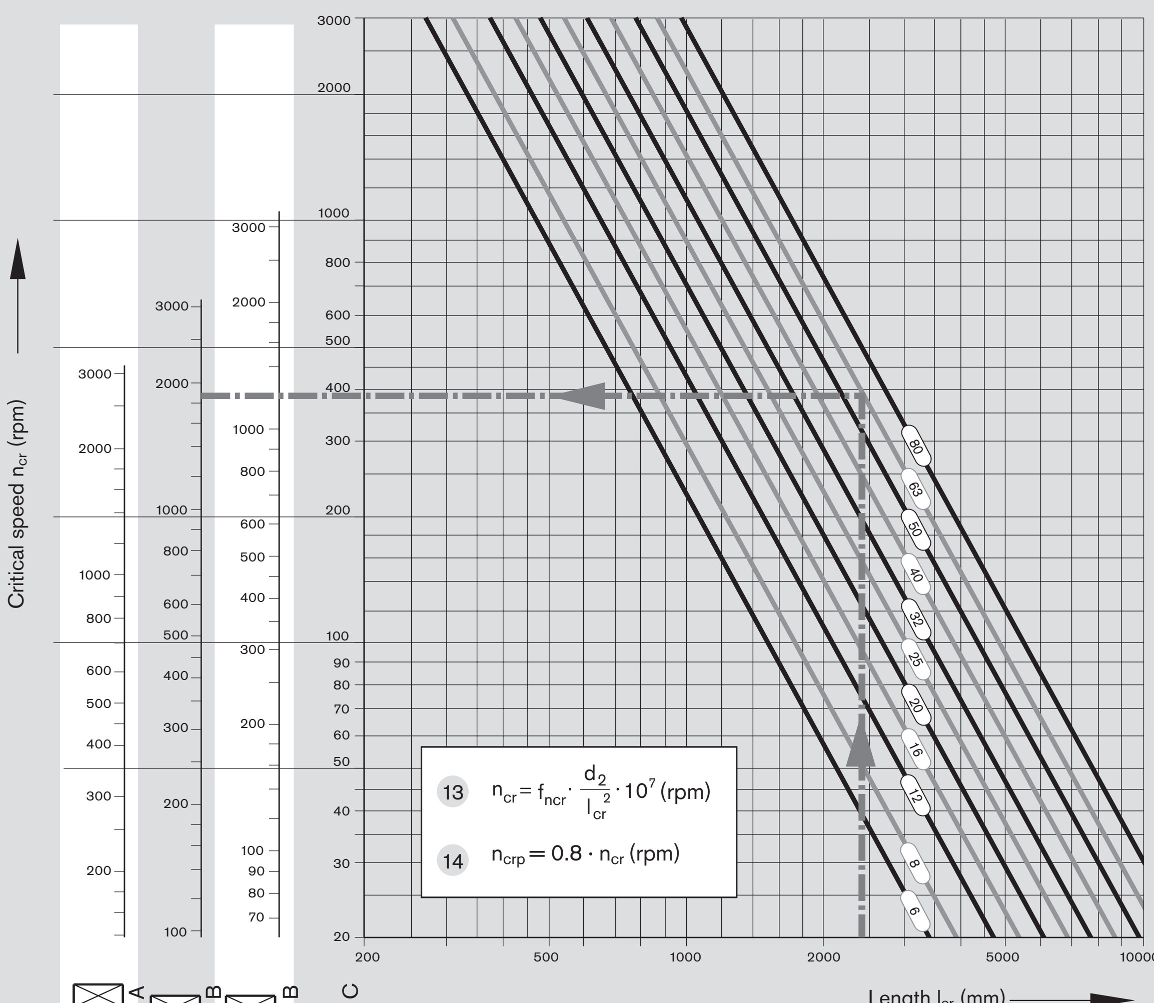
The characteristic speed and the max. permissible linear speed must be taken into account, see "Technical notes" on page 140.

Example

Screw diameter = 63 mm
Length l_{cr} = 2.4 m
End fixity II (fixed bearing - floating bearing)

According to the graph, the critical speed is 1850 rpm.
The permissible operating speed is
1850 rpm x 0.8 = 1480 rpm.

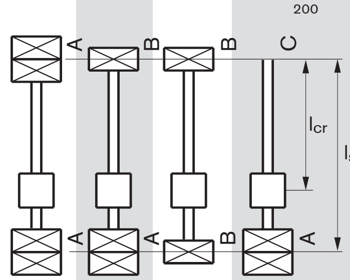
The maximum operating speed in our calculation example of
$n_4 = 1000$ rpm is therefore below the permissible operating speed.



(13) $$n_{cr} = f_{ncr} \cdot \frac{d_2}{l_{cr}^2} \cdot 10^7 \text{ (rpm)}$$

(14) $$n_{crp} = 0.8 \cdot n_{cr} \text{ (rpm)}$$

End fixity:
A = fixed bearing
B = floating bearing
C = without bearing



End fixity	I	II	III	IV
f_{ncr} - value	27.4	18.9	12.1	4.3

n_{cr}	=	Critical speed	(rpm)
n_{crp}	=	Permissible operating speed	(rpm)
f_{ncr}	=	Coefficient determined by bearing	
d_2	=	Root diameter of screw (see dimension tables)	(mm)
l_{cr}	=	Critical length for preloaded nut systems	(mm)
l_s	=	Bearing - bearing distance	(mm)

For non-preloaded nut systems $l_{cr} = l_s$
For screw ends Form 31, the end fixity can be assumed to be "fixed".

Attention: End fixity IV (fixed-floating) – only recommended for short overall lengths if installed horizontally. For longer overall lengths, the floating end must be supported. Please contact our specialist department if you have any questions.

Permissible axial load on screw F_c (buckling load)

The permissible axial load on the screw F_c depends on the diameter of the screw, the type of end fixity, and the effective unsupported length l_c.

A safety factor of s ≥ 2 should be taken into account for axial loading.

Example

Screw diameter	=	63 mm,
Lead	=	10 mm,
Length l_c	=	2.4 m

End fixity IV (fixed bearing - floating bearing)

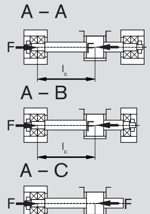
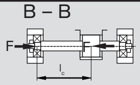
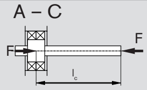
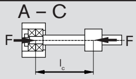
According to the graph, the theoretically permissible axial load is 360 kN. Applying the safety factor 2 yields a permissible axial load on the screw in operation of 360 kN : 2 = 180 kN.

This therefore lies above the maximum operating load of F_1 = 50 kN used in our calculation example.

(15) $$F_c = f_{Fc} \cdot \frac{d_2^4}{l_c^2} \cdot 10^4 \text{ (N)}$$

(16) $$F_{cp} = \frac{F_c}{2} \text{ (N)}$$

- **F_c** = Theoretically permissible axial load on screw (N)
- **F_{cp}** = Permissible axial load on screw during operation (N)
- **f_{Fc}** = Corrector value determined by bearing
- **d_2** = Root diameter of screw, see dimension tables (mm)
- **l_c** = unsupported thread length (mm)

End fixity:	coefficient f_{Fc} nut fixed	nut floating
A – A  A – B A – C	End fixity I 40.6	End fixity IV 20.4
B – B 	End fixity II 20.4	End fixity V 10.2
A – C 	End fixity III 2.6	
A – C 		End fixity VI 2.6

End fixity:

A = fixed bearing
B = floating bearing
C = without bearing

f_{Fc} value	End fixity
2.6	III / VI
10.2	V
20.4	II / IV
40.6	I