Design fundamentals

The following are the relevant calculations which underlie screw design and safe operation.

For detailed information on ballscrew design, please refer to DIN 69051.

«Suitability test» rotational speed characteristics

When selecting a ballscrew it is important to first ensure that the correct nut design for the ball return system required to support the maximum rotational speed demanded by the application is used (independent of the screw length).

The maximum rotational speed is based on the system's rotational speed characteristics and the outer screw diameter:

$$n_{max} = \frac{\text{rotational speed characteristic}}{d_1} \; [min^{-1}]$$

n_{max} = maximum rotational speed [min^{-1}]

d_1 = outer screw diameter [mm]

Rotational speed characteristic [–] for:

- single-thread ball return: 60 000
  (Carry type **...I**)
- tube ball return: 80 000
  (Carry type **...R**)
- end cap ball return: 80 000
  (Carry type **...E**/**...F**)

Calculations at dynamic load

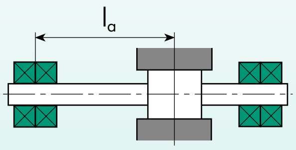
Critical rotational speed n_{per}

Permissible rotational speeds must differ substantially from the screw's own frequency.

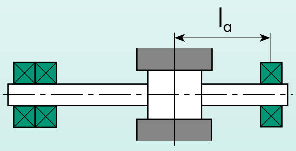
$$n_{per} = K_D \cdot 10^6 \cdot \frac{d_2}{l_a^2} \cdot S_n \ [min^{-1}]$$

n_{per} = permissible rotational speed [min^{-1}]
K_D = characteristic constant [–]
as a function of bearing configuration › see below
d_2 = core screw diameter [mm]
l_a = bearing distances [mm] › see below
(always include maximum allowable l_a in calculation!)
S_n = safety factor [–], usually S_n = 0.5 … 0.8

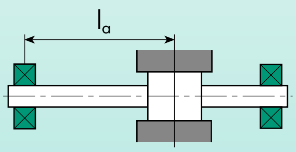
Config. 1: fixed – fixed
→ K_D = 276



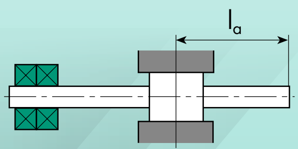
Config. 2: fixed – single
→ K_D = 190



Config. 3: simple – single
→ K_D = 122



Config. 4: fixed – free
→ K_D = 43



Nominal service life L_{10} or L_h

$$L_{10} = \left(\frac{C_{dyn}}{F_m}\right)^3 \cdot 10^6 \ [R]$$

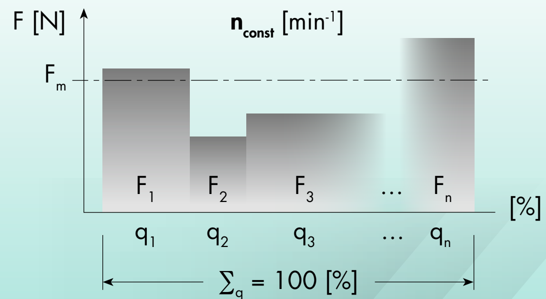
$$L_h = \frac{L_{10}}{n_m \cdot 60} \ [h]$$

L_{10} = service life in revolutions [R]
L_h = service life in hours [h]
C_{dyn} = dynamic load rate [N]
F_m = average axial load [N]
$F_{1…n}$ = load per cycle unit [N]
n_m = average rotational speed [min^{-1}]
$n_{1…n}$ = rotational speed per cycle unit [min^{-1}]
$q_{1…n}$ = cycles [%]
100 = $\sum_q$ (sum of cycles $q_{1…n}$) [%]

Average axial load F_m

at constant rotational speed n_{const} and dynamic load C_{dyn}

$$F_m = \sqrt[3]{F_1^3 \frac{q_1}{100} + F_2^3 \frac{q_2}{100} + \ldots + F_n^3 \frac{q_n}{100}} \ [N]$$



$$\rightarrow L_{10} = \left(\frac{C_{dyn}}{F_m}\right)^3 \cdot 10^6 \ [R]$$

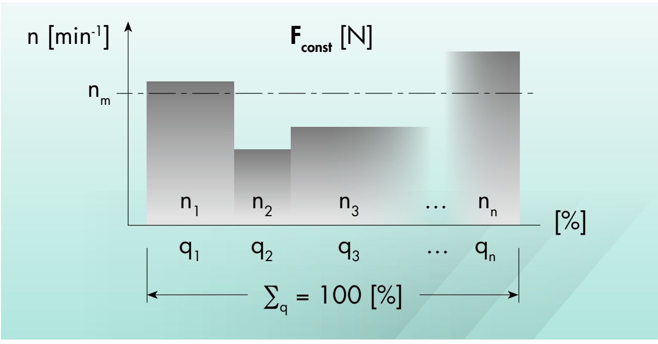
$$\rightarrow L_h = \frac{L_{10}}{n_{const} \cdot 60} \ [h]$$

Calculations at dynamic load (continued)

Average rotational speed n_m

at constant load F_{const} and variable rotational speeds $n_{1...n}$

$$n_m = n_1 \frac{q_1}{100} + n_2 \frac{q_2}{100} + \ldots + n_n \frac{q_n}{100} \quad [\text{min}^{-1}]$$



$$\rightarrow L_{10} = \left(\frac{C_{dyn}}{F_{konst}}\right)^3 \cdot 10^6 \quad [R]$$

$$\rightarrow L_h = \frac{L_{10}}{n_m \cdot 60} \quad [h]$$

Average axial load F_m

at constant rotational speeds $n_{1...n}$ and dynamic load C_{dyn}

$$F_m = \sqrt[3]{\frac{F_1^{\,3} \cdot n_1 \cdot \frac{q_1}{100} + F_2^{\,3} \cdot n_2 \cdot \frac{q_2}{100} + \ldots + F_n^{\,3} \cdot n_n \cdot \frac{q_n}{100}}{n_m}} \quad [N]$$

$$n_m = n_1 \frac{q_1}{100} + n_2 \frac{q_2}{100} + \ldots + n_n \frac{q_n}{100} \quad [\text{min}^{-1}]$$

$$\rightarrow L_{10} = \left(\frac{C_{dyn}}{F_m}\right)^3 \cdot 10^6 \quad [R]$$

$$\rightarrow L_h = \frac{L_{10}}{n_m \cdot 60} \quad [h]$$

Efficiency η (theoretical)

depends upon the type of power transmission

- Case 1: torque → linear movement

$$\eta \approx \frac{\tan \alpha}{\tan(\alpha + \rho)} \quad [-]$$

- Case 2: axial force → torque

$$\eta' \approx \frac{\tan(\alpha - \rho)}{\tan \alpha} \quad [-]$$

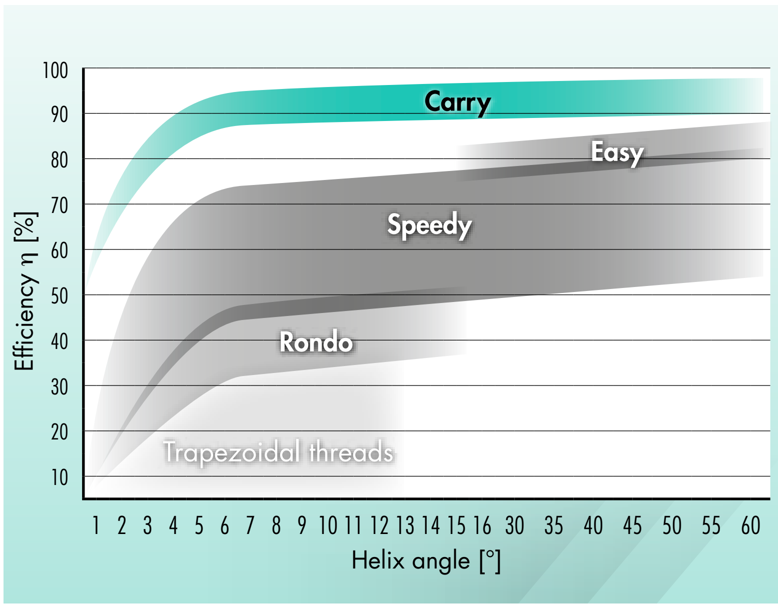
whereby

$$\tan \alpha \approx \frac{p}{d_0 \cdot \pi} \quad [-]$$

η = efficiency [%]
η' = corrected efficiency [%]
p = pitch [mm]
d_0 = nominal screw diameter [mm]
ρ = angle of friction [°] → ρ = 0.30…0.60°

Efficiency η_p (practical)

The efficiency η for Carry ballscrews is better than 0.9



Driving torque M

depends upon the type of power transmission

- Case 1: torque → linear movement

$$M_a = \frac{F_a \cdot p}{2000 \cdot \pi \cdot \eta} \text{ [Nm]}$$

- Case 2: axial force → torque

$$M_e = \frac{F_a \cdot p \cdot \eta'}{2000 \cdot \pi} \text{ [Nm]}$$

M_a = input torque [Nm], case 1
M_e = output torque [Nm], case 2
F_a = axial force [N]
p = pitch [mm]
η = efficiency [%]
η' = corrected efficiency [%]

Input performance P

$$P = \frac{M_a \cdot n}{9550} \text{ [kW]}$$

P = input performance [kW]
n = rotational speed [min^{-1}]

A safety margin of 20% is recommended when selecting drives.

Calculations at static load

Permissible maximum load F_{per}

$$F_{per} = \frac{C_{stat}}{f_s} \text{ [N]}$$

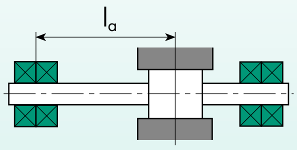
C_{stat} = static load rate [N]
f_s = operating coefficient
→ normal operation: 1 … **2** [–]
→ shock load: 2 … 3 [–]

Permissible buckling force F_B

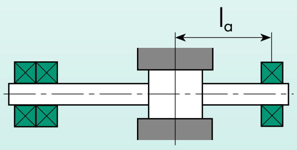
$$F_B = \frac{K_B}{S_B} \cdot \frac{d_2^4}{l_a^2} \cdot 10^3 \text{ [N]}$$

K_B = characteristic constant of load [–]
depends on design › see below
d_2 = core screw diameter [mm]
S_B = buckling safety factor [–] → usually S_B = 2 … 4
l_a = force-transferring screw length [mm]

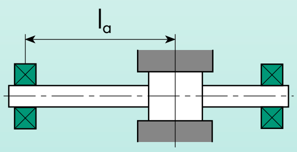
Case 1:
→ K_B = 400



Case 2:
→ K_B = 200



Case 3:
→ K_B = 100



Case 4:
→ K_B = 25