INTERNATIONAL STANDARD

ISO 3408-5

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Ball screws —

Part 5:
Static and dynamic axial load ratings and operational life

Vis à billes —

Partie 5: Charges axiales statiques et dynamiques de base et durée de vie

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 3408-5 was prepared by Technical Committee ISO/TC 39, *Machine tools*.

ISO 3408 consists of the following parts, under the general title *Ball screws*:

— *Part 1: Vocabulary and designation*

— *Part 2: Nominal diameters and nominal leads — Metric series*

— *Part 3: Acceptance conditions and acceptance tests*

— *Part 4: Static axial rigidity*

— *Part 5: Static and dynamic axial load ratings and operational life*

Ball screws —

Part 5:
Static and dynamic axial load ratings and operational life

1 Scope

This part of ISO 3408 specifies the calculation schemes for static and dynamic load ratings, and operational life, in order to obtain comparable values for the design and use of ball screws.

NOTE The calculations have been based primarily on publications by Prof. G. Lundberg and A. Palmgren *Acta Politechnica*, *mech. Eng.* series Vol. I, No. 3, Stockholm, Sweden. Part 7, 1947.

This part of ISO 3408 is applicable under the following preconditions:

— elastic deformation of ball and balltrack;

— hardness of balltrack basically exceeds a minimum of HRC 58;

— conformity f_{rs} and $f_{rn} > 0{,}5$;

— the quality of steel of which the ball screw is made is equivalent to that of ball bearing steel or similar steel alloys;

— optimum lubrification is always provided.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments)

ISO 3408-1, *Ball screws — Part 1: Vocabulary and designation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3408-1 apply.

4 Symbols and subscripts

4.1 Symbols

Symbol	Description	Unit
α	Contact angle	degrees, °
γ	Geometry factor	—
φ	Lead angle	degrees, °
$\rho_{11}, \rho_{12}, \rho_{21}, \rho_{22}$	Reciprocal curvature radii	mm^{-1}
Δl	Axial ball / ball track deflection	µm
C_a	Basic dynamic axial load rating	N
C_{am}	Modified dynamic axial load rating	N
C_i	Dynamic axial load rating for the ball screw per single loaded turn	N
C_n	Dynamic axial load rating for the ball nut per single loaded turn	N
C_s	Dynamic axial load rating for the ball screw shaft per single loaded turn	N
C_{0a}	Basic static axial load rating	N
C_{0am}	Modified static axial load rating	N
D_{pw}	Ball pitch circle diameter	mm
D_w	Ball diameter	mm
f_{ac}	Accuracy factor	—
f_{ar}	Reliability factor	—
f_c	Geometry factor	—
f_h	Hardness factor for dynamic axial load rating	—
f_{h0}	Hardness factor for static axial load rating	—
f_m	Material processing factor	—
f_{op}	Operational preload factor	—
f_{rn}	Conformity factor of ball nut	—
f_{rs}	Conformity factor of ball screw shaft	—
f_1, f_2, f_3	Geometry factor	—
F	Axial load, force	N
F_a	Actual axial load	N
F_{lim}	Limit load at which contact between balls and ball tracks will be lost by operating load	N
F_m	Equivalent axial load	N
F_{ma}	Equivalent actual axial load	N

Symbol	Description	Unit
F_{pr}	Preload	N
i	Number of loaded turns	—
k_0	Characteristic of basic static axial load rating	—
L	Life	revolutions
L_{ar}	Life with reliability factor	revolutions
L_h	Life	h
L_{har}	Life with reliability factor	h
L_{hm}	Modified life	h
L_{hmar}	Modified life with reliability factor	h
L_m	Modified life	revolutions
L_{mar}	Modified life with reliability factor	revolutions
L_{mr}	Modified resulting life	revolutions
L_r	Resulting life	revolutions
n	Rotational speed	min^{-1}
n_m	Equivalent rotational speed	min^{-1}
P_h	Lead	mm
q	Time	%
r_n	Ball track radius of ball nut	mm
r_s	Ball track radius of ball screw shaft	mm
z_l	Number of effectively loaded balls per turn	—
z_u	Number of unloaded balls in the recirculation system where balls are recirculated after one turn	—

4.2 Subscripts

Symbol	Description
j	Number of loadings
1	Refers to load direction 1
2	Refers to load direction 2
(1)	Refers to ball nut 1
(2)	Refers to ball nut 2

5 Basic axial load ratings

5.1 Basic static axial load rating, C_{0a}

The basic axial load rating is calculated from the following equations:

$$C_{0a} = k_0 \cdot z_l \cdot i \cdot \sin\alpha \cdot D_w^2 \cdot \cos\varphi \quad (1)$$

$$z_l = \left(\frac{D_{pw} \cdot \pi}{\cos\varphi \cdot D_w} - z_u \right)_{\text{integer}} \quad (2)$$

$$\varphi = \arctan\left(\frac{P_h}{\pi \cdot D_{pw}} \right) \quad (3)$$

$$k_0 = \frac{27,74}{D_w \cdot \sqrt{(\rho_{11} + \rho_{12}) \cdot (\rho_{21} + \rho_{22})}} \quad (4)$$

$$\rho_{11} = \rho_{21} = \frac{2}{D_w} \quad (5)$$

$$\rho_{12} = \frac{-1}{f_{rs} \cdot D_w} \quad (6)$$

$$\rho_{22} = \frac{\cos\alpha}{\frac{D_{pw}}{2} - \cos\alpha \cdot \frac{D_w}{2}} \quad (7)$$

NOTE The calculation of the basic static axial load rating C_{0a} is based on a maximum deformation of $0,000\,1 \cdot D_w$.

5.2 Basic dynamic axial load rating, C_a

In the case of optimal load distribution (parallel load directions in ball screw shaft and in ball nut), the basic dynamic axial load rating is derived from the following basic interrelations:

$$C_a = C_i \cdot i^{0,86} \quad (8)$$

where

$$C_i = C_s \cdot \left[1 + \left(\frac{C_s}{C_n} \right)^{10/3} \right]^{-0,3} \quad (9)$$

with

$$C_s = f_c \cdot (\cos\alpha)^{0,86} \cdot z_l^{2/3} \cdot D_w^{1,8} \cdot \tan\alpha \cdot (\cos\varphi)^{1,3} \quad (10)$$

$$f_c = 9,32 \cdot f_1 \cdot f_2 \cdot \left(\frac{1}{1 - \frac{1}{2 \cdot f_{rs}}} \right)^{0,41} \quad (11)$$

$$f_1 = 10 \cdot \left(1 - \frac{\sin\alpha}{3}\right) \quad (12)$$

$$f_2 = \frac{\gamma^{0,3} \cdot (1-\gamma)^{1,39}}{(1+\gamma)^{1/3}} \quad (13)$$

$$\gamma = \frac{D_w}{D_{pw}} \cdot \cos\alpha \quad (14)$$

$$\frac{C_s}{C_n} = f_3 \cdot \left(\frac{2 - \dfrac{1}{f_{rn}}}{2 - \dfrac{1}{f_{rs}}} \right)^{0,41} \quad (15)$$

$$f_{rn} = \frac{r_n}{D_w} \quad (16)$$

$$f_{rs} = \frac{r_s}{D_w} \quad (17)$$

$$f_3 = \left(\frac{1-\gamma}{1+\gamma}\right)^{1,72\overline{3}} \quad (18)$$

z_l, see Equation (2)

6 Modified axial load ratings

6.1 Modified static axial load rating, C_{0am}

6.1.1 General equation

$$C_{0am} = C_{0a} \cdot f_{h0} \cdot f_{ac} \quad (19)$$

6.1.2 Correction for surface hardness, f_{h0}

A deviation in hardness has to be corrected by

$$f_{h0} = \left(\frac{\text{actual hardness HV10}}{\text{654 HV10}}\right)^3 \leqslant 1 \quad (20)$$

The hardness factors shall only apply to ball bearing steel or similar steel alloys.

6.1.3 Correction for accuracy, f_{ac}

See Table 1.

Table 1 — Accuracy factor, f_{ac}
(reference data)

Class	**0, 1, 3 and 5**	**7**	**10**
f_{ac}	1	0,9	0,7

6.2 Modified dynamic axial load rating, C_{am}

6.2.1 General equation

$$C_{am} = C_a \cdot f_h \cdot f_{ac} \cdot f_m \qquad (21)$$

6.2.2 Correction for surface hardness, f_h

$$f_h = \left(\frac{\text{actual hardness HV10}}{654\ \text{HV10}} \right)^2 \leqslant 1 \qquad \text{See paragraph immediately following Equation (20)} \qquad (22)$$

6.2.3 Correction for accuracy, f_{ac}

The correction for accuracy, f_{ac}, for dynamic axial load is the same as for static axial load, see Table 1.

6.2.4 Influence of material melting process, f_m

See Table 2.

Table 2 — Material factor, f_m
(reference data)

Ball bearing steel	f_m
Air melted	1,0
Vacuum degassed	1,25
Electro slag remelted	1,44
Vacuum remelted	1,71

If other than air melted steel is used, the ball screw supplier shall specify the selected melting process in the data sheets.

7 Life

7.1 Equivalent rotational speed and equivalent axial load

7.1.1 General

In the case of variable rotational speed and variable axial load, the equivalent values F_m and n_m are used for the life calculation:

— At variable rotational speed the following applies for the equivalent rotational speed n_m (see Figure 1):

$$n_m = \sum_{j=1}^{n} \frac{q_j}{100} \cdot n_j \quad (23)$$

— At variable axial load and variable rotational speed, the following applies for the equivalent axial load F_m (see Figure 2):

$$F_m = \sqrt[3]{\sum_{j=1}^{n} F_j^3 \cdot \frac{n_j}{n_m} \cdot \frac{q_j}{100}} \quad (24)$$

— At variable axial load and constant rotational speed, the following applies for the equivalent axial load F_m (see Figure 2):

$$F_m = \sqrt[3]{\sum_{j=1}^{n} F_j^3 \cdot \frac{q_j}{100}} \quad (25)$$

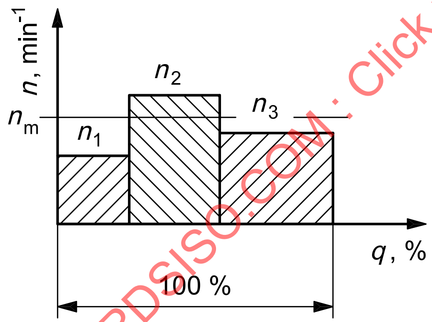


Figure 1 — Equivalent rotational speed n_m

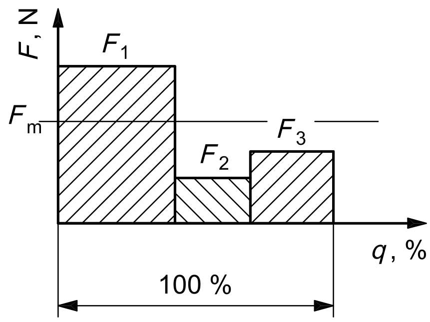
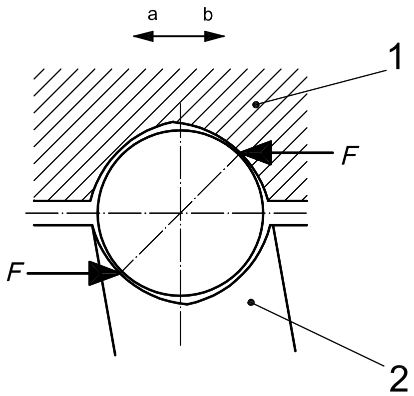


Figure 2 — Equivalent axial load F_m

7.1.2 Ball screw with backlash between ball nut and screw shaft

7.1.2.1 Unidirectional external axial load applied

See Figure 3.



Key

1 ball nut

2 screw shaft

a Forward travel.

s Backward travel.

Figure 3 — Ball screw with backlash and unidirectional axial loading

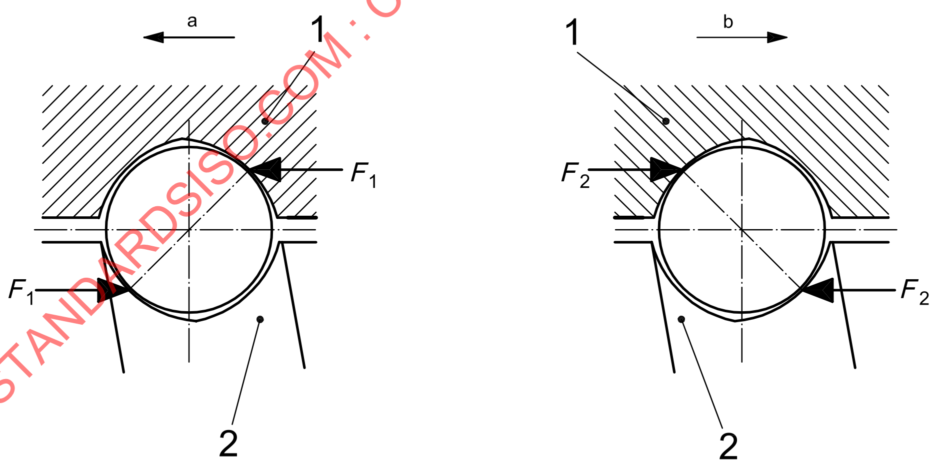
For calculation of equivalent axial load use

— Equation (23) and (24) or variable rotational speed,

— Equation (25) for constant rotational speed.

7.1.2.2 Bidirectional external axial load applied

See Figure 4.



Key

Key

1 ball nut

2 screw shaft

a Forward travel.

s Backward travel.

Figure 4 — Ball screw with backlash and bidirectional axial loading

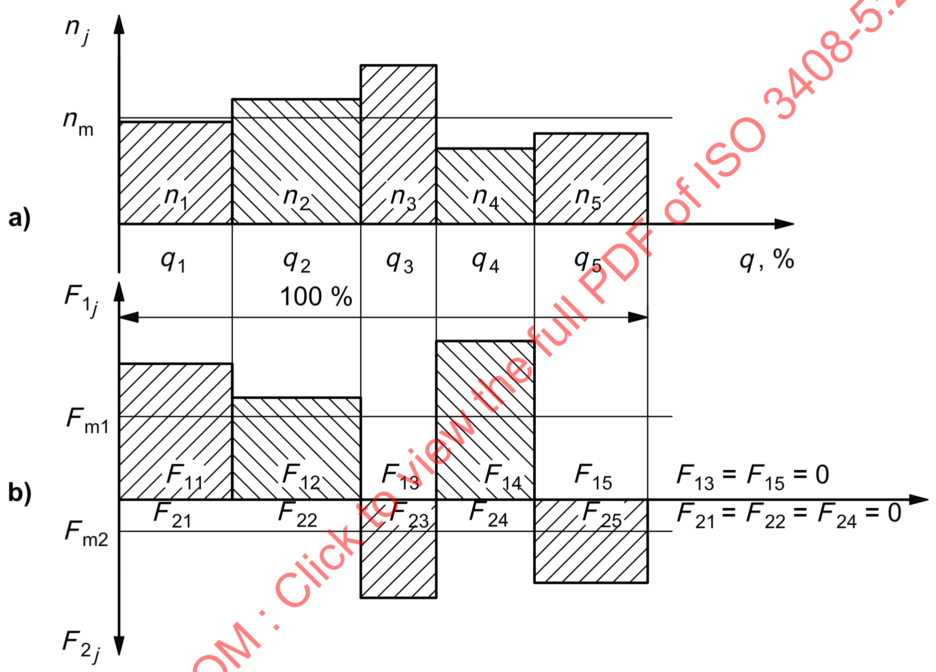
For calculation of equivalent axial load, use

— Equation (23) for variable rotational speed [see Figure 5 a)]

$$F_{m1,2} = \sqrt[3]{\sum_{j=1}^{n} F_{1,2j}^{3} \cdot \frac{n_j}{n_m} \cdot \frac{q_j}{100}} \tag{26}$$

— for constant rotational speed [see Figure 5 b)]

$$F_{m1,2} = \sqrt[3]{\sum_{j=1}^{n} F_{1,2j}^{3} \cdot \frac{q_j}{100}} \tag{27}$$



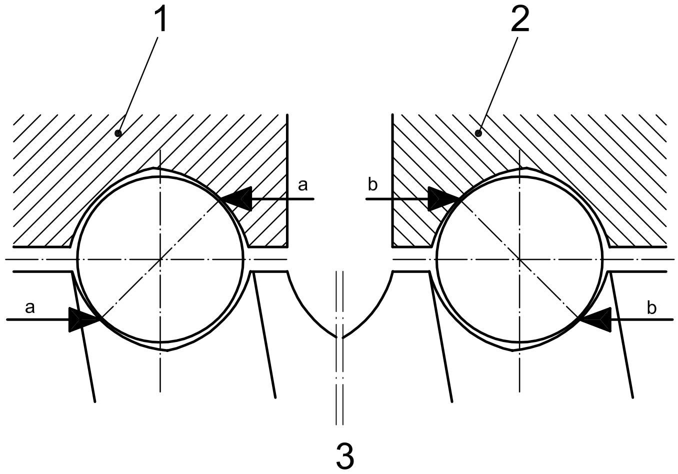
a) Variable speed

b) Bidirectional axial loading

Figure 5 — Calculation of equivalent axial load

7.1.3 Ball screw with preloaded ball nuts on screw shaft

See Figure 6.



Key

1 ball nut (1)

2 ball nut (2)

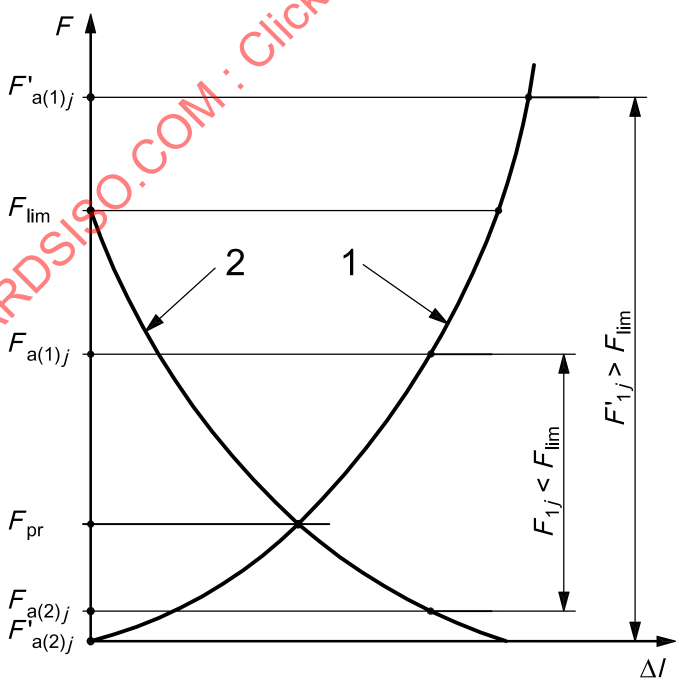
3 screw shaft

a $F_{a(1)j}$

b $F_{a(2)j}$

Figure 6 — Preloaded ball screw

Due to the application of an external axial load to a preloaded ball screw (backlash elimination between nuts and screw shaft), one ball nut will be additionally loaded and the other relieved (see Figure 7).



Key

1 ball nut (1)

2 ball nut (2)

Figure 7 — Preload diagram

$$F_{\text{lim}} = 2^{3/2} \cdot F_{\text{pr}} \tag{28}$$

The preloaded ball nut (1) or (2) will be additionally loaded by an external axial load [see Figure 8 b)]. The actual axial load to this ball nut is

— for the external load F_{1j} or $F_{2j} \leqslant F_{\text{lim}}$, the following equation:

$$F_{\text{a(1),(2)}j} = f_{\text{op}} \cdot F_{\text{pr}} \cdot \left(1 + \frac{F_{1,2j}}{2^{3/2} \cdot f_{\text{op}} \cdot F_{\text{pr}}}\right)^{3/2} \qquad f_{\text{op}} = 0{,}6 \ \text{(reference data)} \tag{29}$$

NOTE Due to the fact that the preload decreases over the operational life of ball screws, the average operational preload is set to 60 % of the original preload.

$$F_{\text{a(2),(1)}j} = F_{\text{a(1),(2)}j} - F_{1,2j} \tag{30}$$

— for the external load F_{1j} or $F_{2j} > F_{\text{lim}}$, then:

$$F_{\text{a(1)}j} = F_{1j} \ \text{or} \ F_{\text{a(2)}j} = F_{2j} \tag{31}$$

and

$$F_{\text{a(2)}j} \ \text{or} \ F_{\text{a(1)}j} = 0 \tag{32}$$

For the calculation, use:

a) at variable rotational speed [see Figure 8 a)]

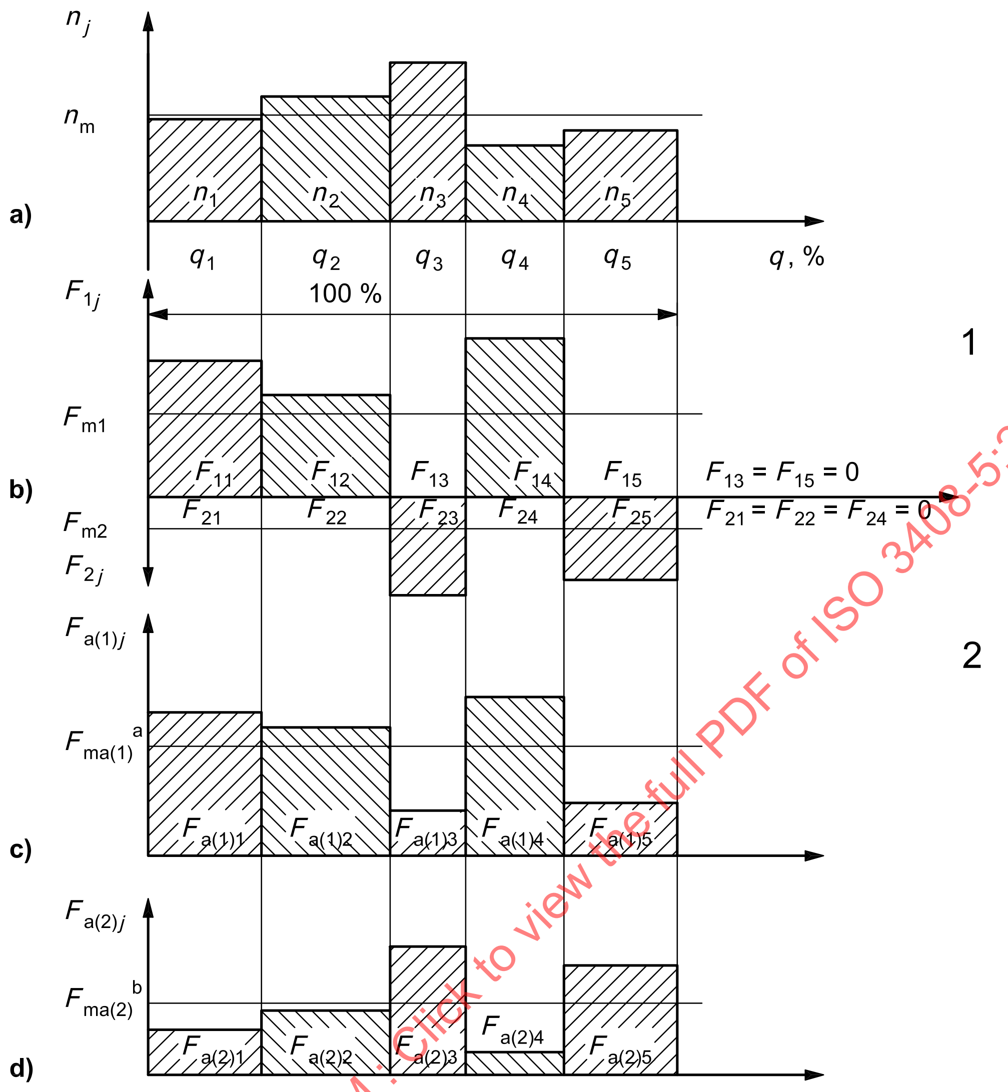
  — Equation (23) for equivalent rotational speed,

  — for the equivalent actual axial load [see Figure 8 c) and d)]

$$F_{\text{ma(1),(2)}} = \sqrt[3]{\sum_{j=1}^{n} F_{\text{a(1),(2)}j}^{3} \cdot \frac{n_j}{n_{\text{m}}} \cdot \frac{q_j}{100}} \tag{33}$$

b) at constant rotational speed

$$F_{\text{ma(1),(2)}} = \sqrt[3]{\sum_{j=1}^{n} F_{\text{a(1),(2)}j}^{3} \cdot \frac{q_j}{100}} \tag{34}$$



a) Variable rotational speed **b) to d) Variable axial loads**

Key

1 load direction 1 is loading ball nut (1)

2 load direction 2 is loading ball nut (2)

a Resulting load for ball nut (1), caused by preload.

b Resulting load for ball nut (2), caused by preload.

Figure 8 — Actual and equivalent actual axial loads

7.2 Nominal life, L or L_h

7.2.1 Ball screw with backlash between ball nut and screw shaft

7.2.1.1 Unidirectional external axial load applied

Life in revolutions:

$$L = \left(\frac{C_a}{F_m}\right)^3 \cdot 10^6 \qquad (35.1)$$

