



BSI Standards Publication

Cranes - General design

Part 3-4: Limit states and proof of competence of machinery - Bearings

National foreword

This British Standard is the UK implementation of EN 13001-3-4:2018.

Users' attention is drawn to the fact that neither BS 2573-1:1983 nor BS 2573-2:1980 should be used in conjunction with the BS EN 13001 series as they are not complementary. The BS 2573 series will remain current until the UK committee has reviewed all published parts of the BS EN 13001 series and determined whether they provide a coherent package of standards in the UK.

The UK participation in its preparation was entrusted to Technical Committee MHE/3/1, Crane design.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Appareils de levage à charge suspendue - Conception générale - Partie 3-4 : États limites et vérification d'aptitude des éléments de mécanismes - Paliers

Krane - Konstruktion allgemein - Teil 3-4: Grenzzustände und Sicherheitsnachweise für Maschinenbauteile - Lager

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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European foreword

This document (EN 13001-3-4:2018) has been prepared by Technical Committee CEN/TC 147 “Cranes - Safety”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2019, and conflicting national standards shall be withdrawn at the latest by June 2019.

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

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annexes ZA, which are an integral part of this document.

This European Standard is one Part of the EN 13001 series. The other parts are as follows:

- Part 1: *General principles and requirements*;
- Part 2: *Load actions*;
- Part 3-1: *Limit states and proof of competence of steel structures*;
- Part 3-2: *Limit states and proof of competence of wire ropes in reeving systems*;
- Part 3-3: *Limit states and proof of competence of wheel/rail contacts*;
- Part 3-5: *Limit states and proof of competence of forged hooks*;
- Part 3-6: *Limit states and proof of competence of machinery — Hydraulic cylinders*;
- Part 3-7: *Limit states and proof of competence of machinery — Gears*;
- Part 3-8: *Limit states and proof of competence of machinery — Shafts*.

Annexes A, B, C and D are informative.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This document is to be used together with EN 13001-1 and EN 13001-2 and as such they specify general conditions, requirements and methods to prevent mechanical hazards of cranes by design and theoretical verification.

NOTE 1 Specific requirements for particular types of crane are given in the appropriate European Standard for the particular crane type.

This document covers bearings in cranes. It is not intended for bearings being part of standard components, e.g. gearboxes, motors ... however those bearings shall be designed using load actions from EN 13001-2 and classification parameters of EN 13001-1.

NOTE 2 EN 13001-3-7 is under preparation for gears and gearboxes and deals with load actions for bearings in gear boxes.

The following is a list of significant hazardous situations and hazardous events that could result in risks to persons during intended use and reasonably foreseeable misuse. Clauses 4 to 7 of this document are necessary to reduce or eliminate risks associated with the following hazards:

- exceeding the limits of strength (yield, ultimate, fatigue);
- exceeding temperature limits of material or components;
- elastic instability of the crane or its parts (buckling, bulging).

This document is not applicable to cranes which are manufactured before the date of its publication as an EN and serves as reference base for the European Standards for particular crane types (see Annex D).

NOTE EN 13001-3-4 deals only with limit state method in accordance with EN 13001-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 10083-1:2006, *Steels for quenching and tempering — Part 1: General technical delivery conditions*

EN 10247:2017, *Micrographic examination of the non-metallic inclusion content of steels using standard pictures*

EN 13001-1, *Cranes — General design — Part 1: General principles and requirements*

EN 13001-2, *Crane safety — General design — Part 2: Load actions*

EN 13001-3-1, *Cranes — General design — Part 3-1: limit states and proof of competence of steel structure*

EN ISO 148-1, *Metallic materials, Charpy pendulum impact test — Part 1: Test method (ISO 148-1)*

EN ISO 683-17, *Heat-treated steels, alloy steels and free-cutting steels — Part 17: Ball and roller bearing steels (ISO 683-17)*

EN ISO 4287:1998, *Geometrical product specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters (ISO 4287)*

EN ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction (ISO 12100:2010)*

ISO 76:2006, *Rolling bearings — Static load ratings*

ISO 281:2007, *Rolling bearings — Dynamic load ratings and rating life*

ISO 4306-1:2007, *Cranes — Vocabulary — Part 1: General*

3 Terms and definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 12100:2010 and ISO 4306-1:2007, Clause 6 for the definitions of loads, and the following applies.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

plain bearing

bearing in which the type of relative movement is sliding but with the exclusion of those operating under conditions of hydrodynamic lubrication

3.1.2

rolling bearing

bearing operating with rolling motion between the parts supporting load and moving in relation to each other, which comprises raceway members and rolling elements with or without means for their spacing and/or guiding

Note 1 to entry: For the purposes of this document, it is designed to support radial, axial, or combined radial and axial load.

[SOURCE: ISO 5593, modified]

3.1.3

slewing ring

slewing ring bearing

large-size rolling-element bearing providing a connection between two adjacent structures and allowing rotation and transmission of loads between them (axial and radial loads and a tilting moment)

Note 1 to entry: Slewing ring is usually provided with holes for fixing bolts, with internal or external gear facilitating the rotation of one structure relative to the other and with lubrication and seals.

3.1.4

nominal contact angle

α

angle between a plane perpendicular to a bearing axis (a radial plane) and the nominal line of action of the resultant of the forces transmitted by a bearing ring or washer to a rolling element (see reference 04.02.10 in Figure 1 below)

[see SOURCE: ISO 5593:1997, definition 04.02.10 and Figures 93, 94]

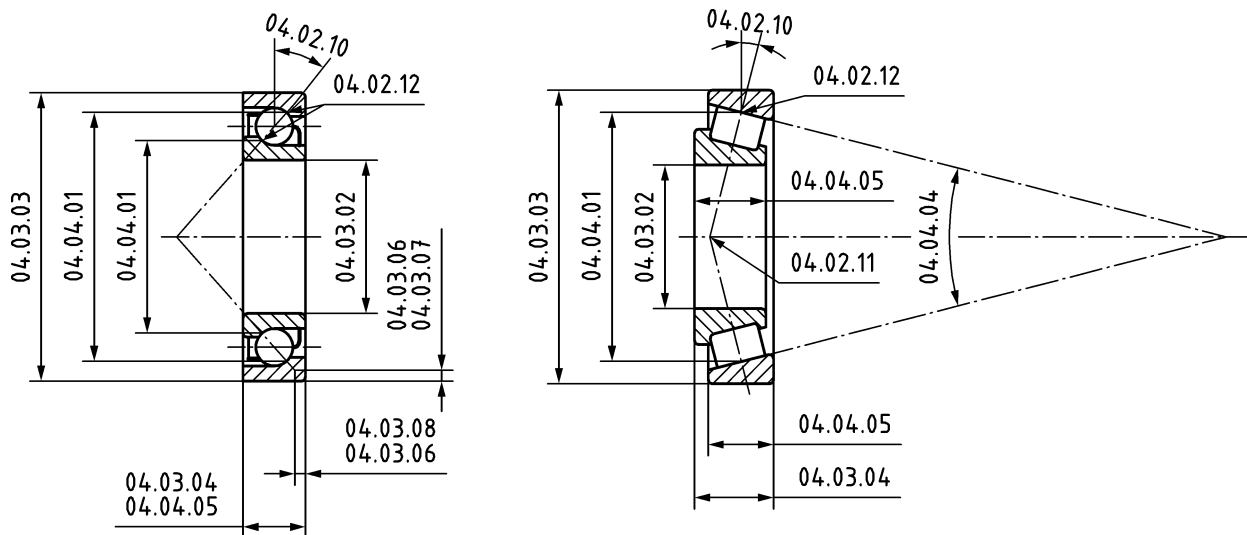


Figure 1 — Rolling bearings dimensions

3.2 Symbols and abbreviations

The symbols and abbreviations used in this document are given in Table 1.

Table 1 — Symbols and abbreviations

Symbols, abbreviations	Description
a_1	Life modification factor for reliability (ISO 281:2007)
A_{pF}	Apportionment factor for axial load F_a (slewing ring)
A_{pM}	Apportionment factor for tilting moment M_T (slewing ring)
A_S	Bolt stress area (fixing element)
b	Distance between two adjacent bolts (slewing ring)
C	Total number of working cycles (EN 13001-1)
C_a	Basic dynamic axial load rating (ISO 281:2007)
C_r	Basic dynamic radial load rating (ISO 281:2007)
$C_{a,Rd}$	Limit design dynamic axial load (slewing ring, rolling bearing)
$C_{r,Rd}$	Limit design dynamic radial load (slewing ring, rolling bearing)
C_{0a}	Basic static axial load rating (slewing ring, rolling bearing, spherical plain bearing)
C_{0r}	Basic static radial load rating (slewing ring, rolling bearing, spherical plain bearing)
$C_{0a,Rd}$	Limit design static axial load rating (slewing ring)
$C_{0r,Rd}$	Limit design static radial load rating (slewing ring)

Symbols, abbreviations	Description
C_1	Tightening torque
D_{in}	Internal diameter (thrust washer)
D_{ex}	External diameter (thrust washer, flanged bush)
D_m	Pitch Circle Diameter of rolling elements (denoted D_{pw} in ISO 76 and ISO 281)
D_{vi}	Pitch Circle Diameter of fixing elements
D_w	Ball diameter (rolling element)
D_{we}	Roller diameter (rolling element)
d	Nominal diameter of a screw/bolt (slewing ring); shaft diameter (plain bearing)
d_k	Sphere diameter of a spherical plain bearing
E	Modulus of elasticity
E_b	Modulus of elasticity of a bolt
E_p	Modulus of elasticity of a slewing ring supporting flange
e_m	Distance (lever arm) between external force F_e and the centre of the supporting width $2 \cdot u$ of the slewing ring
e_m^*	Lever arm of external load F_e to bolt axis (slewing ring)
e_n	Distance between bolt axis and the centre of the supporting width $2 \cdot u$ of the slewing ring
F_a	Axial load
$F_{a,i}$	Axial load, range i (fatigue)
F_b	Bolt load
$F_{b,f}$	Fatigue bolt load
$F_{b,2}$	Equivalent bolt load
F_c	Slewing ring contact load
F_d	Limit force
F_e	External load (slewing ring)
$F_{e,cr}$	Critical opening force for a slewing ring
$F_{e,max}$	Design maximum external load
$F_{e,f,max}$	Design maximum fatigue external load

Symbols, abbreviations	Description
$F_{p,min}$	Minimal preload in bolts
$F_{pb,Sd}$	Design plain bearing force
F_R	Radial load (slewing ring)
$F_{R,i}$	Radial load, range i (fatigue)
F_{Rd}	Limit design forces
$F_{Sd,f,i}$	Design dynamic load (plain bearing)
$F_{Sd,f,eq}$	Mean equivalent radial load (plain bearing)
F_y	Bolt yield force
f_c	Calculation factor (ISO 281:2007)
f_{f1}	Reliability factor (fatigue, slewing ring and rolling bearing)
f'_{f2}	Inclusion factor (fatigue slewing ring)
f_{f2}	Factor for additional influences (fatigue)
f'_{f3}	Surface hardness factor (fatigue)
f_{Rd}	Limit design stress
f_{ub}	Fixing element ultimate strength
f_y	Yield stress of material
f_{yb}	Fixing element yield stress
f_0	Factor for calculation of basic static load rating (ISO 76:2006)
f_1	Factor for shear in slewing ring sub-hardened layer (static)
f'_{f1}	Factor for shear in slewing ring sub-hardened layer (fatigue)
f_2	Deformation influence factor for slewing ring (static)
f'_2	Deformation influence factor for slewing ring (fatigue)
f_3	Surface hardness factor (static)
H_{ring}	Height of slewing ring
H_T	Height of tubular shell (slewing ring)
I_b	Moment of inertia of a bolt (slewing ring)
I_p	Moment of inertia of slewing ring supporting flange
$K_{rep}; K'_{rep}$	Excess load factor for raceway (slewing ring, static and fatigue)

Symbols, abbreviations	Description
$K_{rep,b}$	Excess load factor for bolts (slewing ring)
k_{pb}	Dynamic pressure spectrum factor (plain bearing)
k_{sr}	Dynamic load spectrum factor (slewing ring)
k_{rb}	Dynamic load spectrum factor (rolling bearing)
L_a	Axial loading offset (plain bearing)
L_b	Length of plain bearing
$L_{ci}; L_{ce}$	Internal and external chamfers of plain bearing
L_e	Length of equivalent elastic beam (slewing ring)
L_r	Radial loading offset (plain bearing)
L_{sr}	Length between supports of equivalent beam (slewing ring)
l_k	Effective clamping length
M_r	Tilting moment (slewing ring)
$M_{r,i}$	Tilting moment, range i (fatigue)
M_{fb}	Bolt prying moment (slewing ring)
m	Slope constant of the log p-log N curve (plain bearing)
N	Shaft rotational speed (plain bearing)
$N_{tot,pb}$	Total number of cycles (plain bearing)
n_s	Number of supports (slewing ring)
n	Number of cycles (plain bearing)
n_{sr}	Number of slewing rings during a crane design life
$P_{a,i}$	Design axial dynamic equivalent load, range i
$P_{a,Sd}$	Design axial dynamic load (slewing ring)
$P_{a,Sd,i}$	Design axial dynamic equivalent load, range i (rolling bearing)
$P_{r,i}$	Design dynamic radial equivalent load, range i
$P_{r,Sd}$	Design radial dynamic load (slewing ring)
$P_{r,Sd,i}$	Design radial dynamic equivalent load, range i (rolling bearing)
P_{0a}	Design axial equivalent static load (slewing ring)
$P_{0a,Sd}$	Static equivalent axial load (rolling bearing)
P_{0r}	Design radial equivalent static load (slewing ring)

Symbols, abbreviations	Description
$P_{0r,Sd}$	Static equivalent radial load (rolling bearing)
$P_{spb,Sd}$	Design equivalent load (spherical plain bearing)
p	Life exponent (slewing ring, rolling bearing)
p_{eq}	Equivalent design dynamic plain bearing pressure
p_L	Limit design dynamic plain bearing pressure
$p_{pb,i}$	Design dynamic plain bearing pressure, range i
$p_{pb,max}$	Maximum design dynamic plain bearing pressure
$p_{pb,Sd}$	Design cylindrical plain bearing pressure (static)
$p_{pb,Rd}$	Limit design cylindrical plain bearing pressure (static)
p_{spb}	Design surface pressure (spherical plain bearing)
$p_{spb,L}$	Limit design dynamic spherical plain bearing pressure
$(p \cdot v)_L$	Limit design effective transmitted power density (cylindrical plain bearing)
$(p \cdot v)_{spb,L}$	Limit design effective transmitted power density (spherical plain bearing)
Q_b	Highest contact load for a rolling element (slewing ring)
R_a	Average depth of surface profile in accordance with EN ISO 4287:1998
R_d	Design resistance
R_{ht}	Maximum possible hardened depth for an induction hardening
S_b	Bolt flexibility (slewing ring)
S_c	Flange flexibility (slewing ring)
S_d	Design stress or design force
S_{sr}	Connection flexibility (slewing ring)
$s_{a,cr}$	Critical lever arm of the contact force F_c (slewing ring)
s_a	Lever arm of the contact force F_c (slewing ring)
s_m	Bolt stress history parameter
s_{rb}	Rolling bearing load history parameter
s_{sr}	Slewing ring raceway load history parameter
S_0	Static safety factor (rolling bearing)
T_{max}	Limit operating temperature (plain bearing)
t	Thickness

Symbols, abbreviations	Description
t_{ch}	Projected thickness of plain bearing chamber
t_{af}	Thickness of plain bearing low friction layer
t_p	Supporting flange thickness (slewing ring)
u	Half-supporting width of slewing ring
U_D	Reference number of revolutions (slewing ring, rolling bearing)
U_i	Number of revolutions of range i
$U_{tot,sr}$	Total number of revolutions (slewing ring)
$U_{tot,rb}$	Total number of revolutions (rolling bearing)
v_{eff}	Shaft design effective sliding speed (plain bearing)
v_L	Limit design effective sliding speed (cylindrical plain bearing)
$v_{spb,eff}$	Spherical plain bearing effective sliding speed
$v_{spb,L}$	Limit design effective sliding speed (spherical plain bearing)
$\bar{X}_{ang}$	Average angular displacement (EN 13001-1)
X	Rolling bearing dynamic load factor (ISO 281:2007); plain bearing load factor
X_0	Rolling bearing static load factor (ISO 76:2006)
Y	Rolling bearing dynamic load factor (ISO 281:2007) ; plain bearing load factor
Y_0	Rolling bearing static load factor (ISO 76:2006)
Z_{aF}	Number of active rolling elements
Z_b	Number of slewing ring fixing elements
Z_d	Critical depth of the sub-hardened layer shear
α	Nominal contact angle (see 3.1.4) for slewing rings and rolling bearings; Angle of tilt for spherical plain bearings (ISO 12240)
α_c	Chamfer angle (plain bearing)
β_e	Calculation factor for the determination of the excess load factor K_{rep}
ΔF_b	Additional bolt force (slewing ring)
ΔM_{fb}	Additional prying moment (slewing ring)
$\Delta \sigma_c$	Characteristic fatigue strength
$\Delta \sigma_{Sd}$	Design stress range
$\Delta \sigma_{Rd}$	Limit design stress range

Symbols, abbreviations	Description
γ_m	General resistance factor
γ_n	Risk coefficient (EN 13001-2)
γ_R	Total resistance factor
$\gamma_{Rb,1}; \gamma_{Rb,2}$	Resulting resistance factors for connections loaded in tension
γ_{rbf}	Fatigue strength specific resistance factor of rolling bearing
γ_{sa}	Specific resistance factor for slewing ring raceway (axial)
γ_{sr}	Specific resistance factor for slewing ring raceway (radial)
γ_{srb}	Specific resistance factor for rolling bearings
γ_{srf}	Fatigue strength specific resistance factor of slewing ring
ν_{rb}	Relative total number of revolutions (rolling bearing)
ν_{sr}	Relative total number of revolutions (slewing ring)
ϕ	Stiffness ratio (bolts); total oscillating amplitude angle (plain bearing)
σ_b	Design (bolt) bending stress
σ_n	Design (bolt) tensile stress
σ_{Rd}	Limit design normal stress
σ_{Sd}	Design normal stress
τ	Design (bolt) shear stress
τ_p	Sub-hardened layer shear stress (slewing ring)
ψ_j	Slewing sector of range j (slewing ring)

4 General

4.1 Documentation

The documentation of the proof of competence shall include:

- design assumptions including calculation models;
- applicable loads and load combinations;
- material grades and qualities;
- used bearing provider instructions and requirements;
- relevant limit states;
- results of the proof of competence calculation and tests when applicable.

4.2 Materials

4.2.1 Grades and qualities for slewing rings

4.2.1.1 Grades

European and International Standards specify materials and specific values. This document gives a preferred selection of materials with their mechanical properties.

For raceway rings and rolling elements of slewing rings, steel in accordance with the following European Standards should be used:

- steels for quenching and tempering; Alloy steels: EN 10083-3;
- heat-treated steels, alloy steels and free-cutting steels; Ball and roller bearing steels: EN ISO 683-17.

Grades and qualities other than those mentioned in the above standards may be used if the mechanical properties and the chemical composition are specified in a manner corresponding to relevant European standard.

For slewing rings, the steel grades below are recommended:

- rolling elements: through hardening bearing steel in accordance with EN ISO 683-17 (e.g. 100Cr6).
- the minimum elongation based on gauge length of five diameters for the materials for slewing rings is to be 14 %.

4.2.1.2 Inclusions

As a minimum, the contents of non-metallic inclusions shall comply with the requirements of EN 10083-1.

If an enhanced fatigue performance of the slewing ring is needed, values of the maximum limits of non-metallic inclusions content from EN ISO 683-17 can be used (see A.2.3).

The methods of measurement shall conform to EN 10247:2017. From the data of measurements obtained by those methods, evaluation according to EN 10083-1 and EN ISO 683-17 shall be established (see notably from EN 10247:2017, Annex L).

4.2.1.3 Impact toughness

The slewing ring components shall have sufficient ductility to prevent brittle fracture.

The material shall have a minimum impact toughness of 17 J at $-20\text{ }^{\circ}\text{C}$ (operating temperature $T \geq -30\text{ }^{\circ}\text{C}$), tested in accordance with EN ISO 148-1, after the heat treatment.

For materials quenched and tempered, the minimum impact toughness shall be 27 J at $-20\text{ }^{\circ}\text{C}$ (operating temperature $T \geq -30\text{ }^{\circ}\text{C}$).

4.2.2 Grades and qualities for rolling bearings, except slewing rings

4.2.2.1 Grades

European and International Standards specify materials and specific values. This document gives a preferred selection of materials with their mechanical properties.

For rolling bearings, steel in accordance with following European Standards should be used:

- steels for quenching and tempering; Alloy steels: EN 10083-3;
- heat-treated steels, alloy steels and free-cutting steels; Ball and roller bearing steels: EN ISO 683-17.

Grades and qualities other than those mentioned in the above standards may be used if the mechanical properties and the chemical composition are specified in a manner corresponding to relevant European standard.

For rolling elements, through hardening bearing steel (e.g. 100Cr6) is recommended, in accordance with ISO 683-17.

4.2.2.2 Inclusions

As a minimum, the contents of non-metallic inclusions shall comply with the requirements of EN 10083-1.

If an enhanced fatigue performance of the rolling bearing is needed, values of the maximum limits of non-metallic inclusions content from EN ISO 683-17 can be used.

The methods of measurement shall conform to EN 10247:2017. From the data of measurements obtained by those methods, evaluation according to EN 10083-1 and EN ISO 683-17 shall be established (see notably from EN 10247:2017, Annex L).

4.2.3 Materials for plain bearings

Plain bearings can be made from various steel and low friction materials such as Bronze, Sintered Bronze, Bronze-lead, Bronze-Graphite, Polymers (Polyamide, Polyacetal, Polyetheretherketone-PEEK), Fluorinated polymers (TFE, PTFE) and can have low friction fillers as PTFE, MoS_2 or anti-wear fillers as fibre glass.

For basic properties of the materials below, the following International Standards can be used:

- Fluorinated polymers (PTFE): ISO 6691;
- materials for wrapped bushes: ISO 3547-4;
- Copper alloys (e.g. Bronze): ISO 4382 and EN 1982.

For basic properties of other materials, the designer can refer to specialized data sheets for the plain bearing materials, as provided by the manufacturers.

For the steel backing, steel in accordance with following European Standards should be used:

- steels for quenching and tempering; Alloy steels: EN 10083-3;
- heat-treated steels, alloy steels and free-cutting steels; Ball and roller bearing steels: EN ISO 683-17.

4.3 Bearings

4.3.1 General

The rotational guiding of rotating parts can be ensured by means of:

- slewing rings;
- rolling bearings;
- plain bearings.

4.3.2 Slewing rings

4.3.2.1 General

Manufacturer’s instructions on installation, maintenance and positioning (lubrication, centring, gear backlash ...), shall be adhered to.

Those instructions are only valid for a not polluted environment, e.g. not containing potentially damaging elements (dust, water ...) which can ingress the raceways of the slewing rings.

This European standard deals with suspended and supported installations of slewing rings. Slewing rings are generally installed supported on the lower companion structure: the axial load F_a relieves the bolts. On the contrary, if the installation is suspended, the tension on the bolts are increased by the axial load F_a .

Load paths due to F_a are represented in Table 2 for both types of installation of a three-row roller bearing.

Table 2 — Supported and suspended slewing rings (principle)

Supported slewing ring
Suspended slewing ring
Key F_a is the axial load

4.3.2.2 Supporting structure

A slewing ring is a large diameter rolling bearing, connected to a supporting structure by means of preloaded bolted joint. The preferred construction of supporting structure provides a sufficiently rigid support for the slewing ring, with the stiffness uniformly distributed around the circumference and should consist of a machined flange joined to a tubular shell, in a coaxial arrangement with the slewing ring.

Sufficient stiffness of the supporting structure is usually achieved if the supporting flange thickness t_p is equal to or greater than half of the slewing ring height H_{ring} (see Figure 2).

In order to achieve an optimum distribution of the external forces on the rolling elements, it is recommended that:

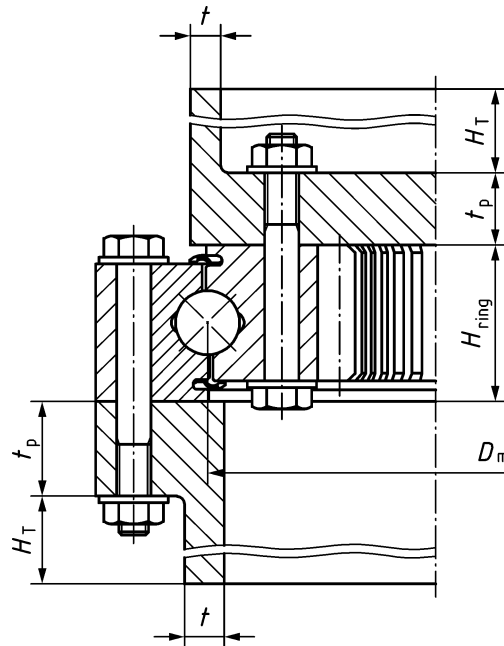
- the thickness of tubular shell t should be equal to or greater than 1/6 of the height of the ring H_{ring} ;
- the height of tubular shell H_T should be equal to or greater than 1/4 of the Pitch Circle Diameter of rolling elements D_m .

Table 3 gives recommended flatness tolerances for non-segmented slewing rings, in accordance with EN ISO 1101. For other slewing rings (e.g. with diameter greater than 8 m), flatness tolerances should be agreed upon between the crane manufacturer and the slewing ring supplier.

Table 3 — Flatness tolerances (EN ISO 1101)

D_m Pitch Circle Diameter of rolling elements <i>(see Figure 2)</i> [mm]	Flatness according to EN ISO 1101, per support surface [mm]		
	Double-row ball bearing with 2 point contacts per ball	Single-row ball bearing with 4 point contacts per ball	Roller bearings
		Double-row ball bearing with 4 point contacts per ball	
≤ 500	0,15	0,10	0,07
$500 < D_m \leq 1\,000$	0,20	0,15	0,10
$1\,000 < D_m \leq 1\,500$	0,25	0,19	0,12
$1\,500 < D_m \leq 2\,000$	0,30	0,22	0,15
$2\,000 < D_m \leq 2\,500$	0,35	0,25	0,17
$2\,500 < D_m \leq 4\,000$	0,40	0,30	0,20
$4\,000 < D_m \leq 6\,000$	0,50	0,40	0,30
$6\,000 < D_m \leq 8\,000$	0,60	0,50	0,40

The machining of the slewing ring bearing surfaces should be done after welding in order to achieve the required flatness tolerances. Grouting compounds can be used as an alternative to machining.



Key

t_p	is the supporting flange thickness
H_{ring}	is the height of the ring
H_T	is the height of turbular shell
D_m	is the pitch Circle Diameter of rolling elements

Figure 2 — Dimensions

4.3.2.3 Hardness

Raceways and rolling elements shall be at least surface hardened in order to support the maximum contact stress they endure.

The raceways should be induction hardened, in order to achieve a minimal specified surface hardness and with an effective hardened depth equal to at least twice the depth of the maximum shear stress. A minimal surface hardness equal to 55 HRC is recommended and if an enhanced fatigue performance of the slewing ring is needed, at least 58 HRC is recommended.

Hardening junction shall be marked and should be located on the filler plug for the ungeared ring and placed as close as possible to the neutral axis of the loads: ideally at zero moment axis. For loaded bearings with intensive duty, soft spot areas shall be ground.

The core crushing effect below the hardened layer shall be taken into account by the slewing ring manufacturer and technically justified.

A minimal surface hardness equal to 60 HRC is recommended for the rolling elements.

4.3.2.4 Retaining bolts

The retaining bolts should – as far as practical – be equally spaced over the 360° circumference.

When an angular sector permanently under compression can be ascertained:

- non-equally spaced bolts can be allowed with a minimum number of bolts at minimum equal to half of the number of bolts on the tension side,
- it shall be justified and recorded in the proof of documentation.

High strength bolts of material grades 8.8, 10.9 or 12.9 shall be used in the connection of slewing ring to its supporting structure. They shall be tightened by controlled means and pre-tensioned to a specified preload state. A bolt grade 10.9 is usually recommended.

The instructions and requirements given by the slewing ring provider/manufacture concerning the bolt grade, the quantity and diameter of the bolts, tightening and retightening, shall be adhered to.

The ratio of the effective clamp length l_k to the nominal bolt diameter d should be greater or equal than 4,5 (see Figure A.4).

The designer should ask the bolt supplier to demonstrate compliance with the requirements regarding the protection against hydrogen embrittlement, for the property classes (bolt grades) 10.9 and 12.9. Technical requirements can be found in EN ISO 15330, EN ISO 4042 and ISO 9587.

4.3.2.5 Lubrication

Slewing rings shall be provided with suitable lubrication, ensuring regular lubrication, and so maintaining the correct operating conditions of its components. Suitable lubricants and lubrication periods specified by the slewing ring manufacturer shall be adhered to.

4.3.3 Rolling bearings

4.3.3.1 General

The choice of rolling bearings and of their mounting shall be appropriate for the acting loads under consideration. When selecting the type of rolling bearings, the temperature limits of the bearings shall be taken into account.

Manufacturer's instructions on installation, maintenance and positioning shall be taken into account. In case where the manufacturer's instructions are not met, it shall be technically justified.

Those instructions are only valid for a not polluted environment, e.g. not containing potentially damaging elements (dust, water ...) which can ingress the raceways of the rolling bearings.

4.3.3.2 Housings

The housings of ball or roller bearings shall be sufficiently rigid to prevent the distortion of the rings (races). A housing thickness of at least 2,5 times the thickness of the outer ring is recommended.

4.3.3.3 Hardness

Raceways and rolling elements shall be at least surface hardened in order to support the maximum contact stress they endure.

A minimal surface hardness equal to 60 HRC is recommended for the rolling elements.

4.3.3.4 Lubrication

Rolling bearings shall be provided with suitable lubrication, ensuring regular lubrication, and so maintaining the correct operating conditions of its components. When regular lubrication is required, suitable lubricants and lubrication periods specified by the rolling bearing manufacturer shall be adhered to.

4.3.4 Plain bearings

4.3.4.1 General

The choice of plain bearings and of their mounting shall be appropriate for the loads acting on shafts under consideration, the shaft speed and its environment.

This standard only deals with the following plain bearings (see Figure 3, including axial and radial acting loads, and Figure 4):

- bush;
- flanged bush;
- thrust washer;
- radial spherical plain bearing;
- angular contact spherical plain bearing;
- thrust spherical plain bearing.

The type of spherical plain bearing is mainly chosen with respect to:

- the ratio between the axial and radial components of acting loads (see 5.2.6.2.1);
- the tilt angle between the shaft axis and the housing axis (denoted α in ISO 12240).

Some polyamide plain bearings (e.g. PA 4.6) might not be suitable for humid atmosphere.

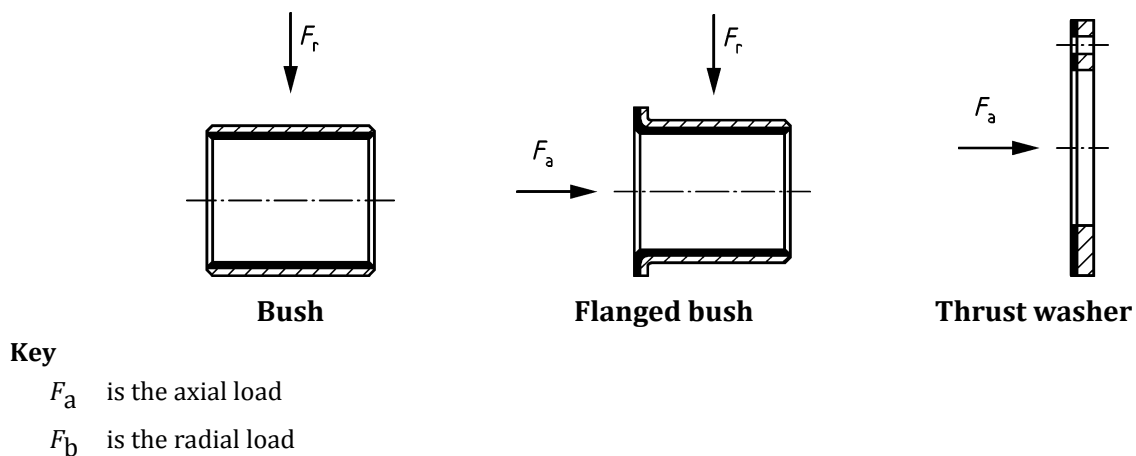


Figure 3 — Three types of cylindrical plain bearings

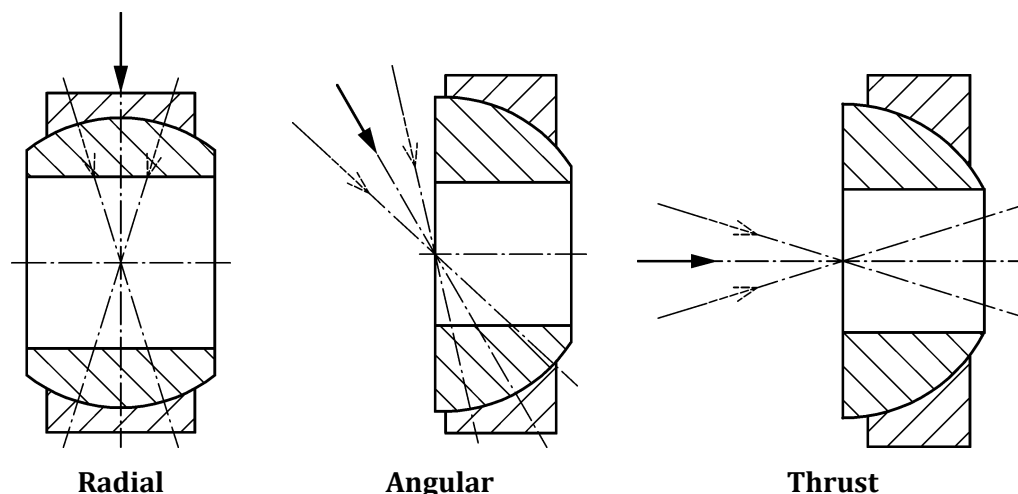


Figure 4 — Three types of spherical plain bearings

Manufacturer's instructions on installation, maintenance and positioning shall be adhered to.

The definitions of plain bearings can be found in the ISO 4378 and ISO 12240 series.

The provided design shall minimize the edge loads and see that clearance is compatible with the lubrication selected and with the expected process. It is recommended that the length of the plain bearing is no longer than 1,2 times the shaft diameter, in order to limit the edge loads.

Low friction bushes are delivered in two different states: finished state or semi-finished state (pre-machining state). The diameters of shaft and housing shall take into account tolerances in order to guarantee good operating condition. For bushes in finished state burnishing could be employed in order to achieve the required clearance tolerance.

In the absence of cylindrical plain bearing manufacturer's instructions, guide rules are given below:

- the maximum clearances, as a function of the shaft diameter d in mm, should be equal to:
 - $1,8 \cdot 10^{-3} \cdot d + 0,11$ for bearings with lubrication pocket for grease lubrication and reserve;
 - $1,6 \cdot 10^{-3} \cdot d + 0,07$ for bearings without lubrication pocket.
- the minimum clearances, as a function of the shaft diameter d , should be equal to:
 - $1 \cdot 10^{-3} \cdot d$ for bearings with lubrication pocket;
 - $3 \cdot 10^{-3} \cdot d$ for plain bearings without lubrication pocket.

For bushes with $p_{pb, Sd} \geq 0,75 \cdot p_{pb, Rd}$ (see 5.2.7) or in case of reversing loads, the above maximum clearances shall be tightened (see [3-9]).

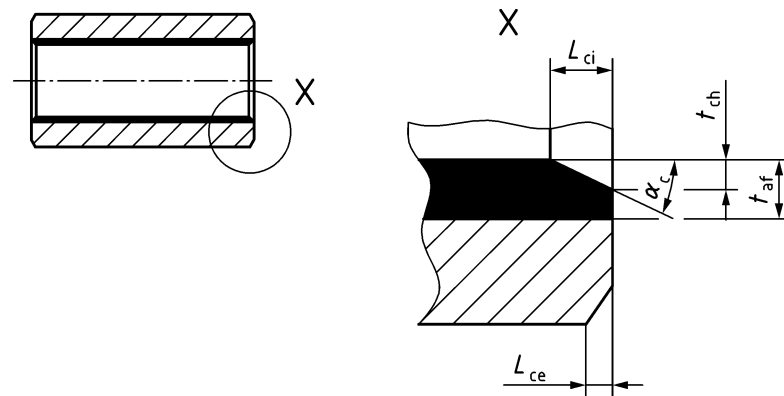
In the absence of manufacturer's instructions, for guidance, the shaft with spherical plain bearings should be machined with at least m6 tolerance and the housing with H7.

For bushes, chamfers on the housing are recommended in order to avoid plastic deformation of the bush at the start of the fitting operation. The chamfer shall be sufficiently large for a flange bearing to accommodate the curvature of the flange. For a bush which is to be machined, an internal chamfer shall be provided in order to reduce shear stress and risk of cracking at the end of the active area between low

friction layer and steel backing. In absence of the plain bearing manufacturer's instructions, it is recommended that:

- the chamfer angle α_c is less or equal than 45° ;
- $t_{ch} \geq 0,66 \cdot t_{af}$ (see Figure 5).

The internal chamfer L_{ci} shall be greater than the external chamfer L_{ce} on account of fatigue strength considerations (see Figure 5).



Key

- L_{ce} is the external chamfer
- L_{ci} is the internal chamfer
- α_c is the chamfer angle

Figure 5 — Bush chamfers

From a general point of view, the interference fit is such that the contact pressure between the bearing bush and its metallic tube backing will be at least equal to 10 MPa. For quasi insulated and severe applications (e.g. plain bearings with design pressures $p_{pb,Sd} > 40$ MPa and $p_{eq} \cdot v_{eff} > 1$ MPa m/s, see 5.2.6.1.2 and 6.4.4.1 resp.), the housing roughness should be $R_a = 0,4 \mu\text{m}$ or better in order to reduce the thermal contact resistance between the bush and the housing.

In the case of high contamination level, bushes with helical groove are recommended in order to reduce extra wear generated by pollutant particles (see [3-3]).

4.3.4.2 Sealing

The sealing of bearing shall be selected to prevent:

- the ingress of polluting fluids;
- the embedment of hard particles in the low friction layer (which could become abrasive);
- the corrosion of the running surfaces.

When seals are used in spherical plain bearings, attention shall be paid to the compatibility of:

- the available space with the tilt angle in order to prevent any contact between the bearing components and their adjacent components;
- the limit temperatures for both the bearing components and the seal;

— the type of lubricant and the frequency of relubrication.

4.3.4.3 Lubrication

Plain bearings requiring the application of lubricant from an external source shall be provided with suitable lubrication, maintaining the correct operating conditions of its components. Suitable lubricants and lubrication periods specified by the plain bearing manufacturer shall be adhered to, notably for components operating at very low temperatures.

With bushes with lubrication pocket operating with large thermal amplitude and temperature lower than 0 °C, it is recommended to use low friction material and grease which do not allow fretting corrosion.

4.3.4.4 Shafts for cylindrical plain bearings

Shaft hardness and roughness values specified by the plain bearing manufacturer shall be used.

In the absence of instructions from the cylindrical plain bearing manufacturer, values of shaft hardness and roughness range given in Table 4 may be used. They are in accordance with EN ISO 4287, after turning and before grinding. For bushes without lubrication pockets, the roughness values shall be decreased.

Table 4 — Shaft hardness and roughness

Cylindrical plain bearing, low friction material	Shaft hardness [HB]	Shaft Roughness R_a [μm]
Bronze	150–400	≤ 1,0
Bronze – Sinter bronze	300–600	≤ 0,4
Bronze – Lead	300–600	≤ 0,4
Bronze – Graphite	300–500	≤ 0,8
POM Composite, in accordance with ISO 3547-4	150–600	≤ 0,8
PTFE composite, in accordance with ISO 3547-4	300–600	≤ 0,4
Fluorinated polymers (PTFE) + sintered bronze + fillers	300–600	≤ 0,4
Filament wound	500–600	0,2–0,4
Polyamide + sintered bronze	200–400	0,4

The shaft shall be protected or adapted to the machinery atmosphere (presence of water or of a conductor fluid) not to create an oxidation-reduction reaction between the shaft and the plain bearing, in case of metallic bearings (e.g. shafts including nickel).

For polymer plain bearings, shaft with hardened steel or with heat treatment should be used.

For multilayer steels (steel backing, metallic low friction layer and eventually, electroplated layer), ISO 4383 recommends shaft surface hardness related to the application.

4.3.4.5 Shafts for spherical plain bearings

Requirements for shaft are slightly different for spherical bearings than for shafts with cylindrical bearings. As any spherical bearing involves at least two components fitted on the shaft and in the housing, it is important to ensure that the expansion of the assembly does not affect the internal clearance of the spherical bearing.

The shaft needs also a minimal hardness for wear resistance and a minimal roughness in order to avoid abrasion on the seal lips and to ensure low wear.

In the absence of spherical bearing manufacturer's or of seal provider's instructions:

- Shaft hardness shall be higher than 50 HRC;
- Shaft roughness R_a shall be lower than 3,2 μm ;
- Shaft roughness R_z shall be lower than 10 μm .

Concerning the internal clearances of spherical bearing, the radial and axial clearances between the inner ring and the outer ring, these parameters are defined by the supplier who provides the interference fits for the shaft and for the housing.

4.4 Proofs of competence for bearings

The object of the proof of competence is to demonstrate that the design stresses or forces do not exceed the design resistances R_d :

$$S_d \leq R_d \quad (1)$$

The design stresses or forces S_d shall be determined by applying the relevant loads, load combinations and partial safety factors in accordance with EN 13001-2.

In the following clauses, the design resistances R_d are represented as:

- limit stresses (slewing ring bolted connection);
- limit load ratings (slewing rings and rolling bearings);
- limit pressures (plain bearings);
- limit power densities (plain bearings).

The following proofs shall be demonstrated for bearings:

- Proof of static strength, in accordance with Clause 5;
- Proof of fatigue strength in accordance with Clause 6;
- Proof of elastic stability in accordance with Clause 7.

All those proofs are based on nominal stresses, i.e. stresses calculated using traditional elastic theory of the strength of materials which in general neglect localized stress non-uniformities, but the proofs of strength of the slewing rings allow the determination of optimized values of many factors based on advanced methods such as Finite Element models.

As mentioned in EN 13001-1, alternatively, advanced and recognized theoretical or experimental methods may be used in general, provided that they conform to the principles of this series of standard. Those methods can be sophisticated programs (e.g. of the rolling bearing or plain bearing industries). Conformity to the principles of EN 13001 series means notably that:

- the classification parameters of the bearing under consideration shall be issued from EN 13001-1;
- the most unfavourable load effects (proof of static strength) and the load history (proof of fatigue strength) shall be issued from the load combinations A, B or C, in accordance with EN 13001-2;

— separate proofs shall be executed for both static and fatigue strengths.

5 Proof of static strength

5.1 General

A proof of static strength by calculation is intended to prevent excessive deformations due to yielding of the material, elastic instability (see Clause 7) and fracture of machinery components. Dynamic factors given in EN 13001-2 are used to produce equivalent static loads to simulate dynamic effects.

The proof shall be carried out for machinery components, with the most unfavourable load effects from the load combinations A, B or C in accordance with EN 13001-2 taken into account and with the resistances calculated in accordance with 5.2.

5.2 Limit design stresses and forces

5.2.1 General

The limit design stresses and forces shall be calculated from:

$$\text{Limit design stresses or limit design pressures} = \text{function}(f_k, \gamma_R); \text{ or} \quad (2a)$$

$$\text{Limit design power densities or limit load ratings} = \text{function}(F_k, \gamma_R) \quad (2b)$$

where

f_k or F_k are characteristic values (or nominal);

γ_R is the total resistance factor $\gamma_R = \gamma_m \times \gamma_s$;

γ_m is the general resistance factor $\gamma_m = 1,1$ (see EN 13001-2);

γ_s is the specific resistance factor applicable to specific machinery components as given in the clauses below. γ_s and γ_s are generic symbols that will be applied for different components and different proofs, each time with a specific index.

NOTE Limit design values are equivalent to R / γ_m in EN 13001-1.

5.2.2 Limit design forces and stresses for slewing rings

5.2.2.1 General

The proof of static strength of the raceways and of the rolling elements of slewing rings is mainly based on ISO 76:2006.

The proof of static strength of bolted connection of the slewing ring shall be carried out using the design stresses and limit design stresses defined in 5.2.2.4. They are an extension of the requirements for bolted connections of the EN 13001-3-1 which do not cover bolts subjected to bending or connections prone to a local opening, situation inherent in the mounting arrangement of the slewing ring bolts.

5.2.2.2 Static equivalent loads for raceways and rolling elements

5.2.2.2.1 General

The loads acting on a slewing ring are calculated using load combinations A, B or C in accordance with EN 13001-2.

They consist of the following forces and moment (see Figure 6):

- axial load F_a ;
- radial load F_r ;
- tilting moment M_r .

The design loads P_{0a} (design axial equivalent static load) and P_{0r} (design radial equivalent static load) shall be determined from these loads, in 5.2.2.2.3.

Q_b is the highest contact load on a rolling element.

Q_b and P_{0a} depend on the nominal contact angle α .

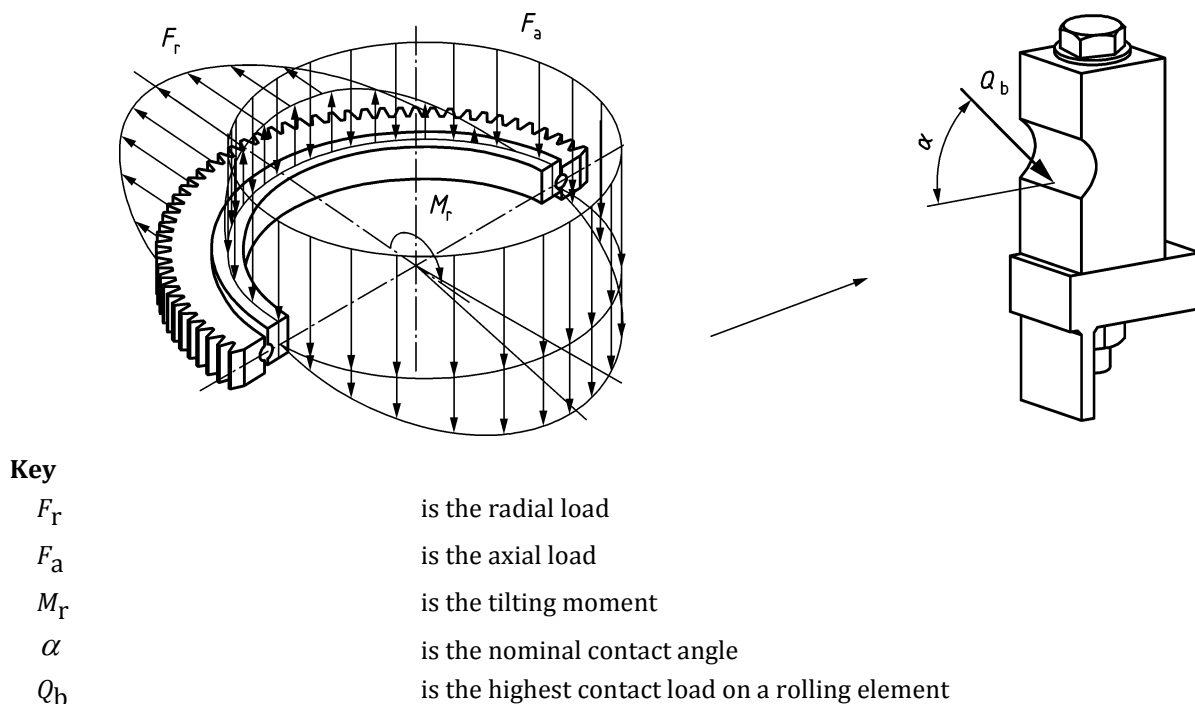


Figure 6 — Loads applied to a slewing ring, load Q_b on rolling element

The determination of the design loads for a critical sector of a slewing ring is based on the following simplified assumptions regarding the distribution of applied loads on the rolling elements:

- Sinusoidal distribution of the tilting moment M_r ;
- uniform distribution of the axial load F_a (eventually including the axial load equivalent to the radial load F_r);

- substituting the equivalent axial load for the radial load F_r . This substitution of F_r does not apply to three-row roller bearings, where F_r is distributed on the separate vertical row (see Tables 5 and 6, last case).

Those assumptions are valid under the following conditions:

- supporting structure of sufficient stiffness (see recommendations in 4.3.2.2),
- a sufficiently high number of fixing elements (bolts, studs), uniformly distributed;
- opening of the gap in the connection between the slewing ring rings and their supporting structure is prevented.

If the above conditions are not satisfied, the distribution of loads and moments into the rolling elements of the slewing ring will deviate from that assumed due to the presence of hard spots (e.g. with a weak, low-stiffness flange mounted directly onto a frame as opposed to a tubular shell, slewing ring sections adjacent to stiffeners, gussets, supporting beams below the supporting flange). To take into account this unequal distribution among the rolling elements or fixing elements in an analytical calculation, the resulting force calculated from the nominal loads and moments shall be multiplied by an excess load factor K_{rep} greater than 1,0 (see A.1 for the determination of K_{rep}).

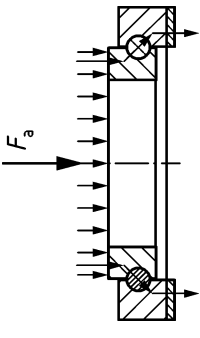
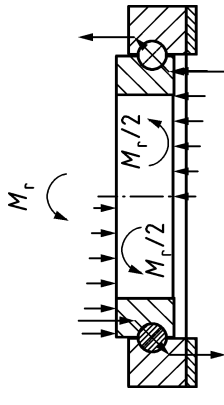
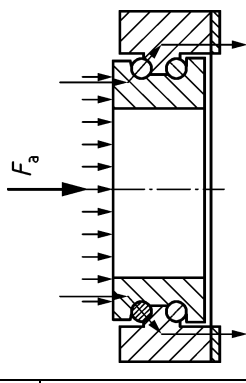
5.2.2.2.2 Apportionment of the applied loads

In the absence of a more accurate information (e.g. from slewing ring manufacturer, finite element analysis) the apportionment of the distributed loads between the raceways of the slewing ring defined in Table 5 (supported installations) and Table 6 (suspended installations) for five different types of slewing rings shall be used.

Slewing rings can have one or more raceways and the apportionment of the applied loads depends on the type of slewing ring and on the external load under consideration.

Tables 5 and 6 define this apportionment (factors A_{pF} and A_{pM}) and the corresponding number of active (i.e. transmitting the external load) rolling elements related to the number Z of rolling elements of each raceway under consideration (single, upper or lower). The apportionment factors A_{pF} and A_{pM} will be used in Formula (3) defining the design equivalent load P_{0a} .

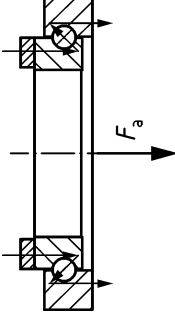
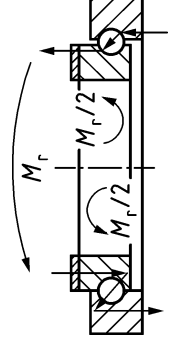
Table 5 — Apportionment of applied loads and number of active rolling elements to raceways (supported installations)

Type of slewing ring a	Raceway and number Z of rolling elements	Axial load F_a		Tilting moment M_r	
		Load path	Apportionment factor A_{pF}	Number of active rolling elements Z_{aF}	Apportionment factor A_{pM}
Single-row ball bearing with four-point contact per ball (two contact lines per ball)	Single Z_1		1,0	Z_1	1,0
					
Double-row ball bearing with two point contacts per ball (one contact line per ball) c	Upper Z_2		1,0	Z_2	1
	Lower Z_3		-1,0 where $\frac{M_r}{F_a} > \frac{D^m}{4}$	Z_3	1,0 where $\frac{M_r}{F_a} > \frac{D^m}{4}$
	Upper Z_2		1,4	$Z_2 + Z_3$	1,4

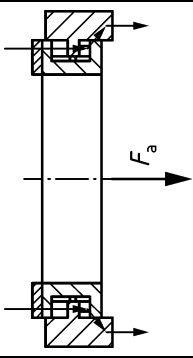
Type of slewing ring ^a	Raceway and number Z of rolling elements	Axial load F_a		Tilting moment M_r	
		Load path	ApF	Number of active rolling elements Z_aF	ApM
Double-row ball bearing with four point contacts per ball (two contact lines per ball); ball size and number of balls identical for both rows ^b	Lower Z_3				
Single-row crossed roller bearing (one contact line per roller)	Single Z_1		1	$Z_1/2$	1
Three-row roller bearing (one contact line per roller) ^c	Upper Z_2		1,0	Z_2	1
	Lower Z_3		-1,0 where $\frac{M_r}{F_a} > \frac{D_m}{4}$	Z_3	1,0 where $\frac{M_r}{F_a} > \frac{D_m}{4}$

Type of slewing ring ^a	Raceway and number Z of rolling elements	Axial load F_a		Tilting moment M_r	
		Load path	Apportionment factor A_{pF}	Load path	Apportionment factor A_{pM}

Table 6 — Apportionment of applied loads and number of active rolling elements to raceways (suspended installations)

Type of slewing ring ^a	Raceway and number <i>Z</i> of rolling elements	Axial load F_a		Tilting moment M_r	
		Load path	Apportionment factor A_{pF}	Load path	Apportionment factor A_{pM}
Single-row ball bearing with four-point contact per ball (two contact lines per ball)	Single Z_1		1,0		1,0

Type of slewing ring a	Raceway and number Z of rolling elements	Axial load F_a		Tilting moment M_r	
		Load path	ApF	Number of active rolling elements $Z_a F$	Load path
Double-row ball bearing with two point contacts per ball (one contact line per ball) c	Upper Z_2		-1,0 where $\frac{M_r}{F_a} > \frac{D_m}{4}$	Z_2	
	Lower Z_3		1,0	Z_3	
Double-row ball bearing with four point contacts per ball (two contact lines per ball); ball size and number of balls identical for both rows b	Upper Z_2		1,4	$Z_2 + Z_3$	
	Lower Z_3				
Single-row crossed roller bearing (one contact line per roller)	Single Z_1		1	$Z_1/2$	
Three-row roller bearing (one contact line per roller) c	Upper Z_2		-1,0 where $\frac{M_r}{F_a} > \frac{D_m}{4}$	Z_2	
					1,0 where $\frac{M_r}{F_a} > \frac{D_m}{4}$

Type of slewing ring a	Raceway and number Z of rolling elements	Axial load F_a		Tilting moment M_r		
		Load path	ApF	Number of active rolling elements Z_aF	Load path	ApM
			A_{pF}	Z_{aF}		A_{pM}
	Lower Z_3		1,0	Z_3		1

a Dash lines indicate load path or rotation axis, thin lines indicate contact line and arrows indicate force axis (full for moment M_r). Values of A_{pF} in Table 6 are valid only for the downward direction of F_a .

b The 1,4 apportionment factor reflects the assumed 70/30 load distribution on the two raceways, not knowing which one is the most loaded. A smaller value may be used, not lower than 1,10, taking into account tight tolerances, stiffness of supporting structure and variation of internal dimensions between the bearing rows, with technical justifications such as test results.

c Lower raceway: where $\frac{M_r}{F_a} \leq \frac{D_m}{4}$, only the upper raceway is loaded ($A_{pF} = A_{pM} = 0$ for lower raceway).

- a Dash lines indicate load path or rotation axis, thin lines indicate contact line and arrows indicate force axis (full for moment M_r). Values of A_{pF} in Table 6 are valid only for the downward direction of F_a .
- b The 1,4 apportionment factor reflects the assumed 70/30 load distribution on the two raceways, not knowing which one is the most loaded. A smaller value may be used, not lower than 1,10, taking into account tight tolerances, stiffness of supporting structure and variation of internal dimensions between the bearing rows, with technical justifications such as test results.
- c Lower raceway: where $\frac{M_r}{F_a} \leq \frac{D_m}{4}$, only the upper raceway is loaded ($A_{pF} = A_{pM} = 0$ for lower raceway).