International Standard

ISO 16281

Rolling bearings — Methods for calculating the modified reference rating life for universally loaded rolling bearings

Roulements — Méthodes de calcul de la durée nominale de référence corrigée pour les roulements chargés universellement

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 4, *Rolling bearings*, Subcommittee SC 8, *Load ratings and life*.

This first edition of ISO 16281 cancels and replaces the first edition of ISO/TS 16281:2008, which has been technically revised. It also incorporates the Technical Corrigendum ISO/TS 16281:2008/Cor 1:2009.

The main changes are as follows:

— the coordinate system used in drawings and derivation of formulae has been changed to a right-handed coordinate system;

— the calculation of load distribution of cylindrical and tapered bearings has been described in greater detail and provisions for the calculation of load distribution and rating life of spherical roller bearings have been added;

— additional formulae have been given for the calculation of load distribution of hybrid bearings;

— reference geometries and the description of static equilibrium calculation for different bearing types have been moved to an informative annex.

This document is intended to be used in conjunction with ISO 281.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Since publication of the first edition of ISO 281:1990, additional knowledge has been gained regarding the influence on bearing life of contamination, lubrication, internal stresses from mounting, stresses from hardening, fatigue load limit of the material etc. It is therefore now possible to consider factors that have influence on bearing life in a more complete way in the life calculation.

ISO 281 provides a method to put into practice this new knowledge in a consistent way when the modified rating life of a bearing is calculated. However, the calculation method given in ISO 281 cannot consider the influence on life of tilted or misaligned bearings and the influence on life of bearing clearance during operation. ISO/TS 16281:2008 already describes an advanced calculation method, which makes it possible to consider these influences, and in addition provides the most accurate method for estimating the influence of contamination and other factors.

In addition to the content of ISO/TS 16281:2008, this document also addresses the analysis of hybrid bearings with rolling elements made of silicon nitride.

The primary purpose of this document is to provide a unified and manufacturer-independent advanced calculation method that allows for the consideration of actual operating conditions, thus enabling the end user to compare different bearing solutions on the same calculation basis. It is also intended to serve as a manufacturer-independent neutral basis for certification purposes, e.g. as required per IEC 61400-4[1] for bearings in wind turbine gearboxes.

This document is intended to be used for computer programs and together with ISO 281 covers the information needed for life calculations. For accurate life calculations under the operating conditions specified above, this document or advanced computer calculations should be used for determining the dynamic equivalent reference load under different loading conditions.

This document is not intended to supersede other advanced bearing analysis methods that are currently used in the design process as the primary tool for bearing design and selection.

Rolling bearings — Methods for calculating the modified reference rating life for universally loaded rolling bearings

1 Scope

This document defines the calculation of the modified reference rating life taking into consideration lubrication, contamination, and fatigue load limit of the bearing material, as well as tilting or misalignment, operating clearance of the bearing and internal load distribution on rolling elements. The calculation method provided in this document covers influencing parameters additional to those described in ISO 281.

The general directions and limitations given in ISO 281 apply to this document. The calculation methods pertain to the fatigue life of the bearings. Other mechanisms of failure, like wear or microspalling (gray-staining), lie outside the scope of this document.

This document applies to single- and multi-row radial and thrust ball bearings, subjected to radial and axial load and with radial clearance and tilt taken into account. It also applies to single- and multi-row radial and thrust roller bearings, subjected to radial and axial load and with radial clearance, edge stress and tilt taken into account. References to methods for the analysis of the internal load distribution under general load are given.

The calculation of load distribution and basic reference rating life is also applicable to hybrid bearings, using the dynamic load ratings per ISO 20056-1[2]. The calculation of the modified reference rating life is not applicable to hybrid bearings.

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.

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

ISO 5593, *Rolling bearings — Vocabulary*

ISO 15241, *Rolling bearings — Symbols for physical quantities*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 281, ISO 5593 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
basic reference rating life
rating life associated with 90 % reliability for rolling bearings manufactured with commonly used high quality material, of good manufacturing quality, under consideration of actual load distribution in the bearing

3.2
modified reference rating life
rating life for 90 % or other reliability, for rolling bearings manufactured with commonly used high quality material, of good manufacturing quality, under consideration of actual load distribution, lubrication conditions, lubricant contamination and bearing fatigue load limit

Note 1 to entry: Life values for reliabilities higher than 90 % are denoted by the index *n*, where *n* = 100 – percentage of reliability.

3.3
deflection
change in position caused by elastic deformation, e.g. in a contact

3.4
displacement
change in position caused by rigid body motion, e.g. axial movement of rolling elements caused by tilting of the inner ring

3.5
initial contact angle
free contact angle
contact angle at initial contact between rolling element and both raceways, when an infinitesimal small axial load on bearing is applied

Note 1 to entry: The initial contact angle, α_0, is generally not identical to the nominal contact angle, α, in ISO 281.

4 Symbols

For the purpose of this document, the symbols given in ISO 15241 and the following apply.

A	distance between raceway groove curvature centres of ball bearing having no clearance and having an initial contact angle, in millimetres
a	semi-major axis of the contact ellipse of ball bearings, in millimetres
a_{ISO}	life modification factor based on a systems approach of life calculation
$a_{\mathrm{ISO}k}$	life modification factor for lamina k of a roller bearing, based on a systems approach of life calculation
$a_{\mathrm{ISO}m}$	life modification factor for row m of a multi-row ball bearing, based on a systems approach of life calculation
a_1	life modification factor for reliability
b	semi-minor axis of the contact ellipse of a ball bearing, in millimetres
C_{a}	basic dynamic axial load rating according to ISO 281 or ISO 20056-1, in newtons
C_{r}	basic dynamic radial load rating according to ISO 281 or ISO 20056-1, in newtons
C_{u}	fatigue load limit, in newtons
c_{L}	spring constant of a rolling element with line contact, in newtons per millimetre to the power of 10/9
c_P	spring constant of a rolling element with point contact, in newtons per millimetre to the power of 3/2
c_{s}	spring constant of a roller lamina, in newtons per millimetre to the power of 10/9
c_{T}	spring constant of a tapered roller, in newtons per millimetre to the power of 10/9

D_{pw} pitch diameter of ball or roller set, in millimetres

D_{pwk} pitch diameter at lamina k for bearings having rollers with non-constant diameter, in millimetres

D_w nominal ball diameter, in millimetres

D_{we} roller diameter applicable in the calculation of load ratings, in millimetres

D_{wk} roller diameter at lamina k for rollers with non-constant diameter, in millimetres

d distance to the centre of contact of a tapered roller bearing, measured from the axial locating face of the outer ring, in millimetres

E modulus of elasticity, in megapascals (1 MPa = 1 N/mm^2)

NOTE 1 Elasticity constants used in this standard are based on E_{st} = 207 000 MPa for steel and E_{ce} = 300 000 MPa for Si_3N_4.

$E(\chi)$ complete elliptic integral of the second kind

$F(\rho)$ relative curvature difference for point contact

$F_e(\rho)$ relative curvature difference for point contact at outer ring

$F_i(\rho)$ relative curvature difference for point contact at inner ring

e subscript for outer ring or housing washer

e_C contamination factor

F_a bearing axial load (axial component of actual bearing load) acting at bearing rotation axis, in newtons

F_r bearing radial load (radial component of actual bearing load) acting at centre of bearing, in newtons

$f[j,k]$ load correction function for consideration of edge load

$f_e[j,k]$ load correction function for consideration of edge load at outer ring contact

$f_i[j,k]$ load correction function for consideration of edge load at inner ring contact

$G_{r\,op}$ radial operating clearance of bearing, in millimetres

i subscript for inner ring or shaft washer

i number of rows of rolling elements

j subscript for individual rolling element

$K(\chi)$ complete elliptic integral of the first kind

$K(\chi_e)$ complete elliptic integral of the first kind for point contact at outer ring

$K(\chi_i)$ complete elliptic integral of the first kind for point contact at inner ring

k subscript for individual lamina of a roller

L_{nmr} modified reference rating life, in million revolutions

NOTE 2 The subscript r in L_{nmr} denotes “reference”.

L_{we} effective contact length of a roller applicable in the calculation of load ratings, as defined in ISO 281, in millimetres

NOTE 3 For rollers of cylindrical and spherical roller bearings, L_{we} is defined along the roller axis. For tapered roller bearings, L_{we} is defined along the roller contact line.

L_{10r} basic reference rating life, in million revolutions

M_z moment acting on tilted bearing, in newton millimetres

m subscript for individual row of a multi-row bearing

NOTE 4 Subscripts are used in the order j,k,m, separated by commas, e.g. $q_{j,k,m}$ denotes the load on lamina k of roller j of row m.

n speed of rotation, in revolutions per minute

n_s number of laminae per roller

P dynamic equivalent load per ISO 281, in newtons

$P(x_k)$ profile function, in millimetres

$P_{ref\,a}$ dynamic equivalent reference axial load, in newtons

$P_{ref\,am}$ dynamic equivalent reference axial load of row m, in newtons

$P_{ref\,r}$ dynamic equivalent reference radial load, in newtons

$P_{ref\,rm}$ dynamic equivalent reference radial load of row m, in newtons

P_{sk} dynamic equivalent load of a bearing lamina k, in newtons

$P_{sk,m}$ dynamic equivalent load of a bearing lamina k of row m, in newtons

p_{He} contact stress at the contact of outer ring and rolling element, in megapascals

p_{Hi} contact stress at the contact of inner ring and rolling element, in megapascals

Q nominal force between a rolling element and the raceways, in newtons

Q_c rolling element load for the basic dynamic load rating of the bearing per ISO/TR 1281-1[3], in newtons

Q_{ce} equivalent nominal force between a rolling element and the raceways for the basic dynamic load rating of outer ring or housing washer, in newtons

Q_{ci} equivalent nominal force between a rolling element and the raceways for the basic dynamic load rating of inner ring or shaft washer, in newtons

Q_{ee} dynamic equivalent rolling element load on outer ring or housing washer, in newtons

$Q_{ee\,m}$ dynamic equivalent rolling element load on outer ring or housing washer of row m, in newtons

Q_{ei} dynamic equivalent rolling element load on inner ring or shaft washer, in newtons

$Q_{ei\,m}$ dynamic equivalent rolling element load on inner ring or shaft washer of row m, in newtons

Q_j rolling element load of rolling element j, in newtons

q_{ce} basic dynamic load rating of a bearing lamina at the outer ring or housing washer contact, in newtons

q_{ci} basic dynamic load rating of a bearing lamina at the inner ring or shaft washer contact, in newtons

$q_{ee\,k}$ dynamic equivalent rolling element lamina load of lamina k at outer ring or housing washer, in newtons

$q_{ee\,k,m}$ dynamic equivalent rolling element lamina load of lamina k of row m at outer ring or housing washer, in newtons

$q_{ei\,k}$ dynamic equivalent rolling element lamina load of lamina k at inner ring or shaft washer, in newtons

$q_{ei\,k,m}$ dynamic equivalent rolling element lamina load of lamina k of row m at inner ring or shaft washer, in newtons

$q_{j,k}$ load on the lamina k of roller j, in newtons

$q'_{j,k}$ corrected load on the lamina k of roller j, in newtons

R_i distance between the centre of curvature of the inner raceway groove and the axis of rotation, in millimetres

R_p convex curvature radius of spherical rollers, in millimetres

r_e cross-sectional raceway groove or spherical raceway curvature radius of outer ring or housing washer, in millimetres

r_i cross-sectional raceway groove or raceway curvature radius of inner ring or shaft washer, in millimetres

T total width of a tapered roller bearing, in millimetres

x, y, z axes of a right-handed coordinate system, where x is defined along the rotation axis of the bearing

x_k distance between centre of lamina k and roller centre, in millimetres

NOTE 5 x_k is measured along the rolling element axis for cylindrical and spherical roller bearings, and along the lateral surface for tapered roller bearings.

Z number of rolling elements in a single-row bearing; number of rolling elements per row of a multi-row bearing with the same number of rolling elements per row

α nominal contact angle, in degrees

α_j operating contact angle of the rolling element j, in degrees

α_0 initial contact angle, in degrees

β half cone angle of a tapered roller, in degrees

γ auxiliary parameter, $\gamma = D_w \cos\alpha / D_{pw}$ for ball bearings, $\gamma = D_{we} \cos\alpha / D_{pw}$ for roller bearings

γ_k auxiliary parameter for the load correction function, $\gamma_k = D_{wk} \cos\alpha / D_{pwk}$ for rollers with non-constant diameter

δ total elastic deflection of both contacts of a rolling element, in millimetres

δ_a relative axial displacement of centre points on axis of both bearing rings, in millimetres

δ_e elastic deflection at outer ring point contact of a rolling element, in millimetres

δ_i elastic deflection at inner ring point contact of a rolling element, in millimetres

δ_j elastic deflection of both contacts of the rolling element j, in millimetres

$\delta_{j,k}$ elastic deflection of both contacts of the lamina k of the roller j, in millimetres

δ_L total elastic deflection of both contacts of a rolling element with line contact, in millimetres

δ_r relative radial displacement of centre points on axis of the bearing, in millimetres

κ viscosity ratio per ISO 281

λ reduction factor for the consideration of stress concentrations

ν adjustment factor for exponent variation

ν_E Poisson's ratio

NOTE 6 Elasticity constants used in this standard are based on ν_{Est} = 0,3 for steel and ν_{Ece} = 0,26 for Si_3N_4.

ρ curvature of the contact surface, in reciprocal millimetres

$\Sigma\rho_e$ curvature sum of point contact at outer ring, in reciprocal millimetres

$\Sigma\rho_i$ curvature sum of point contact at inner ring, in reciprocal millimetres

ϕ auxiliary angle for integration over contact ellipse, in radians

φ_j angular position of rolling element j, in degrees

χ_e ratio of semi-major to semi-minor axis of the contact ellipse at outer ring of ball bearings, a / b

χ_i ratio of semi-major to semi-minor axis of the contact ellipse at inner ring of ball bearings, a / b

ψ total misalignment between inner raceway and outer raceway, in degrees

ψ_j total misalignment between inner raceway and outer raceway in the plane of rolling element j, in degrees

5 Rating life analysis

5.1 General

This clause describes the analysis of the basic and modified reference rating life for ball and roller bearings.

This life analysis is based on the calculation of each rolling element load for the basic dynamic load rating and each force between rolling element and raceway. Methods for the calculation of each force between rolling element and raceway are described in Annex A.

Calculation methods concerning the analysis of bearings of different geometry or for more complex load cases can be derived from the formulae in Annex A.

In the life analysis for multi-row bearings, it is assumed that all rows are symmetrical and have identical rolling element sets. Formulae for multi-row bearings with deviating geometry can be derived from the formulae given in this clause and in ISO/TR 1281-1[3].

Four-point-contact ball bearings can be approximated as double-row angular contact ball bearings, if these are mounted radially free to take predominantly thrust load, i.e. having only two-point contacts at every ball.