TECHNICAL SPECIFICATION

ISO/TS 16281

First edition
2008-06-15

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

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

Reference number
ISO/TS 16281:2008(E)

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Foreword

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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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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/TS 16281 was prepared by Technical Committee ISO/TC 4, *Rolling bearings*, Subcommittee SC 8, *Load ratings and life*.

Introduction

Since publication of ISO 281 in 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 281:2007 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 281:2007 cannot consider the influence on life of tilted or misaligned bearings and the influence on life of bearing clearance during operation. This Technical Specification describes an advanced calculation method, which also makes it possible to consider these influences, and by that in addition provide the most accurate support for estimating the influence of contamination and other factors.

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

1 Scope

This Technical Specification contains recommendations for 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 Technical Specification covers influencing parameters additional to those described in ISO 281.

The directions and limitations given in ISO 281 apply to this Technical Specification. 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 Technical Specification.

This Technical Specification applies to tilted single-row radial ball bearings, subjected to radial and axial load and with radial clearance and tilt taken into account. It also applies to tilted single-row roller bearings, subjected to pure radial 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 analysis of internal load distribution and modified reference rating life for multi-row bearings or bearings of a more complex geometry can be derived from the equations given in this Technical Specification. For these bearings, the load distribution for each individual row has to be considered.

This Technical Specification is primarily 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, it is recommended that either this Technical Specification or advanced computer calculations provided by bearing manufacturers, for determining the dynamic equivalent reference load under different loading conditions, be used.

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) applies.

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

ISO 15241, *Rolling bearings — Symbols for quantities*

3 Symbols

For the purpose of this document, the symbols given in ISO 15241 and the following apply. See also the terms and definitions in ISO 281:2007, Clause 3 and other definitions in ISO 281.

A	distance, in millimetres, between raceway groove curvature centres of ball bearing having no clearance and having an initial contact angle
a_{ISO}	life modification factor, based on a systems approach of life calculation
a_1	life modification factor for reliability
C_a	basic dynamic axial load rating, in newtons
C_r	basic dynamic radial load rating, in newtons
C_u	fatigue load limit, in newtons
c_L	spring constant, in newtons per millimetre to the power of 10/9, of a rolling element with line contact
c_P	spring constant, in newtons per millimetre to the power of 3/2, of a rolling element with point contact
c_s	spring constant, in newtons per millimetre to the power of 8/9, of a roller lamina
D_pw	pitch diameter, in millimetres, of ball or roller set
D_w	nominal ball diameter, in millimetres
D_we	roller diameter, in millimetres, applicable in the calculation of load ratings
E	modulus of elasticity, in megapascals [1)]
$E(\chi)$	complete elliptic integral of the second kind
e	subscript for outer ring or housing washer
e_C	contamination factor
$F(\rho)$	relative curvature difference
F_a	bearing axial load (axial component of actual bearing load), in newtons
F_r	bearing radial load (radial component of actual bearing load), in newtons
$f[j,k]$	stress correction function for consideration of edge load
i	subscript for inner ring or shaft washer
i	number of rows of rolling elements
$K(\chi)$	complete elliptic integral of the first kind
$L_{n\mathrm{mr}}$	modified reference rating life, in million revolutions
L_we	effective roller length, in millimetres, applicable in the calculation of load ratings
$L_{10\mathrm{r}}$	basic reference rating life, in million revolutions
M_z	moment, in newton millimetres, acting on tilted bearing

1) 1 MPa = 1 N/mm^2

n_s number of laminae

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

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

$P(x)$ profile function, in millimetres

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

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

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

Q rolling element load, in newtons

Q_{ce} rolling element load, in newtons, for the basic dynamic load rating of outer ring or housing washer

Q_{ci} rolling element load, in newtons, for the basic dynamic load rating of inner ring or shaft washer

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

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

Q_j rolling element load, in newtons, of rolling element j

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

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

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

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

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

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

R_p crown radius, in millimetres, of spherical rollers

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

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

s radial operating clearance, in millimetres, of bearing

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

Z number of rolling elements

α nominal contact angle, in degrees, of a bearing

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

α_0 initial contact angle, in degrees

γ auxiliary parameter, $\gamma = D_w \cos\alpha / D_{pw}$

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

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

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

δ_a relative axial displacement, in millimetres, of both bearing rings

δ_r relative radial displacement, in millimetres, of both bearing rings

λ reduction factor for the consideration of stress concentrations

ν adjustment factor for exponent variation

ν_E Poisson's ratio

ρ curvature, in reciprocal millimetres, of the contact surface

$\Sigma\rho$ curvature sum, in reciprocal millimetres

φ_j angular position, in degrees, of rolling element j

χ ratio of semi-major to semi-minor axis of the contact ellipse

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

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

4 Ball bearings

4.1 General

This clause describes the analysis of the internal load distribution for radial ball bearings and thrust ball bearings under radial and axial load, taking into account radial clearance and tilt. Calculation methods concerning the analysis of bearings of different geometry or for more complex load cases can be derived from the equations given in this Technical Specification.

The bearing internal load distribution is calculated for a static equilibrium; dynamic effects like centripetal and gyroscopic forces are considered insignificant. This assumption is generally valid for low and moderate speeds. At high speeds, centripetal and gyroscopic forces can become predominant and significantly alter the bearing internal load distribution.

4.2 Bearing internal load distribution

4.2.1 Elastic deflection of point contact

The elastic deflection of a point contact can be calculated from Hertzian theory. The elastic deflection of a single point contact, δ, is given by

$$\delta = \sqrt[3]{4{,}5\left(\frac{1-\nu_E{}^2}{\pi E}\right)^2}\; K(\chi)\sqrt[3]{\frac{\Sigma\rho}{\chi^2 E(\chi)}}\; Q^{2/3} \tag{1}$$

The ratio, χ, of the semi-major to semi-minor ellipses is the root of Equation (2)

$$1-\frac{2}{\chi^2-1}\left[\frac{K(\chi)}{E(\chi)}-1\right]-F(\rho)=0 \tag{2}$$

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

$$K(\chi)=\int_0^{\pi/2}\left[1-\left(1-\frac{1}{\chi^2}\right)(\sin\varphi)^2\right]^{-1/2}\mathrm{d}\varphi \tag{3}$$

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

$$E(\chi) = \int_0^{\pi/2} \left[1 - \left(1 - \frac{1}{\chi^2} \right) (\sin\varphi)^2 \right]^{1/2} \mathrm{d}\varphi \tag{4}$$

the curvature sum at the inner ring contact, $\Sigma\rho_\mathrm{i}$

$$\Sigma\rho_\mathrm{i} = \frac{2}{D_\mathrm{w}} \left(2 + \frac{\gamma}{1-\gamma} - \frac{D_\mathrm{w}}{2r_\mathrm{i}} \right) \tag{5}$$

and curvature sum at the outer ring contact, $\Sigma\rho_\mathrm{e}$

$$\Sigma\rho_\mathrm{e} = \frac{2}{D_\mathrm{w}} \left(2 - \frac{\gamma}{1+\gamma} - \frac{D_\mathrm{w}}{2r_\mathrm{e}} \right) \tag{6}$$

and the relative curvature difference at the inner ring contact, $F_\mathrm{i}(\rho)$

$$F_\mathrm{i}(\rho) = \left(\frac{\gamma}{1-\gamma} + \frac{D_\mathrm{w}}{2r_\mathrm{i}} \right) \Big/ \left(2 + \frac{\gamma}{1-\gamma} - \frac{D_\mathrm{w}}{2r_\mathrm{i}} \right) \tag{7}$$

and the relative curvature difference at the outer ring contact, $F_\mathrm{e}(\rho)$

$$F_\mathrm{e}(\rho) = \left(\frac{-\gamma}{1+\gamma} + \frac{D_\mathrm{w}}{2r_\mathrm{e}} \right) \Big/ \left(2 - \frac{\gamma}{1+\gamma} - \frac{D_\mathrm{w}}{2r_\mathrm{e}} \right) \tag{8}$$

The total elastic deflection of both contacts at inner ring and outer ring, δ, is given by

$$\delta = \sqrt[3]{4,5 \left(\frac{1-\nu_\mathrm{E}^2}{\pi E} \right)^2} \left[K(\chi_\mathrm{i}) \sqrt[3]{\frac{\Sigma\rho_\mathrm{i}}{\chi_\mathrm{i}^2 E(\chi_\mathrm{i})}} + K(\chi_\mathrm{e}) \sqrt[3]{\frac{\Sigma\rho_\mathrm{e}}{\chi_\mathrm{e}^2 E(\chi_\mathrm{e})}} \right] Q^{2/3} \tag{9}$$

This leads to Equation (10) for load-deflection

$$Q = c_\mathrm{P}\, \delta^{3/2} \tag{10}$$

with the spring constant, c_P

$$c_\mathrm{P} = 1{,}48 \frac{E}{1-\nu_\mathrm{E}^2} \left[K(\chi_\mathrm{i}) \sqrt[3]{\frac{\Sigma\rho_\mathrm{i}}{\chi_\mathrm{i}^2 E(\chi_\mathrm{i})}} + K(\chi_\mathrm{e}) \sqrt[3]{\frac{\Sigma\rho_\mathrm{e}}{\chi_\mathrm{e}^2 E(\chi_\mathrm{e})}} \right]^{-3/2} \tag{11}$$

4.2.2 Static equilibrium

For a radial ball bearing with diametrically measured radial operating clearance, s, having an initial contact angle, $\alpha_0 = \arccos\,[1 - (s/2A)]$, the total elastic deflection of the rolling element, δ_j, is given by

$$\delta_j = \left\langle \sqrt{\left(A\cos\alpha_0 + \delta_\mathrm{r}\cos\varphi_j \right)^2 + \left(A\sin\alpha_0 + \delta_\mathrm{a} + R_\mathrm{i}\sin\psi\cos\varphi_j \right)^2} - A \right\rangle \tag{12}$$

The right-hand side of Equation (12) is set to zero if it is negative.

NOTE The initial contact angle, α_0, is generally not identical to the nominal contact angle, α, in ISO 281.