TECHNICAL REPORT

ISO/TR 1281-1

Second edition
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Rolling bearings — Explanatory notes on ISO 281 —

Part 1: **Basic dynamic load rating and basic rating life**

Roulements — Notes explicatives sur l'ISO 281 —

Partie 1: Charges dynamiques de base et durée nominale de base

Reference number
ISO/TR 1281-1:2021(E)

Contents

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.

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 documents 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 second edition cancels and replaces the Technical Corrigendum 1 (ISO/TR 1281-1:2008/Cor 1:2009) and the first edition (ISO/TR 1281-1:2008), which has been technically revised.

The main changes compared to the previous edition are as follows:

— The old Clause 7 "Life adjustment factor for reliability" of ISO/TR 1281-1:2008 has been deleted, this subject is covered in ISO/TR 1281-2 (see ISO/TR 1281-1:2008/Cor 1:2009).

— The derivation of the old Formulae (29) and (46) [Formulae (28) and (45) in this edition] has been corrected.

— Typing errors have been corrected in Formulae (30) and (31) and in the derivation of the factor Y_3.

A list of all parts in the ISO/TR 1281 series can be found on the ISO website.

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

ISO/R281:1962

A first discussion on an international level of the question of standardizing calculation methods for load ratings of rolling bearings took place at the 1934 conference of the International Federation of the National Standardizing Associations (ISA). When ISA held its last conference in 1939, no progress had been made. However, in its 1945 report on the state of rolling bearing standardization, the ISA 4 Secretariat included proposals for definition of concepts fundamental to load rating and life calculation standards. The definitions it contained are in essence those given in ISO 281:2007 for the concepts “life” and “basic dynamic load rating” (now divided into “basic dynamic radial load rating” and “basic dynamic axial load rating”).

In 1946, on the initiative of the Anti-Friction Bearing Manufacturers Association (AFBMA), New York, discussions of load rating and life calculation standards started between industries in the USA and Sweden. Chiefly on the basis of the results appearing in Reference [5], an AFBMA standard, *Method of evaluating load ratings of annular ball bearings*[3], was worked out and published in 1949. On the same basis, the member body for Sweden presented, in February 1950, a first proposal to ISO, “Load rating of ball bearings”.

In view of the results of both further research and a modification to the AFBMA standard in 1950, as well as interest in roller bearing rating standards, in 1951, the member body for Sweden submitted a modified proposal for rating of ball bearings as well as a proposal for rating of roller bearings.

Load rating and life calculation methods were then studied. Reference [6] was then of considerable use, serving as a major basis for the sections regarding roller bearing rating.

ISO 281-1:1977

In 1964, in view of the development of improved bearing steels, the time had come to review ISO/R281 and submitted a proposal

In 1969, on the other hand, TC 4 followed a suggestion by the member body for Japan and reconstituted its WG 3, giving it the task of revising ISO/R281. The AFBMA load rating working group had at this time started revision work.

The major part of ISO 281-1:1977 constituted a re-publication of ISO/R281, the substance of which had been only very slightly modified. However, based mainly on American investigations during the 1960s, a new clause was added, dealing with adjustment of rating life for reliability other than 90 % and for material and operating conditions.

Furthermore, supplementary background information regarding the derivation of mathematical expressions and factors given in ISO 281-1:1977 was published as ISO/TR 8646:1985.

ISO 281:1990

ISO 281:1990 was published as “First edition” and entitled “Dynamic load ratings and rating life”. It is referred to as the “technical revision” of ISO 281-1:1977. The new rating factor b_m for “contemporary, normally used material and manufacturing quality, the value of which varies with bearing type and design” was the introduction as a co-value to the basic dynamic load ratings.

ISO 281:2007 (second edition)

Since the publication of ISO 281:1990 additional knowledge regarding the influence on bearing life of contamination, lubrication, internal stresses from mounting, stresses from hardening, fatigue load limit of the material, has been gained. In ISO 281:1990/Amd.2:2000, a general method was presented to consider such influences in the calculation of a modified rating life of a bearing. The said Amendment was incorporated into the second edition, which also provides a practical method to consider the influence on bearing life of lubrication conditions, contaminated lubricant and fatigue load of bearing material. The life modification factors for reliability, a_1, have been slightly adjusted and extended to 99,95 % reliability.

Rolling bearings — Explanatory notes on ISO 281 —

Part 1:
Basic dynamic load rating and basic rating life

1 Scope

This document specifies supplementary background information regarding the derivation of mathematical expressions and factors given in ISO 281:2007.

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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 281:2007 apply.

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

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

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

4 Symbols

A constant of proportionality

A_1 constant of proportionality determined experimentally

B_1 constant of proportionality determined experimentally

C_1 basic dynamic radial load rating of a rotating ring

C_2 basic dynamic radial load rating of a stationary ring

C_a basic dynamic axial load rating for thrust ball or roller bearing

C_{a1} basic dynamic axial load rating of the rotating ring of an entire thrust ball or roller bearing

C_{a2} basic dynamic axial load rating of the stationary ring of an entire thrust ball or roller bearing

C_{ak} basic dynamic axial load rating as a row k of an entire thrust ball or roller bearing

C_{a1k} basic dynamic axial load rating as a row k of the rotating ring of thrust ball or roller bearing

C_{a2k} basic dynamic axial load rating as a row k of the stationary ring of thrust ball or roller bearing

C_e	basic dynamic load rating for outer ring
C_i	basic dynamic load rating for inner ring
C_r	basic dynamic radial load rating for radial ball or roller bearing
D_{pw}	pitch diameter of ball or roller set
D_w	ball diameter
D_{we}	mean roller diameter
E_o	modified modulus of elasticity
F_a	axial load
F_r	radial load
J_1	factor relating mean equivalent load on a rotating ring to Q_{max}
J_2	factor relating mean equivalent load on a stationary ring to Q_{max}
J_a	axial load integral
J_r	radial load integral
L	bearing life
L_{10}	basic rating life
L_{we}	effective contact length of roller
L_{wek}	L_{we} per row k
N	number of stress applications to a point on the raceway
P_a	dynamic equivalent axial load for thrust bearing
P_r	dynamic equivalent radial load for radial bearing
P_{r1}	dynamic equivalent radial load for the rotating ring
P_{r2}	dynamic equivalent radial load for the stationary ring
Q	normal force between a rolling element and the raceways
Q_C	rolling element load for the basic dynamic load rating of the bearing
Q_{C1}	rolling element load for the basic dynamic load rating of a ring rotating relative to the applied load
Q_{C2}	rolling element load for the basic dynamic load rating of a ring stationary relative to the applied load
Q_{max}	maximum rolling element load
S	probability of survival, reliability
V	volume representative of the stress concentration
V_f	rotation factor
X	radial load factor for radial bearing

X_a radial load factor for thrust bearing

Y axial load factor for radial bearing

Y_a axial load factor for thrust bearing

Z number of balls or rollers per row

Z_k number of balls or rollers per row k

a semimajor axis of the projected contact ellipse

a_1 life adjustment factor for reliability

b semiminor axis of the projected contact ellipse

c exponent determined experimentally

c_c compression constant

e measure of life scatter, i.e. Weibull slope determined experimentally

e limiting value of F_a / F_r for the applicability of different values of factors X and Y in the new edition

f_c factor which depends on the geometry of the bearing components, the accuracy to which the various components are made, and the material

h exponent determined experimentally

i number of rows of balls or rollers

l circumference of the raceway

r cross-sectional raceway groove radius

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

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

t auxiliary parameter

z_o depth of the maximum orthogonal subsurface shear stress

α nominal contact angle

α' actual contact angle

γ $D_w \cos \alpha / D_{pw}$ for ball bearings with $\alpha \neq 90°$

D_w / D_{pw} for ball bearings with $\alpha = 90°$

$D_{we} \cos \alpha / D_{pw}$ for roller bearings with $\alpha \neq 90°$

D_{we} / D_{pw} for roller bearings with $\alpha = 90°$

ε parameter indicating the width of the loaded zone in the bearing

η reduction factor

λ reduction factor

μ factor introduced by Hertz

ν factor introduced by Hertz, or adjustment factor for exponent variation

σ_{max} maximum contact stress

$\Sigma\rho$ curvature sum

τ_o maximum orthogonal subsurface shear stress

φ_o one half of the loaded arc

5 General

The derivation of the basic dynamic load ratings is described in Formulae (1) to (46). The dynamic equivalent load and the radial and axial load factors are covered in Formulae (47) to (82), while basic rating life is described in Formulae (83) to (89).

6 Basic dynamic load rating

6.1 General

The background to basic dynamic load ratings of rolling bearings according to ISO 281 appears in References [5] and [6].

The expressions for calculation of basic dynamic load ratings of rolling bearings develop from a power formula that can be written as follows:

$$\ln \frac{1}{S} \propto \frac{\tau_o^c N^e V}{z_o^h} \qquad (1)$$

where

S is the probability of survival;

τ_o is the maximum orthogonal subsurface shear stress;

N is the number of stress applications to a point on the raceway;

V is the volume representative of the stress concentration;

z_o is the depth of the maximum orthogonal subsurface shear stress;

c, h are experimentally determined exponents;

e is the measure of life scatter, i.e. the Weibull slope determined experimentally.

For “point” contact conditions (ball bearings) it is assumed that the volume, V, representative of the stress concentration in Formula (1) is proportional to the major axis of the projected contact ellipse,

$2a$, the circumference of the raceway, l, and the depth, z_o, of the maximum orthogonal subsurface shear stress, τ_o:

$$V \propto 2a\, z_o l \tag{2}$$

Substituting Formula (2) into Formula (1):

$$\ln \frac{1}{S} \propto \frac{\tau_o^c N^e a l}{z_o^{h-1}} \tag{3}$$

“Line” contact was considered in References [5] and [6] to be approached under conditions where the major axis of the calculated Hertz contact ellipse is 1,5 times the effective roller contact length:

$$2a = 1{,}5 L_{we} \tag{4}$$

In addition, b/a should be small enough to permit the introduction of the limit value of ab^2 as b/a approaches 0:

$$ab^2 = \frac{2}{\pi} \frac{3Q}{E_o \sum \rho} \tag{5}$$

(for variable definitions, see 6.2).

6.2 Basic dynamic radial load rating, C_r, for radial ball bearings

From the theory of Hertz, the maximum orthogonal subsurface shear stress, τ_o, and the depth, z_o, can be expressed in terms of a radial load F_r, i.e. a maximum rolling element load, Q_{max}, or a maximum contact stress, σ_{max}, and dimensions for the contact area between a rolling element and the raceways. The relationships are:

$$\tau_o = T \sigma_{max}$$

$$z_o = \zeta b$$

$$T = \frac{(2t-1)^{1/2}}{2t(t+1)}$$

$$\zeta = \frac{1}{(t+1)(2t-1)^{1/2}}$$

$$a = \mu \left(\frac{3Q}{E_o \sum \rho} \right)^{1/3}$$

$$b = \nu \left(\frac{3Q}{E_o \sum \rho} \right)^{1/3}$$

where

σ_{max} is the maximum contact stress;

t is the auxiliary parameter;

a is the semimajor axis of the projected contact ellipse;

b is the semiminor axis of the projected contact ellipse;

Q is the normal force between a rolling element and the raceways;

E_o is the modified modulus of elasticity;

$\Sigma\rho$ is the curvature sum;

μ, ν are factors introduced by Hertz.

Consequently, for a given rolling bearing, τ_o, a, l and z_o can be expressed in terms of bearing geometry, load and revolutions. Formula (3) is changed to a formula by inserting a constant of proportionality. Inserting a specific number of revolutions (e.g. 10^6) and a specific reliability (e.g. 0,9), the formula is solved for a rolling element load for basic dynamic load rating which is designated to point contact rolling bearings introducing a constant of proportionality, A_1:

$$Q_C = \frac{1,3}{4^{(2c+h-2)/(c-h+2)} 0,5^{3e/(c-h+2)}} A_1 \left(\frac{2r}{2r-D_w}\right)^{0,41} \frac{(1\mp\gamma)^{(1,59c+1,41h-5,82)/(c-h+2)}}{(1\pm\gamma)^{3e/(c-h+2)}} \times \left(\frac{\gamma}{\cos\alpha}\right)^{3/(c-h+2)} D_w^{(2c+h-5)/(c-h+2)} Z^{-3e/(c-h+2)} \quad (6)$$

where

Q_C is the rolling element load for the basic dynamic load rating of the bearing;

D_w is the ball diameter;

γ is $D_w \cos\alpha / D_{pw}$;

in which

D_{pw} is the pitch diameter of the ball set;

α is the nominal contact angle;

Z is the number of balls per row.

The basic dynamic radial load rating, C_1, of a rotating ring is given by:

$$C_1 = Q_{C1}\ Z \cos\alpha\ \frac{J_r}{J_1} = 0,407\ Q_{C1}\ Z \cos\alpha \quad (7)$$

The basic dynamic radial load rating, C_2, of a stationary ring is given by:

$$C_2 = Q_{C2}\ Z \cos\alpha\ \frac{J_r}{J_2} = 0,389\ Q_{C2}\ Z \cos\alpha \quad (8)$$

where

Q_{C1} is the rolling element load for the basic dynamic load rating of a ring rotating relative to the applied load;

Q_{C2} is the rolling element load for the basic dynamic load rating of a ring stationary relative to the applied load;

$J_r = J_r\,(0{,}5)$ is the radial load integral for zero diametral clearance (see Table 3);

$J_1 = J_1\,(0{,}5)$ is the factor relating mean equivalent load on a rotating ring to Q_{max} for zero diametral clearance (see Table 3);

$J_2 = J_2\,(0{,}5)$ is the factor relating mean equivalent load on a stationary ring to Q_{max} for zero diametral clearance (see Table 3).

The relationship between C_r for an entire radial ball bearing, and C_1 and C_2, is expressed in terms of the product law of probability as:

$$C_r = C_1\left[1+\left(\frac{C_1}{C_2}\right)^{(c-h+2)/3}\right]^{-3/(c-h+2)} \tag{9}$$

Substituting Formulae (6), (7) and (8) into Formula (9), the basic dynamic radial load rating, C_r, for an entire ball bearing is expressed as:

$$C_r = 0{,}41\frac{1{,}3}{4^{(2c+h-2)/(c-h+2)}\ 0{,}5^{3e/(c-h+2)}}A_1\left(\frac{2r_i}{2r_i-D_w}\right)^{0{,}41}\frac{(1-\gamma)^{(1{,}59c\,+\,1{,}41h\,-\,5{,}82)/(c-h+2)}}{(1+\gamma)^{3e/(c-h+2)}}\gamma^{3/(c-h+2)}\times$$
$$\left[1+\left\{1{,}04\left[\frac{r_i}{r_e}\left(\frac{2r_e-D_w}{2r_i-D_w}\right)\right]^{0{,}41}\left(\frac{1-\gamma}{1+\gamma}\right)^{(1{,}59c\,+\,1{,}41h\,+\,3e-\,5{,}82)/(c-h+2)}\right\}^{(c-h+2)/3}\right]^{-3/(c-h+2)}\times$$
$$(i\cos\alpha)^{(c-h-1)/(c-h+2)}\ Z^{(c-h-3e+2)/(c-h+2)}D_w^{\ (2c+h-5)/(c-h+2)} \tag{10}$$

where

A_1 is the experimentally determined proportionality constant;

r_i is the cross-sectional raceway groove radius of the inner ring;

r_e is the cross-sectional raceway groove radius of the outer ring;

i is the number of rows of balls.

Here, the contact angle, α, the number of rolling elements (balls), Z, and the ball diameter, D_w, depend on bearing design. On the other hand, the ratios of raceway groove radii, r_i and r_e, to a half-diameter of a rolling element (ball), $D_w/2$ and $\gamma = D_w \cos\alpha/D_{pw}$, are not dimensional, therefore it is convenient in practice that the value for the initial terms on the right-hand side of Formula (10) to be designated as a factor, f_c:

$$C_r = f_c\,(i\cos\alpha)^{(c-h-1)/(c-h+2)}Z^{(c-h-3e+2)/(c-h+2)}D_w^{\ (2c+h-5)/(c-h+2)} \tag{11}$$

With radial ball bearings, the faults in bearings resulting from manufacturing need to be taken into consideration, and a reduction factor, λ, is introduced to reduce the value for a basic dynamic radial load rating for radial ball bearings from its theoretical value. It is convenient to include λ in the factor, *fc*. The value of λ is determined experimentally.

$$f_{\mathrm{c}} = 0,41\ \lambda\ \frac{1,3}{4^{(2c+h-2)/(c-h+2)}\,0,5^{3e/(c-h+2)}}\ A_1 \left(\frac{2r_{\mathrm{i}}}{2r_{\mathrm{i}}-D_{\mathrm{w}}}\right)^{0,41} \frac{(1-\gamma)^{(1,59c+1,41h-5,82)/(c-h+2)}}{(1+\gamma)^{3e/(c-h+2)}}\ \gamma^{3/(c-h+2)} \times$$

$$\left[1+\left\{1,04\left[\frac{r_{\mathrm{i}}}{r_{\mathrm{e}}}\left(\frac{2r_{\mathrm{e}}-D_{\mathrm{w}}}{2r_{\mathrm{i}}-D_{\mathrm{w}}}\right)\right]^{0,41}\left(\frac{1-\gamma}{1+\gamma}\right)^{(1,59c+1,41h+3e-5,82)/(c-h+2)}\right\}^{(c-h+2)/3}\right]^{-3/(c-h+2)} \qquad (12)$$

Based on References [5] and, [6] the following values were assigned to the experimental constants in the load rating formulae for ball bearings:

$$e = \frac{10}{9}$$

$$c = \frac{31}{3}$$

$$h = \frac{7}{3}$$

Substituting the numerical values into Formula (11) gives the following, however, a sufficient number of test results are only available for small balls, i.e. up to a diameter of 25,4 mm (1 inch), and these show that the load rating may be taken as being proportional to $D_{\mathrm{w}}^{1,8}$. In the case of larger balls, the load rating appears to increase even more slowly in relation to the ball diameter, and $D_{\mathrm{w}}^{1,4}$ can be assumed where $D_{\mathrm{w}} > 25,4$ mm:

$$C_{\mathrm{r}} = f_{\mathrm{c}}\ (i\ \cos\alpha)^{0,7}\ Z^{2/3}\ D_{\mathrm{w}}^{1,8}$$
for $D_{\mathrm{w}} \leq 25,4$ mm (13)

$$C_{\mathrm{r}} = 3,647\, f_{\mathrm{c}}\ (i\ \cos\alpha)^{0,7}\ Z^{2/3}\ D_{\mathrm{w}}^{1,4}$$
for $D_{\mathrm{w}} > 25,4$ mm (14)

$$f_{\mathrm{c}} = 0,089\, A_1\ \ 0,41\ \lambda \left(\frac{2r_{\mathrm{i}}}{2r_{\mathrm{i}}-D_{\mathrm{w}}}\right)^{0,41} \frac{\gamma^{0,3}(1-\gamma)^{1,39}}{(1+\gamma)^{1/3}} \times$$

$$\left[1+\left\{1,04\left[\frac{r_{\mathrm{i}}}{r_{\mathrm{e}}}\left(\frac{2r_{\mathrm{e}}-D_{\mathrm{w}}}{2r_{\mathrm{i}}-D_{\mathrm{w}}}\right)\right]^{0,41}\left(\frac{1-\gamma}{1+\gamma}\right)^{1,72}\right\}^{10/3}\right]^{-3/10} \qquad (15)$$

Values of f_{c} in ISO 281:2007, Table 2, are calculated by substituting raceway groove radii and reduction factors given in Table 1 into Formula (15).

The value for $0,089A_1$ is 98,066 5 to calculate C_{r} in newtons.