
Spherical plain bearings — Derivation of the load rating factors

Rotules lisses — Explication sur le calcul des charges de base

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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.

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Introduction

Different calculating methods for static and dynamic load ratings of spherical plain bearings have been used in different countries, thus making it difficult to compare different solutions. A unified method for the calculation of static and dynamic load ratings has been standardized in ISO 20015.

ISO 20015 leaves the load rating factors to the manufacturers to determine because they are dependent on design and material. Bearing manufacturers don't have unified methods to determine these factors themselves. This document gives the supplementary background information regarding the derivation of factors in ISO 20015.

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Spherical plain bearings — Derivation of the load rating factors

1 Scope

This document gives supplementary background information regarding the derivation of factors given in ISO 20015.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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	contact area on bearing sliding surface, in square millimetres (mm ²)
B	inner ring width, in millimetres (mm)
C	outer ring width, in millimetres (mm)
$\bar{C}$	effective width of distribution of contact load, in millimetres (mm)
$\bar{C}(\theta)$	effective width of distribution of contact load function versus θ , in millimetres (mm)
C_a	dynamic axial load rating, in newtons (N)
C_r	dynamic radial load rating, in newtons (N)
C_{0a}	static axial load rating, in newtons (N)
C_{0r}	static radial load rating, in newtons (N)
D	outside diameter, in millimetres (mm)
D_{S1}	smallest diameter of sliding contact surface of the outer ring, in millimetres (mm)
D_{S2}	largest diameter of sliding contact surface of the outer ring, in millimetres (mm)
d	bore diameter, in millimetres (mm)
d_k	sphere diameter, in millimetres (mm)
F_a	axial load, in newtons (N)

F_r	radial load, in newtons (N)
f_a	factor for the calculation of dynamic axial load ratings of the sliding contact area, which depends on design and material, in newtons per square millimetre (MPa)
$f_a(\tau)$	factor for the calculation of axial load ratings of the sliding contact area for angular contact radial spherical plain bearings and angular contact thrust spherical plain bearings, function versus τ , in newtons per square millimetre (MPa)
$f_{ar}(\theta_0, \tau)$	factor for the calculation of radial load ratings of the sliding contact area for angular contact radial spherical plain bearings, function versus θ_0 and τ , in newtons per square millimetre (MPa)
f_{0a}	factor for the calculation of static axial load ratings of the sliding contact area, which depends on design and material, in newtons per square millimetre (MPa)
f_r	factor for the calculation of dynamic radial load ratings of the sliding contact area, which depends on design and material, in newtons per square millimetre (MPa)
$f_r(\varepsilon)$	factor for the calculation of radial load ratings of the sliding contact area for radial spherical plain bearing, function versus ε , in newtons per square millimetre (MPa)
f_{0r}	factor for the calculation of static radial load ratings of the sliding contact area, which depends on design and material, in newtons per square millimetre (MPa)
$g_a(\beta)$	axial contact stress distribution dimensionless function versus β
$g_{ar}(\theta, \zeta)$	contact stress distribution dimensionless function versus θ and ζ for angular contact radial spherical plain bearing
$g_r(\theta)$	radial contact stress distribution dimensionless function versus θ
$I(\theta_0)$	surface integral of radial contact stress distribution dimensionless function versus θ_0
$J(\tau)$	surface integral of axial contact stress distribution dimensionless function versus τ
k	factor affecting the accuracy for manufacturing ($k \leq 1$)
$p(\theta)$	contact stress function versus θ , in newtons per square millimetre (MPa)
$p(\beta)$	contact stress function versus β , in newtons per square millimetre (MPa)
$p(\theta, \beta)$	contact stress function versus θ and β , in newtons per square millimetre (MPa)
$p(\theta, \varphi)$	contact stress function versus θ and φ , in newtons per square millimetre (MPa)
$p_a(\theta)$	axial contact stress function versus θ , in newtons per square millimetre (MPa)
$p_a(\beta)$	axial contact stress function versus β , in newtons per square millimetre (MPa)
$p_a(\theta, \beta)$	axial contact stress function versus θ and β , in newtons per square millimetre (MPa)
$p_r(\theta)$	radial contact stress function versus θ , in newtons per square millimetre (MPa)
$p_r(\beta)$	radial contact stress function versus β , in newtons per square millimetre (MPa)
$p_r(\theta, \beta)$	radial contact stress function versus θ and β , in newtons per square millimetre (MPa)
$p_r(\theta, \zeta)$	radial contact stress function versus θ and ζ , in newtons per square millimetre (MPa)
$\bar{p}$	allowable contact stress of bearing material, in newtons per square millimetre (MPa)

r	variable of integration of radius of contact area
S	width of contact area in spherical surface direction, in millimetres (mm)
s	variable of integration of width of contact area in spherical surface direction
T	bearing width, in millimetres (mm)
z	coordinate variable along z axis
α	variable angle in arising contact area, in radians (rad) (see Figure 3)
β	variable angle in arising contact area, in radians (rad) (see Figure 3)
ε	dimensionless parameter of radial internal clearance ratio versus sphere diameter
ζ	dimensionless variable ($\zeta = z/\bar{C}$)
$\zeta_0(\theta)$	boundary value of dimensionless variable ζ versus θ
θ	variable of integration of load distribution angle along the circumferential direction, in radians (rad)
θ_0	maximum angle of load distribution along the circumferential direction, in radians (rad)
μ	factor of effective contact width of outer ring of bearing
τ	bearing nominal contact angle, in radians (rad)
τ_{S1}	smallest contact angle to diameter of sliding contact surface, in radians (rad)
τ_{S2}	largest contact angle to diameter of sliding contact surface, in radians (rad)
φ	variable of integration of load distribution angle perpendicular to the circumferential direction, in radians (rad)
$\varphi_{\max}$	maximum angle of load distribution perpendicular to the circumferential direction, in radians (rad)

5 General

The calculation of the radial load rating and the axial load rating for radial spherical plain bearings, angular contact thrust spherical plain bearings and angular contact radial spherical plain bearings is explained in [Formulas \(1\) to \(42\)](#).

6 Radial spherical plain bearings

6.1 Bearing load distribution on the sliding contact area

When the bearing supports a radial load F_r , the radial load distribution on the bearing sliding contact area is shown in [Figures 1 and 2](#).

along a circumferential direction under radial load F_r

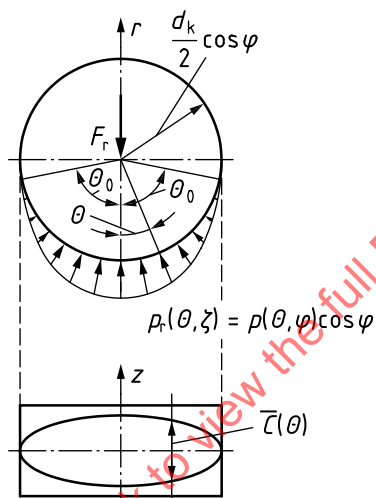


Figure 2 — Radial load distribution and projected contact area on the bearing contact area along a circumferential direction under radial load F_r

The contact distributed load $p(\theta, \varphi)$ is a function of θ and φ . The radial load F_r is the integral of the component of the distributed load $p(\theta, \varphi)$ acting in the direction of the radial load F_r on the bearing contact area along the circumferential direction.

$$\int_A p(\theta, \varphi) \cos \theta \cos \varphi dA = F_r \quad (1)$$

where

$$dA = \frac{dz}{\cos \varphi} \frac{d_k}{2} \cos \varphi d\theta = \frac{d_k}{2} d\theta dz \quad (2)$$

The limits of integration area A of contact stress is set by

$$-\theta_0 \leq \theta \leq \theta_0, \quad -\frac{\bar{C}(\theta)}{2} \leq z \leq \frac{\bar{C}(\theta)}{2} \quad (3)$$

Then, [Formula \(1\)](#) can be changed as

$$\begin{aligned} \int_A p(\theta, \varphi) \cos \theta \cos \varphi dA &= \int_{-\theta_0}^{\theta_0} \int_{-\bar{C}(\theta)/2}^{\bar{C}(\theta)/2} p(\theta, \varphi) \cos \theta \cos \varphi \frac{d_k}{2} d\theta dz \\ &= \frac{d_k}{2} \int_{-\theta_0}^{\theta_0} \cos \theta d\theta \int_{-\bar{C}(\theta)/2}^{\bar{C}(\theta)/2} p(\theta, \varphi) \cos \varphi dz = F_r \end{aligned} \quad (4)$$

If we set $p_r(\theta, \zeta) = p(\theta, \varphi) \cos \varphi$ and $\zeta = z/\bar{C}$, $-\zeta_0(\theta) \leq \zeta \leq \zeta_0(\theta)$, then

$$\int_{-\bar{C}(\theta)/2}^{\bar{C}(\theta)/2} p(\theta, \varphi) \cos \varphi dz = \bar{C} \int_{-\zeta_0(\theta)}^{\zeta_0(\theta)} p_r(\theta, \zeta) d\zeta \quad (5)$$

Thus [Formula \(1\)](#) becomes

$$\int_A p(\theta, \varphi) \cos \theta \cos \varphi dA = \bar{C} \frac{d_k}{2} \int_{-\theta_0}^{\theta_0} \int_{-\zeta_0(\theta)}^{\zeta_0(\theta)} p_r(\theta, \zeta) \cos \theta d\theta d\zeta = F_r \quad (6)$$

[Formula \(6\)](#) is the basis of calculating the radial load ratings of the radial spherical plain bearings.

6.2 Bearing load rating

When the radial load reaches the load rating, and if we set

$$p_r(\theta, \zeta) = \bar{p} g_r(\theta, \zeta) \quad (7)$$

Then the [Formula \(6\)](#) becomes

$$\bar{C} \frac{d_k}{2} \bar{p} \int_{-\theta_0}^{\theta_0} \int_{-\zeta_0(\theta)}^{\zeta_0(\theta)} g_r(\theta, \zeta) \cos \theta d\theta d\zeta = C_r \quad (8)$$

If we set

$$I(\theta_0) = \frac{1}{2} \int_{-\theta_0}^{\theta_0} \int_{-\zeta_0(\theta)}^{\zeta_0(\theta)} g_r(\theta, \zeta) \cos \theta d\theta d\zeta \quad (9)$$

Then the radial load rating is

$$C_r = \bar{C} d_k \bar{p} I(\theta_0) \quad (10)$$

6.3 Bearing load rating calculation for engineering

If the nominal bearing sizes (C, d_k) are used to calculate the load rating of the bearing, and taking into account the influence of manufacturing errors of the bearing, the radial load rating can be expressed by:

$$C_r = C d_k f_r(\varepsilon) \quad (11)$$

where

$$f_r(\varepsilon) = \bar{p} k \mu I(\theta_0) = \frac{1}{2} \bar{p} k \mu \int_{-\theta_0}^{\theta_0} \int_{-\zeta_0(\theta)}^{\zeta_0(\theta)} g_r(\theta, \zeta) \cos \theta d\theta d\zeta \quad (12)$$

$$\bar{C} = \mu C \quad (13)$$

$f_r(\varepsilon)$ is related to the radial spherical plain bearing design, sizes, material and manufacturing quality. For the static load rating, $\bar{p}$ could be taken as the damage limit of the material. For the dynamic load rating, $\bar{p}$ could be taken as the wear limit of the material.

For radial spherical plain bearings, the values of $f_r(\varepsilon)$ may be agreed with the manufacturing company for the respective materials.

The static and dynamic radial load rating C_{0r} and C_r are calculated with factors f_{0r} and f_r , which can be defined based on the calculated values of the factor $f_r(\varepsilon)$. And for the basic load ratings the manufacturing company may be consulted to select f_{0r} and f_r for engineering.

Typical values of factors f_{0r} and f_r for radial spherical plain bearings with steel/steel contacting surfaces are shown in [Table A.1](#).

7 Angular contact thrust spherical plain bearings

7.1 Bearing load distribution on the sliding contact area

When the bearing supports an axial load F_a , the axial load distribution on the bearing sliding contact area is shown in [Figures 3](#) and [4](#).

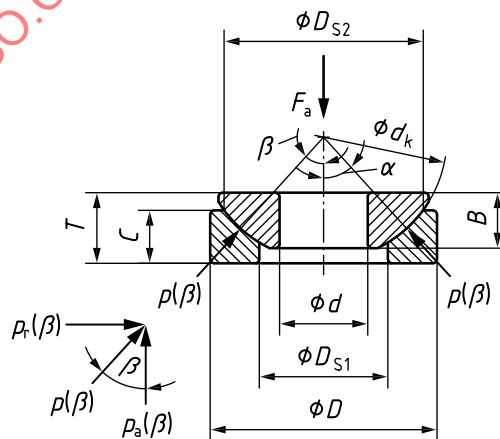


Figure 3 — Angular contact thrust spherical plain bearing under axial load F_a

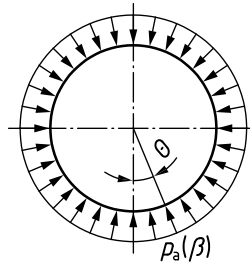


Figure 4 — Axial load distribution on the bearing contact area along a circumferential direction under axial load F_a

The contact distributed load $p(\theta, \beta)$ is a function of θ and β . In this case, $p(\theta, \beta)$ has a uniform distribution along θ . Therefore, $p(\theta, \beta)$ becomes $p(\beta)$. In the radial and axial direction, contact distributed loads are respectively

$$p_r(\theta, \beta) = p(\theta, \beta) \sin \beta \quad (14)$$

$$p_a(\theta, \beta) = p(\theta, \beta) \cos \beta \quad (15)$$

The integral of the distributed load is

$$\int_A p_r(\theta, \beta) \cos \theta dA = 0 \quad (16)$$

$$\int_A p_a(\theta, \beta) dA = F_a \quad (17)$$

For axial load, if

$$dA = 2\pi r ds = 2\pi r dr / \cos \beta \quad (18)$$

Then [Formula \(17\)](#) is rewritten as:

$$\int_A p_a(\theta, \beta) dA = \int_s p(\theta, \beta) \cos(\beta) 2\pi r ds = 2\pi \int_{D_{S1}/2}^{D_{S2}/2} p(\beta) r dr = F_a \quad (19)$$

[Formula \(19\)](#) is the basis of calculating the axial load rating of the angular contact thrust spherical plain bearings.

7.2 Bearing load rating

When the axial load reaches the load rating, and if we set

$$p(\beta) = \bar{p} g_a(\beta) \quad (20)$$

Then [Formula \(19\)](#) becomes

$$2\pi \int_{D_{S1}/2}^{D_{S2}/2} p(\beta) r dr = 2\pi \bar{p} \int_{D_{S1}/2}^{D_{S2}/2} g_a(\beta) r dr = C_a \quad (21)$$

If we set

$$J(\tau) = 2\pi \int_{D_{S1}/2}^{D_{S2}/2} g_a(\beta) r dr \quad (22)$$

Then the axial load rating is

$$C_a = \bar{p} J(\tau) \quad (23)$$

7.3 Bearing load rating calculation for engineering

When the bearing is loaded at an axial direction, p has a uniform distribution, $g_a(\beta) = 1$. The contact sizes (D_{S1} , D_{S2}) of the bearing are used to calculate the sliding contact area.

NOTE Chamfer blending may be considered when calculating the sliding contact area.

Then

$$J(\tau) = \pi \left[\left(\frac{D_{S2}}{2} \right)^2 - \left(\frac{D_{S1}}{2} \right)^2 \right] = \frac{\pi}{4} [(D_{S2} - D_{S1})(D_{S2} + D_{S1})] \quad (24)$$

where

$$D_{S1} = d_k \sin(\tau_{S1}) \quad (25)$$

$$D_{S2} = d_k \sin(\tau_{S2}) \quad (26)$$

While considering the influence of the bearing manufacturing errors, the axial load rating can be expressed by, then

$$C_a = f_a(\tau) \pi \left[\left(\frac{D_{S2}}{2} \right)^2 - \left(\frac{D_{S1}}{2} \right)^2 \right] \quad (27)$$

where

$$f_a(\tau) = k \bar{p} \quad (28)$$

$f_a(\tau)$ is related to the angular contact thrust spherical plain bearing design, sizes, material and manufacturing quality. For the static load rating, $\bar{p}$ could be taken as the damage limit of the material. For the dynamic load rating, $\bar{p}$ could be taken as the wear limit of the material.

For angular contact thrust spherical plain bearings, the values of $f_a(\tau)$ may be agreed with the manufacturing company for the respective materials.

The static and dynamic axial load rating C_{0a} and C_a are calculated with factors f_{0a} and f_a , which can be defined based on the calculated values of the factor $f_a(\tau)$. And for the basic load ratings the manufacturing company may be consulted to select f_{0a} and f_a for engineering (see Annex A.2).

8 Angular contact radial spherical plain bearings

8.1 Bearing load distribution on the sliding contact area

When the bearing supports radial load F_r and axial load F_a as shown in Figure 5. In this case, the distribution of contact pressure is more complicated. To simplify the calculation, the contact pressure is decomposed to radial and axial. The radial load distribution on bearing sliding contact area by the radial load F_r is shown in Figure 6 a). The axial load distribution on bearing sliding contact area by the axial load F_a is shown in Figure 6 b).

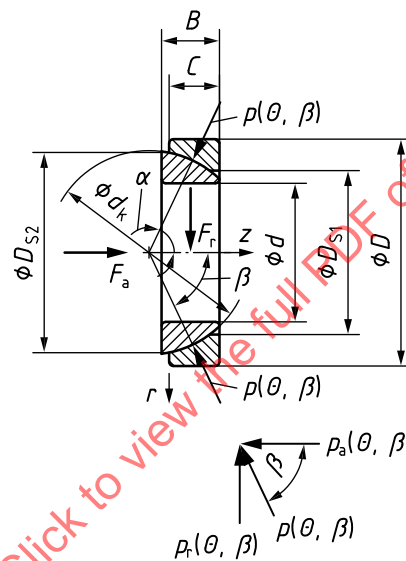
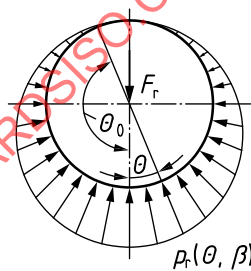
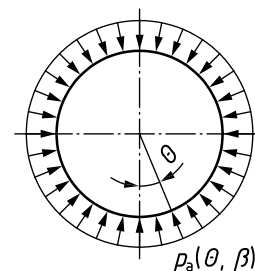


Figure 5 — Angular contact radial spherical plain bearing under radial load F_r and axial load F_a



a) Radial load distribution



b) Axial load distribution

Figure 6 — Load distribution on the bearing contact area along a circumferential direction under radial load F_r and axial load F_a

The integral of the distributed load is

$$\int_A p_r(\theta, \beta) \cos \theta dA = F_r \quad (29)$$

$$\int_A p_a(\theta, \beta) dA = F_a \quad (30)$$

where

$$p_r(\theta, \beta) = p(\theta, \beta) \sin \beta \quad (31)$$

$$p_a(\theta, \beta) = p(\theta, \beta) \cos \beta \quad (32)$$

8.2 Bearing load rating

8.2.1 General

For angular contact radial spherical plain bearings, the radial load rating and the axial load rating may be considered respectively.

8.2.2 Radial load rating

If only the radial load rating is considered, similar to the radial spherical plain bearings, the bearing radial load rating is

$$C_r = \bar{C} d_k \bar{p} I(\theta_0, \tau) \quad (33)$$

where

$$I(\theta_0, \tau) = \frac{1}{2} \int_{-\theta_0}^{\theta_0} \int_0^{\zeta_0(\theta)} g_{ar}(\theta, \zeta) \cos \theta d\theta d\zeta \quad (34)$$

$g_{ar}(\theta, \zeta)$ is contact stress distribution dimensionless function for angular contact radial spherical plain bearing, under axial load rating and radial load rating. $-\theta_0 \leq \theta \leq \theta_0, 0 \leq z \leq \bar{C}(\theta), \zeta = z/\bar{C}, 0 \leq \zeta \leq \zeta_0(\theta), p_r(\theta, \zeta) = \bar{p} g_{ar}(\theta, \zeta)$ [see Figure 6 a)].

8.2.3 Axial load rating

If only the axial load rating is considered, similar to the angular contact thrust spherical plain bearings, the bearing axial load rating is

$$C_a = \bar{p} J(\tau) \quad (35)$$

where

$$J(\tau) = 2\pi \int_{D_{S1}/2}^{D_{S2}/2} g_a(\beta) r dr \quad (36)$$

If p_a is assumed as uniform distribution, $g_a(\beta) = 1$ [See Figure 6 b)]. Then

$$J(\tau) = \pi \left[\left(\frac{D_{S2}}{2} \right)^2 - \left(\frac{D_{S1}}{2} \right)^2 \right] = \frac{\pi}{4} [(D_{S2} - D_{S1})(D_{S2} + D_{S1})] \quad (37)$$

where

$$D_{S1} = d_k \sin(\tau_{S1}) \quad (38)$$

$$D_{S2} = d_k \sin(\tau_{S2}) \quad (39)$$