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ANALYSIS OF THE INFLUENCE OF INTERNAL RADIAL CLEARANCE ON THE STATIC LOAD RATING OF THE ROLLING BEARING

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Abstract. *In the design of the bearing arrangements, load rating is the most relevant exploitational characteristic to be taken into consideration in selection of bearing. One of the most important factors effecting the load distribution between rolling elements, and thereby the load rating of the bearing - is the internal radial clearance. In this paper it was investigated how internal radial clearance influences on the static load rating of the deep groove ball bearing. This effort included a comparative analysis of the static load rating determined under the ISO recommendations, on the one side, and the real load rating, on the other, from the standpoint of the influence of internal radial clearance.*

Key words: *rolling bearing, static load rating, load distribution factor*

1. INTRODUCTION

In selection of bearing for some application, in addition to operational conditions (character and intensity of external load, rotation frequency, service life) the only characteristic of the bearing that must be known is the load rating. Every rolling bearing is characterised by the static and the dynamic load rating. The dynamic load rating becomes prominent in the case of bearings with operational rotation frequency above 10 min^{-1}, due to the appearance of fatigue. However, the static load rating is a relevant characteristic of every bearing, regardless of the rotation frequency.

The static load rating of a rolling bearing denotes that external load at which certain admissible plastic deformation develops at the place of contact of the bearing's parts. The admissible plastic deformation for standard wide-purpose bearings is approximately 10^{-4} of the rolling element diameter and does not have any substantial influence on the bearing performances (vibration, noise, stiffness, friction moment, etc.).

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The static load rating of a rolling bearing depends on the elastic properties of the material and on the geometry of the parts, as well as on the distribution of the external load between rolling elements. One of the most important factors that influences on the distribution of load between rolling elements, and thereby also the static load rating of the bearing is the internal radial clearance.

For many years researches were conducted in the area of static load rating of the bearings in an effort to establish a suitable way by which largest possible number of relevant factors would be included in the calculation. However, expressions found in modern technical literature and standard calculations of static load rating do not take into account all the relevant influences (including, among others, the internal radial clearance).

2. THE STATIC LOAD RATING OF THE DEEP GROOVE BALL BEARING

The external load on the bearing is carried from one ring to another one through the rolling elements (balls), which are under pressure. Under the impact of compressive force at the contact surface between the balls and the raceways plastic deformations may develop. Huge plastic contact deformations may cause, among others, substantial vibrations, greater noise, and appearance of stress concentration. However, plastic contact deformations that are relatively small in relation to rolling elements' and raceways' dimensions do not have any major influence on the operational ability of bearing.

The admissible plastic deformation at the place of the most loaded ball, which does not produce any significant influence on the exploitational characteristics of the bearing, is determined by the following relation [1]:

$$\frac{\delta^{pl}}{D_{\mathrm{w}}} = k^{*} \cdot 10^{-4}$$

where:

D_{w} – ball diameter;

k^{*} - coefficient whose value depends on the conditions of the bearing's application.

With the standard wide-purpose bearings it is accepted that $k^{*} = 1$. With the precision bearings, the coefficient $k^{*} < 1$, and depends on the wanted performances of the bearing (vibration, noise, resistance to wear and other). At a set value of the coefficient k^*, the admissible load shall depend on the bearing construction and load character, i.e. on the function connecting the external and maximum load in the contact of the balls with the raceways.

To the admissible load on the bearing and admissible plastic deformation at the point of the most loaded ball corresponds the contact stress σ_{max}.

Under ISO-76-1987, static load rating of the deep groove ball bearing denotes that radial load which corresponds to computed contact stress of 4200 MPa in the centre of the contact surface between the most loaded ball and the raceway of the inner, i.e. outer ring, with the larger of them being relevant.

The procedure for the determination of the static load rating of the bearing is based on the analytical expressions of the *Hertz*'s theory of contact stresses and on the experimental studies. The characteristic value of the contact stress for the ball bearings of 4200 MPa was obtained experimentally, and to it corresponds the admissible plastic deformation of the bearings' contacting surfaces, which amounts $10^{-4}D_w$.

Standard expression for the determination of the static load rating of the single-raw radial ball bearing is as given under [4]:

$$C_{or} = \frac{Z}{S} Q_{max} \tag{1}$$

where:

Z – total number of balls in the bearing;

Q_{max} – maximum perpendicular load at the contact of the balls and the raceways;

$S = \begin{cases} 4{,}37, & e = 0 \\ 5, & e > 0 \end{cases}$ - *Stribeck's* number;

e – internal radial clearance of the bearing.

Maximum load at the contact of the balls with the raceways depends on:

- the inner geometry of the bearing (ball diameter, bearing pitch diameter, radius of the raceway, radius of the raceway profile).
- the maximum admissible stress at the contact of the balls and the raceways

Expect by the stated factors, static load rating is effected by the load distribution between rolling elements. Namely, load distribution determines how much of the external load shall be imposed on the most loaded ball, referred to in the static load rating definition. One of the most important factors that influences the distribution of the load between rolling elements, and thereby the static load rating of the bearing, is the internal radial clearance [2]. However, standard expressions for static load rating (1) do not take into account the internal radial clearance size, but only its presence (S constant).

3. Influence of the Internal Radial Clearance on the Static Load Rating of the Rolling Bearing

The deep groove ball bearing, exposed to external radial load is shown in Figure 1. The external load F_R is of constant direction and intensity. Line of the external load goes through the center of the one of the balls, conditionally designated with "0." From the standpoint of the load distribution, this case of the orientation of the external load direction is the most unfavourable one. Namely, the "0" ball bears the biggest part of the external load:

$$F_0 > F_1 > ... > F_i > ... > F_n$$

where:

F_i – load the i- ball in the bearing's load zone;

$n = \frac{Z_s - 1}{2}$ - auxiliary value;

Z_s – number of simultaneously active balls participating in load distribution [2].

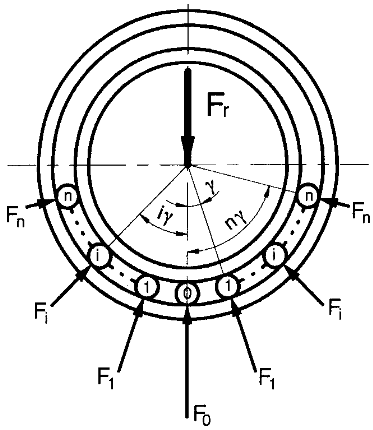

Fig. 1. Load distribution between rolling elements of bearing

Load on the "0" ball can be determined on the basis of the following expression [3]:

$$F_0 = K_{r0} F_R \tag{2}$$

where:

K_{r0} – load distribution factor.

Factor of the load distribution between rolling elements with the internal radial clearance is given by the following expression [3]:

$$K_{ro} = \frac{\left(1 - \frac{e}{2w}\right)^{\frac{3}{2}}}{\left(1 - \frac{e}{2w}\right)^{\frac{3}{2}} + 2\sum_{j=1}^{n}\left(\cos(j\gamma) - \frac{e}{2w}\right)^{\frac{3}{2}} \cos(j\gamma)\Phi(\delta_j)} \tag{3}$$

where:

w – relative radial movement of rings under the influence of the external radial load;

$\Phi(\delta_j) = \begin{cases} 1, & \cos(j\gamma) > \frac{e}{2w} \\ 0, & \cos(j\gamma) \le \frac{e}{2w} \end{cases}$ - contact function;

$\gamma = \frac{2\pi}{Z}$ - angle between the balls (Fig. 1).

If the external radial load corresponds to the static load rating of the bearing is

$$F_R = C_{0r},$$

then the load on the most loaded "0" ball corresponds to computed contact stress Q_{max}:

$$F_0 = Q_{max}.$$

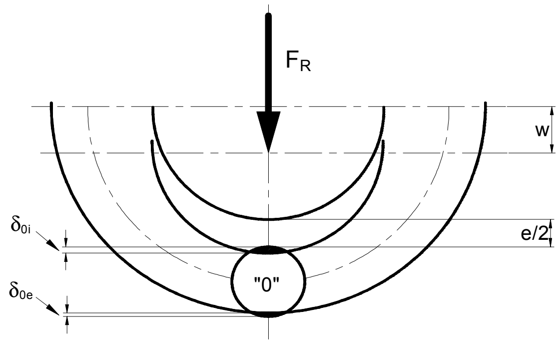

Fig. 2. Radial displacement of rings under the external load

Introduction of the stated equivalencies into the expression (2) gives the expression for static load rating of the bearing in the following form:

$$C_{0r} = \frac{1}{K_{r0}} Q_{\max} \tag{4}$$

Comparison of the expressions (1) and (4) shows that the ISO expression (1) for the static load rating of the bearings takes the load distribution into account through the *Z*/*S* relation, which represents the function of the total number of balls and the *Stribeck's* number, and does not depend on the size of the internal radial clearance.

When substituting the expression (3) by expression (4), the following can be written:

$$C_{0r} = \left(1 + 2 \frac{\sum_{j=1}^{n} \left(\cos(j\gamma) - \frac{e}{2w} \right)^{\frac{3}{2}} \cos(j\gamma) \Phi(\delta_j)}{\left(1 - \frac{e}{2w} \right)^{\frac{3}{2}}} \right) Q_{\max} \tag{5}$$

The relative radial movement of rings *w* in the expression (5) is determined by the external load, that corresponds to the static load rating ($F_R = C_{0r}$), and amounts (Fig. 2):

$$w = \frac{e}{2} + \delta_0^{el} + \delta_0^{pl} \tag{6}$$

where:

$\delta_0^{el} = \delta_{0i}^{el} + \delta_{0e}^{el}$ - total elastic contact deformation of the bearing parts at the place of "0" ball;

$\delta_{0i(e)}^{el}$ - elastic deformation at the contact of the "0" ball and inner (outer) ring;

$\delta_0^{pl} = \delta_{0i}^{pl} + \delta_{0e}^{pl}$ - total plastic contact deformation of the bearing parts at the place of "0" ball;

$\delta_{0i(e)}^{pl}$ - plastic deformation at the contact of the "0" ball and inner (outer) ring – the larger one equals 10^{-4} of the ball diameter.

Figure 3 shows a diagram of dependence of the static load rating of bearingon the internal radial clearance and total number of the bearing's balls. It is observed that the increase in the clearance and reduction in the number of balls result in the decrease of the static load rating of the rolling bearing. This is conditioned by the increase in an unequal load distribution, i.e. increase in the load imposed on the most loaded "0" ball. In this case load distribution factor increases, and its reciprocal value decreases (4). Due to this, static load rating of the bearing is lowered.

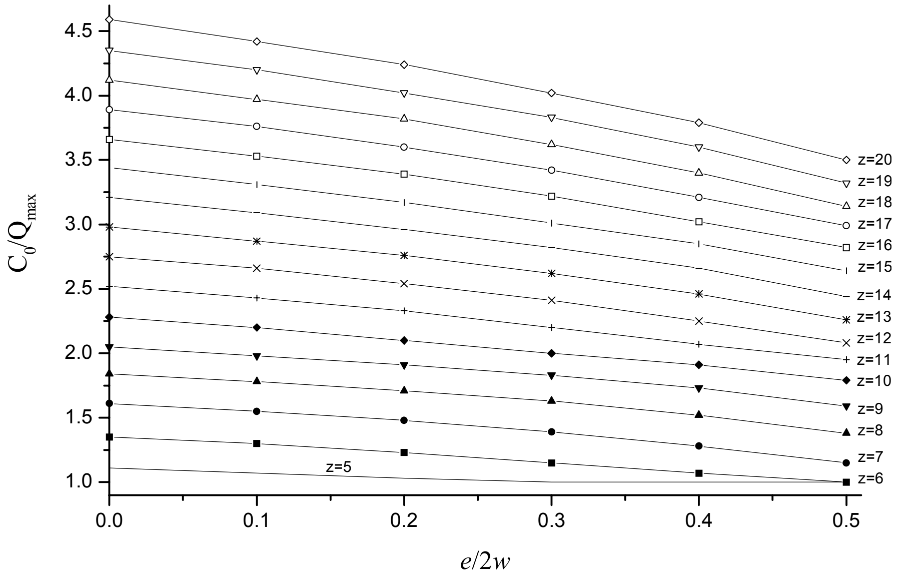

Fig. 3. Static load rating versus internal radial clearance

Figure 4 shows dependence of the static load rating on the total number of balls for different values of the internal radial clearance. Based on the given diagram it can be concluded that with the increase of the total number of balls also the load rating of the bearing is increased, which is conditioned by an even load distribution. The same diagram also gives a graphic presentation of the dependence defined by the expression (1). In the case of bearings with zero internal clearance ($e = 0$), static load rating values determined under the expression (5) coincide almost fully with those determined under ISO expression (1) for $S = 4{,}37$. However, in the case of bearings with a clearance, ISO proposes only one computing value of the static load rating that corresponds to a mean value of the clearance. Given diagram shows that the actual value of the static load rating differs from the value determined under ISO expressions, and that the degree of aberration depends on the size of the internal radial clearance and the total number of the balls.

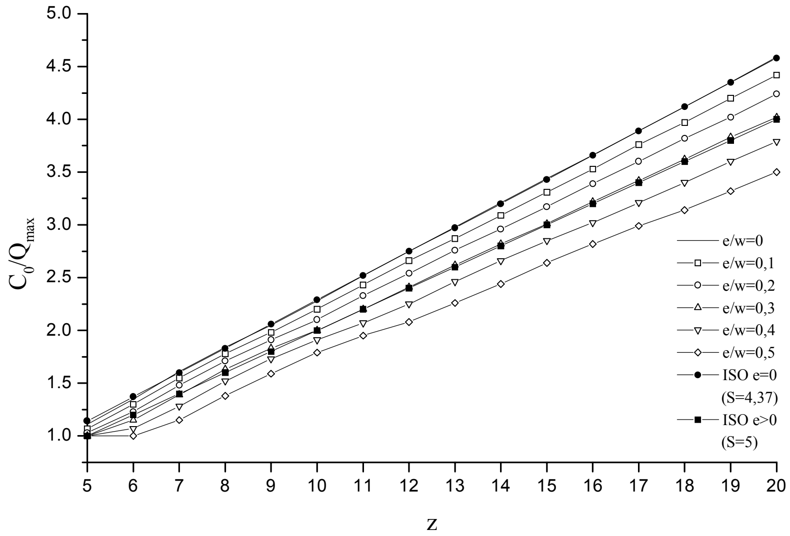

Fig. 4. Dependence of static load rating on total number of balls in bearing

Figure 5 shows a comparative diagram of the actual load rating and the load rating determined according to the ISO recommendations. In case of a bearing with zero clearance, these values coincide. With the increase in the clearance the aberration C_0^{ISO} from C_0 increases and at $e/2w \approx 0{,}12$ it comes to 11%. Difference between C_0^{ISO} and C_0 decreases until zero value at $e/2w \approx 0{,}315$. With further increase in the clearance C_0^{ISO} aberration from C_0 increases and at $e/2w \approx 0{,}5$ it is 12%.

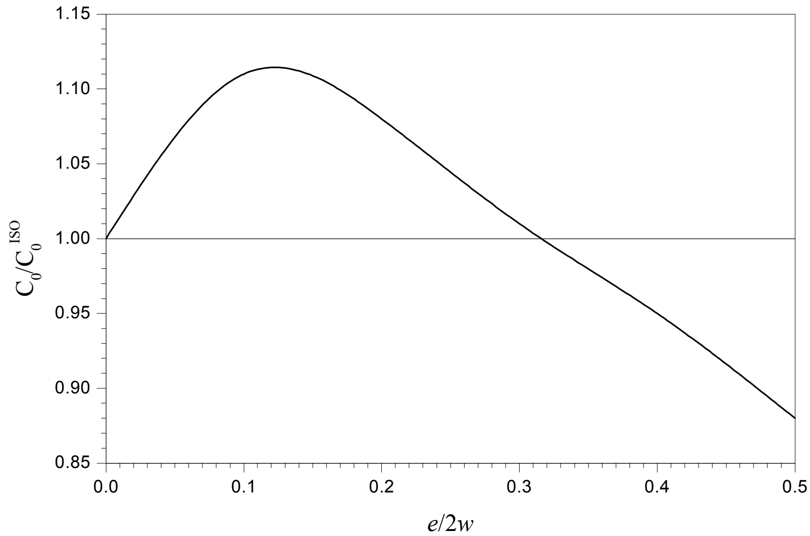

Fig. 5. Relative static load rating versus internal radial clearance

On the basis of the diagram given in Figure 5, we can write:

$$\frac{C_0}{C_0^{ISO}}\begin{cases} >1, & \dfrac{e}{2w}<0{,}315 \\ =1, & \dfrac{e}{2w}=0{,}315 \\ <1, & \dfrac{e}{2w}\geq 0{,}315 \end{cases}$$

Accordingly, with smaller clearances, when $C_0 > C_0^{ISO}$, the static load rating determined under ISO recommendations is below the actual load rating of the bearing. Consequently, this means that the bearing selected for a specific application by determining its static load rating under the ISO recommendations is over-dimensioned. With larger clearances, when $C_0 < C_0^{ISO}$, value of the actual load rating of the given bearing is below the one computed from ISO expressions. In such case, the life of the bearing can be shorter than determined by calculations.

4. Conclusion

Expressions for the static load rating of the rolling bearing found in modern technical literature are standardised and given in the ISO-76-1987 standard. Analysis of the given expressions has showed that the influence of the internal radial clearance size on the static load rating of the bearing has not been fully taken into account. Therefore, this papers develops an expression for the static load rating of the ball rolling bearings with radial contact, by introducing in a new way defined value: load distribution factor between rolling elements. This factor fully defines the influence of the internal radial clearance on the load distribution between rolling elements, and thereby on the static load rating of the bearing. This new (corrected standard) expression was used in the consideration of the influence of the internal radial clearance on the static load rating of the bearing.

Results of the here presented analyses allow for the following conclusions:

1. The static load rating of the rolling bearing depends on the size of the internal radial clearance.
2. Standard expressions for the static load rating of the bearings do not take into account the size of the internal radial clearance, but only its presence.
3. The actual static load rating and the static load rating determined under ISO standard expressions are equal in the case of zero clearance and a mean clearance, while in other cases aberrations are evident.

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ANALIZA UTICAJA UNUTRAŠNJEG RADIJALNOG ZAZORA NA STATIČKU NOSIVOST KOTRLJAJNOG LEŽAJA

Radivoje Mitrović

Pri konstruisanju uležištenja vratila i osovina mehanizama i mašina, najrelevantnija eksploataciona karakteristika na osnovu koje se vrši izbor kotrljajnih ležaja je nosivost. Jedan od najvažnijih faktora koji utiče na raspodelu opterećenja na kotrljajna tela, a time i na nosivost ležaja je unutrašnji radijalni zazor. U cilju egzaknijeg određivanja statičke nosivosti kotrljajnog ležaja u odgovarajuće standardne izraze uvedena je, na novi način definisana veličina – faktor raspodele opterećenja na kotrljajna tela ležaja, čija vrednost zavisi od veličine unutrašnjeg radijalnog zazora. Na osnovu korigovanih standardnih izraza, razmatran je uticaj veličine unutrašnjeg zazora na statičku nosivost kugličnog kotrljajnog ležaja sa radijalnim dodirom. Pri tome je izvršena i uporedna analiza statičke nosivosti ležaja određene na osnovu ISO preporuka i stvarne nosivosti sa aspekta uticaja unutrašnjeg radijalnog zazora i utvrđen stepen aproksimacije.

Ključne reči: *kotrljajni ležaj, statička nosivost, faktor raspodele opterećenja*