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INFLUENCE OF ROTATION ANGLE ON BEARING ROLLING BODIES LOAD DISTRIBUTION. PART 2: SIMULATION RESULTS

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Abstract: *The results of the simulation conducted in order to highlight the influence of rotation angle on bearing rolling bodies load distribution for a deep groove ball bearing and for a cylindrical roller bearing are presented in this paper. The simulation was based on the mathematical model for calculating load distribution developed using the internal bearing geometry and material properties and presented in [5]. The variations of the radial ring shift and the maximum rolling body deflection were analyzed in this paper also.*
Key words: *rolling bodies load distribution, radial ring shift*

1. INTRODUCTION

Radial bearings are one of the most used elements in all rotating machines. Their main purpose is to support and keep a revolving shaft turning smoothly by spreading the load around its inner surface on a set of free running balls or rollers. The functionality, accuracy and performance of an entire system in which a bearing is incorporated depend on the working characteristics of rolling bearings, of which, the load distribution on rolling elements is one of the most important operating parameters.

When a ball or roller bearing is subjected to a radial load, the load is transferred unequally to the rolling elements making up the bearing assembly. Usually, less than half of the rolling elements are loaded at any given time [4], but the exact number of active rolling elements is essential because it has a decisive influence on the basic static and dynamic load rating of a rolling bearing, on his dynamic behavior, on a level of noise and vibrations generated by the bearings, working ability, working accuracy and working life of a rolling bearing.

The main objective of this paper is to present and discuss the influence of rotation angle on the load distribution and on the number of active rolling elements. Regarding the goal of the paper, the mathematical model developed in [**5**] has been used. The variations of the radial ring shift and the maximum rolling body deflection during shaft rotation have been studied.

2. INFLUENCE OF RADIAL LOADS ON DEFLECTION RESPONSE OF BEARING ROLLING BODIES

The bearings considered in this paper are deep groove ball bearings and NNU series cylindrical roller bearings.

Fig. 1 Deep groove ball bearing

Deep groove ball bearings (Fig. 1) are one of the most widely used bearings. They have deep, uninterrupted raceway grooves. These bearings carry mainly radial loads and a part of axial loads in both directions due to the close osculation that the groove raceways have with the balls. Deep groove ball bearings are generally manufactured with normal radial clearance [2]. In order to operate correctly, especially in case of operating under heavy loads, a minimum load must be applied on them. Due to their low friction torque, they can be used in a wide variety of applications where high speed and low power loss is required.

Fig. 2 Cylindrical roller bearing

Cylindrical roller bearings are bearings in which cylinders are used as the rolling elements as opposed to balls in ball bearings. Their rollers are in linear contact with the inner and outer raceways. The cylindrical shape allows the inner ring to have axial movement relative to the outer ring. These bearings have a relatively high radial load capacity and are suitable for high speed applications. Bearings from NNU series are double row cylindrical roller bearings. They have a very low cross sectional height and provide a higher degree of stiffness than other series. NNU types are widely used in machine tool spindles due to their high rigidity.

Using the mathematical model developed in [5] for a deep groove ball bearing and a cylindrical roller bearing, a simulation was conducted in order to emphasize the influence of rotation angle on bearing rolling bodies load distribution. The mathematical model allows determining the load distribution and the rolling elements deflections for a rolling radial bearing with internal clearance s that was loaded with a constant external radial load denoted by F_r. According to [5], for a rolling bearing with Z rolling elements, the separation angle between the rolling elements given by the following equation:

$$\varphi_Z = \frac{2 \cdot \pi}{Z}$$

Taking into account a shaft rotation of angle φ, the deflection of the k-th rolling element is:

$$\boldsymbol{\delta_k = [\max(\Delta_{max} \cos\varphi_k - 1, 0)]^n;\ k = 1, 2, \dots, Z}$$

and its load is:

$$\boldsymbol{Q_k = K_n\, \delta_k^n;\ k = 1, 2, \dots, Z}$$

where

$$\Delta_{max} = \left(\frac{2\delta_{max}}{s} + 1\right) \cdot \frac{1}{\cos\varphi}$$

δ_{max}= maximum rolling body deflection

φ= rotation angle

and

$$\varphi_k = (k-1) \cdot \varphi_Z + \varphi;\ k = 1, 2, \dots, Z$$

Further on, will be presented the simulations results for a deep groove ball bearing and a cylindrical roller bearing.

2.1 Deep groove ball bearing case

First, a single row ball bearing 6206 with the internal radial clearance of 0.02 mm was chosen for simulation. The total number of the rolling elements of this bearing is Z=9 and the effective coefficient of the bearing stiffness is K_n=3.31·10^5 N/mm^n, where n=3/2. The obtained load distribution values, according to the models developed in [1], [3], [5] and , 2013

[**6**-8], are given in Table 1, for an external radial load of F_r=9 kN, at apex position.

Table 1

Load distribution on rolling elements at apex position.

6206		Cf. [1]	Cf. [3]	Cf. [6-8]	Cf. [5]
F_r		9 kN	9 kN	9 kN	9 kN
i	±i·40°	Q_i (N)	Q_i (N)	Q_i (N)	Q_i (N)
0	0	4370.6	4617.7	4620.5	4617.7
1	±40°	2693.4	2854.6	2852.8	2854.6
2	±80°	18.04	25.27	25.31	25.27

In this example, the loads corresponding to the first and 9-th ball (last one) have the following variation during shaft rotation of an rotation angle φ:

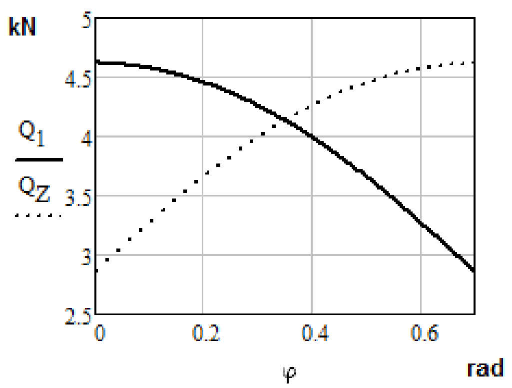

Fig. 3 Loads on the first and ninth ball during shaft rotation

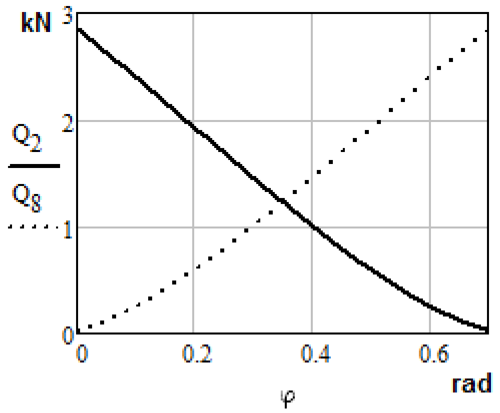

Fig. 4 Load on the second and eighth ball during shaft rotation

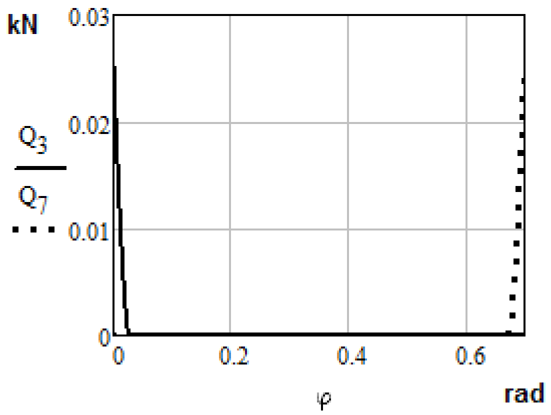

Fig. 5 Load on the third and seventh ball during shaft rotation

The load supported by the second ball of the ball bearing decreases almost linearly with the increase of the rotation angle while the load supported by the eighth ball increases almost linearly as shown in Fig. 4. The load on the third ball decreases dramatically while the load on the seventh ball increases dramatically with the increase of the rotation angle (Fig. 5).

The loads on rest of the balls from this deep groove ball bearing (from the fourth to the sixth) are equal to zero.

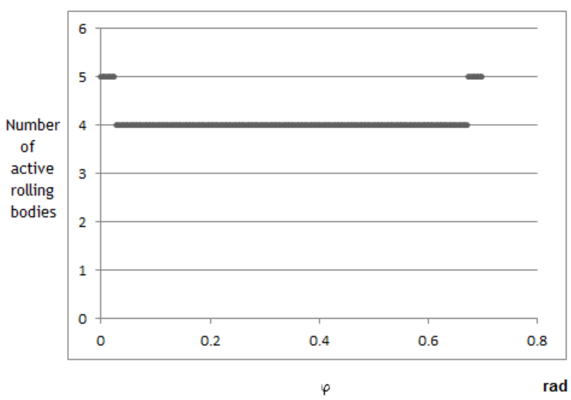

Fig. 6 Number of active rolling elements during shaft rotation

Analyzing the loads on the balls, it can be observed that, for an external radial load of F_r =9 kN, the 6206 deep groove ball bearing has four or five active rolling elements depending on the rotation angle (Fig. 6).

The variation of the number of active rolling bodies during shaft rotation can also be found for a radial load of F_r =2 kN, when, the same bearing has three or four loaded balls depending on the rotation angle.

The ring radial shift also varies during shaft rotation. For a load of F_r =0.07 kN, the variation has a convex parabolic shape. As the load increases up to 2 kN, the variation of the ring radial shift turns into a concave parabolic shape as shown in Fig. 7. If one continues to increase the radial load up to 26 kN, the variation changes its shape back into a convex parabola (Fig. 8).

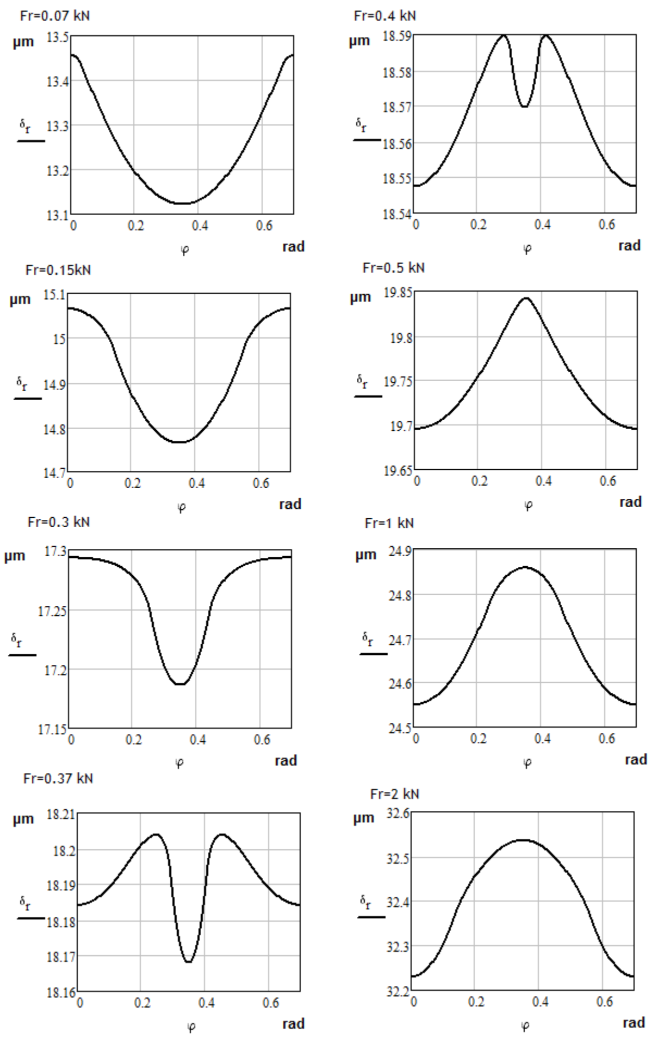

Fig. 7 Ring radial shift during shaft rotation for F_r=0.07…2 kN

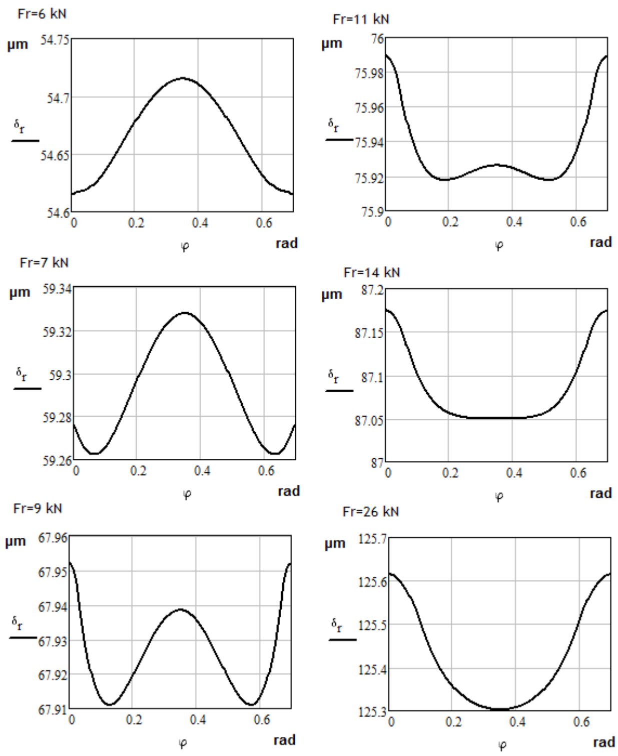

Fig. 8 Ring radial shift during shaft rotation for F_r=6…26 kN

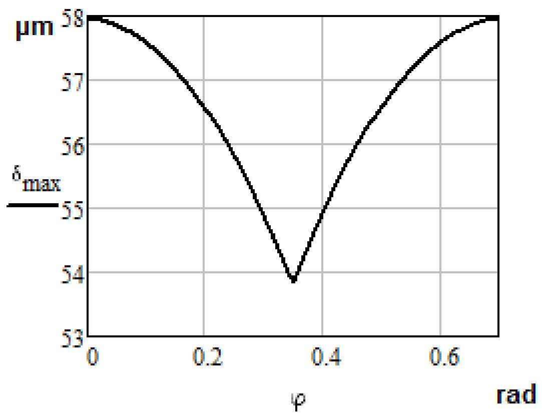

Fig. 9 Variation of the maximum ball deflection during shaft rotation

For the chosen deep groove ball bearing, with a load of F_r=9 kN, the the first ball has the maximum deflection for a rotation angle $0 <= \varphi < \varphi_Z/2$, while the Z-th ball experiences the maximum deflection for $\varphi_Z/2 < \varphi < \varphi_Z$.

2.2 Cylindrical roller bearing case

The load distribution was also studied for the double row cylindrical roller bearing NNU 101708 with the internal radial clearance of 0.225 mm. The total number of the rolling elements in this bearing is Z=21 and the effective coefficient of the bearing stiffness is $K_n=1.624 \cdot 10^6$ N/mm^n, where n=10/9. For an external radial load of F_r=60 kN (corresponding to a single row of rollers), the loads on the first and last roller take, during shaft rotation, the values shown in Fig. 10:

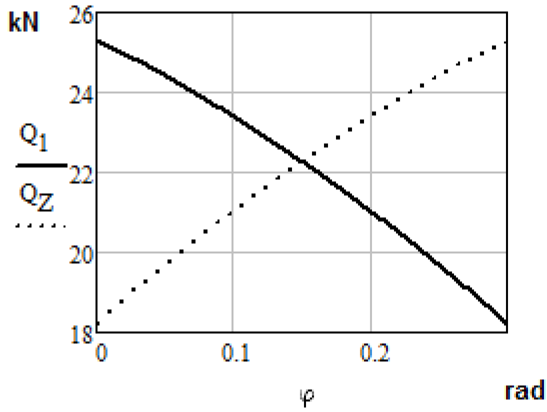

Fig. 10 Load on the first and last roller during shaft rotation

The load supported by the second roller of the cylindrical roller bearing decreases almost linearly with the increase of the rotation angle, while the load supported by the 20-th roller increases almost linearly as shown in Fig. 11.

The loads on rest of the rollers from this cylindrical roller bearing (from the 3-rd to the 19-th roller) are equal to zero.

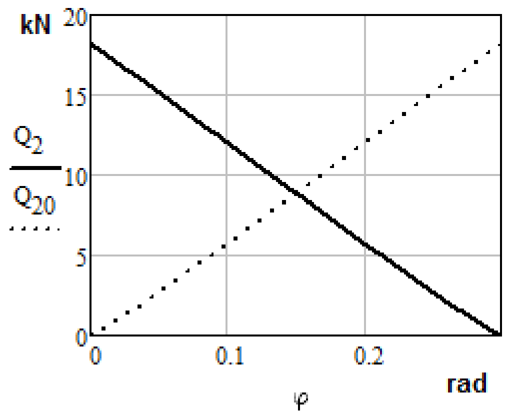

Fig. 11 Load on second and 20-th roller during shaft rotation

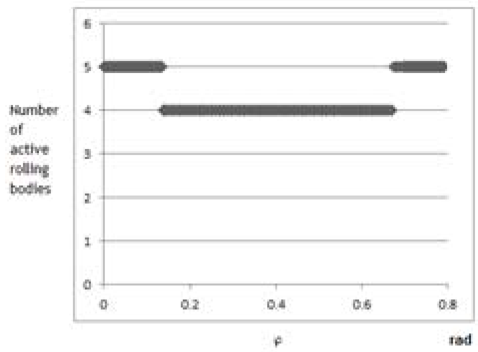

Fig. 12 Number of active rollers during shaft rotation for F_r=130 kN

Analyzing the loads on the rollers, one can observe that, for an external radial load of F_r =60 kN, the NNU 101708 cylindrical roller bearing has four active rolling elements during shaft rotation. The interesting thing is that at apex position it has only three active rollers. For the same bearing, the number of active rollers varies during shaft rotation for a load of F_r =130 kN as shown in Fig. 12.

The variation of the number of active rollers during shaft rotation can also be found for a radial load of F_r =580 kN, when, the same bearing has seven or eight loaded rollers depending on the rotation angle.

The ring radial shift varies during shaft rotation for this bearing too. For a constant external radial load of F_r =5 kN, it has a convex parabolic shape.

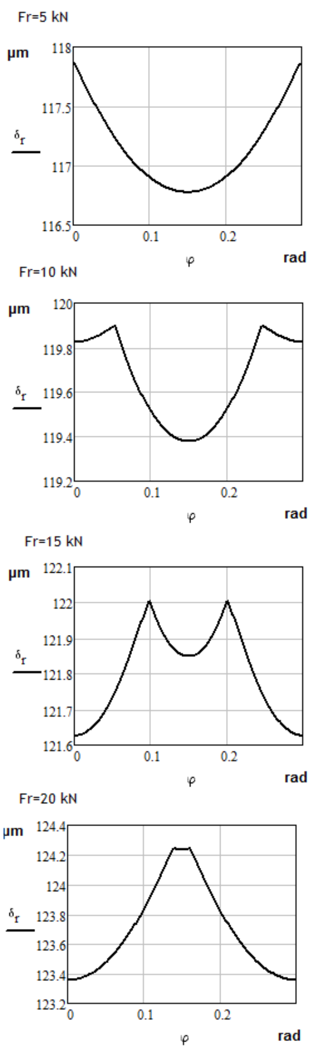

Fig. 13 Variations of radial ring shift during shaft rotation

As the load increases up to 20 kN, the variation of the ring radial shift turns into a concave parabolic shape as shown in Fig. 13.

If one continues to increase the radial load up to 60 kN, the variation changes its shape back into a convex parabola as shown in Fig. 14.

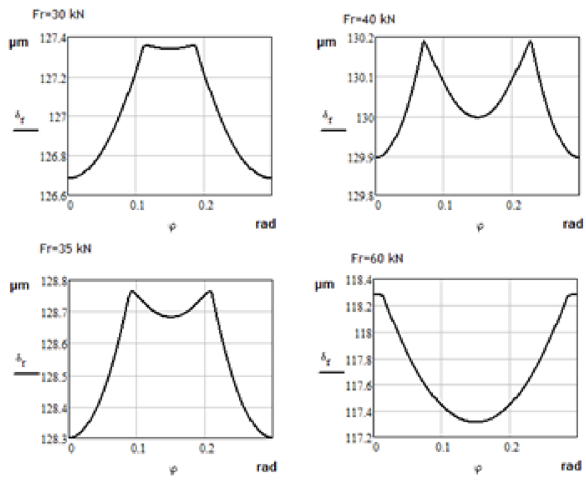

Fig. 14 Variations of radial ring shift during shaft rotation

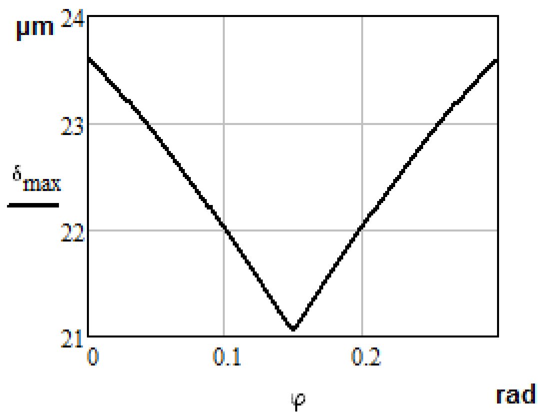

Fig. 15 Variation of the maximum roller deflection during shaft rotation

For the chosen cylindrical roller bearing, with a load of F_r=60 kN, the the first roller has the maximum deflection for a rotation angle $0 <= \varphi < \varphi_Z/2$, while the Z-th roller experiences the maximum deflection for $\varphi_Z/2 < \varphi < \varphi_Z$.

3. CONCLUSIONS

Based on the above approaches studied in this paper one can draw the following conclusions:

- For both bearings considered in this study the number of the active rolling elements does not always remain constant during shaft rotation.
- For a rotation angle $0 <= \varphi < \varphi_Z/2$ the first rolling body is the most loaded one and for $\varphi_Z/2 < \varphi < \varphi_Z$ the Z-th rolling body becomes the most loaded one.
- During shaft rotation the radial ring shift changes its value. Further investigation can be undertaken to find out if the change follows a recursive formula.
- The maximum radial ring shift is not always obtained at apex position. In addition, it depends on the radial external load, and not on the oddness or evenness bearing rolling elements number.

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INFLUENȚA UNGHIULUI DE ROTAȚIE ASUPRA DISTRIBUȚIEI FORȚELOR PE CORPURILE DE RULARE ALE RULMENȚILOR. PARTEA 2: REZULTATELE SIMULĂRII

Rezumat: În această lucrare sunt prezentate rezultatele simulării realizate pentru a pune în evidență influența unghiului de rotație asupra corpurilor de rulare pentru un rulment radial cu bile şi un rulment cu role cilindrice. Simularea s-a bazat pe modelul matematic pentru calculul distribuției forțelor dezvoltat în [5], model care foloseşte geometria internă a rulmentului şi proprietățile de material ale acestuia. De asemenea, au fost analizate în această lucrare variația apropierii radiale dintre centrele inelelor rulmenților şi variația deformării maxime a corpurilor de rulare.

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