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The Load Distribution Characteristics of The Cylindrical Roller Bearing

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Abstract: In the present research, a load distribution model for the cylindrical roller bearing (CRB) is proposed. Based on the model, the load distribution characteristics for the CRB bearing is analyzed. In detail, the effects of bearing load, bearing speed, clearance and the number of roller on the load distribution of the CRB bearing are discussed. It is found that the effects of such factors on the contact forces for rollers at different angle positions differ significantly. The conclusions, arrived at the end of this paper, are helpful to a better design of the CRB bearing.

Keywords: Cylindrical roller bearing; Load distribution; Speed; Clearance; Number of roller

1. Introduction

The CRB bearing plays an important role in the rotating machinery such as aero-engine, wind turbine, machine tools etc. The steady operation of the CRB bearing is crucial to the safeties of these machines. As a result, the mechanical characteristics of the CRB bearing attract more and more attention of the engineers. With regard to the CRB bearing, a basic problem is the load distribution with exterior load and rotating speed. Many researchers have devoted themselves in the relevant studies.

Without considering the effect of friction, Mul et al. [1, 2] researched the load distributions for both ball and roller bearings. In that study, five degrees of freedom of the bearing were considered. Also, Houpert [3] proposed a uniform analytical approach to study the load distribution for ball and roller bearings. Xu and Li [4] focused on the dynamic load of the ball bearing using as joint in planar multi-body systems. It provided an idea for the determination of the dynamic load of the CRB bearing. Later, Ye and Wang [5] researched the effect of misalignment of CRB bearing on its load distribution. Considering the effect of roller geometry, Oswald et al. [6] investigated the relation between the load and the bearing life. Also, Warda et al. [7] focused on the effect of the roller profile. Their research was about the fatigue life of the CRB bearing, which is related to the load distribution of the bearing. Taking the defect size of ball bearing into account, Petersen et al. [8] presented an analytical formulation to determine the load distribution of the bearing. Using the boundary element method, Yang et al. [9] performed an analysis for the four-row tapered roller bearing. From the above researches, one can find that the characteristics of the load distribution for the CRB bearing have not been focused on sufficiently. However, the characteristics of the load distribution are very important. It can facilitate the designers to an optimized design of the CRB bearing. In addition, it also can help the engineers to have a deep knowledge of bearing and then make a good choice from the bearing list. As a result, the present study is carried out. First, a load distribution model of the CRB bearing will be proposed. Subsequently, based on the proposed model, the effect of bearing load, bearing speed, clearance and number of roller on the characteristics of the load distribution will be discussed. Finally, the conclusions of the present study are shown.

2. The Load Distribution Model of the CRB Bearing

2.1. Determination of the contact zone for the bearing

Because of the existence of clearance in the CRB bearing, not all of the rollers contact with both of the races under a specific load condition. In order to ascertain the load distribution of the bearing, the first thing that should be done is to determine the load zone of the bearing. Obviously, at the boundary of the load zone, the roller (if it exists) will contact with the inner race of the bearing, but without any load. Therefore, the following equation can be used to determine the critical position angle of the load zone.

$$\delta\cos\gamma - P_d/2 = 0 \tag{1}$$

In Eq. (1), δ, γ and P_d denotes the radial displacement of the bearing, the critical position angle and the clearance of the bearing, respectively. Obviously, Eq. (1) can be transformed into the following format

$$\gamma = a\cos\left(\frac{P_d}{2\delta}\right) \tag{2}$$

Using the critical angle γ expressed by Eq. (2), one can determine the load zone of the bearing.

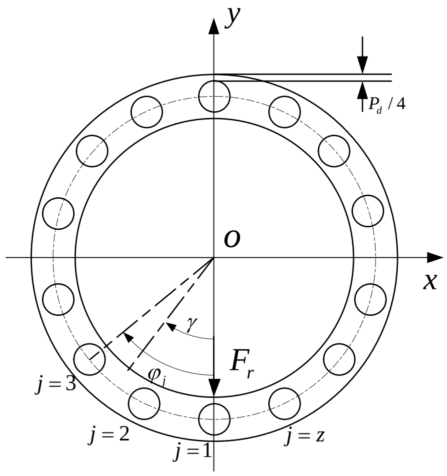

Figure 1. Schematic diagram of the CRB bearing.

2.2. Equilibrium equations of the roller

To determine the load distribution of the CRB bearing, forces exerted on the roller must be analyzed carefully. According to the geometrical structure of the CRB bearing, loads from the inner and outer rings may exert on the roller. Also, centrifugal force has effect on the roller due to the rotational motion of the bearing. In order to simplify the expression, φj is defined as the position angle of the *j*th roller. Then, the equilibrium equation of the roller in the load zone can be expressed as

$$F_{oj} - F_{ij} - F_{cj} = 0 \qquad \varphi_j < \gamma \tag{3}$$

In Eq. (3), F_{oj}, F_{ij} and F_{cj} respectively denote the force between the roller and the outer race, the force between the roller and the inner race and the centrifugal force for the *j*th roller. According to the Hertzian theory, the contact forces between the *j*th roller and the races are

$$F_{oj} = K\delta_{oj}^{n} \tag{4}$$

$$F_{ij} = K\delta_{ij}^{n} \tag{5}$$

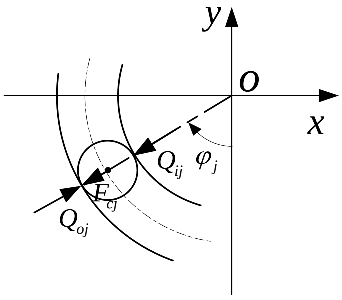

Figure 2. Forces on the roller.

In Eqs. (4) and (5), *K* represents the contact constant of the bearing. It can be ascertained according to the geometrical parameters and material properties of the bearing according to literature [10]. For the CRB bearing, *n* equals 10/9. δ_{oj} and δ_{ij} are the contact deformations of roller-outer race and roller-inner race for the *j*th roller. With regard to the relationship of the contact deformation and the displacement of the bearing, it satisfies

$$\delta\cos\varphi_j - \delta_{ij} - \delta_{oj} = 0 \qquad \varphi_j < \gamma \tag{6}$$

For the roller out of the load zone, the roller does not contact with the inner race. Then, there is

$$\delta_{ij} = 0 \tag{7}$$

The centrifugal force of the jth roller can be determined as

$$F_{cj} = m_j R\omega_{mj}^2 \tag{8}$$

where m_j, *R* and ω_{mj} are the mass of the *j*th roller, the diameter of the orbit circle for the roller and the orbital speed of the *j*th roller.

With respect to the roller out of the load zone, the roller does not contact with the inner race. Therefore, the equilibrium equation for the *j*th roller will be

$$F_{oj} - F_{cj} = 0 \qquad \varphi_j \ge \gamma \tag{9}$$

2.3. Equilibrium equation of the inner ring

Based on the above deduction, the equilibrium equation of the inner ring is

$$F_r - \sum F_{ip}\cos\varphi_p = 0 \tag{10}$$

where *p* represents the serial number of the roller in contact with the inner race of the bearing.

Eqs. (2-10) form the system of nonlinear algebraic equations to determine the load distribution of the CRB bearing. The basic unknown variables are the displacement of the bearing and the contact deformations of the rollers. Utilizing the Newton-Raphson method, one can solve the problem.

3. Results and Discussion

In this part, the effectiveness of the load distribution model will be verified. Subsequently, the effects of some factors, such as bearing load, bearing speed, clearance and number of roller on the load distribution will be discussed. A 209CRB bearing is chosen for the numerical calculation. Its parameters are shown in Table 1. In this table, D, l, and dm denote the diameter of the roller, the effective length of the roller and the diameter of the pitch circle. The constant ρ represents the density of the bearing while z denotes the number of rollers.

Table 1 Parameters of the 209CRB bearing

Parameter	***Value***
D (mm)	10
L (mm)	9.6
d_m (mm)	65
ρ (kg · m^{-3})	7728
z	14

3.1. Verification of the load distribution model

The comparison of results obtained from the present model and the one from literature [10] is shown in Fig.3. One can find that the results coincide with each other very well. It manifests that the load distribution model presented here is effective.

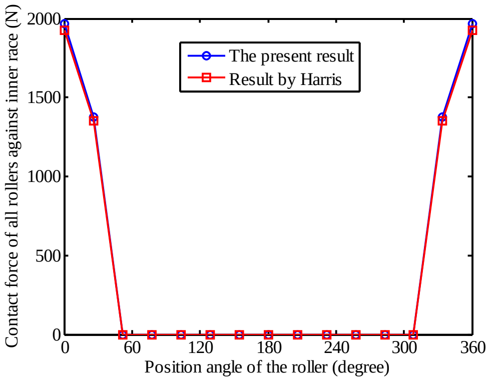

Figure 3. Contrast between the present result and the one by Harris

3.2. The effect of bearing load

The effect of bearing load on the contact forces of the rollers is shown in Fig. 4. It can be seen that the bearing load has a great effect on the contact forces. Due to the symmetry of the bearing structure, the contact forces for all the rollers are also symmetrical relative to the acting line of the bearing load. With the increasing of the bearing load, contact forces for the rollers in the load zone increase rapidly. However, even the bearing load increases from 1000 N to 10000 N, there are about four rollers locating in the load zone all the time. It means that the load zone almost does not change.

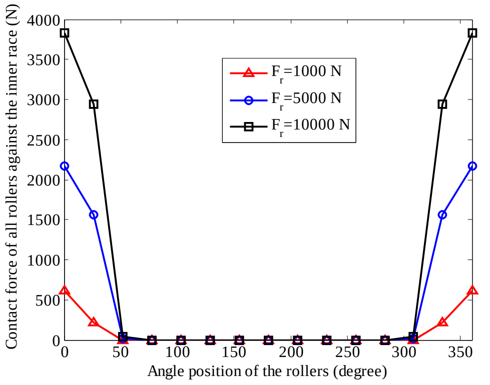

Figure 4. n=6000 rpm Pd =0.041 mm

3.3. The effect of bearing speed

In this part, the contact forces of the first and second roller are chosen to carry out the discussion. In Fig.5, one can see that the contact force for the first roller increases with the increasing of shaft speed. It is easy to understand. If the bearing is rotating or there is load exerted on it, the first roller will always in the load zone. With the increasing of the shaft speed, it will bear more loads. However, the change of the contact force for the first ball is not obvious.

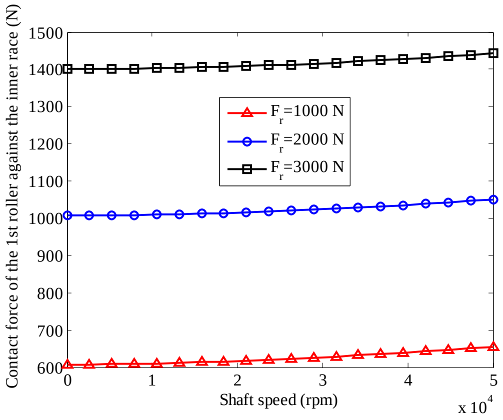

Figure 5. Variation of contact forces for the first roller, Pd=0.041 mm

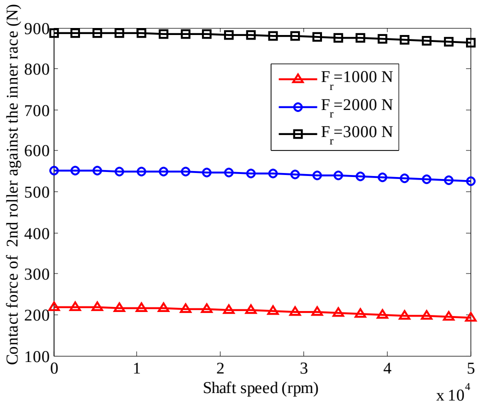

Figure 6. Variation of contact forces for the second roller, Pd =0.041 mm

Similarly, Fig. 6 shows the variation of contact force for the second roller. The most obvious difference is that contact forces for the second roller decrease as the increase of the shaft speed. It is because that the roller will press onto the outer race of the bearing with the increasing of the shaft speed. As a result, the second roller has a tendency to move out of the load zone. Then, its contact force against the inner race will decrease.

3.4. The effect of clearance

Fig. 7 shows the variation of the contact force for the first roller with different clearance. One can find that the contact force for the first roller is larger for a larger clearance. It is because a larger clearance leads to a smaller load zone. Then, fewer rollers bear load exerted on the bearing and more loads are shared by the first roller.

With respect to the second roller, the variation of contact force is complicated. With zero clearance, the contact force increases with the increasing of the shaft speed. Nevertheless, with a nonzero clearance, the contact force for the second roller decreases. It can be explained as follows.

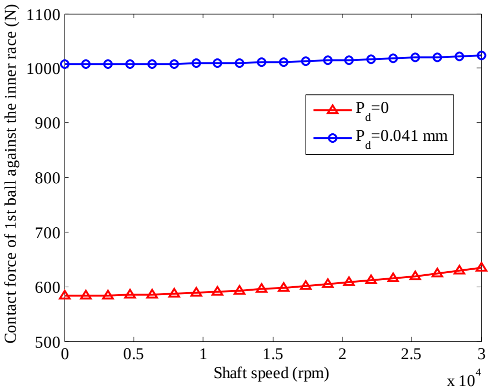

Figure 7. Contact force of the first roller, Fr=2000 N

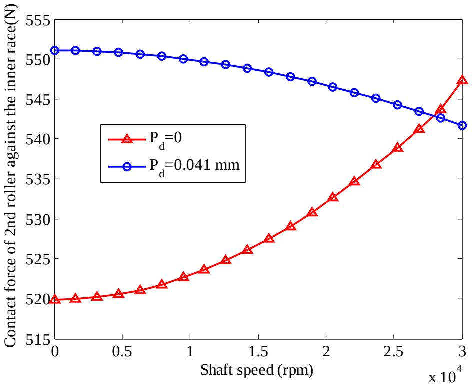

Figure 8. Contact force of the second roller, Fr=2000 N

While the clearance is zero, most of the rollers are in contact with the inner race. With the increase of the shaft speed, more and more rollers will come out of the load zone. Therefore, the rollers near the acting line of the bearing load will share more loads. Thus, contact force of the second roller will increase. With regard to the condition of nonzero clearance, the second roller with separate from the inner race gradually with the increase of the shaft speed. Therefore, its contact force against the inner race will decrease.

3.5. The effect of number of roller

Number of roller in the CRB bearing is a very important parameter. Fig. 9 shows the variation of the contact force for the first roller while the total number of roller changes. Obviously, the more the rollers are, the smaller the contact force for the first roller is. The reason for this is apparent, because more rollers take part in bearing the load.

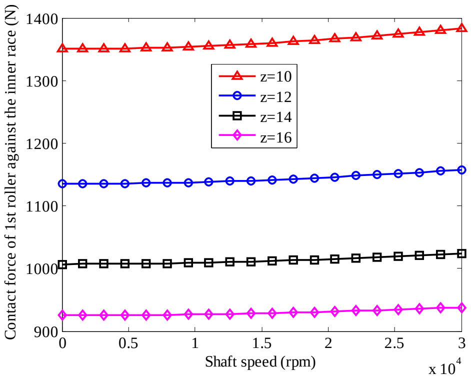

Figure 9. Contact force of the first roller , Pd =0.041 mm, Fr =2000

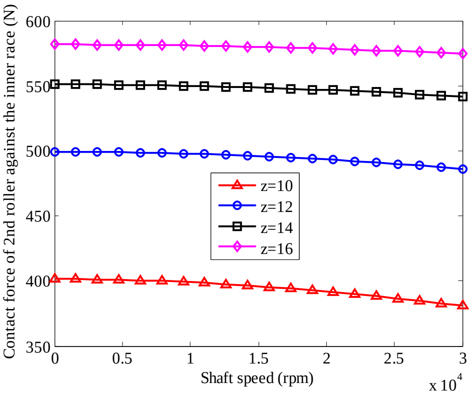

Figure 10. Contact force of the second roller , Pd =0.041 mm, Fr =2000

However, the variation of contact force for the second roller changes conversely with respect to the first roller. It is also can be explained reasonably. With the increase of roller number, the location of the second roller will be nearer to the acting line of the bearing load. Thus, it will share more load with the first roller. As a result, its contact force against the inner race increases.

4. Conclusions

In this paper, a load distribution model of the CRB bearing is proposed. Then, the analysis of the characteristics of the load distribution is carried out. The following conclusions are arrived at.

The bearing load has a great effect on the contact force of rollers in the load zone. The bearing speed can change the contact forces of rollers against the inner race. However, the change is not obvious. To some extent, the effect of the clearance on the load distribution of the bearing is complicated. The number of rollers also has an obvious effect on the load distribution of the bearing. Its effects on the contact forces for the rollers on and near the acting line of the bearing load are converse.

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