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Influence of Inner Ring Roundness Deviation on the Dynamic Characteristics of Cylindrical Roller Bearing

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Abstract. The difference between the maximum and minimum deviation of the actual contour relative to the ideal circle is roundness deviation caused by uneven temperature and wear of the ring during production and operation, which will lead to abnormal force. In this paper, a rigid flexible coupling dynamic model of cylindrical roller bearing considering the roundness deviation of inner ring is established to study the dynamic characteristics of bearing. And the dynamic characteristics of stress and contact force of raceway or cage under different roundness parameters are studied. It is concluded that the stress, contact force and trajectory of the inner ring are largely influenced by its roundness deviation. The stress and contact force will rise with the increasing of the deviation. Meanwhile, the displacement amplitude increases and the trajectory of the inner ring gradually tends to be irregular shape. The force on the cage will be increased due to the existence of roundness deviation, but the degree of deviation has little effect on the dynamics of the cage.

Keywords. Inner ring roundness, dynamic characteristics, rigid flexible coupling dynamic model, cylindrical roller bearing

1. Introduction

The roundness deviation which is the difference between large diameter and small diameter of raceway of bearing rings, will be produced by uneven temperature and wear of bearing rings. The force and the clearance between the roller and the raceway will be changed. Therefore, it is particularly important to analyze the influence of the bearings inner ring roundness deviation on its dynamic characteristics.

The research on the influence of bearing part errors on bearing dynamic characteristics have been carried out by domestic and foreign scholars. Based on the established nonlinear differential equation, Harsha [1] obtained the influence law of waviness located in raceway surface of ball bearing on the radial runout of bearings. Bhateja et al. [2] considered the roller shape error, and the rotation accuracy model

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without cage of rolling bearing was established to obtain the influence law of roller and raceway deviation on bearing rotation accuracy. Chunsan [3] obtained the influence law of the geometric and dimensional error of the outer ring and the roller on axis center trajectory of the ball bearing through experimental methods. Okamoto et al. [4] studied the influence law of the number, size error and raceway shape error of the roller on the axis center trajectory by using the method of numerical simulation, and conducted an experimental study. Huang Jian et al. [5] considered raceway roundness deviation, established the analysis model of rolling bearing, further studied the effect of ring roundness deviation on its operating including rotation accuracy and service life.

Although some studies on the influence of the trajectory of bearing, but the study on the stress and contact force of ring and cage is few. In this paper, the roundness deviation of inner ring is introduced into the dynamic model. And the influence of inner ring roundness on dynamic characteristics of raceway and cage is analyzed, which will provide theoretical support for the roundness deviation control and application.

2. Dynamic Model Considering Roundness Deviation of Cylindrical Roller Bearing Inner Ring

2.1. Features of Inner Ring Roundness

The structure of cylindrical roller bearings as shown in figure 1. D and d are the diameter of outer and inner respectively. B is the width. D_W and l are the diameter and length of roller. d_m is the diameter of pitch circle of roller.

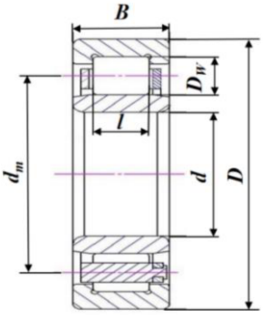

Figure 1. Structure of cylindrical roller bearing.

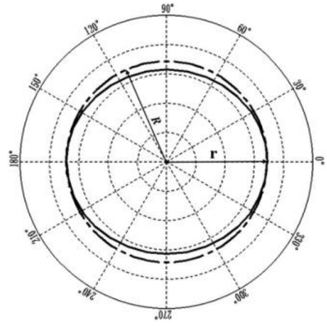

Figure 2. Features of inner ring roundness.

The features of cylindrical roller bearing inner ring roundness is shown in figure 2. The ideal circle radius and the large diameter of the ellipse are R and r as the actual large and small diameters of the contour.

2.2. Rigid Flexible Coupling Dynamic Model with Roundness Deviation of Inner Ring

The rigid flexible coupling model is established as shown in figure 3. The change and influence of raceway and cage under the roundness deviation of inner ring are mainly studied to reveal the change of stress. Therefore, inner ring and cage are set as flexible bodies. A four-node tetrahedron element is adopted considering the calculation accuracy and calculation speed comprehensively, the minimum mesh size is 5mm, and the finite element model contains 324,857 elements and 68,892 nodes.

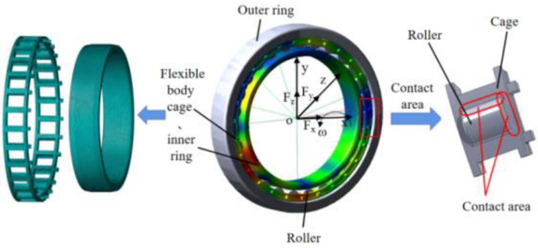

Figure 3. Dynamic model of cylindrical roller bearing.

2.3. Interaction between Cylindrical Roller Bearing

Impact method is adopted for the contact force calculation of raceways, cage and so on, which is represented by:

$$F=\begin{cases} K(\delta_0-\delta)^e - C_{\max}(\frac{d\delta}{dt})\times step(\delta,\delta_0,-d,1,\delta_0,0), & \delta\le\delta_0 \\ 0, & \delta>\delta_0 \end{cases} \tag{1}$$

where, K is the stiffness coefficient. δ_0 and δ are the distances of two objects. e and C are the collision and damping coefficient respectively. $d\delta/dt$ is the relative velocity between two colliding objects. d is the penetration depth of the object. Relevant parameters can be obtained from literature [6].

The stiffness coefficient is obtained by:

$$K=\frac{4}{3}R^{\frac{1}{2}}E^* \tag{2}$$

where, $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}$, R_1 and R_2 are the contact radius of two collision objects (mm). $\frac{1}{E^*}=\frac{1-\mu_1^2}{E_1}+\frac{1-\mu_2^2}{E_2}$, μ_1 and μ_2 are the Poisson's ratio of two contact objects. E_1 and E_2 are the elastic modulus between two contacting objects (N·mm).

The friction force is based on Coulomb formula, and the friction coefficient is determined by the relative sliding speed between two contact parts.

$$\mu=\begin{cases} -sign(v)\cdot d, & |v|>v_d \\ -step(|v|,v_s,\mu_s,v_d,\mu_d)\cdot sign(v), & v_s\le|v|\le v_d \\ step(v,-v_s,\mu_s,v_s,-\mu_s), & -v_s<v<v_s \end{cases} \tag{3}$$

where, μ_d , μ_s , v_d and v_s are the coefficient and conversion speed of dynamic and static friction. v is the relative sliding speed between two objects.

2.4. Model Validation

A cylindrical roller bearing (FL-NU1088M) is taken as the object, and its structural parameters are given in table 1.

Table 1. FL-NU1088M parameters.

Name	Value	Name	Value
Outer race diameter D (mm)	650	Roller length l (mm)	52
Inner race diameter d (mm)	440	Pitch diameter d_m (mm)	545
Bearing width B (mm)	94	Number of rollers Z	27
Diameter of roller D_W (mm)	52		

The material of outer ring and inner ring is made of GCr18Mo, roller is GCr15SiMn, and cage is ZCuAl10Fe3Mn2.

Table 2. Comparison of contact force and speed simulation with theory.

Name	Inner ring and roller	Outer ring and roller	Cage speed
Theoretical value	19479.73N	19479.73N	536.4deg/s
Simulation value	20182.77N	20678.35N	530deg/s
Error value	3.61%	6.15%	1.20%

The contact force of raceway and the speed of the cage can be calculated by the Hertz contact formula at radial load (128910N) and the speed (198r/min). The comparison results of simulation and theory are shown in table 2. It is concluded that the simulation is consistent with the theory.

3. Dynamic Characteristics of Bearing under Inner Ring Roundness Deviations

3.1. Influence of Roundness Deviation on Bearing Ring

Four groups different roundness with 0,0.044, 0.088 and 0.132 of the inner ring are selected and simulated. The stress(σ_i) change of bearing inner raceway under different roundness are shown in figure 4. It can be concluded that the stress of inner ring is largely influenced by its roundness deviation. The stress presents an upward trend first, and it is significantly higher than normal with the constant increasing of its roundness. Meanwhile, the normal stress of inner ring changes steadily with time, while the stress after roundness changes periodically with time. The changes of resultant force(F_m) of raceway and cage are analyzed under the roundness deviation of inner ring.

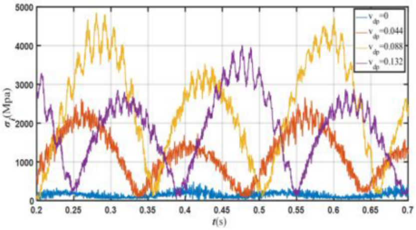

Figure 4. Inner ring stress with different roundness

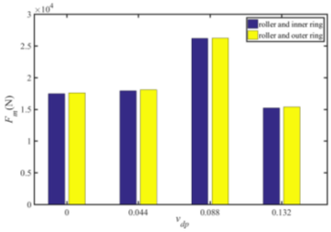

Figure 5. Raceway force with different roundness

The raceway force of with different roundness is fluctuated and averaged as shown in figure 5, in which the axial force of raceway changes significantly in the direction of the resultant force. The force increases first, and both reach the maximum at the value of 0.088 as the roundness of the inner ring continues to increase, which is consistent with the stress analysis results.

3.2. *Influence of Roundness Deviation on the Cage*

The change of cage stress under the roundness deviation of inner raceway is shown in figure 6, in which the cage stress fluctuates. The cage maximum stress value is between 30Mpa-45Mpa, which has little effect by inner ring roundness. The change of cage force is shown in figure 7. It is clearly seen that the force on cage will be increased due to the existence of roundness deviations, and the value of deviation has little influence on the dynamics of cage as the roundness of inner ring increases, which is consistent with the stress analysis results in the figure above.

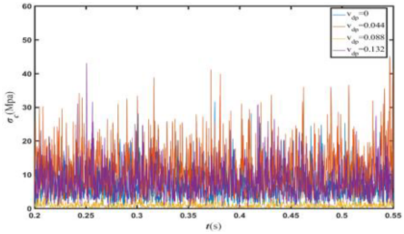

Figure 6. Cage stress with different roundness.

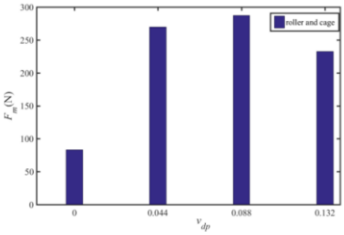

Figure 7. Cage force with different roundness.

3.3. *Influence of Inner Ring Roundness on Vibration of Bearing Inner Ring*

The trajectory of inner ring as shown in figure 8. The vibration amplitude increases and the trajectory of the inner ring tends to be irregular with the increasing of the roundness of the inner ring, but have no obvious change with certain roundness deviation.

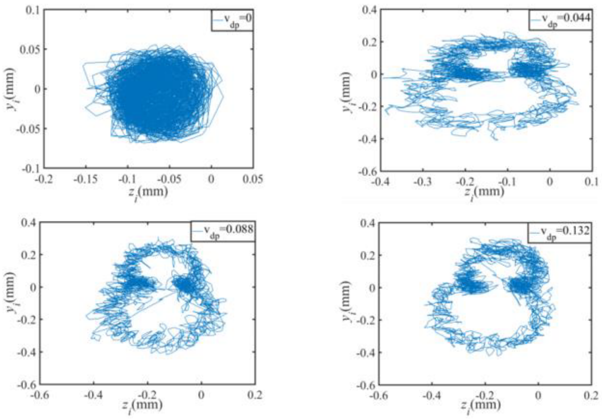

Figure 8. Trajectory of inner ring with different roundness.

4. Conclusion

In this paper, a rigid-flexible coupling dynamic model considering the inner ring roundness is established, and the dynamic characteristics between inner ring and cage affected by the roundness change of inner ring are studied. It can be concluded that:

(1) The stress, force and trajectory will be affected by inner ring roundness.

(2) The stress and contact force of raceway increase, and reach peak at the value of 0.088. And value of deviation has little effect on the cage. Meanwhile, the trajectory of the inner ring gradually tends to irregular shape, and the amplitude of vibration increases with the increasing roundness deviation of the inner ring.

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