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Analysis of Failure Effect of Cage Thickness on Spherical Roller Bearings

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Abstract. Spherical roller bearings are important parts of high-frequency crushers. Using the finite element analysis software to carry out the transient dynamics analysis to the bearing obtains the bearing deformation, the pressure and so on characteristics. Then, by contrasting and analysing, it is found that under pure radial load, radial load and axial load mixed force, influence of cage thickness on bearing performance. The results show that the thickness of the cage has little effect on the deformation of the bearing under pure radial load. Under the combined action of the radial load and the axial load, the radial deformation of the bearing decreases compared with the pure radial load. The deformation of the cage under the mixed load is increased than that under the radial load.

1. Introduction

The high-frequency crushers is an excavator attachment tool that crushes the target rock by the eccentric force generated by the eccentric component \(^1\). The Spherical roller bearing is an important part of the high-frequency crushers. It as a joint role in the working process. Its structural design has an important influence on the overall performance of the high-frequency crushers. Because self-aligning roller bearings bear a larger load in the use process, so easy to self-aligning roller bearings failure. To improve the performance of the bearing, the dynamic analysis of the bearing is performed by Ansys WorkBench finite element analysis software to find out the role played by the cage in the use of the bearing. The simulation result can be a product. Further design and optimization provide a basis for judgment.

At present, many scholars at home and abroad have carried out dynamic and static simulation analysis of bearings. The components of the bearing have a very important influence on the reliability of their use. However, there are relatively few comparative studies on this aspect. The quasi-static analysis of the optimized analytical model is carried out, and the load distribution of the double-row tapered roller bearing under the complex force and ultimate load is obtained respectively\(^2\). The axial clearance value under the maximum fatigue life curve, the literature uses the finite element analysis method and theoretical calculation to study the characteristics of the deep groove ball bearing cage and the steel ball during operation\(^3\). The important influence on the cage and the relationship between the change of the number of steel balls and the bearing load analyzed the dynamics of the cylindrical roller bearing, and obtained the force of the cage and the rolling element\(^4\). The literature shows the position of the contact area of the bearing body during the use of the rolling element and the inner and outer rings of the bearing during the use of the dynamic finite element dynamic response analysis\(^5\). The literature through the use of display dynamics finite element analysis the stress distribution at different speeds was studied\(^6\). It was found that the contact stress between the rolling
element and the outer ring was positively correlated with the rotational speed. The force of the outer ring hardly changed with the rotational speed. The traditional Newton-Raphson iterative method is improved, the reliability of the solution result is effectively improved, and the solution result is verified by controlling the value of the contact angle [7]. The literature has been subjected to the cylindrical roller bearing by finite element method [8]. Force analysis shows that the stress is symmetrically distributed along the contact point to both sides of the bearing. The above analysis of bearings rarely involves the comparative analysis of double-row spherical roller bearings. In view of this, the cage bearings with different parameters are compared and analyzed. The characteristics of cage bearing with different parameters and the influence of cage on bearing force are found out. It provides a reference for the further research and optimization of bearing.

2. Bearing installation structure and research method

2.1 Analysis of the structure of spherical roller bearings

The self-aligning roller bearing, the helical gear and the eccentric block are arranged on the same shaft of the gear box. The bearing and the shaft are matched by the interference fit. The bearing acts as the supporting part of the gear and the eccentric block, and its performance directly affects the running efficiency of the crusher. During the working process, the hydraulic pump of the crusher drives the eccentric block and the bearing on the main shaft by driving the helical gear. Under the action of Centrifugal Force, the eccentric block drives the bucket teeth to impact the rock with a certain frequency. The force will have a certain impact on the bearing, and the arrangement of the parts on the shaft is shown in Figure 1.

![Figure 1. Part assembly drawing](image)

1. Bearing 2. helical gear 3. Eccentric block 4. axis

According to the working principle of the high-frequency crushers, the formula for calculating the excited force generated by the eccentric block [1] is

$$F_j = 2m \left( \frac{2\pi \cdot e \cdot n}{60} \right)^2 \cdot \sin \left( \frac{2\pi \cdot n \cdot t}{30} \right)$$  \hspace{1cm} (1)

Where $F_j$ is the eccentric mass excitation force, N; $m$ is the mass of eccentric block, kg; $n$ is the eccentric block rotation speed, r/min

$e$——eccentric block eccentricity, mm

The excited force is generated by the eccentric mass centrifugal motion. When the center of gravity of the eccentric block is in the vertical direction, the excited force at this time is at the maximum value. After calculation, the maximum excited force is 303.3kN.

The unbalanced force is generated during the movement, and the eccentric block only produces the radial load. The force generated by the helical gear on the bearing can be decomposed into the axial load and the radial load. The calculation formulas are respectively

$$F_t = \frac{2\pi \cdot F \cdot d \cdot \tan \alpha}{\cos \beta}$$  \hspace{1cm} (2)

$$F_r = \frac{F \cdot \tan \alpha \cdot \cos \beta}{\cos \beta}$$  \hspace{1cm} (3)

$$F_a = F_t \cdot \cos \beta$$  \hspace{1cm} (4)

Where $F_t$ is the circumferential force, N; $F_r$ is the radial force, N; $F_a$ is the axial force, N
Using the calculated values of radial load and axial load of the bearing, according to principle of moment balance, the acting force produced by the eccentric block and the helical gear on the bearing is superposed and calculated and it is found that the bearing close to the eccentric block is subjected to a large force and is subjected to Force analysis and theoretical calculation [9] show that the maximum radial force of the bearing is 273060N, and the maximum axial force is 54611N.

A high-frequency crushers of a factory uses a double-row spherical roller bearing of type 22322CA, and the cage material is cage. The specific material property parameters are shown in Table 1.

### Table 1. Spherical roller bearing related parameters

| Material | Density /kg.m$^3$ | Elastic Modulus /N.m$^2$ | Radial load /kN | Axial load /kN | Number of rollers | Poisson’s ratio |
|----------|------------------|---------------------------|-----------------|----------------|------------------|---------------|
| GCr15    | 7830             | 2.19E+11                  | 273.06          | 54.611         | 30               | 0.3           |
| Cage     | 8800             | 8.00E+10                  |                 |                |                  | 0.35          |

### 2.2 Basic theory of transient dynamics

Transient dynamics can be used to analyze the linear and nonlinear dynamic responses of structures under steady, transient and harmonic loads. When the system is subjected to the impact load, the transient dynamic equation that the system needs to satisfy is [10]:

$$\begin{bmatrix} K \end{bmatrix} [u] + [R] [u'] + [M] [u''] = [P] - [I] \quad (5)$$

Where $[M]$ is the mass matrix; $[C]$ is the damping matrix; $[K]$ is the stiffness matrix; $[u]$ is the displacement of each node; $[u']$ is the velocity of each node; $[u'']$ is the Node acceleration; $[P]$ is the external force of each node; $[I]$ is the force within each node.

It can be seen that the amount of displacement deformation is directly related to structural stiffness, damping, velocity, and acceleration.

### 3. Finite element model establishment

The transient dynamics analysis is suitable for solving the dynamic response of the impact load. Because the calculation process requires a large amount of computational memory, the model is simplified under the premise of ensuring the reliability of the result. Ignore structures such as rounded corners [11].

In the course of Finite Element Analysis, the grid division plays an important role. The quality of the grid directly affects the reliability of the calculated results. Therefore, in the course of the grid division, Different Grid Division methods are adopted for different parts of the bearing. The hexahedral Mesh method is adopted for the inner and Outer Rings of the bearing model, while the Tetrahedral Mesh method with good adaptability is adopted for the roller and cage of the bearing. The check result of grid quality is that the grid quality of the contact area of key parts such as roller is above 0.89, as shown in figure 2.

**Figure 2. grid quality map**
4. Comparison of finite element analysis results

4.1 Deformation under pure radial load

Pure radial load is almost non-existent in the actual operation of the bearing. In order to compare and analyze the simulation results of spherical roller bearing under combined load and observe the deformation region of spherical roller bearing under single load, the spherical roller bearing is analyzed. By changing the thickness of cage, the working condition of self-aligning roller bearing under pure radial load is analyzed, and the total deformation of bearing and cage is compared and analyzed. The simulation results are shown in figure 3.

It can be seen from the simulation results in the Figure 3, that the effects of changing the thickness of the bearing cage on the overall deformation of the bearing is almost unchanged. The total deformation of the bearing varies slightly with the thickness of the cage when the load is constant, which is mainly due to the role of the cage in keeping the roller position under pure radial load. Because there are different degrees of collision between the roller and the cage during the working process. When the load is constant, the thickness of the cage increases. Which increases its own bearing capacity, so the thick cage deformation is relatively small. Under load, the maximum load area of bearing and cage is invariable.

4.2 Deformation under Combined load

The force produced by the high-frequency crusher in the course of its operation is largely due to the centrifugal motion of the eccentric block, because of the combined action of helical gear and eccentric block, and the spherical roller bearing bears both radial and axial combined load. The existence of combined load leads to the eccentric load effect of self-aligning roller bearing, which has an important
influence on the service life of the bearing. Therefore, it is very important to study the bearing under eccentric load. By changing the thickness of cage, the effect of cage under combined load is analyzed, the results are shown in Table 2.

**Table 2.** Bearing Total Deformation parameters under combined load

| Cage Thickness | Total Deformation (μm) | Cage Total Deformation (μm) |
|----------------|------------------------|----------------------------|
| 5mm            | 20.134                 | 12.03                      |
| 10mm           | 19.958                 | 11.575                     |

As it can be seen from the simulation results in Table 2. When the thickness of the cage increases, the total deformation of the bearing and the deformation of the cage also decreases. This is because the axial load is much smaller than the radial load. The bearing performance is improved to some extent by increasing the thickness of cage. Compared to the pure radial load, the load on the cage is increased. This is because the axial load causes the bearing to appear the partial load, then squeezes the cage to cause.

![Image](a) 5mm cage Total Deformation of rollers

![Image](b) 10mm cage Total Deformation of rollers

**Figure 4.** Total Deformation of the roller

It can be seen from the simulation results in Figure 4. The maximum deformation of the roller occurs on the opposite side of the axial load application position, which is caused by the axial load. And the opposite side of the roller is subjected to extrusion, so the amount of deformation is larger than other rollers. Due to the existence of eccentric load, the roller of the upper half ring is subjected to different degrees of load. The maximum load region of roller is located directly below the radial load on the bearing, and the load of roller on both sides decreases gradually to both sides. In addition, through comparative analysis, it can be seen that the increase of cage thickness can improve the roller force environment.

4.3 **Equivalent Stress under Combined load and pure radial load**

Stress is another important value that needs to be referenced under bearing load. In order to further study and analyze the spherical roller bearing, the stress of the cage under different thickness and different loads is simulated and analyzed. Compare the simulation results, as shown in Table 3.

**Table 3.** Cage Equivalent Stress parameter

| Cage Thickness | Pure radial load /N  | Combined load /N |
|----------------|----------------------|------------------|
|                | Equivalent Stress/MPa| Equivalent Stress/MPa |
| 5mm Cage       |                       |                  |
| 10mm Cage      |                       |                  |

5
According to the values in the Table 3, under the single load or combined load, the average stress value of the cage is reduced with the increase of the thickness of the cage. Under combined load, the average stress of cage with the same thickness is greater than that of pure radial load. The simulation results further confirm that the damage of the bearing by the combined load is more serious, and the increase of the thickness of the cage can increase the service life of the cage.

5. Conclusion

(1) The increase in the thickness of the cage under pure radial loading enables the bearing and cage itself to have better deformation resistance.

(2) Under the action of the combined load, the bearing is squeezed, on the one hand, the bearing roller on the opposite side of the force contact zone is subjected to a large force, and on the other hand, the roller of the upper half ring of the bearing is subjected to different degrees of load; The thickness is inversely related to the amount of deformation of the bearing.

(3) Under pure radial load or combined load, the load on the rollers at the middle position of the lower half ring of the bearing is maximum. And the load on the rollers on both sides is symmetric, and decreases gradually.

(4) The combined load has a more serious influence on the bearing failure than the single load. Through the analysis of the bearing deformation and the average stress, it can be seen that the increase in bearing cage thickness increases the service performance and life of the bearing.

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