Working Performance Analysis of Rolling Bearings Used in Mining Electric Excavator Crowd Reducer

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Abstract. Refer to the statistical load data of digging process, on the basis of simulation analysis of crowd reducer system dynamics, the working performance simulation analysis of rolling bearings used in crowd reducer of large mining electric excavator is completed. The contents of simulation analysis include analysis of internal load distribution, rolling elements contact stresses and rolling bearing fatigue life. The internal load characteristics of rolling elements in cylindrical roller bearings are obtained. The results of this study identified that all rolling bearings satisfy the requirements of contact strength and fatigue life. The rationality of bearings selection and arrangement is also verified.

1. Introduction
Large mining electric excavator with standard bucket capacity of 55m³ is an important equipment used for intermittent mining opencast pit which annual output is more than 20 million tons [1,2]. The digging process of mining electric excavator is completed by coordinating of crowd mechanism and hoist mechanism [3], as shown in figure 1. The crowd reducer is an important component of crowd mechanism of electric excavator used for transfer crowd force. In digging process, dipper driving bucker to press material is completed due to crowd force (as $F_c$ shown in figure 1). And bearings used in crowd reducer play the role of supporting reducer shaft system. The bearings installed on the input shaft and the medium shaft are rolling bearings (paper studying objects), and which installed on the output shaft (crowd shaft) are sliding bearings.

Based on the design of crowd reducer of large mining electric excavator, the computer aided analysis software of Romax Designer is used for simulation analysis of rolling bearings internal load distribution and contact stresses [4], in order to provide reference for related design and research.

2. Basic information and working conditions of rolling bearings
Kinematic sketch of electric excavator crowd mechanism (as shown in figure 2) shows that excavator crowd reducer contain 3 shafts that are input shaft, medium shaft and output shaft respectively. The rack is fixedly connected with excavator dipper. Both ends of each shaft are supported by a bearing. Thereinto, the bearings supporting the input shaft and the medium shaft are rolling bearings, and which supporting the output shaft are sliding bearings. Because crowd reducer adopts two stages involute straight spur gear transmission, theoretically, there is no axial force to act on shafts. But it is
inevitable that slight axial force acts on shafts in practice. Therefore, cylindrical roller bearings are chosen to support input shaft and medium shaft. Bearing on the one side of shaft has no capacity of axial fixing, and the bearing on the other side of shaft has capability of axial bidirectional fixing. Through this bearing combination, radial and axial supporting for input shaft and medium shaft of crowd reducer are realized.

![Diagram of excavator digging process](image)

**Figure 1.** Diagram of excavator digging process

Bearings arrangement of excavator crowd reducer as shown in figure 3, bearing 1 to bearing 4 are rolling bearings, bearing 5 and bearing 6 are sliding bearings. The model and description of each rolling bearing are shown in table 1. (Bearing selection and combination of designed excavator crowd reducer in paper are different from existing product. Compared to tapered roller bearings, this design can almost ignore the negative influence of axial force on drive system)
Table 1. Model and description of rolling bearings of crowd reducer

| Bearing number | Bearing model | Description                  |
|----------------|---------------|------------------------------|
| Bearing 1      | NH332R        | Both inner ring and outer ring have bilateral ribs |
| Bearing 2      | NU2332R       | Outer ring has bilateral ribs, inner ring has no rib |
| Bearing 3      | NH2336        | Both inner ring and outer ring have bilateral ribs |
| Bearing 4      | NU3336        | Outer ring has bilateral ribs, inner ring has no rib |

In addition, the lube of designed crowd reducer is VG 220 synthetic oil, and its working temperature is 70 °C. Bearing and shaft are connected by shrink fit with basic bore system; bearing and housing are connected by transition fit with basic shaft system [5]. Radial clearance of each bearing conforms to its standard radial clearance [6].

The three-dimensional model created by engineering software Romax Designer is shown in figure 4. Since the difference of statistical maximum crowd force of electric excavator at different digging position is very small, and the maximum crowd force within one digging process occurs at the digging position III in usual, the boundary conditions applied to the bearing analysis all conform to the statistical maximum crowd force condition at digging position III [7]. Under this digging condition, loads on the crowd reducer are shown in figure 5. In this diagram, crowd force is $F_c=1272.9\text{kN}$; The force belt acting on pulley is $F_B=65\text{kN}$; Output torque is $M=222.76\text{N}\cdot\text{m}$; Input revs of reducer is $463\text{r/min}$; Input power is $528\text{kW}$; $\alpha=45^\circ$, $\theta=90^\circ$.

3. Analysis of rolling bearings working characteristics

3.1. Analysis of internal load distribution in rolling bearings

The revs of each bearing of crowd reducer is low, therefore, the impact of rolling elements inertia force is neglected in analysis. Under radial load, due to radial clearance and contact deformation of cylindrical roller bearings, the load magnitudes of each rolling element within angle range of load area are not exactly the same [8] (as shown in figure 6). For cylindrical roller bearings, the loads on each roller conform to [9]

$$Q_{\psi} = Q_{\text{max}} \left[ 1 - \frac{1}{2\varepsilon} (1 - \cos \psi) \right]^{10/9}$$

Among this equation, the $\varepsilon$ is written as
\[ \varepsilon = \frac{1}{2} \left( 1 - \frac{P_d}{2\delta} \right) \]  

(2)

In equation (1) and equation (2), \( Q_\psi \) is normal load of rolling element within load range from different angles (\( \psi \) is location angle); \( Q_{\text{max}} \) is the normal load value of rolling element subjected to the maximum normal load (i.e., \( F_0 \) in figure 6); \( \varepsilon \) is load distribution factor; \( P_d \) is bearing radial clearance; \( \delta \) is radial movement of bearing ring in location of \( \psi=0^\circ \).

Based on above theory, by simulation of software Romax Designer, the internal load distributions of cylindrical roller bearings used in excavator crowd reducer are obtained. The polar diagrams of load distribution at the contact point between rolling elements and raceway (including inner raceway and outer raceway) are shown in figure 7. (In this figure, the polar angle is location angle, its unit is \( ^\circ \); and the pole diameter is normal load of the rolling element, its unit is N.) The number of loaded rolling elements and the load value of rolling element under maximum normal load are shown in table 2.

![Figure 6. Diagram of rolling bearing internal load distribution](image)

Figure 7 shows that the loads applied to each rolling element by inner raceway and outer raceway are almost equal. It is attributed to the radial balance of rolling elements of the rolling bearings. And table 2 shows that the number of rolling elements under load is more than 1/3 of total number of rolling element.

| Bearing number | Total number of rolling element | The number of rolling element under load | Maximum load of rolling bearing \( Q_{\text{max}}/N \) |
|---------------|---------------------------------|----------------------------------------|-----------------------------------------------|
| Bearing 1     | 14                              | 5                                      | 23040                                         |
| Bearing 2     | 14                              | 5                                      | 57035                                         |
| Bearing 3     | 17                              | 7                                      | 82776                                         |
| Bearing 4     | 17                              | 7                                      | 59345                                         |

3.2. Analysis of internal contact stresses in rolling bearings

The contact stress analysis of rolling bearing includes the contact stress between the rolling elements and inner raceway, and the contact stress between the rolling elements and outer raceway. For cylindrical roller bearings, the contact region between rolling element and the raceway is line before loading, and then it will change into small surface contact after loading. Based on the analysis of rolling bearing internal loads of excavator crowd reducer, using software Romax Designer, the contact
Stresses between rolling elements and raceways (inner raceway and outer raceway) are solved. The simulation results are shown in figure 8. (In this figure, the polar angle is location angle, its unit is °; and the polar diameter is the normal contact stress of rolling element, its unit is MPa.) The contact stress values of rolling element under the maximum load are shown in table 3.

![Figure 7](image_url)

**Figure 7.** Polar diagram of each rolling bearing internal load distribution of crowd reducer

| Bearing number | Contact value between rolling element and inner raceway/MPa | Contact value between rolling element and outer raceway /MPa |
|---------------|-------------------------------------------------------------|-------------------------------------------------------------|
| Bearing 1     | 1276                                                        | 1059                                                        |
| Bearing 2     | 1426                                                        | 1173                                                        |
| Bearing 3     | 1716                                                        | 1450                                                        |
| Bearing 4     | 1867                                                        | 1578                                                        |
Figure 8. Polar diagram of each rolling bearing internal stress distribution of crowd reducer

The allowable contact stress of cylindrical roller bearings is 4000MPa [10], therefore, all bearings used in excavator crowd reducer satisfy the requirements of contact strength. Furthermore, it can be known from figure 8 and table 3 that the contact stresses between rolling elements and inner raceway are greater than contact stresses between rolling elements and inner raceway. This is because the synthetic curvature of contact between the rolling element and inner raceway is greater than synthetic curvature of contact between rolling element and the outer raceway. According to Hertz contact theory [11], the greater synthetic curvature is, the greater contact stress is.

3.3. Analysis of fatigue life of rolling bearings

According to international standard of ISO/TS 16281, the fatigue life of rolling bearings used in excavator crowd reducer is obtained [12]. The simulation analysis results are shown in table 4.
Table 4. The fatigue life of each roller bearing

| Bearing number | Fatigue life/h |
|----------------|---------------|
| Bearing 1      | 10194000      |
| Bearing 2      | 1161100       |
| Bearing 3      | 138240        |
| Bearing 4      | 92148         |

The simulation results show that the fatigue life of each bearing satisfy the design requirements of 40000 hours at least.

4. Conclusions
Through the working performance simulation analysis of rolling bearings used in excavator crowd reducer in the process of operation, the following conclusions can be drawn. For the same rolling element, the force acted from inner raceway is equal to the force acted from outer raceway, but the contact stress with inner raceway is greater than contact stress with outer raceway. Besides, all rolling bearings satisfy the requirements of contact strength and fatigue life. Therefore, the rationality of bearings selection and arrangement is also verified.

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