New Curve Fitting Based Roller Modification Method for Spherical Roller Bearing

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Abstract: In the field of roller modification affecting the service life of rolling bearings, different from point contact of ball bearing and line contact of cylindrical or tapered roller bearing, Spherical roller bearing is very special because it has the characteristics of point contact and line contact at the same time. To solve the problem that the spherical roller cannot be modified by line contact type roller modification method, this paper provides a new modification method of spherical roller. The spherical roller profile is divided into two parts: non modification profile and modification profile. Curve fitting is carried out in the non modified part, and then the fitting logarithmic curve is used in the modified part of the spherical roller. This method can provide reference for engineering application.

1. Introduction
Rolling bearings are widely used in machinery as mechanical joints which can be classified as ball bearings and roller bearings. In the field of roller bearings, the contact stress of rollers and raceways of inner and outer rings has attracted great attention from the Hertz contact theory in 1882[1]. The inner part of ball bearing such as deep groove ball bearing is point contact and the roller bearing such as cylindrical roller bearing and tapered roller bearing is line contact. Point contact and line contact have been analyzed a lot in which the analysis of line contact was to solve the problem of edge stress concentration on the end of rollers especially. In 1939 Lundberg[2] proposed the logarithmic curve modification method of roller which can solve the problem perfectly. However, the logarithmic curve modification can't be processed at first because of the manufacturing limitations at that time. So the roller with two ends of circular arc modification is developed. With the development of technology, logarithmic curve modification has been realized. But the problem of machining accuracy still needs to be studied. Until now, many researchers put forward different equations of practice curve modification and get engineering application.

Spherical roller bearings(SRB) are special as one kind of roller bearings. The surface of a spherical roller is not a straight line but a spherical surface. Based on Hertz contact theory and finite element method, the contact stress distribution of the roller and inner raceway of spherical roller bearing is analyzed. The calculated maximum stress of the bearing is located at the roller end[3]. The contact between the spherical roller and the raceway of the inner and outer rings has the characteristics of both point contact and line contact. The uncertain contact state is described and a non Hertz contact model is proposed. It can be seen that the spherical roller bearing has the state of point contact and line contact at the same time[4]. The modification of spherical roller is still in the exploratory stage and
there is no widely accepted method of modification design in the engineering field\cite{5-6}. Therefore, based on the modification theory of line contact and curve fitting method, a method of spherical roller modification is proposed in this paper.

2. Modifications of line contact bearing
The common linear contact bearings including cylindrical roller bearing (CRB, fig.1a), tapered roller bearing (TRB, fig.1b) and thrust roller bearing (fig.1c), etc. When the bearing is under working force, the contact area of the roller and the raceway is similar to a rectangle but with a very small width. That causes the rectangle to be like a straight line. So this type of contact is called line contact. In order to avoid the end stress concentration, the roller surface needs curve modification.

![Figure 1: The common linear contact bearings](image1)

The common modification curves in engineering are as follows.

2.1. All convex modification
As shown in Fig.2, the all convex shape is an arc with radius R for the whole length of the roller line.

![Figure 2: All convex modification](image2)

Modification equation as

\[ y = R - \sqrt{R^2 - x^2} \quad (0 \leq |x| \leq L_{we}) \]

2.2. Modification of arc and line intersection without tangent
As shown in Fig.3, an arc with radius R shall be reshaped in the local range of both ends of the roller. the arc and the straight line segment are intersection without tangent.

![Figure 3: Modification of arc and line intersection without tangent](image3)
Modification equation as

\[
y = \begin{cases} 
0 & 0 \leq |x| \leq c \\
\sqrt{R^2 - c^2} - \sqrt{R^2 - x^2} & c < |x| \leq L_{we}
\end{cases}
\]

2.3. Modification of arc and line intersection and tangent

As shown in Figure 4, an arc with radius R shall be reshaped in the local range of both ends of the roller. And the arc is tangent to the line.

![Figure 4](image)

Figure 4 Modification of arc and line intersection and tangent

Modification equation as

\[
y = \begin{cases} 
0 & 0 \leq |x| \leq c \\
R - \sqrt{R^2 - (x - c)^2} & c < |x| \leq L_{we}
\end{cases}
\]

2.4. Lundberg logarithmic curve modification

![Figure 5](image)

Figure 5 Lundberg logarithmic curve modification

Logarithmic curve, expressed as

\[
y = 2 \times \frac{1 - v^2}{\pi E} \times \frac{W}{L_{we}} \times \ln \frac{1}{1 - (2x/L_{we})^2} \quad 0 \leq |x| < L_{we}
\]

It can be seen that there are many kinds of modification curves of rollers. The essence of roller modification is the gap between two contact bodies. The middle part of the roller is in contact with the raceway. And a gap is left between the two ends and the raceway to avoid the problem of stress concentration at the end of deformed roller. Not all practice curves are listed.

3. Modification of spherical roller

3.1. Theoretical basis

First of all, spherical roller and raceway are not in linear contact, but in spherical contact. There is a natural gap between the two contact bodies. As shown in Figure 6, the radius of spherical roller is R3 and the radius of outer raceway is R4.

![Figure 6](image)

Figure 6 Contact geometry of spherical roller and outer race
gap equation as (1) and the curve formed by this equation is defined as the original gap curve, as shown in Figure 7. It can be seen from the figure that the trend of change is not a logarithmic curve trend.

\[ Y_3 = \left( R_3 - \sqrt{R_3^2 - x^2} \right) - \left( R_4 - \sqrt{R_4^2 - x^2} \right) \] (1)

![Figure 7 Original clearance curve](image)

It needs to be taken into account that the aligning performance of spherical roller bearings requires that the roller cannot be reshaped in the full length range but only in the end of the roller. In this paper, a new modified logarithmic curve is fitted in the middle of the roller according to the Lundberg logarithmic curve form. So that the arc in the middle of the roller without modification has the logarithmic curve feature. And the new modified logarithmic curve is used to modify the shape at the end of the roller. Finally, considering the processing problem of logarithmic curve, the new modified logarithmic curve is fitted by another arc curve at the roller end. As a result, the surface of the spherical roller consists two kinds of arcs. The middle section of the roller is the same as before and at both ends section is a new arc. In addition, the gap between roller and raceway has logarithmic curve characteristics which is considered to be a better modification curve. And the arc curve is easier to machining.

The new modified logarithmic curve equation is defined as

\[ Y_4 = A_x \ln \frac{1}{1-(2x/L_{w_e})^2} \] (2)

Where \( A_x \) is an unknown fitting coefficient.

The proportion of the not modified section is defined as \( m \), then

\[ c = m \times \frac{L_{w_e}}{2} \] (3)

Equation (2) was used to fit curve equation (1) in the section \( 0 \leq x < c \). Establish objective function as

\[ f_3 = \text{Min} \sum_i (Y_3 - Y_4)^2 \quad 0 \leq x < c \] (4)

And the fitting coefficient \( A_x \) is solved as

\[ A_x = \frac{-\sum Y_3 \ln \left[1-(2x/L_{w_e})^2\right]}{\sum \ln \left[1-(2x/L_{w_e})^2\right]} \] (5)

The new modified logarithmic curve equation (2) is obtained. Then define the arc curve equation (6) in the section \( c \leq x < L_{w_e}/2 \) as

\[ Y_5 = Y_3(c) + \sqrt{R_5^2 - c^2} - \sqrt{R_3^2 - x^2} \quad c \leq |x| < \frac{L_{w_e}}{2} \] (6)

the curve equation (6) is fitted by (2) to get the value of \( R_5 \) in the section \( c \leq x < L_{w_e}/2 \).

The modification curve of spherical roller is obtained through above steps. The roller is modified by equation(10) in the section \( c \leq x < L_{w_e}/2 \). And the profile of the roller does not change in the section \( 0 \leq x < c \). The connection of two kinds of arc curves is also very good at point \( c \). Because of gap has the logarithmic curve feature, the contact between the roller and the raceway will be better when the
bearing is working.

The calculation flow chart is shown in Figure 8.

\[
Y_3 = (R_3 - (R_3 - x)^2)^{0.5} - (R_4 - (R_3 - x)^2)^{0.5}
\]
\[
Y_4 = A_3 \ln(1 - \frac{2x}{L_{we}})
\]
\[
Y_5 = (R_3 - (R_3 - x)^2)^{0.5} + (R_4 - (R_3 - x)^2)^{0.5} + (R_3 - x)^{0.5} - (R_3 - x)^{0.5}
\]
\[
Y = \sum (Y_3 - Y_4)^2
\]

3.2. Calculation case

Taking a spherical roller bearing as an example, the roller effective length \( L_{we} = 114 \) mm, the radius \( R_3 = 360 \) mm, and the radius of outer race \( R_4 = 368 \) mm. Setting \( m = 0.85 \). Convergence accuracy setting \( \text{eps} = 1 \times 10^{-10} \) mm. the calculation result modified logarithmic equation:

\[
Y_4 = 0.0674 \times \ln \left( \frac{1}{1 - \left( \frac{2x}{L_{we}} \right)^2} \right)
\]

The fitting arc radius \( R_5 = 2994 \) mm, the maximum original gap of roller and raceway is 0.0999 mm, and the maximum gap after modification is 0.2215 mm. The fitted curve result is shown in Figure 9.
4. Conclusion
A modification method of spherical roller bearing is proposed which complements the modification curve type of roller bearing. Compared with the modification of linear contact bearing, the spherical roller bearing is just beginning. More research is needed to make engineering applications successful.

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