Improvement in Reliability of Spherical Roller Bearings

H. YASUDA Y. TAKEDA K. OTSUKA

Ever increasing productivity through reliability is a requirement for mechanical elements used in industrial applications, where spherical roller bearings are subjected to severe operating conditions. In order to meet the severe application requirements, JTEKT has optimized spherical roller bearings with symmetrical rollers to achieve larger load ratings. Physical testing was completed to evaluate the performance and confirm the theoretical design. As a result, it was confirmed that the rollers move steadily, which led to less temperature rise and contributed to both high speed and better axial loading performance. After the bench testing was complete, both the physical evaluation and the theoretical analysis (CAE) show very good correlation.

Key Words: *spherical roller bearing, roller, temperature rise, axial load, high speed, CAE, reliability improvement*

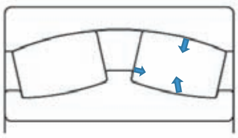
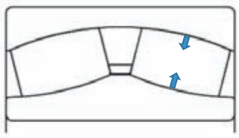
1. Introduction

Due to their superior alignment, large load rating and good ability to integrate, spherical roller bearings are widely used in general industrial machinery such as reducers and construction machines as well as steel production equipment[1, 2]. These bearings are also commonly used as main shaft bearings in wind turbine generators[3]. Recently, with the improvement in productivity of industrial machinery, bearings must perform in increasingly severer conditions. This report introduces spherical roller bearings developed by JTEKT that have upgraded high speed performance and axial loading performance to satisfy these requirements.

2. Types of spherical roller bearings

Table 1 shows the different types of spherical roller bearings[4], which are the asymmetrical roller type and the symmetrical roller type. In the asymmetrical type, which contains guide ribs in the center of the inner ring, the roller load is balanced at three points on each outer ring raceway, inner ring raceway, and inner ring center rib. This concept enables rollers to stabilize at high speed. In contrast, with the symmetrical type, there are no inner ring center rib because the roller load is balanced at two points on each outer ring raceway and inner ring raceway. Therefore the longer rollers, which lead to higher load rating, are implemented to the bearings, which are applied to high loading applications.

Table 1 Types of spherical roller bearings

Types	Convex asymmetrical roller	Convex symmetrical roller
Structure	 Roller load: Balanced at 3-points	 Roller load: Balanced at 2-points
Inner ring	With center rib	Without center rib (Guide ring)

3. Purpose of developed product

The asymmetrical roller type spherical roller bearing is believed to have a large temperature rise due to sliding contact between center rib of the inner ring and roller end face, and therefore inner center rib was not included in the developed bearing. In addition, suppression of temperature rise was achieved for the symmetrical roller type bearing, which can withstand a high load rating, by stabilizing roller movement. High speed rotation performance and axial load performance were also upgraded within the bearings to improve bearing reliability.

4. Forces influencing roller movement

In the symmetrical roller type spherical roller bearing, the roller is supported by two points, which include the outer ring raceway and the inner ring raceway. The moment of the force influencing roller movement is derived in the order shown below.

Figure 1 shows the procedure for calculating the moment of the force influencing roller movement. The details of this procedure are explained in order.

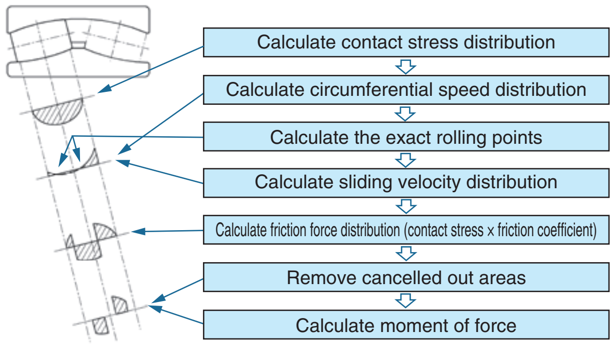


Fig. 1 Calculation flow of moment of force

Figure 2 shows the x-axis and dimensions used in the formula. In both the inner ring contact and outer ring contact, the origin is set as the center of the contact area, and the x-axis is set along the central axis of the roller in the direction of the diameter widening.

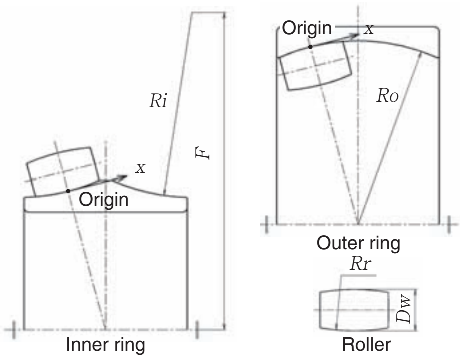


Fig. 2 x axis and dimensions

The circumferential speed nearby the contact points can be described using the below formula.

$$\text{Inner ring}\quad Vi(x)=\{F-\sqrt{Ri^2-x^2}\cos\theta+x\sin\theta\}\omega i \quad (1)$$

$$\text{Roller}\quad Vr(x)=\{Dw/2-Rr+\sqrt{Rr^2-x^2}\}\omega r \quad (2)$$

$$\text{Outer ring}\quad Vo(x)=\{\sqrt{Ro^2-x^2}\cos\theta+x\sin\theta\}\omega o \quad (3)$$

θ: Contact angle, ωi: Angular velocity of inner ring, ωr: Angular velocity of roller, ωo: Angular velocity of outer ring

F, Ri, Dw, Rr, Ro: Refer to **Fig. 2**

The balance of sliding friction force is described as follows.

$$\text{Inner ring side}\int\frac{Vi(x)-Vr(x)}{|Vi(x)-Vr(x)|}Pi(x)\,dx=0 \quad (4)$$

$$\text{Outer ring side}\int\frac{Vo(x)-Vr(x)}{|Vo(x)-Vr(x)|}Po(x)\,dx=0 \quad (5)$$

$Pi(x)$: Contact stress distribution of roller and inner ring
$Po(x)$: Contact stress distribution of roller and outer ring

The values of x are determined for the inner ring side and outer ring side. These values of x represents the exact rolling points.

The exact rolling points are described by

$Vi(x)=Vr(x)$, $Vo(x)=Vr(x)$

Subsequently, the sliding velocity distribution of the bearing ring is determined at each position of the contact area.

Inner ring side $Vi(x)-Vr(x)$

Outer ring side $Vo(x)-Vr(x)$

Considering the direction of the sliding velocity, the friction force distribution $S(x)$ is determined.

$$\text{Inner ring side}\quad Si(x)=\mu i\frac{Vi(x)-Vr(x)}{|Vi(x)-Vr(x)|}Pi(x)=0 \quad (6)$$

$$\text{Outer ring side}\quad So(x)=\mu o\frac{Vo(x)-Vr(x)}{|Vo(x)-Vr(x)|}Po(x)=0 \quad (7)$$

μi: Inner ring friction coefficient, μo: Outer ring friction coefficient

The moment $M(x)$ of the sliding friction force is obtained by integrating the product of friction force distribution and distance from the origin within the contact area. Therefore,

$$\text{Inner ring side}\quad Mi(x)=\int x\cdot Si(x)\,dx \quad (8)$$

$$\text{Outer ring side}\quad Mo(x)=\int x\cdot So(x)\,dx \quad (9)$$

It is thought that roller movement can be controlled by balancing the moment of force from the outer ring side and inner ring side. Therefore, we confirmed the behavior of the roller due to the changes in bearing internal geometry through an evaluation test.

5. Evaluation Test

5. 1 Confirmation of bearing inner element behavior

A parameter study was implemented to confirm the behavior of the roller due to the difference in internal geometry of the bearing. First, the factors stabilizing the movement of the spherical roller bearing were selected from the FTA related to roller movement shown in **Fig. 3**. Five factors were selected as a result, and a parameter study was conducted using a total of 27 combinations taken from these five factors and three levels. The contribution ratios of each factor influencing the roller movement were calculated in a design of experiments.

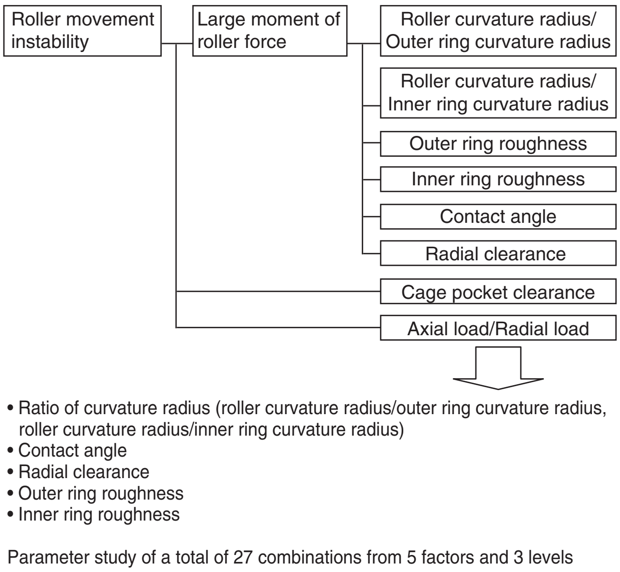


Fig. 3 Fault tree analysis of roller movement

The test measured roller movement and was conducted with 27 evaluated bearings created from five factors and three levels. **Figure 4** shows the method for measuring roller movement. Gap sensors were placed vertically to the roller end-face to conduct measurement, and roller movement was analyzed from the output waveform. The measured position was at the load applying row side, and gap sensors were installed at six locations along the perimeter.

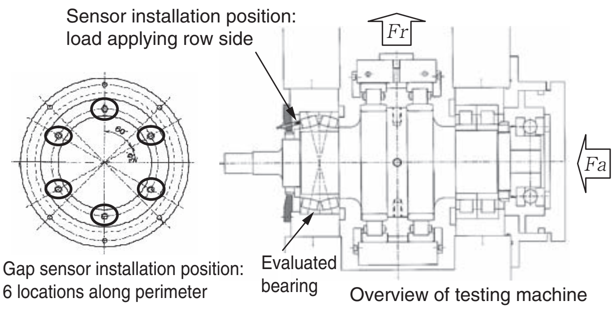


Fig. 4 Measurement method of roller movement

The results of three roller movements are shown to exemplify the measurements of the 27 evaluated bearings. **Table 2** shows a summary of the evaluated bearings, and **Fig. 5** shows the results of the roller measurements. A difference in roller movement was observed due to differing internal geometry. A good tendency of roller movement stabilization was confirmed when both the curvature ratio between inner ring raceway and rollers (roller curvature radius/inner ring curvature radius) is smaller than the ratio between outer ring raceway and rollers (roller curvature radius/outer ring curvature radius), and inner ring raceway roughness is smoother than the outer ring raceway. A tendency of roller movement instability was observed only when the ratio of axial to radial load (axial load/radial load) was in between 0.2 and 0.5.

The calculation of the contribution ratios from the practical test of the 27 bearings using the design of experiments revealed large contribution ratios for roughness and the ratio of curvature radius.

Table 2 Summary of evaluated bearings

Evaluated bearing No.	Ratio of curvature radius		Roughness		Contact angle	Radial clearance
	Roller curvature radius/Outer ring curvature radius	Roller curvature radius/Inner ring curvature radius	Outer ring	Inner ring		
1	Small	Large	Large	Small	Small	Small
2	Small	Large	Large	Small	Medium	Medium
3	Large	Small	Large	Small	Large	Large

Test conditions
1) Main dimensions of evaluated bearing: $\phi 110 \times \phi 180 \times 69$
2) Rotational ring: Inner ring
3) Rotational speed: 72 min^{-1}
4) Radial load: 37 kN Constant
5) Lubrication: Grease lubrication

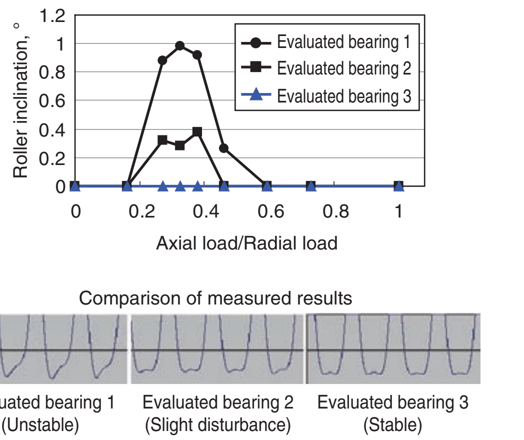


Fig. 5 Measurement result of roller movement

The combination ratios of the factors influencing roller movement were confirmed through the results of the parameter study of 27 combinations, as shown above.

Furthermore, a comparison of the practical test results was made through CAE. **Figure 6** shows the comparison of the practical test results and theoretical analysis. The practical test results and theoretical analysis are

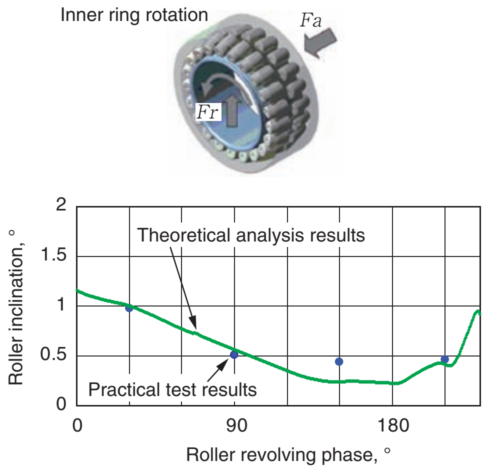


Fig. 6 Results of correlation between practical test and theoretical analysis

practically consistent, allowing for future simulation of roller behavior through an analysis technique utilizing CAE.

5. 2 Bearing performance evaluation

Roller movement stability was achieved within the developed symmetrical roller type spherical roller bearing. To confirm this result, the performance of the developed bearing was compared with the performance of the asymmetrical roller type bearing, which is mass produced bearings.

Figure 7 shows the results of the high speed test. The results of the practical test show that the developed spherical roller bearing has superior high speed performance and better suppression of temperature rise than the bearing undergoing mass production.

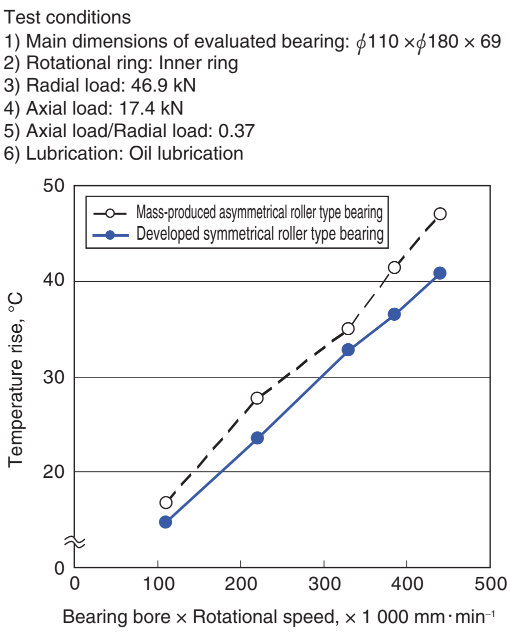


Fig. 7 Test results of high speed rotation

In addition, the kinematic viscosity of the lubricant during operation is greater for the developed bearing due to better suppression of temperature rise than the mass-produced bearing, and therefore oil film thickness can be maintained. As a result, the state of the lubrication is significantly improved compared with the mass-produced bearing, leading to longer life. **Figure 8** shows a life comparison of the mass-produced bearing and developed bearing with consideration to the state of the lubrication.

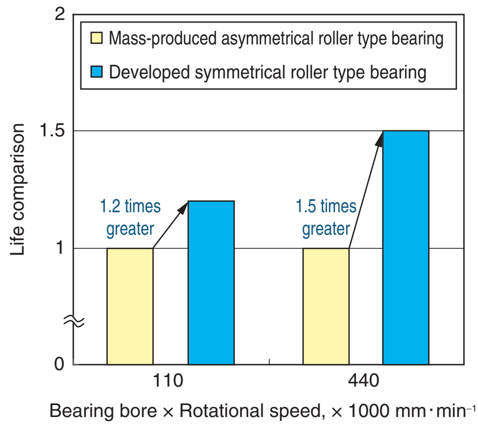


Fig. 8 Life comparison between mass-produced and upgraded bearings considering influence of lubrication

Moreover, the results of the developed spherical roller bearing were also confirmed on super large bearings. **Figure 9** shows the results of the axial loading performance test. The test results confirm that the developed bearing has better suppression of temperature rise than the mass-produced bearing and superior axial load performance.

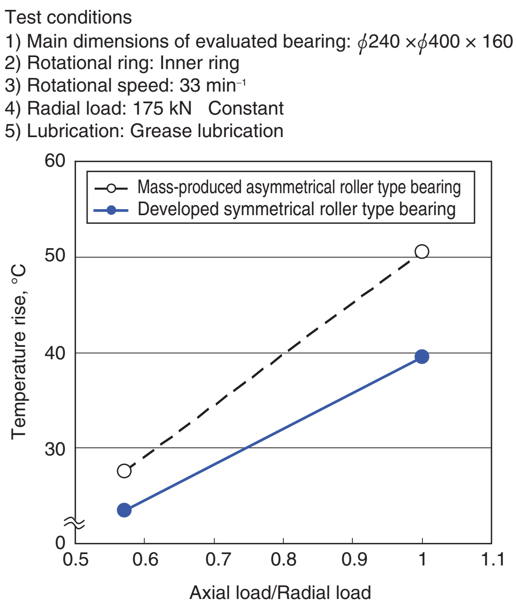


Fig. 9 Test results of axial loading performance

6. Conclusion

In response to the increasingly severe application conditions of spherical roller bearings, JTEKT has improved bearing performance of the symmetrical roller type spherical roller bearing, which can withstand large load rating. The evaluation test results of the developed bearing demonstrated that the bearing has stable roller movement with suppression of temperature rise, as well as superior high speed rotation performance and axial load performance. Furthermore, an evaluation technique for measuring roller behavior was developed, and, as the measurement results were closely consistent with CAE analysis results, an analysis technique using CAE was also established.

JTEKT will strive towards further improving the performance of the entire spherical roller bearing through the utilization of the developed analysis technique as well as evaluations using testing machines of equal size to the actual machines of use, and by expanding the scope of application to ultra-large spherical roller bearings.

References

1) JTEKT CORPORATION: Mechanism and structure of rolling bearings, SHUWA SYSTEM CO., LTD. (2011) 17 (in Japanese).
2) R. Hosaka, N. Yasuda: JTEKT ENGINEERING JOURNAL, No.1004E (2008) 42.
3) Y. Kobayashi: JTEKT ENGINEERING JOURNAL, No.1010E (2013) 48.
4) JTEKT: Ball & Roller Bearings, CAT No. B2001E.



H. YASUDA* Y. TAKEDA* K. OTSUKA**

* Industrial Machinery Application Engineering Dept., Bearing Operations Headquarters
** Experiment & Analysis Dept., Bearing Operations Headquarters