Study on Low Torque Deep Groove Ball Bearing by Cage Profile Optimization*1

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Deep groove ball bearings can support radial load and axial load in both directions and are widely used as bearings for automobiles and industrial machineries because of advantages such as low torque, low noise and low cost. In recent years, the introduction of automobile fuel economy regulation has been advanced worldwide and will be further strengthened in the future. In the field of industrial machinery, energy saving is also progressing. Deep groove ball bearings used in these fields are required to have lower torque. In many cases, deep groove ball bearings are used for grease lubrication and until now low torque has been promoted by improving grease but there is a limit to the reduction of torque with only improvement of grease, we report on the achievement of low torque by developing a cage of new structure without other performance decreasing.

***Key Words**: deep groove ball bearing, low torque, cage, bearing, friction torque*

1. Introduction

Deep groove ball bearings are widely used as bearings for automobiles and industrial machinery because they can support radial loads and axial loads in both directions, and have the advantages of low torque, low noise, and low cost. Recently, however, fuel efficiency regulations for automobiles have been introduced worldwide, and these will become stricter in coming years. Also, more energy-saving designs are expected to be implemented in the industrial machinery field as well. Consequently, there have been calls for lower torque in the deep groove ball bearings used in these fields. Balls are used as the rolling elements in deep groove ball bearings. The symmetrical, arc-shaped, deep grooves in the inner and outer rings function as the ball's rolling raceway. When adjacent rolling elements come into contact, the surface velocities of each rolling element are equal in magnitude and opposite in direction at the contact area, and so the average velocity is zero. Therefore, a lubricating oil film is not formed in this contact area, causing increased torque and wear of the rolling elements. For this reason, there is a cage that acts as a separator to separate the rolling elements. Deep groove ball bearings, in particular, are assembled by eccentrically aligning the inner and outer rings, inserting the balls between the inner and outer rings, and then centering the inner ring. Due to the limitations arising from this assembly method, deep groove ball bearings have a small filling range of rolling elements in relation to the raceway length (about 50%), and so there is a large space without rolling elements in the raceway, and a cage is necessary to avoid uneven distribution of the rolling elements[1)]. The appearance and structure of a deep groove ball bearing is shown in **Fig. 1**. The torque of a rolling bearing is a result generated from the lubricant agitation resistance, rolling viscosity resistance, sliding friction resistance due to ball spin and differential slip, and sliding friction resistance between the balls and the cage[2)-5)]. In order to reduce the agitation resistance and rolling viscosity resistance of lubricants, it is effective to reduce the viscosity of the lubricant[6)], and this has been widely implemented in recent years. However, although this method can achieve low torque, it often reduces other performance characteristics such as the service life. Deep groove ball bearings are often used with grease lubrication, and until now, low torque has been implemented by improving the grease[7)-11)]. However, there is a limit to how much the torque can be reduced by simply improving the grease. In this paper, the grease behavior inside deep groove ball bearings was visualized to develop guidelines to optimize the cage shape used under grease lubrication for reducing the torque of the deep groove ball bearings used under grease lubrication. This paper also presents the development of a new cage structure that achieves low torque by reducing the grease shear resistance and grease agitation resistance without affecting other performance characteristics.

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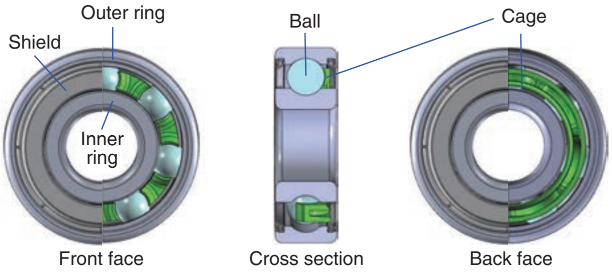

Fig. 1 Deep groove ball bearing (Conventional type)

2. Basic Experiments for Developing New Cage

2. 1 Sample Bearing

The dimensional specifications of the deep groove ball bearings that were used as sample bearings are shown in **Table 1**. Bearings commonly used for automobiles and industrial machinery were selected. In this paper, in order to eliminate the influence of factors other than the cage on the torque, a shielded deep groove ball bearing which does not use a contact seal and has a non-contact system was selected. A conventional deep groove ball bearing used as the sample bearing used a resin crown cage, which has become mainstream in recent years. The crown cage used in a conventional deep groove ball bearing is shown in **Fig. 2**. The type of conventional crown cage is called a rolling element guide system, and the cage is positioned by the claws of the cage holding the rolling elements.

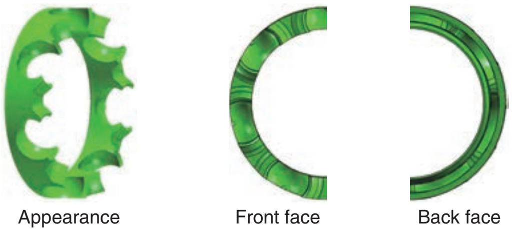

Fig. 2 Cage (Conventional type)

Table 1 Specification of sample deep groove ball bearing

Sample bearing	6302 ZZ
Bearing bore diameter, mm	15
Bearing outside diameter, mm	42
Bearing width, mm	15
Basic dynamic load rating, kN	14.3
Basic static load rating, kN	5.45
Number of ball	7
Material of cage	66 polyamide

2. 2 Grease Distribution Visualization Test

An X-ray CT system was used to visualize the inside of a deep groove ball bearing after a rotation test in order to assess the state of the grease inside the deep groove ball bearing and to examine methods for reducing torque. A photograph of the bearing used for visualization is shown in **Fig. 3**, and **Table 2** shows a detailed list of the component parts. The X-ray irradiation conditions are shown in **Table 3**, and the conditions for the rotation test performed before the visualization test are shown in **Table 4**. Because grease has high X-ray transmittance, low-power X-rays (tube voltage: 100 kV) were irradiated to enable identification of grease and air by their different characteristics. To enable visualization inside a deep groove ball bearing even with low power X-rays, the component parts were made of materials with high X-ray transmittance. The inner and outer rings were made of acrylic resin, the rolling elements (balls) were made of quartz glass, the cage was made of 66 polyamide, and the shield was made of ABS resin. In the rotation test before the visualization test, an axial load of 20 N was applied and the inner ring was rotated at 1 800 min^{-1} for 5 minutes. The rotation test was performed with the same test rig used for the torque measurement under the light load conditions described in the next section.

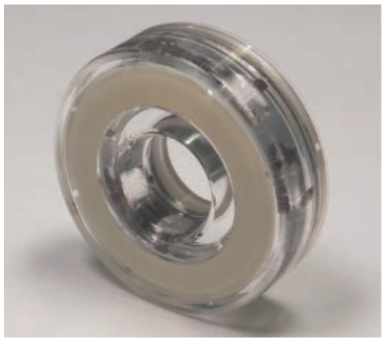

Fig. 3 Sample bearing for visualization

Table 2 Components of sample bearing for visualization

Inner ring		Acrylic resin
Outer ring		Acrylic resin
Ball		Quartz glass
Cage		66 polyamide
Shield		ABS resin
Grease	Thickener	Lithium soap
	Penetration	250
	Kinematic viscosity of the base oil, 40℃, mm^2/s	26
	Amount of grease, g	0.84

Table 3 X-ray condition

X-ray tube voltage, kV	100
X-ray tube current, A	460

Table 4 Rotation test condition

Axial load, N	20
Rotational speed, min^{-1}	1 800
Operating time, min	5

2. 3 Torque Measurement Test

Torque measurements were carried out under two different load conditions. Typical operating conditions for deep groove ball bearings include supporting axial loads only and supporting both axial and radial loads. Under conditions where only an axial load is applied, the force between the rolling element and the cage is expected to be small, and under conditions where radial and axial loads are applied simultaneously, the force between the rolling element and the cage is expected to be large because the rolling element has lead lag. The test rig that was used to measure the torque under light load conditions is shown in **Fig. 4**, and the test conditions are shown in **Table 5**. The test rig that was used to measure the torque under high load conditions is shown in **Fig. 5**, and the test conditions are shown in **Table 6**. The inner ring of the deep groove ball bearing was rotated, and the torque generated in the outer ring was measured using a load cell. Under light load conditions, the deep groove ball bearings were applied to axial loads only, while under heavy load conditions, the deep groove ball bearings were applied to a combined load of the axial and radial loads. The torque of a deep groove ball bearing was measured with high accuracy by applying axial and radial loads through a air bearing. The rotational speed was reduced in 2 000 min^{-1} steps from the maximum rotational speed at each load condition to 2 000 min^{-1}. At each rotational speed, the torque was held for one minute, and the average value of the torque during that time was read as the torque value for that rotational speed.

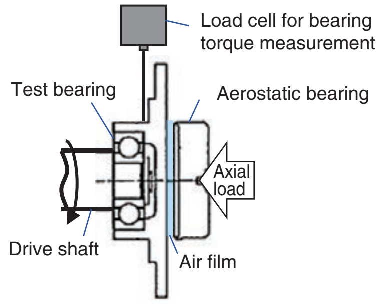

Fig. 4 Test rig (Light load condition)

Table 5 Test condition (Light load condition)

Axial load, N	1
Radial load, N	0
Rotational speed, min^{-1}	14 000→12 000→10 000→ 8 000→6 000→4 000→2 000

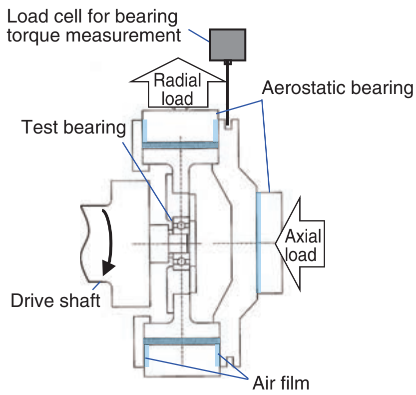

Fig. 5 Test rig (High load condition)

Table 6 Test condition (High load condition)

Axial load, N	1 000
Radial load, N	1 000
Rotational speed, min^{-1}	10 000→8 000→6 000→ 4 000→2 000

2. 4 Grease Distribution Visualization Test Results

The grease distribution inside the grease-lubricated deep groove ball bearing was observed after the rotation test using an X-ray CT system. The results are shown in **Fig. 6**. The grease distribution inside the bearing could be visualized as the difference in shading based on the X-ray transmittance of each bearing component part. The grease clumped together and adhered to the outer ring side by centrifugal force. There was a small clearance between the inner ring side and the grease clump. In a conventional cage, the pockets and the rolling elements are in contact with each other on a surface, and grease is trapped between the pockets and the rolling elements, which is thought to cause torque due to grease shear.

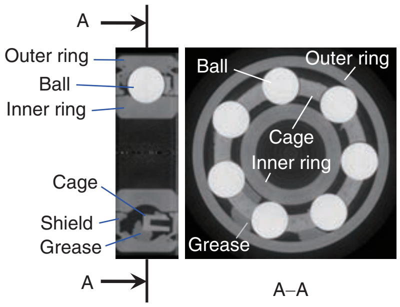

Fig. 6 X-ray CT observation results (Conventional)

3. Cage Shape for Lower Torque

We will examine methods of reducing the torque of deep groove ball bearings by developing a cage with a new structure. From our observation results by X-ray CT, the following guidelines for lowering torque can be seen.

①Shear of grease between the cage and the rolling elements should be minimized because it is a factor in generating torque.
②Because grease adheres to the outer ring side due to centrifugal force, the cage should be located as close as possible to the inner ring side to reduce grease agitation resistance and shear resistance.

Based on these findings, the following cage structure was adopted to achieve lower torque.

①Point contact is made between the cage and the rolling elements.
②A raceway guide system is used instead of the rolling element guide system in which the cage holds the rolling element. There are two possible types of raceway guide systems: an inner ring raceway guide system and an outer ring raceway guide system. The inner ring raceway guide system was selected to reduce grease agitation resistance and shear resistance.

The conventional cage and the new developed cage structure are shown in **Fig. 7** and **Fig. 8**. **Figure 7**a) shows the contact between the cage pocket and the rolling elements in a conventional cage. Since the conventional cage has a rolling element guide system, the conventional cage and the rolling elements make surface contact with each other. **Figure 7**b) shows the contact between the cage pocket and the rolling elements in the developed cage. It can be seen that the developed cage and the rolling elements are in point contact. **Figure 8** shows the guide system of the conventional and developed cages. The conventional cage has a rolling element guide system,

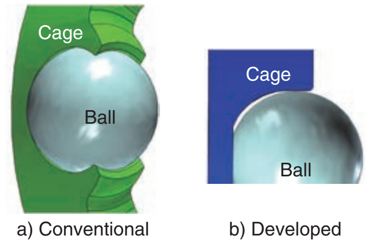

Fig. 7 Ball-cage contact in the deep groove ball bearing

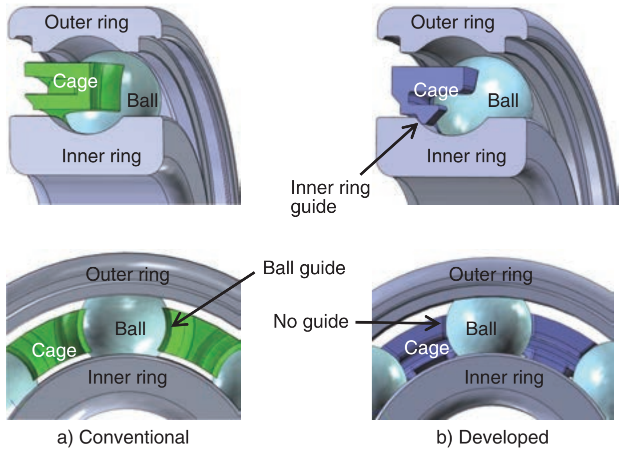

Fig. 8 Guide of deep groove ball bearing

and the cage is assembled on the rolling element. The developed cage has an inner ring raceway guide system, and the cage is assembled on the inner ring.

4. Measurement Results for New Developed Cage Structure

4. 1 Grease Distribution Visualization Test Results

To confirm that the new developed cage structure was functioning as designed, the grease distribution inside the deep groove ball bearing assembled the newly developed cage was observed. The results are shown in **Fig. 9**. The contact area between the developed cage and the rolling elements was confirmed to be a point contact as intended in the design. Since grease adheres as clumps to the outer

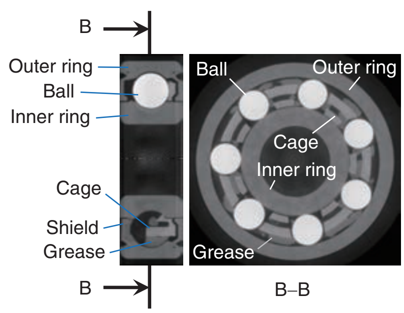

Fig. 9 X-ray CT observation results (Developed)

ring side by centrifugal force and there is little grease adhering to the inner ring side, it was confirmed that the inner ring raceway guide system has a structure that prevents grease from being subjected to agitation and shearing.

4. 2 Torque Measurement Results

Torque measurements were carried out on conventional bearings and on deep groove ball bearings assembled with the new developed structure cage (called “developed bearings” below). **Figure 10**a) and **Fig. 11**a) show the value of the torque measurement results, and **Fig. 10**b) and **Fig. 11**b) show the ratio of the torque of the developed bearing to that of the conventional bearing. Two bearings each were measured for both conventional and developed bearings, and they appear as Conventional 1 and 2 and Developed 1 and 2 in the figures. In contrast to the conventional bearing assembled with a rolling element guide cage, the developed bearing with a raceway guide cage has a lower torque under both light and heavy load conditions. **Figure 10** shows that under light load conditions, the developed bearing has a significant torque reduction effect even though the absolute value of torque is low. In conventional bearings, the torque tends to increase as the rotational speed increases, but in the developed bearing, the change in torque as the rotational speed increases is small, and so the torque reduction effect is greater in the high-speed rotation range. At the highest rotational speed measured, 14 000 min^{-1}, the torque of the developed bearing was about 80% lower than that of the conventional bearing. Under light load conditions, the ratio of reduction in the grease agitation resistance and shear resistance to the bearing torque is considered to be high. Thus, the torque reduction effect on the bearing is significant because the new cage structure greatly reduces grease agitation resistance and shear resistance. From **Fig. 11**, we see that the torque increases as the load increases for both conventional and developed bearings. However, the increase in torque with increasing load is smaller for the developed bearing than for the conventional bearing, and the torque reduction effect of the developed bearing is observed in all measured rotational speed ranges even under high load conditions. It was confirmed that the torque of the developed bearing was about 20% to 40% lower than that of the conventional bearing. Under high load conditions, factors other than the cage, such as rolling viscosity resistance and differential slip, have a greater influence on the generation of torque, and so the ratio of torque reduction by the cage is estimated to be smaller than under light load conditions. Even so, a noticeable reduction effect was obtained. When radial and axial loads are applied simultaneously,

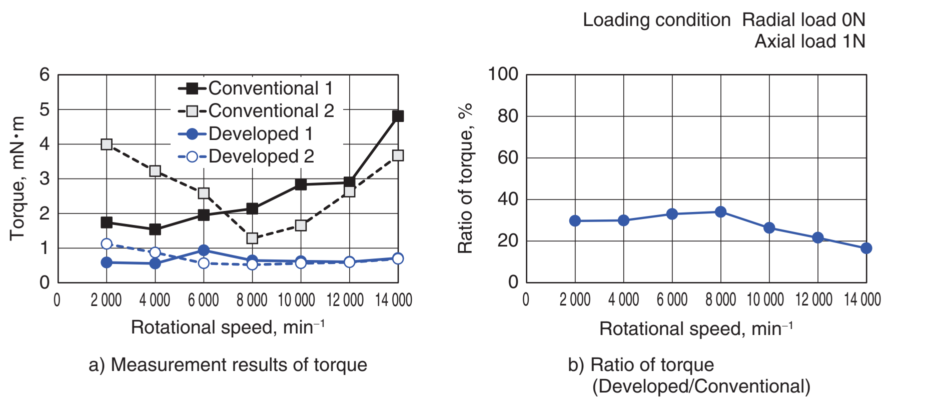

Fig. 10 Torque of deep groove ball bearing (Light load condition)

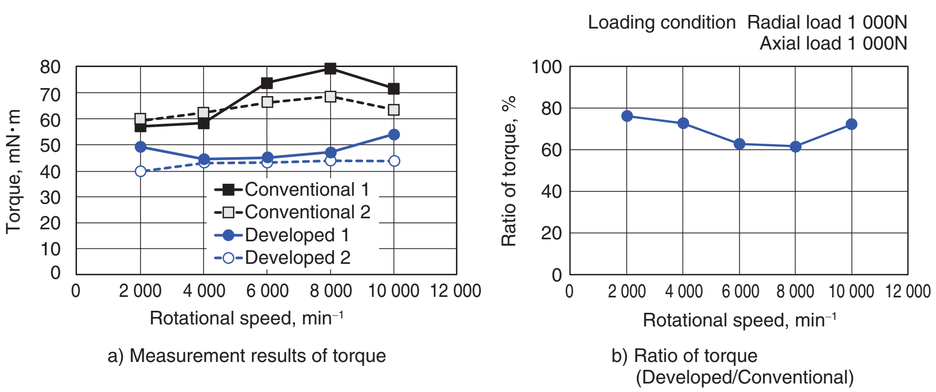

Fig. 11 Torque of deep groove ball bearing (High load condition)

the angle at which each rolling element contacts the inner and outer rings is different, which results in a change in the radius of rotation at which the rolling element passes over the raceway, resulting in a non-uniform velocity of the rolling element. The non-uniformity of the rolling element velocity is a phenomenon called rolling element lead lag. Due to the non-uniformity of the rolling element velocity, the load pressing on the contact area between the cage and the rolling element acts more heavily. However, it is thought that the torque was reduced because the new cage structure reduced the resistance generated when the grease in that area was agitated and sheared.

5. Conclusion

We attempted to reduce the torque of deep groove ball bearings, which has typically been done by improving the grease, by developing a cage with a new structure that does not affect the loading capacity. Our results are shown below.

1) X-ray CT observation of grease-lubricated deep groove ball bearings suggested that grease shear between the cage and the rolling elements contributed to torque loss.
2) X-ray CT observation results showed that the grease adhered to the outer ring side by centrifugal force. It was suggested that the cage should be an inner ring guide in order to reduce the agitation resistance and shear resistance caused by the grease.
3) By developing a new cage structure, the torque under light axial loads was successfully reduced by more than 60% over the entire speed range.
4) The new developed cage structure also significantly reduced the torque under high combined radial and axial loads.

References

1) JTEKT CORPORATION: Basics and Structures of Rolling Bearings, SHUWA SYSTEM CO., LTD (2011) (in Japanese).
2) R. YAMASHITA: EHL in Rolling Bearings, Journal of Japanese Society of Tribologists, Vol. 49, No. 4 (2004) 330 (in Japanese).
3) Tohoku Innovative Materials Technology Initiatives for Reconstruction: Ultra-low Friction Technology Area, Newsletter, 4 (2014) (in Japanese).
4) J. BRANDLEIN, P. ESCHMANN, L. HASBARGEN & K. WEIGAND: Die Walzlagerpraxis, Kogyo Chosakai Publishing Co., Ltd. (1996) 193 (in Japanese).
5) E. WATABAYASHI, H. TAHARA: Bearingu no Ohanashi, Japanese Standards Association (1987) 105 (in Japanese).
6) E. OIKAWA, N. INAMI, M. HOKAO, A. YOKOUCHI & J. SUGIMURA: Bearing Torque Characteristics of Lithium Soap Greases with Some Synthetic Base Oils, J. Engineering Tribology, 226, 6 (2012) 575.
7) K. OONO and N. ABE: Grease and Bearing Torque, Junkatsu, 8, 4 (1963) 243 (in Japanese).
8) M. HOSHINO: Flow Properties of Lubricating Greases and Torque in Rolling Bearings (Part 2), Junkatsu, 25, 8 (1980) 555 (in Japanese).
9) T. OGUCHI: Gurihsu Mikake Nendo ni Tsuite, Junkatsu, 3, 3 (1958) 135 (in Japanese).
10) P. V. LIDDEL & D. V. BOGER: Yield Stress Measurements with the Vane, Journal of Non-Newtonian Fluid Mechanics, 63, 2-3 (1996) 235.
11) M. NITTA, T. TSUDA, H. ARAI, K. SAKAMOTO and K. SAKAI: Effects of Transition Point of Viscoelasticity of Diurea Grease and Molecular Structure of Thickener on Running Torque of the Ball Bearing -Effects of the Alkyl Chain Length of Aliphatic Diurea-, Journal of Japanese Society of Tribologists, 61, 10 (2016) 699 (in Japanese).



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