Efforts towards a More Efficient Resin Cage for Ball Bearings

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In response to the demand for more efficient, faster products using bearings, we JTEKT are continuing the development of highly efficient bearings. For more efficient ball bearings, we are advancing the change to resin materials for cages in order to utilize the benefits of resin. We have therefore developed the resin cage, which achieves improved low torque and high speed performance. The low-torque feature of the developed cage reduces the amount of lubricant accumulation inside the bearing, and its high-speed performance raises the cage's rigidity. In this report, we will introduce the resin cage.

Key Words: *ball bearing, cage, resin, low friction torque, high-speed rotation*

1. Introduction

In recent years, developments have been advancing in industries such as automotive, industrial machinery and home electrical appliance in response to the demand for higher efficiency aimed at reducing CO_2 emissions amidst heightened environmental consciousness, and higher speed in order to improve product performance. Rolling bearings used in these industries require the same higher performance. (High efficiency and high speed capability).

The bearings are generally made with mild steel cages from the perspective of versatility however resin cages are applied increasingly for ball bearings in order to achieve high performance such as low-torque and high-speed. Generally, resin cages are lighter than steel cages and have some advantage such as self-lubrication and flexibility, therefore engineers can utilize these features when developing new products.

This paper introduces a new resin cage for ball bearings.

2. Requirements and Challenges for Resin Cages in Ball Bearings

JTEKT has been developing new resin cages in order to achieve superior low-torque, high-speed performance based on application requirements. **Table 1** shows the performance requirements for bearings and the characteristics of resin materials.

The purpose of a cage is to separate rolling elements at equal intervals around the bearing centerline. The material and shape of the cage has significant influence on bearing performance. Performance requirements vary from application to application.

Table 1 Performance requirements for bearings and the characteristics of resin materials

Bearing performance requirements	Characteristics of resin materials								
	Self-lubricating	High elasticity	Anti-shock property	Corrosion proof	Lightweight	Heat resistant	Rigidity	Lubricant resistance	Dimensional variation
Low-torque	○				○				
High-speed capability	○	○	○		○				
Reduced bearing temperature elevation	○	○			○				
Durability performance under high temperature conditions.	○					△	△	△	△
Acoustic performance	○		○		○				
Corrosion resistance				○					
Lightweight					○				

○ : Beneficial material characteristics
△ : Problematic material characteristics

2. 1 Low-Torque Performance

The low-torque performance of bearings is essential for higher efficiency products. The contributors to drag loss (friction on ball bearings) are shown in **Fig. 1**.

1) Rolling viscosity resistance between the balls and the raceway: Mv
2) Lubricant agitation resistance: Md
3) Rolling friction resistance (Elastic hysteresis loss + differential sliding motion + spin sliding): Mb
4) Sliding friction resistance (Friction between balls and cage + friction between raceway and cage): Mc

Table 2 shows the influence of bearing internal design factors on ball bearing drag loss. Changes of bearing internal design factors are effective in lower drag, however in order to reduce drag without changing these factors, changing the cage shape and the reduction of lubricant flow into the bearing are effective.

Moreover, apart from the cage, ball configuration, raceway curvature, raceway roughness and other internal design features influence the reduction of bearing drag losses, therefore those changes are also need consideration.

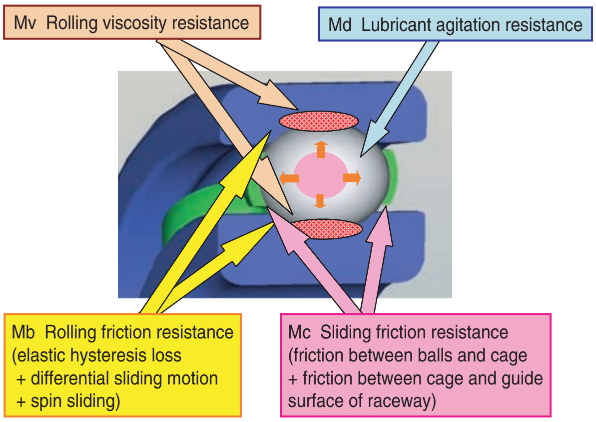


Fig. 1 Elements of ball bearing torque

Table 2 Influence of inner bearing factors on the elements of ball bearing torque

		Mv	Mb	Md	Mc
Bearing internal design factors	Ball configuration	○	○	○	○
	Raceway curvature	○	○	–	–
	Raceway roughness	○	○	–	–
	Clearance	○	○	–	–
	Raceway hardness	○	○	–	–
Agitation factor	Cage design	–	–	○	○
	Lubricant amount	–	–	○	–

○ : Influence – : No influence

2. 2 High-Speed Performance

Using resin cages which are lightweight and self-lubricating is effective in improving the high-speed performance of bearings. However, resin cages may become deformed due to an increased of centrifugal force with high-speed rotation. Deformation of the cage could lead to problems such as bearing temperature elevation due to interference between the cage and balls, increased cage stress leading to breakage, etc. Therefore a cage design should consider the rigidity of the cage to avoid such problem.

2. 3 Challenges of Resin Cages

Compared with steel cages, resin cages are generally inferior regarding heat resistance, rigidity and lubricant resistance. Measures such as increasing size would improve cage rigidity however limitations on bearing size must be considered. JTEKT has implemented countermeasures for the challenges of resin cages through design incorporating CAE analysis and experimental confirmation regarding rigidity, material selection considering heat resistance for temperatures in common use and compatibility experiments with lubricants to confirm resistance to damage.

3. Features of the Developed Cage

3. 1 Low-Torque Cage

3. 1. 1 Overview of the Low-Torque Cage

The authors developed a cage with excellent low-torque performance in a lubricant-immersed environment (**Fig. 2**). A key factor of the development was controlling the amount of oil flow into the bearing by modifying the cage shape. It is already known through the development of tapered roller bearings that controlling the amount of oil flow is beneficial towards reducing torque[1]. **Table 3** shows a comparison between the current cage and the developed cage. The current steel cage and resin snap cage have large clearances between the inner ring O.D. - cage I.D., and the outer ring I.D. - cage O.D., therefore a large amount of oil easily enters and remains in the

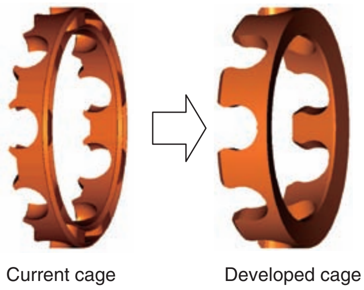
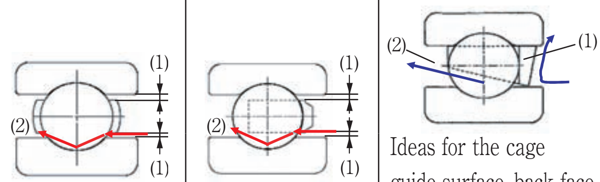


Fig. 2 Form of developed cage

Table 3 Cage form comparison

Current cage		Developed cage
Steel cage	Resin snap cage	Low-torque resin cage
		Ideas for the cage guide surface, back face angle and I.D. form
(1) Oil influx easily increasing the amount of oil inside the bearing (2) Small amount discharged from inside the bearing		(1) Suppress Oil influx (2) Encourage discharge of oil from inside bearing

←← : Oil flow

bearing. In the developed cage, JTEKT has optimized the guide clearance between outer ring and cage in order to suppress the influx of oil inside the bearing. Furthermore, Tapered back face of the cage suppress oil influx due to centrifugal force created during cage rotation. Also, re-design of cage bore shape promote the discharging of oil from inside the bearing, the remained oil amount within the bearing has been reduced.

The results of CAE analysis to verify the effects of these changes and results of optimizing shape of each part are shown below.

<Fluid analysis>

A fluid analysis was performed on the current and developed cages in order to compare and confirm the oil flow around and inside the bearing. **Table 4** shows a fluid analysis model and analysis conditions, while **Fig. 3** shows the results of the fluid analysis. In contrast with the current cage, whereby a large amount of oil easily enters and remains within the bearing, the following advantages were confirmed in regards to the developed cage.

(1) The guide clearance labyrinth is able to suppress oil influx.
(2) The tapered back face and centrifugal force causes the oil flow direction to change from downwards to upwards.
(3) The pumping effect of the tilted shape aids in discharging oil from the bearing.
(4) The pumping effect prevents a reflux of the oil into the bearing.

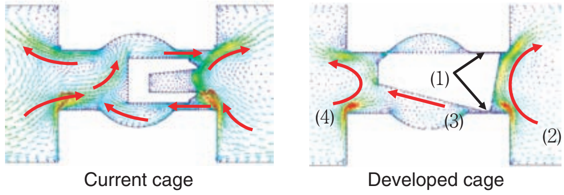


Fig. 3 Results of fluid analysis

<Form optimization>

In order to achieve the optimal design for the developed cage, the authors compared the oil amount entering the bearing with cage guide type, back face angle of the cage and guide clearance between cage and raceway as parameters (**Fig. 4**). **Table 5** gives the test conditions, while **Fig. 5** shows the test equipment and **Fig. 6** gives the measurement results of the penetrated oil. The cage shape that had the smallest amount of oil penetration was a combination of an outer ring guide and back face angle (b3) and guide clearance (c1). The developed cage with an optimized design had more than 90% less oil penetration than the current cage.

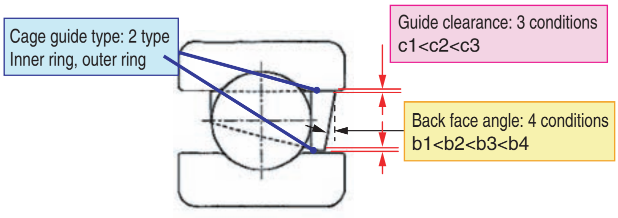


Fig. 4 Cage form parameters

Table. 4 Fluid analysis model and analysis conditions

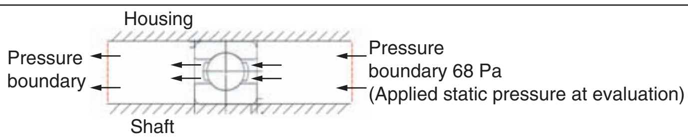
Basic bearing number	6206 (I.D. ϕ30 × O.D. ϕ62 × W16)
Rotational speed, min^{-1}	5 000
Oil bath condition	Applied 68 Pa of pressure difference to the left and right in a oil bath condition
Oil type	CVT oil
Oil temperature, ℃	30
Fluid analysis model	

Table 5 Test conditions

Basic bearing number	6206 (I.D. ϕ30 × O.D. ϕ62 × W16)	6206 (I.D. ϕ30 × O.D. ϕ62 × W16)
Test conditions	Combined load	Radial load
Radial load, N	2 000	2 000
Axial load, N	1 000	0
Lubricating method	Circulating lubrication	Circulating lubrication
Oil type	ATF	ATF
Oil temperature, ℃	30 ± 2	30 ± 2
Oil amount, fixed*	Shaft center level (shaft center – 10mm)	Shaft center level (shaft center – 10mm)

* Adjust supplied lubricant so that the lubricant surface is a fixed height.

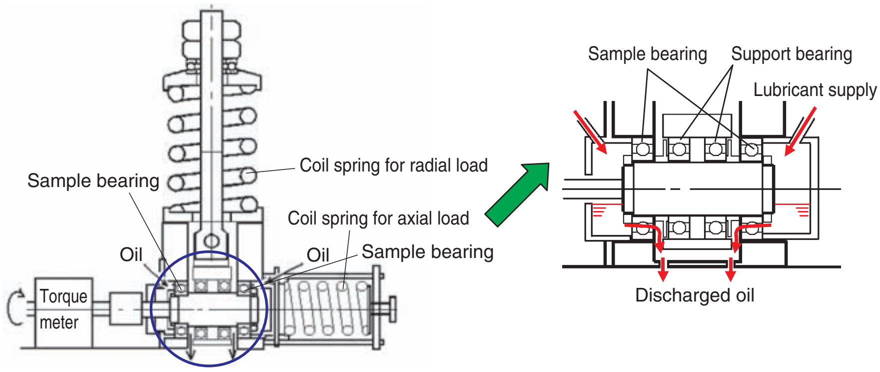


Fig. 5 Test equipment

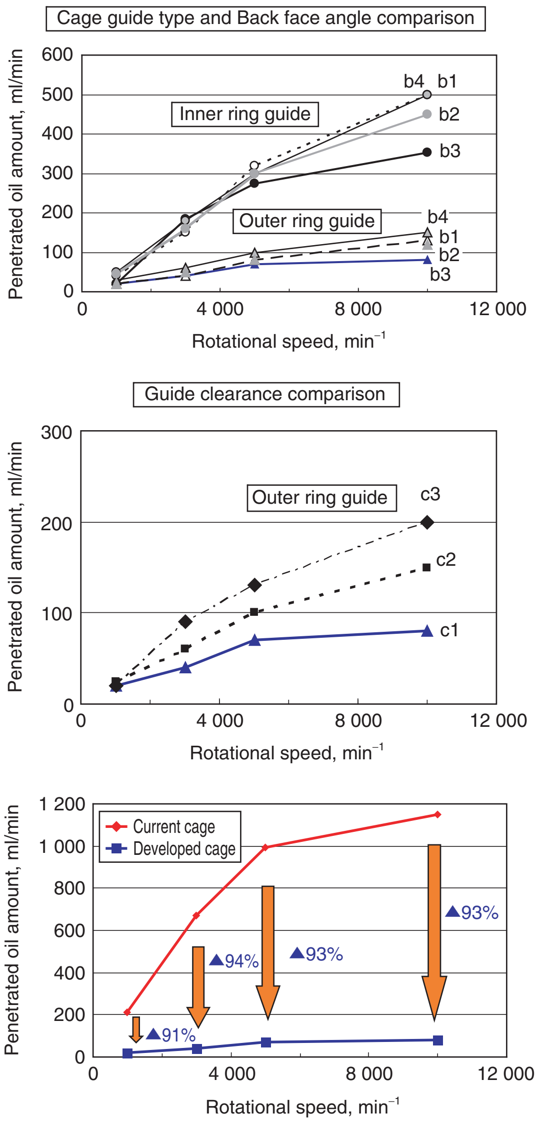


Fig. 6 Results of penetrated lubricant measurement

3. 1. 2 Confirmation of Effectiveness

The authors conducted an experiment to confirm the effectiveness of the developed cage on reducing rotation torque.

Figure 7 shows the measurement results of rotational torque. Compared to a bearing with a current cage, the rotational torque of the bearing with the developed cage was reduced by a maximum of 31% under radial load conditions and a maximum of 16% under combined load conditions, proving that the developed cage was effective in reducing torque. The difference of the rotational torque between the two load conditions is believed to mainly be due to the rolling friction resistance caused by the difference in load.

The elevated temperature property was also confirmed, as seizure is believed to be a trade-off when the amount of oil is reduced. **Table 6** shows the test conditions while **Fig. 8** shows the results of an elevated temperature test. The elevated temperature property of the developed cage was equivalent to that of the current cage, confirming there was no influence regarding lubricantion of the bearing.

As described above, the reduction of oil remaining in the ball bearing made it possible to reduce the agitation resistance of the oil and achieve lower torque.

Table 6 Test conditions

Basic bearing number	6206 (I.D. ϕ30 × O.D. ϕ62 × W16)
Radial load, N	1 200
Axial load, N	600
Lubricating method	Circulating lubrication
Oil type	ATF
Oil temperature, ℃	100 ± 5
Oil amount, ml/min	50

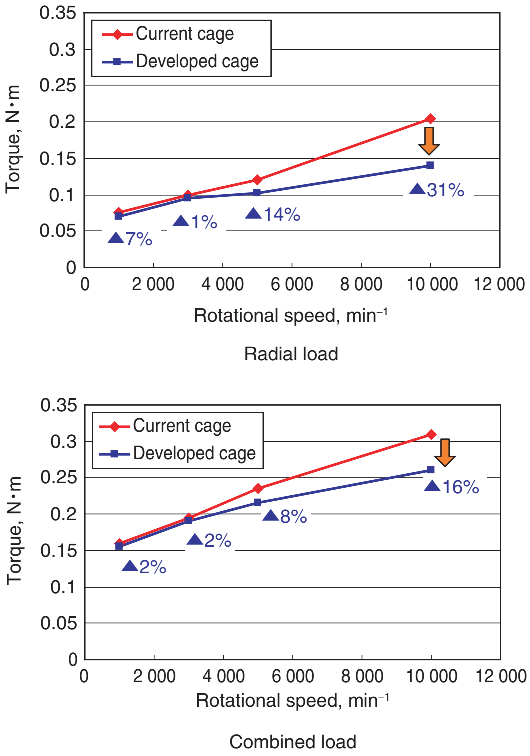


Fig. 7 Results of torque measurement

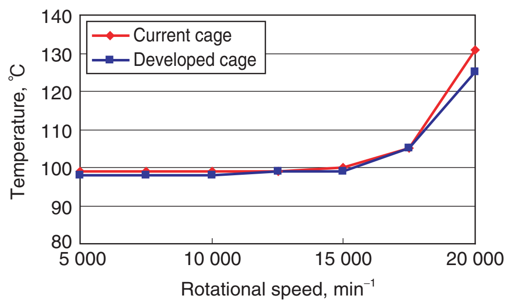


Fig. 8 Results of elevated temperature test

3. 2 High-Speed Rotation Cage

3. 2. 1 Overview of Cage for application in High speeds

JTEKT has developed a cage with superior high-speed performance when used in lubricant-immersed environments (**Fig. 9**). The key focus of the development was, in order to increase cage rigidity, altering the design from a single-support shape used current cage to a dual-support shape, and suppressing the deformation of the cage with centrifugal force under high-speed rotational condition, thereby preventing interference with the balls and suppressing temperature elevation. Furthermore, outer ring guide and a flat surface on pocket I.D. to create point contact were adopted in order to increase high-speed performance even further.

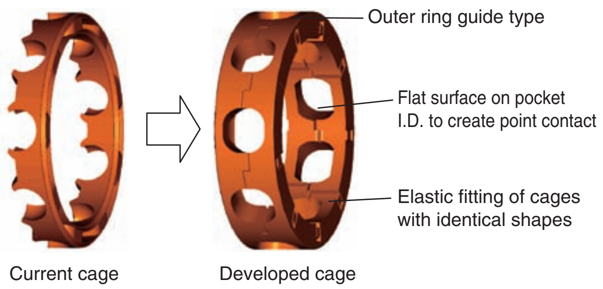


Fig. 9 Form of developed cage

3. 2. 2 Confirmation of Effectiveness

(1) Deformation analysis

A deformation analysis using centrifugal force was performed using the current cage and developed cage. **Table 7** shows the analysis conditions, while **Fig. 10** shows the analysis results. It was confirmed that, while there was large deformation of the current cage causing interference with the balls, there was only slight deformation upon high-speed rotation for the developed cage, therefore no interference with the balls.

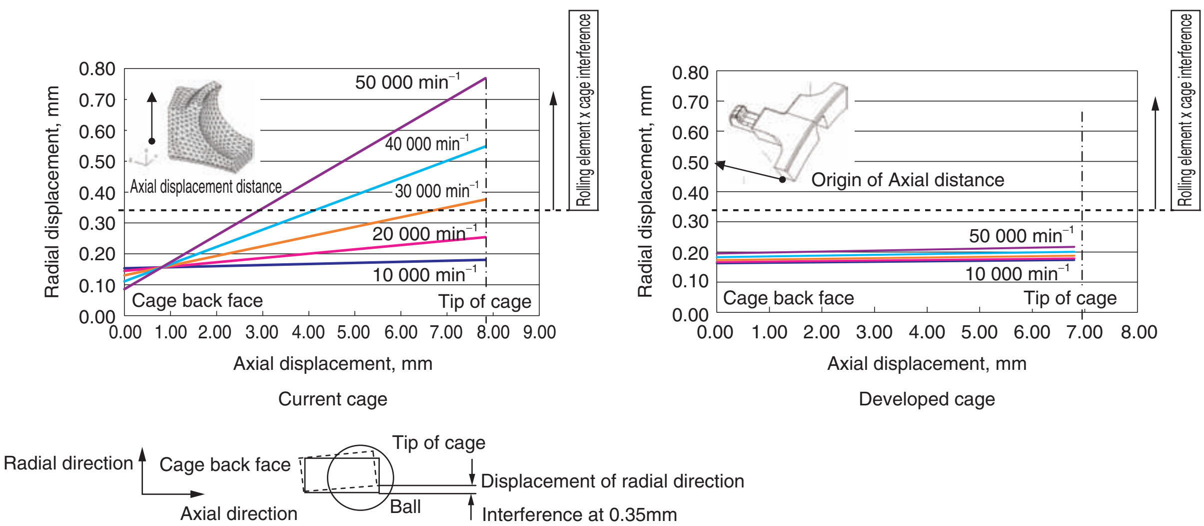


Fig. 10 Analysis results

Table 7 Analysis conditions

Basic bearing number	60/32 (I.D. ϕ32×O.D. ϕ58×W13)
Rotational speed, min^{-1}	10 000⇒20 000⇒30 000……50 000 (step-up 10 000 each time)
Temperature, ℃	100

(2) Experimental Confirmation

An experiment was conducted using bearings with the current cage and developed cage in order to confirm the effectiveness in reducing temperature elevation. **Table 8** shows the test conditions, while **Fig. 11** shows the measuring results of elevated temperature for both the current cage bearingand developed cage bearing. Compared with the current cage bearing, temperature elevation performance was significantly improved on the developed cage bearing. Experimental confirmation showed that the developed cage did not interfere with the balls with high-speed rotation and increased high-speed performance was possible.

Table 8 Test conditions

Basic bearing number	6204 (I.D. ϕ20×O.D. ϕ47×W14)
Radial load, N	0
Axial load, N	550
Lubricating method	Drop lubrication
Oil type	ATF
Supplied oil, ml/min	100

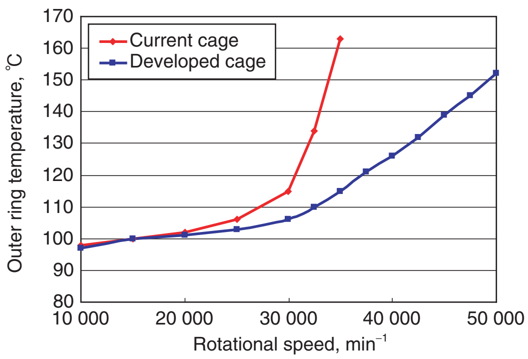


Fig. 11 Results of elevated temperature measurement

4. Conclusion

It is predicted that demands on ball bearings to achieve even higher performance will intensify in the automotive industry, and all industrial areas, in the future. Moreover, to accompany the harsher conditions of use, diversification and higher performance requirements, further advancements will also be required for the cages utilized in bearings.

JTEKT will continue to further advance the development of fundamental technologies of bearings which include cage development aiming to accommodate technical innovation by JTEKT advanced bearing technology in the future.

References

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