1. Introduction

In recent years, machine tools are becoming faster, more efficient, more accurate, and more compact. Accordingly, there is a great demand for faster, more rigid, longer-lasting, higher output, and smaller main-spindle servomotors. To meet the engineering needs of such servomotors, bearings must run faster or achieve high \( \text{dmn} \) values. Today, a low-cost and easy-handling deep groove ball bearing is desired to satisfy those needs in the operation range traditionally and primarily served by angular contact ball bearings.

Having realized the situations, NTN developed a "next generation deep groove ball bearing for high-speed servomotors" that provides "high-speed" and "long life."

This paper outlines this new bearing.

2. Bearing structure

Sealed and greased deep groove ball bearings are typically used for motors. Among those bearings, some are used for high-speed motors. Because the cage of such a bearing is subject to large centrifugal force, the bearings for high-speed motors typically use pressed steel cage that is made of highly rigid metallic sheet.

The pressed steel cage can produce relatively large collision noise (cage noise) upon impact with the balls.

For this reason, more synthetic-resin cages are used now. They are easy to manufacture, lightweight, and self-lubricating. The synthetic-resin crown-type cage, however, is subject to deformation due to centrifugal force at high-speed ranges. The deformation causes interference between the cage...
and other parts, resulting in temperature rise of the bearing and increase in the rotational torque.

The deep groove ball bearing developed this time has resolved the above problems with the synthetic-resin crown-type cages and improved its "high-speed" performance. This new bearing also improved endurance of the grease, thereby "extending bearing life."

(1) New cage

[Features of new cage]

1. High-speed
2. Improved lubrication
3. Improved productivity designing

① High-speed

The traditional synthetic-resin crown-type cage (see Photo 1) is open to one side. This profile causes the prongs on the open side to widen due to centrifugal force in high-speed operation (see Fig. 1). This deformation leads to interference with the balls and other components, which in turn contributes to the rise in the bearing temperatures and the rotational torque.

The configuration of the new cage assumed the structure of a traditional pressed steel cage and combined two resin-molded wave-type rings of identical shapes (see Photo 2).

Compared to the traditional crown-type cage, the new cage does not have openings, which improves rigidity of the pockets and dramatically reduces deformation by centrifugal force in high-speed operation.

[FEM analysis of new cage deformation by centrifugal force]

Table 1 shows the analysis conditions.

<table>
<thead>
<tr>
<th>Table 1 Condition of FEM analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing</td>
</tr>
<tr>
<td>Inner ring rotating speed, min⁻¹</td>
</tr>
<tr>
<td>Ambient temperature, ˚C</td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Density</td>
</tr>
<tr>
<td>Modulus of vertical elasticity of material, MPa</td>
</tr>
<tr>
<td>Modulus of linear expansion of material, /k</td>
</tr>
</tbody>
</table>

* $d$: Bearing ID mm, $d_n$: Rolling element pitch circle diameter mm, $n$: Rotating speed min⁻¹

[FEM analysis results]

The analysis was made to the pocket and a single joint. The calculations assumed that the cage was subject to centrifugal force only in high-speed operations.

Fig. 2 shows the analysis results of the cage deformation. Expansion was observed generally in the radial direction. The largest deformation was found at the joints due to the joint clearance (set in the radial direction for easy assembly). Nevertheless, deformation of the pockets is restricted and the calculations confirmed that there would be no interference between the cage and other components.
Improved lubrication

The new cage has grease grooves inside the pockets (see Photo 3), thus improving lubrication inside the pockets. They also improve the bearing life and reduce the bearing noise.

Improved productivity designing

With the metallic-sheet wave-type cages, coupling is typically accomplished by crimping the rivets (see Fig. 3). However, the new synthetic-resin cage simply requires pressing together the coupling prongs of the two wave-type rings, reducing the assembly time.

The coupling portions are designed such that the two wave-type rings are of an identical profile, which requires only one mold for manufacturing (see Fig. 4).
(2) Long-life grease "ME-1"
(For details, see Page 20, "Development of high-speed, long-life grease.")
The new long life grease "ME-1" was developed with attention paid to oxidation stability of the base oil and selection of the most effective oxidation inhibitor. This grease almost doubled the life of NTN’s standard motor grease (MP-1). This grease is now adopted as standard for the "next generation deep groove ball bearing for high-speed servomotors."

Composition and properties of ME-1 grease
ME-1 grease uses urea compound as thickener and, for the base oil, it uses a mixture of special ester oil and PAO. To prevent oxidation of the base oil, an appropriate anti-oxidant is added, increasing the grease life.

Table 2 shows the composition and properties of ME-1 grease.

<table>
<thead>
<tr>
<th>Composition and properties of ME-1 grease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickener: Urea</td>
</tr>
<tr>
<td>Mixture thickness, 60W, 25°C: 250 (JIS K2220.7)</td>
</tr>
</tbody>
</table>

High temperature endurance
A high-temperature endurance test (ASTM D3336) was carried out on the new grease (ME-1). Fig. 5 shows the test results of a commercially available grease and ME-1 grease.
As compared to commercially available grease A, endurance of ME-1 grease is more than five times, and to commercially available urea grease B and MP-1 it is 1.5 to 2 times.

3. Results of functionality confirmation test

(1) High-speed operation
To evaluate the high-speed performance, a temperature rise test was conducted.

Bearing specifications: See Table 3.

<table>
<thead>
<tr>
<th>Bearing</th>
<th>Cage</th>
<th>Grease</th>
<th>Amount of grease sealed</th>
<th>Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6308</td>
<td>Synthetic resin crown type cage</td>
<td>New grease (ME-1)</td>
<td>80% of static space</td>
<td>Non-contact type rubber seal</td>
</tr>
</tbody>
</table>

Test conditions
[Maximum rotating speed]
\[ n = 15,000 \text{min}^{-1} \]
\[ (d_n \text{ value} = 0.6 \text{ million}, d_{m1} \text{ value} = 0.95 \text{ million}) \]

[Temperature]
Room temperature

[Test machine]
Rapid acceleration/deceleration test machine (see Fig. 6)

Fig. 5 Endurance test result

Fig. 6 Rapid acceleration/deceleration test machine
3 Test results

Fig. 7 shows the relationship between the rotating speed and the outer-ring temperature rise. Temperatures were read when it stabilized. The test was terminated as soon as the temperature exceeded 100°C.

No significant difference was observed between the synthetic-resin crown-type cage and the new synthetic-resin cage up to $n=12,000\, \text{min}^{-1}$ ($dn$ value=0.45 million, $d_{an}$ value=0.75 million). At $n=15,000\, \text{min}^{-1}$ ($dn$ value=0.6 million, $d_{an}$ value=0.95 million), the crown-type cage showed abnormal temperature rise and the test was interrupted. No abnormal temperature rise was noticed with the new cage except for that possibly caused by grease resistance.

The bearing inspection after the test and the FEM analysis results confirmed that the abnormal temperature rise found with the crown-type cage was caused by its contact with the other bearing components due to cage deformation by centrifugal force.

2) Endurance

To evaluate high-temperature endurance of the cages, a high-temperature, high-speed endurance test was conducted.

1 Bearing specifications: See Table 4.

<table>
<thead>
<tr>
<th>Table 4 Test bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
</tbody>
</table>

* Synthetic resin: PA46 + GF25%

2 Test conditions

[Rotating speed]
A: $n=11,111\, \text{min}^{-1}$  
($dn$ value=0.5 million, $d_{an}$ value=0.7 million)
B: $n=13,333\, \text{min}^{-1}$  
($dn$ value=0.6 million, $d_{an}$ value=0.85 million)

[Bearing temperatures]
130°C (at bearing’s outer diameter)

[Test machine]
High-temperature, high-speed endurance test machine (see Fig. 8)
3. Test results

Fig. 9 shows the relationship between the cage type and the test duration.

The new synthetic resin cage + new grease (ME-1) demonstrated three time and greater endurance than the pressed steel cage + traditional grease (MP-1), despite the fact that it was run at even higher rotating speeds.

This superb endurance is attributable to excellent high-temperature endurance of the new grease (ME-1) and to improved lubrication characteristics of the new cage.

4. Conclusion

By adopting the new synthetic-resin cage, the “Next generation deep groove ball bearing for high-speed servomotor” can successfully prevent abnormal temperature rise at the $dn$ value of 0.6 million (the $da$ value of 0.85~0.95 million) which the traditional design was unable to resolve. Additionally, adoption of the new grease “ME-1” realized a longer life of this bearing. Furthermore, the unique cage profile has reduced the assembly time and minimized the cost-increase associated with the traditional types (pressed steel cage, synthetic-resin crown-type cages) by controlling the mold costs.

We believe that this bearing can contribute to the development of the servomotors for machine-tool main spindles in the areas of high-speed operation and longer service life. We will continue to develop new products that support advancing performance of the latest machine-tool motors.

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