1. Introduction

Due to a recent increase of small engines and ISG-mounted vehicles focused on downsizing technology, layout of engine auxiliary system has become complex with greater restrictions on placement of auxiliary belts and bearings for pulleys. Degree of freedom for placement layout increases by reducing pulley diameters; however, that forces the bearings for pulleys to rotate at higher speeds.

In addition, requirements for improving comfort and reliability of automobiles are demanding bearings for pulleys to acquire higher functionality such as measures against hooting noises when running cold and protection against brittle flaking, as well as low torque properties.

High Speed Rotation Ball Bearings for Pulleys are capable of enduring up to 20,000 rotations (outer wheel rotation) per minute by suppressing a rise in heat by optimizing the cage, seal, inner/outer rings, balls and grease.

At the same time, they achieved retaining and improving measures against hooting noises when running cold, protection against brittle flaking and low torque properties.

This developed product is introduced in the following:

2. Characteristics

The following are the characteristics of the High Speed Rotation Ball Bearings for Pulleys:

- High speed: permitted rotational speed of 20,000min⁻¹ (in rotation with outer ring size of 6203)
- Hooting noise when running cold: no noise at -40˚C
- Protection against brittle flaking: equivalent to the conventional product (under NTN test conditions)
- Running torque: 10% reduction (compared to NTN conventional product)
- Durability against high temperature: equivalent to the conventional product (under NTN test conditions)

3. Structure and performance

3.1 High speed

Fig. 1 shows issues associated with high speed rotation of bearings for pulleys.

In high speed rotation, cages can deform due to centrifugal force causing friction with steel balls and outer rings which produces heat. In addition, as the bearings for pulleys are used for outer ring rotation,
centrifugal force is also applied to the seal lips, causing heating or damage to seal properties due to a change of seal reaction force. Furthermore, seizure or bearing life reduction may be caused by shortage of grease supply and increased rolling friction. Due to these issues, the permitted rotational speed of bearings for pulley was conventionally around 15,000min⁻¹.

3.2. Design objectives of developed product
The cage, seal, inner/outer rings and steel balls of the High Speed Rotation Ball Bearings for Pulleys (hereafter "developed product") are made to endure high speed rotation.

3.2.1 Cage
For the shape of cage of the developed product, resin cage developed for Grease Lubrication Type High Speed Deep Groove Ball Bearings for EVs and HEVs 2) was adopted.

Fig. 2 shows the comparison with the conventional resin cages.

The following 3 points were improved to reduce deformation during high-speed rotation.
(1) Thicker pocket bottom
   → improvement of cage rigidity
(2) Reduction of material between cage pockets
   → reduction of centrifugal force
(3) Adoption of high strength material
   → improvement of cage rigidity

The results of centrifugal analysis of the cages are shown in Fig. 3 and 4.
3.2.2 Seal

Fig. 5 shows an overview of NTN’s standard bearing seal for pulley.

Fig. 5 NTN standard bearing seal for pulley

The standard bearing seal for pulley consists of 3 lips.

(1) Grease lip
- Penetration of grease to the area around the main lip is reduced by the labyrinth structure with the inner seal groove to prevent grease leakage.

(2) Main lip
- Prevention of grease leakage and penetration of water/dust, as well as low torque are ensured, maintaining interference even with centrifugal force due to rotation of the outer ring.

(3) Dust lip
- Penetration of foreign objects from outside is reduced by the labyrinth structure with the inner seal groove.
- Even when penetration occurs, they can be ejected by the tapered shape of the dust lip.

For the shape of the developed seal, the center of gravity of the seal lip and thickness of the waist section of the lip are optimized to minimize variation of reaction force in the high-speed rotation range for reducing heat and to keep low torque. The result of analysis of the seal reaction force is shown in Fig. 6 and 7.

With the conventional products, seal reaction force tends to decrease when rotational speed increases regardless of the initial seal interference, and heat generation due to seal interference becomes unstable even at a high rotational speed range around 20,000 min⁻¹, because of large variance of seal reaction force.

On the other hand, with the developed products, variance of seal reaction force is small, which reduces heat generation at high rotational speed range even with different initial seal interference, as the center of gravity of seal lips is optimized.

Seal interference and torque (calculated value) of the conventional and developed products are shown in Fig. 8 and 9.

The seal interference of the developed product is increased to improve the seal lip followability. On the other hand, lip rigidity is reduced, which achieved low torque and low heat generation by optimizing the thickness of the waist section of the seal lip.

Fig. 6 Seal centrifugal force analysis (Current)

Fig. 7 Seal centrifugal force analysis (Developed)

Fig. 8 Seal calculation interference (Comparison of current and developed)
3.2.3 Bearing internal specification

Bearing internal specification of the developed product was set to maintain load carrying capacity compared to the conventional product, and to decrease PCD and reduce heat generation by revising steel ball size.

Table 1 shows the bearing internal specification.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Conventional bearings</th>
<th>Developed bearings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key dimensions (mm)</td>
<td>φ17xφ40x12</td>
<td></td>
</tr>
<tr>
<td>Size and number of steel balls</td>
<td>9/32in x 7</td>
<td>17/64in x 8</td>
</tr>
<tr>
<td>Basic dynamic load rating (N)</td>
<td>9,600</td>
<td>9,500</td>
</tr>
<tr>
<td>Basic static load rating (N)</td>
<td>4,600</td>
<td>4,700</td>
</tr>
</tbody>
</table>

3.3 Other requirements of bearings for pulleys and their measures

3.3.1 Hooting noise when running cold

Hooting noise when running cold is a high pitch tone, like a whistle generated when running in low temperatures, known to be generated for a few seconds from the bearings for pulleys when an engine starts.

Fig. 10 shows the presumed mechanism of the hooting noise. Since a decrease of grease consistency in low temperatures is assumed to be the cause of the hooting noise, newly developed grease with improved low temperature fluidity was adopted for the developed product.

Table 2 shows a comparison of the grease characteristics for the conventional product and developed product.

The developed grease lowered the fluid point in low temperatures with softer consistency. This achieved 100% pass rate of hooting noise (no hooting noise) when running cold at -40˚C from 70% of the conventional products under the NTN measurement conditions.

3.3.2 Protection against brittle flaking

Brittle flaking is a singular flaking including microstructural change which is observed in the bearings used for accessories of automotive engines and occasionally in the bearings for pulleys, as well. Fig. 11 shows the presumed mechanism of the brittle flaking.

The developed product suppresses slipping of steel balls and penetration of hydrogen by adjusting grease additives and thermal treatment of inner/outer rings to ensure protection against brittle flaking equivalent to the conventional products.

Table 2 Grease characteristics comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Conventional grease (1)</th>
<th>Conventional grease (2)</th>
<th>Developed grease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base oil</td>
<td>Ester + PAO</td>
<td>Ester</td>
<td>Ester + PAO</td>
</tr>
<tr>
<td>Thickener</td>
<td>Urea</td>
<td>Urea</td>
<td>Urea</td>
</tr>
<tr>
<td>Base oil fluid point (˚C)</td>
<td>−42.5</td>
<td>−42.5</td>
<td>−50 or less</td>
</tr>
<tr>
<td>Worked penetration</td>
<td>270</td>
<td>280</td>
<td>286</td>
</tr>
</tbody>
</table>

Fig. 11 Generation mechanism of brittle flaking
3.4. Evaluation results of developed product
3.4.1 Test of elevation in temperature

Elevation of temperature due to an increase in rotational speed was confirmed in the test. The test conditions are shown in Table 3, appearance of tester is shown in Fig. 12 and the test results are shown in Fig. 13, respectively.

Elevation of temperature of the developed product at 20,000min\(^{-1}\) was less than that of the conventional product at 15,000min\(^{-1}\). The developed product achieved a permitted rotational speed of 20,000min\(^{-1}\).

### Table 3 Test condition

<table>
<thead>
<tr>
<th>Test condition</th>
<th>6203</th>
<th>960</th>
<th>180</th>
<th>100</th>
<th>115</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radial load (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belt winding angle (°)</td>
<td>180</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmosphere temperature (°C)</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 12 Temperature rising tester](image_url)

### Table 4 Test condition

<table>
<thead>
<tr>
<th>Test condition</th>
<th>6203</th>
<th>960</th>
<th>20,000</th>
<th>80</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radial load (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belt winding angle (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulley rotational speed (min(^{-1}))</td>
<td></td>
<td></td>
<td>20,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmosphere temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Operating time (h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>400</td>
</tr>
</tbody>
</table>

![Fig. 14 Appearance of after test sample](image_url)

3.4.2 High speed durability test

Durability at the rotational speed of 20,000min\(^{-1}\) was confirmed. The test conditions are shown in Table 4 and the appearance of the test product after the test is shown in Fig. 14.

The durability equivalent to the conventional product was confirmed after 400 hours of operating time without flaking, seizure, damage or abnormal noise.

### Table 5 Test condition

<table>
<thead>
<tr>
<th>Test condition</th>
<th>6203</th>
<th></th>
<th>0→12,000 (60s sweep)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing size</td>
<td></td>
<td>No-load</td>
<td>(only the weight of test jig)</td>
</tr>
<tr>
<td>Radial load (N)</td>
<td></td>
<td></td>
<td>(only the weight of test jig)</td>
</tr>
<tr>
<td>Inner ring rotational speed (min(^{-1}))</td>
<td></td>
<td></td>
<td>0→12,000 (60s sweep)</td>
</tr>
<tr>
<td>Outer ring temperature (°C)</td>
<td></td>
<td></td>
<td>-40</td>
</tr>
</tbody>
</table>

![Fig. 13 Temperature rising test result](image_url)

3.4.3 Running torque

Torque reduction effects were confirmed in the low temperature torque test. The test conditions are shown in Table 5 and the test results in Fig. 15.

The low temperature torque of the developed product was confirmed to be approx. 15% lower than the conventional product.
4. Conclusion

In this paper, we have introduced the High Speed Rotation Ball Bearings for Pulleys. This developed product achieved outer ring rotational speed of 20,000 min⁻¹ with the size of 6203, and met the requirements of bearings for pulleys (measures against hooting noises when running cold, protection against brittle flaking and low torque properties), simultaneously, by optimizing design of the cage, seal, grease and bearing internal specifications.

The developed product is expected to contribute to downsizing and fuel efficiency of engines and will be actively marketed. We are poised to promote development of new products to meet the requirements of ongoing improvement of functionality.

References