Low Temperature Rise and Low Torque Tapered Roller Bearing

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Power transmission devices such as automobile transmissions and differentials are becoming smaller due to environmental regulations, and the use of low-viscosity oil and reduced oil quantity are advancing for high efficiency and power savings. The tapered roller bearings used in such power transmission devices are required to withstand severe conditions and to have low friction. In order to meet these demands, **NTN** has developed a tapered roller bearing with a new shape resin cage and incorporated design technology for low torque improvement and low temperature rise, thus attaining the world's highest level for both low torque performance and high seizure resistance. This paper introduces the structure and performance of the developed product "Low Temperature Rise and Low Torque Tapered Roller Bearing".

1. Introduction

The automotive industry is facing major changes[1] such as the transition to Connected, Autonomous, Shared, Electric (CASE) and smart mobility.

As companies boost their social responsibility toward the environment with measures such as Corporate Average Fuel Economy (CAFE) regulations[2], increasingly stringent CO_2 regulations means companies are focusing on electrification as a viable solution.

With the growing need for safety and comfort while driving, efforts are not only focusing on automated driving and collision safety, but also on achieving a greater freedom of layout design and more cabin space with the use of compact power transmission units.

The background to this shift in mobility is that automotive power transmission devices like the transmission and differential use an internal lubricant with lower viscosity and reduced quantity because such devices are becoming more compact with lower torque performance.

Tapered roller bearings that have a high load capacity are used in power transmission devices. However, these bearings have a higher rotational torque compared to ball bearings and as such suffer from sudden temperature increases under severe lubrication conditions. To achieve a longer operating life and lower temperature rises, **NTN** released the "ULTAGE Tapered Roller Bearing for Automotive Application"[3] in 2017.

Tapered roller bearings that support the power transmission devices mounted in vehicles required even lower torque and greater protection against seizure, so efforts into enhancing these technologies were continued with the development of a new resin cage shape to meet such demands. This was combined with lower torque and lower temperature rise design technologies to develop the "Low Temperature Rise and Low Torque Tapered Roller Bearing" that achieves the world's highest level in low torque performance and protection against seizure. This article outlines the structure and features of this bearing.

2. Structure

An overview of the structure of the developed Low Temperature Rise and Low Torque Tapered Roller Bearing is shown in **Fig. 1**. The features ① to ④ shown in **Fig. 1** correspond to the following explanations of the structures in the developed product.

● New resin cage shape

① The inner diameter on the small side of the cage has been reduced for a smaller clearance with the inner ring small side rib outer diameter surface. This suppresses the amount of lubricant inflow into the bearing, which reduces stirring resistance due to the lubricant to achieve a lower torque.

② An open concave shape has been applied to the inner diameter side of the cage pocket large side edge. The corners within the concave shape retain lubricant inside the concave shape due to surface tension, and feed lubricant to the roller end face after operation starts, thus limiting any sudden temperature increases.

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● Optimal design between the roller end face and inner ring large side rib
  ③ An optimal design has been used to improve lubricity of the sliding contact between the roller end face and inner ring large side rib.

● Optimized design of rollers
  ④ A more compact roller design and smaller roller pitch circle diameter design have been used. The former decreases the rolling contact line between the rollers and the inner and outer rings. Reducing the rolling contact line decreases the rolling viscosity resistance, which achieves a lower torque. The latter reduces the circumferential speed of the rolling contact between the rollers and the inner and outer rings, which limits rolling resistance to achieve a lower torque.

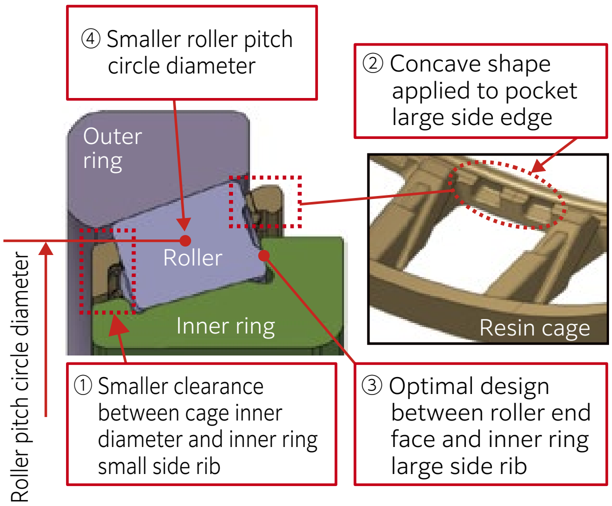


Fig. 1 Structure of “Low Temperature Rise and Low Torque Tapered Roller Bearing”

3. Features

The features of the Low Temperature Rise and Low Torque Tapered Roller Bearing (hereafter, the developed product) compared to conventional tapered roller bearings (conventional product)[4] are as shown below.

(1) World’s highest level in low torque performance
  : reduces rotational torque by 66 % compared to conventional product
(2) World’s highest level in protection against seizure
  : up to 10-times protection against seizure compared to conventional product

3.1 Reduced Rotational Torque

3.1.1 Reduced Lubricant Stirring Resistance

The raceway of tapered roller bearings is inclined with respect to the center of rotation, which creates a phenomenon called pumping action where lubricant flows from the small side to the large side of the developed product when it is rotating. To prevent more lubricant than is necessary flowing into the bearing due to pumping action, the developed product uses the cage shape in **Fig. 1** ①, which limits torque loss caused by lubricant stirring resistance and thus achieves a lower torque.

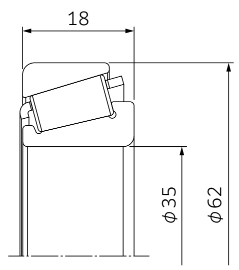
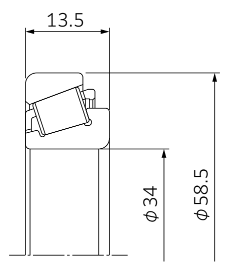
3.1.2 Bearing Internal Optimal Design

The internal design for a longer operating life used in **NTN**’s proprietary “ULTAGE Tapered Roller Bearing for Automotive Application” technology, as well as an optimal design[5] of factors affecting the bearing load rating (such as outer ring angle, and angle and length of rollers), have been used to limit the decrease in bearing rated life while allowing for smaller size, and as a result achieving lower torque.

Table 1 shows an example of tests conducted on the small and lightweight design with load conditions expected to be acting on transmission support bearings of medium size passenger vehicles. The developed product test example has a 25 % reduction in bearing width dimension and 44 % lighter weight compared to conventional tapered roller bearings. This results in a shorter rolling contact length as well as a smaller roller pitch circle diameter, which helps to achieve low torque.

In contrast, the smaller size results in a reduction in the bearing dynamic load rating and operating life, so carbonitriding treatment was used to maintain the operating life.

Table 1 Study example of downsizing and weight reduction by applying the development specification

	① Conventional Product	② Developed Product
	Tapered roller bearing 32007X[4]	Tapered roller bearing
Scale drawing of bearing cross-section		
Size	φ 35 × φ 62 × 18	φ 34 × φ 58.5 × 13.5 (width reduced by 25 %)
Mass (kg)	0.223	0.125(44 % lighter weight)
Dynamic load rating (N)	46,000	28,500
Material heat treatment	Carburized case-hardened steel	Carbonitrided bearing steel
Operating life	Meets standards	Meets standards
Contact stress	Meets standards (with edge stress)	Meets standards (without edge stress)

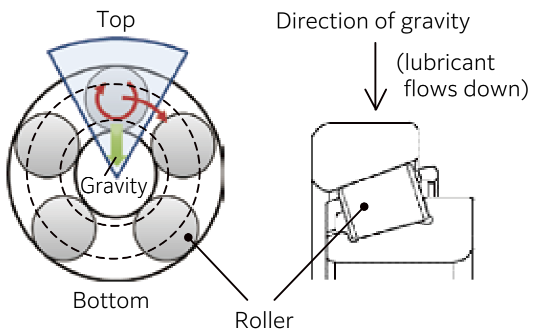
3.2 Greater Protection Against Seizure

3.2.1 Concave Shape Applied to Pocket Large Side Edge

The effectiveness of the lubricant retention function that the concave shape applied to the cage pocket large side edge achieves was verified using flow analysis of the lubricant. The analysis conditions were as shown below.

<Lubricant flow analysis conditions>

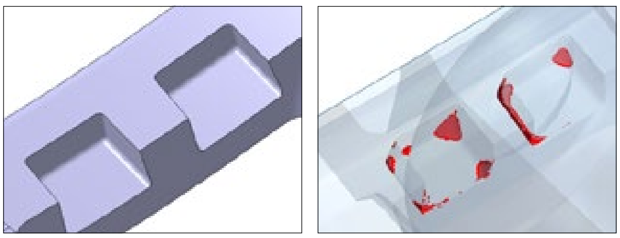
- Model conditions **(Fig. 2)**: the analyzed cage pocket was positioned at the bearing top (12 o'clock) to simulate supporting a horizontal shaft (selected the position with the worst lubricant retention)
- Lubricant: ATF (120 ℃)
- Analysis conditions: unsteady flow analysis of multi-phase flow (VOF)
- Analysis step 1 : rotate bearing in lubricant until lubricant flow within bearing is steady
- Analysis step 2 : stop rotation of bearing. Stop supplying lubricant
- Analysis step 3 : analysis ends when outflow (movement) of lubricant within bearing stops



(a) Analysis model image of bearing front (b) Direction of gravity and bearing top position cross-sectional image

Fig. 2 Definition of oil flow analysis

The analysis results are shown in **Fig. 3**. Lubricant was observed being retained in the concave shape of the cage pocket large side edge. This analysis helped determine the optimum shape within the concave section for retaining an amount of lubricant that can be supplied to the roller end face.



(a) Cage concave shape (same view as **Fig. 3** (b)) (b) Lubricant flow analysis results(red parts: lubricant) (bearing shown as semi-transparent)

Fig. 3 Oil flow analysis results (Enlarged view of large diameter end face recessed shape of cage pocket)

3.2.2 Optimized Shape of Tapered Rollers

The inner ring large side rib and roller end face of tapered roller bearings make sliding contact with each other, leading to concerns over sudden temperature increases due to the lack of oil film formation when there is insufficient lubricant or low-viscosity lubricant is used. As such, the lubricity (oil film formation) needs to be improved on the sliding contact components to ensure greater protection against seizure.

The inner ring large side rib uses a straight shape to make this sliding contact more steady, and the roller end face uses an optimal rounded design to improve lubricity (oil film formation).

Fig. 4 shows the results of seizure protection tests of the development specifications with a rounded roller end face used to check the effectiveness of this design. The test conditions were set to abundant lubricant conditions (oil rich) and extremely low lubricant (oil poor). Better lubricity (oil film formation) was achieved under both conditions for the development specifications with a rounded roller end face, thus indicating better protection against seizure compared to the conventional standard specifications.

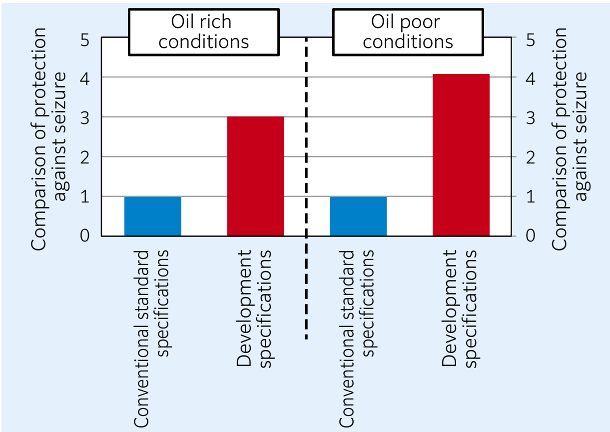


Fig. 4 Seizure resistance evaluation results for development specification roller end face radius (Comparison result when the seizure resistance of the conventional standard specification is set to 1)

4. Bearing Performance

4.1 Rotational Torque Test

A rotational torque test was conducted on the bearing itself to check the effectiveness of reduced torque of the developed product.

The test results are shown in **Fig. 5**. As outlined in the previous section, the developed product was found to have a significant 66 % reduction in torque compared to the conventional product due to the effects of lower rolling friction and lower stirring resistance of the lubricant.

<Test conditions>
・Tested bearing size: Conventional product ø35 × ø62 × 18 (**Table 1** ① bearing)
Developed product ø34 × ø62 × 16
(same internal structure as **Table 1** ② bearing, with different dimensions for outer diameter and assembled width)
・Axial load : 3,000 N
・Rotational speed : 5,000 min^{-1}
・Lubricant conditions : oil bath lubrication, ATF (50 ℃)

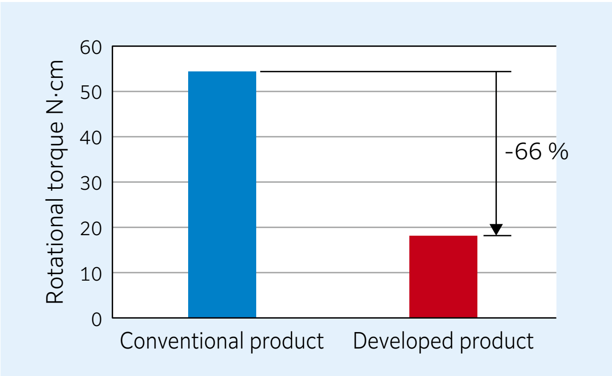


Fig. 5 Bearing rotational torque test results

4.2 Protection Against Seizure Evaluation Test

An evaluation test under the following conditions was conducted to check the effects of protection against seizure of the developed product. Test conditions were set with a low amount of lubricant based on the assumption of using a low-viscosity lubricant in power transmission devices or simulating the quick acceleration of electric vehicles. The bearing was applied with a set miniscule amount of lubricant, and then operated at room temperature in a non-lubricated state to test the time taken until the temperature of the bearing outer ring reached 100 ℃.

The test results are shown in **Fig. 6**. The conventional product standard steel plate cage has no lubricant retention function, and the rib between the inner ring and rollers is the standard design, and thus the bearing reached 100 ℃ in 72 seconds. In contrast, the developed product features the new resin cage shape outlined in the previous section, and in this test the initial amount of adhered lubricant increased 1.3 times compared to the conventional product. With the optimized roller end face and inner ring large rib, the test duration was approximately 10 times longer at 710 seconds, which is an immense improvement to protection against seizure.

<Test conditions>
・Tested bearing size: Conventional product ø35 × ø62 × 18 (**Table 1** ① bearing)
Developed product ø34 × ø62 × 16
(same internal structure as **Table 1** ② bearing, with different dimensions for outer diameter and assembled width)
・Lubricant : ATF (25 ℃)
・Rib contact stress : approx. 200 MPa
・Rib sliding speed : approx. 2.5 m/s

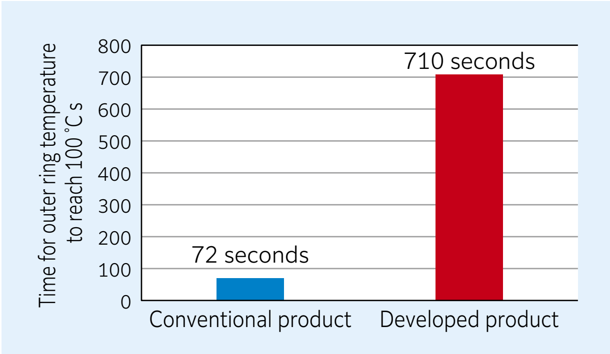


Fig. 6 Seizure resistance evaluation test results

4.3 Longer Operating Life Under Lubrication Conditions that Contain Contaminants

An operating life test was conducted on the developed product under lubrication conditions containing hard contaminants. The operating life of power transmission devices may be affected if hard contaminants are mixed in with lubricant. While there are various conditions of hard contaminants contained in the lubricant of power transmission devices, this test assessed the operating life under the following conditions.

The test results are shown in **Fig. 7**. Under the contaminant conditions of this test, the developed product was deemed to have an ample effective operating life with respect to the rated operating life. Furthermore, no deformation or other wear was observed in the new plastic cage shape after the test.

<Test conditions>
・Tested bearing
➢ Developed product : carbonitrided bearing steel
➢ Size : ø30 × ø65 × 22
➢ Dynamic load rating : 47,500 N
・Load conditions : 42 % of dynamic load rating
・Rotational speed : 2,000 min^{-1}
・Lubricant : ATF (approx. 70 ℃)
・Contaminant average particle diameter : ① 20 μm, ② 90 μm (tested with a mix of ① and ② contaminants)
・Total amount of contaminants : 0.1 g/L
・Rating life (L_{10h}) : 149 h

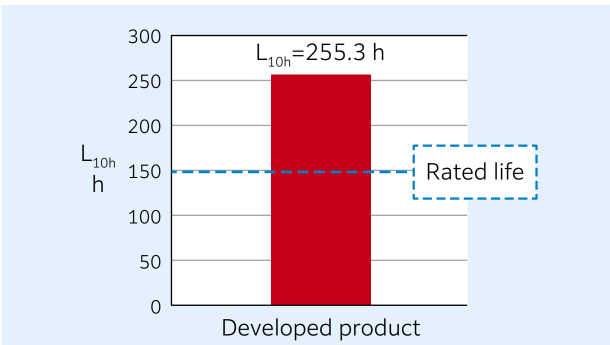


Fig. 7 Life test results under contamination lubrication condition

4.4 Comparison with Tandem Type Double Row Angular Contact Ball Bearing

In recent years during the bearing selection stage, there have been cases where ball bearings are selected to achieve lower torque instead of tapered roller bearings. With this in mind, a functional comparison was made between the developed product and the Tandem Type Double Row Angular Contact Ball Bearing **(Fig. 8)** that is used to support differential pinion shafts.

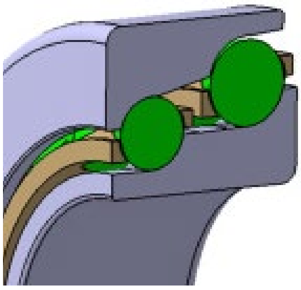
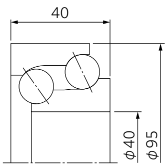
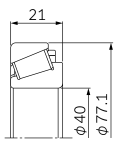
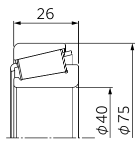


Fig. 8 Structure example of tandem type double row angular contact ball bearing

Table 2 Study example of "Low Temperature Rise and Low Torque Tapered Roller Bearing" with the same calculation life as tandem type double row angular contact ball bearing

	① Ball Bearing	② Developed Product	③ Conventional Product
	Tandem type double row angular contact ball bearing	Tapered roller bearing	Tapered roller bearing 33108U[4]
Scale drawing of bearing cross-section			
Size	φ 40 × φ 95 × 40	φ 40 × φ 77.1 × 21	φ 40 × φ 75 × 26
Mass (kg)	1.06	0.423 (60 % lighter weight compared to ① Ball bearing)	0.498 (53 % lighter weight compared to ① Ball bearing)
Dynamic load rating (N)	Large side: 50,000 Small side: 42,500	83,500	88,000

The sizes of the ① Ball bearing and the ② Developed product in **Table 2** were selected to simulate operating life under load and rotational speed conditions expected when used as a rear differential pinion shaft support bearing for large size passenger vehicles. As a reference comparison, the ③ Conventional tapered roller bearing (33108U) is shown, as it has the same inner diameter as the ② Developed product and a similar outer diameter and dynamic load rating. The results of this bearing comparison revealed that the ② Developed product was 60 % lighter weight than the ① Ball bearing.

For the bearings shown in **Table 2**, rotational torque was calculated at conditions based on the rotational speed expected with large size passenger vehicles. The calculation results are shown in **Fig. 9**.

The ③ Conventional product is shown with the highest rotational torque, and while the ② Developed product had a higher torque than the ① Ball bearing up to a vehicle speed of 5 km/h, it was observed with a lower torque than the ① Ball bearing at speeds over 5 km/h.

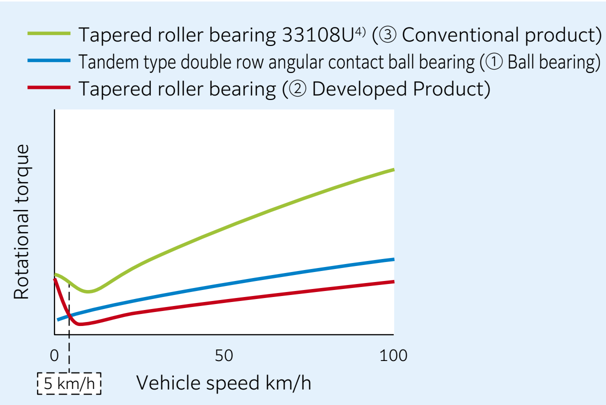
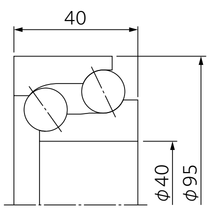
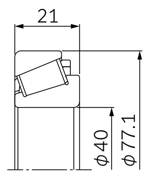
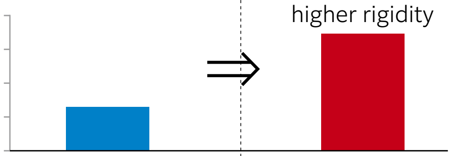
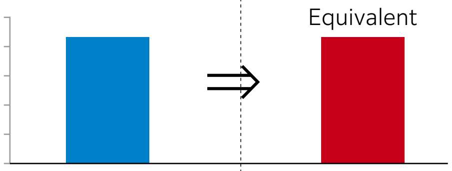


Fig. 9 Bearing rotational torque calculation results

Comparisons of the calculation results of bearing rigidity with applied load in both the radial and axial directions are shown in **Table 3**. Although the ② Developed product has a smaller size than the ① Ball bearing, both radial rigidity and axial rigidity were verified as equivalent or better.

Table 3 Bearing rigidity calculation results

	① Ball Bearing	② Developed Product
	Tandem type double row angular contact ball bearing	Tapered roller bearing
Scale drawing of bearing cross-section		
Radial rigidity		2.6-times higher rigidity
Axial rigidity		Equivalent

5. Conclusion

The automotive industry is said to be facing a once-in-a-100-year period of change, and while usage conditions of bearings will become even more stringent than before, they will be expected to have an even higher level of reliability. The “Low Temperature Rise and Low Torque Tapered Roller Bearing” featured in this article is a new product that is sure to help vehicles achieve a higher mechanical efficiency and better electrical efficiency, as well as contribute to increased uptake of electric vehicles. **NTN** will focus on technical innovation of the new technologies attained through this development and continue contributing to a smooth “smart mobility society” with the release of this new product.

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4) NTN “Ball and Roller Bearings Catalog” CAT. No. 2203/J
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