Product Development of Rolling Bearings for Railway Vehicles

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In order to ensure the safety of railway transportation, it is required to develop bearings for railway vehicles with respect for high reliability of products. Providing bearings to public transportation services such as railway transportation service and contributing to society is significant as corporate activity. **NTN** has been working on development of bearings for railway vehicles for many years. This article introduces our product development activity of bearings for railway vehicles.

1. Introduction

Bearings used in the axles, drive units, and traction motors of railway machinery **(Fig. 1)** are crucial to the overall safety of the vehicle. They are therefore required to meet particularly high quality and reliability standards for an industrial application.

These bearings must have the strength and performance to withstand not only large static loads, but also the elevated dynamic loads associated with operation of the vehicle. The bearings must also withstand continued exposure to extreme temperature environments, humidity, and dust.

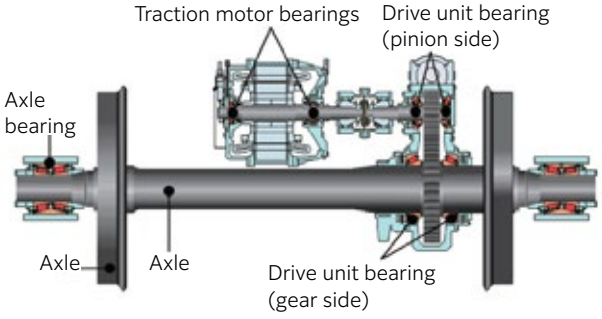

Fig. 1 Railway Bearing Application

To meet these reliability requirements, we at **NTN** have worked for many years to develop high quality bearings for axle, drive unit and traction motor applications. **NTN** is also a leading supplier of railway bearings both inside and outside the country of Japan.

In 2010, **NTN** acquired the International Railway Industry Standard (IRIS)[Note 1)] certification, further establishing **NTN** as a leader among Japanese companies in ensuring quality management systems that conform to international standards for manufacturers of railway vehicles bearings.

This article introduces efforts to develop bearings for railway vehicles.

Note 1) The specifics of these provisions were inherited by the International Standard Technical Specification ISO/TS22163 (Railway Quality Management System (RQMS)) in 2017.

2. Technology trends in bearings for railway vehicles and development efforts

2.1 More compact and highly functional axle bearings

Axle bearings for railway applications need to support both the static weight of the vehicle and the dynamic loading created during operation. Double row tapered roller bearings and double row cylindrical roller bearings with outer diameter dimensions of φ 210– φ 250 mm are commonly used for this application and double row tapered roller bearings with grease lubrication are more common today.

To meet the need for higher speeds and longer maintenance cycles, **NTN** has developed and improved special-purpose bearings that employ oil seals to reduce heat generation during operation. Reinforced resin cages and measures to suppress fretting between the inner ring and backing ring[Note 2)] are also used.

Note 2) Fretting occurs at the contact surface due to repetitive minute relative displacement of the inner ring and rear cap during axle bearing use. Our patented technology (patent no.: 4060232) suppresses fretting and prevents ingress of wear debris into the bearing by mounting a metal plate with gasket.

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In addition to development aiming at improving basic performance, **NTN** has also developed products to meet the need for compactness and increased functionality in recent years. Examples of these developments include the short-type sealed axle bearing unit and the ceramic coated insulated axle bearing.

2.1.1 Development of short-type sealed axle bearing unit

(1) Background

Shortening the axial dimension of the axle bearing unit makes the structure around the axle box more compact and improves rigidity, making for an effective solution at preventing fretting wear. However, there have been limitations to this approach due to constraints with the oil seal size.

Occasionally this issue is resolved by using a shield plate instead of an oil seal. However, the simpler design of the shield plate often introduces issues with sealing performance.

NTN developed the short-type sealed axle bearing unit to simultaneously achieve good sealing performance while also minimizing the axial dimension of the axle bearing unit for increased fretting resistance. **(Table 1, Fig. 2)**.

(2) Features and specifications

- More compact, lighter weight
- Fretting resistance
- Improved reliability, reduced maintenance costs

Table 1 Specification of short-type sealed axle bearing unit

Item	Specifications
Bearing type	Sealed double row tapered roller bearing
Bearing main dimensions	ϕ 130 × ϕ 240 × 160/160 mm
Basic dynamic load rating	1,040 kN
Basic static load rating	1,870 kN
Axial dimension of bearing unit	Compared with our conventional product −15 %
Bearing unit weight	Compared with our conventional product −10 %

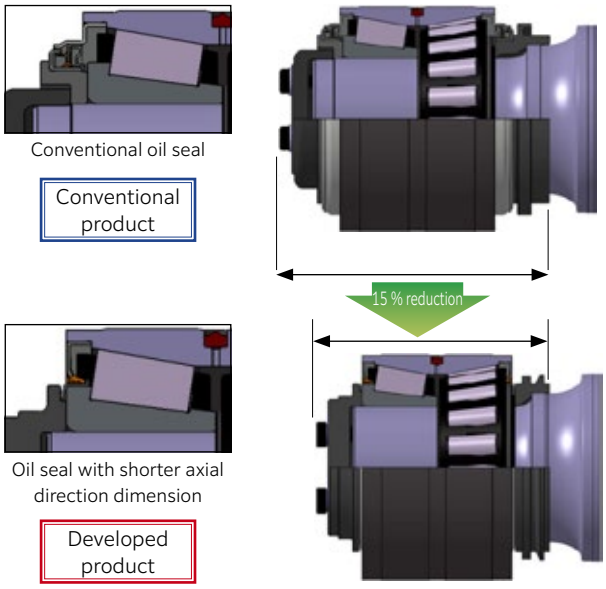

Fig. 2 Short-type sealed axle bearing unit

(3) Evaluation test

(3-1) Bearing rotating test

A durability test was carried out equivalent to running 1.2 million km at 420 km/h. There was no abnormal rise in temperature during testing, and no problems were evident in the bearing or grease condition after testing **(Table 2, Fig. 3)**.

Table 2 Test condition

Item	Conditions
Radial load	91.4 kN (fixed)
Axial load	16.7 kN (5 s load, 25 s no load)
Rotational speed	Max. 2,685 min^{-1} (equivalent to 420 km/h) Forward/reverse rotation (4 h cycle)
Wind cooling speed	10 m/s
Test time	3,429 h (equivalent to 1.2 million km)

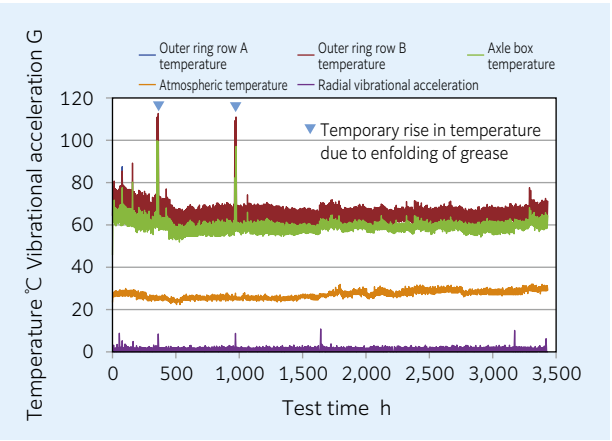

Fig. 3 Bearing rotating test result

(3-2) Test to check sealing performance

A rotational vibration test confirmed that grease sealing performance of the short-type sealed axle unit bearing is superior to the shield plate specifications, and comparable to the conventional product **(Table 3, Fig. 4)**.

Table 3 Test condition

Item	Conditions
Rotational speed	Max. 2,685 min^{-1} (equivalent to 420 km/h)
Vibration frequency	50 Hz
Acceleration	50 – 200 m/s^2 Increased in 50 m/s^2 increments every 24 h

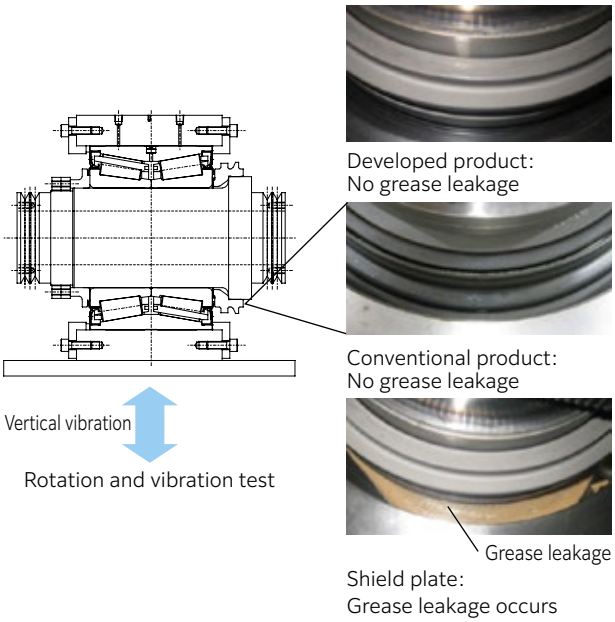

Fig. 4 Sealing test result

2.1.2 Development of ceramic coated insulated axle bearing

(1) Background

Insulation is often employed around the axle bearings in railway vehicles to prevent electrical corrosion, which can cause a multitude of performance issues depending on the specific operating condition. However, the most effective measure for countering electrical corrosion is to insulate the bearing itself. To optimize electrical corrosion prevention in railway applications, **NTN** has worked to develop a ceramic coated insulated axle bearing. **(Table 4, Fig. 5)**

(2) Features and specifications

- Ceramic coating on outer ring
- Prevention of electrical corrosion
- Improved reliability and reduced maintenance cost

Table 4 Specification of ceramic-insulated axle bearing

Item	Specifications
Bearing type	Sealed double row tapered roller bearing
Insulation specifications	Ceramic coating on outer ring
Bearing dimensions	φ 135 × φ 240 × 140/130 mm
Basic dynamic load rating	770 kN
Basic static load rating	1,270 kN
Insulation resistance	10 M Ω min. (DC500 V)

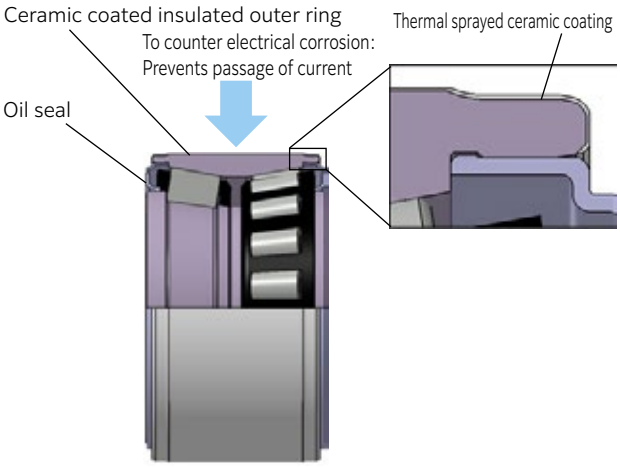

Fig. 5 Ceramic-insulated axle bearing

(3) Evaluation test

A strength evaluation was carried out of the ceramic coating under load conditions equivalent to actual use conditions. No cracking, chipping or other damage to the coating was evident after testing, and there were confirmed to be no problems with insulation resistance **(Table 5, Fig. 6)**.

Table 5 Test condition

Item	Conditions
Static strength test	Radial load: Max. 110 kN
Fatigue strength test	Radial load: 28.6 – 54.3 kN Number of loading cycles: 10^7

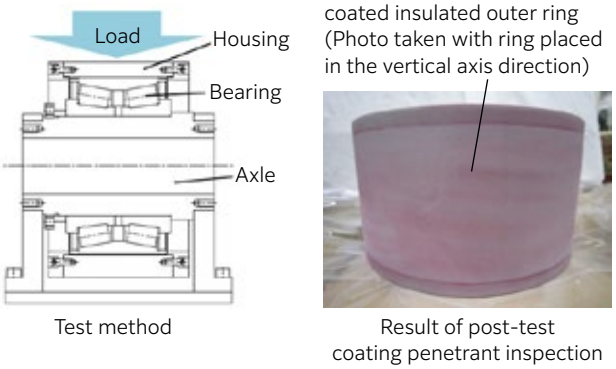

Fig. 6 Strength test result of ceramic-insulation coating

2.2 Improved reliability of resin-insulated bearing for traction motor

In the traction motor, NU type cylindrical roller bearings are used on the drive side, and deep groove ball bearings are used on the counter-drive side. These bearings support the rotor.

The drive and counter-drive side bearings are both typically grease lubricated with an outer diameter of φ 120 – φ 170 mm.

To prevent electrical corrosion within these induction motors, **NTN** has developed a ceramic-insulated bearing in which the ceramic is plasma sprayed on the outer ring. **NTN** has also developed a resin-insulated bearing made with injection molded reinforced resin **(Table 6, Fig. 7)**. The former is mainly used in Shinkansen (bullet train) vehicles, while the latter is mainly used for conventional railroad lines.

To better manage changes in the environmental conditions of traction motor bearings which have occurred in recent years, **NTN** has also been working to develop resin-insulated bearings with improved heat dissipation.

2.2.1 Development of resin-insulated bearings

(1) Background

To reduce lifecycle cost, railway manufacturers are increasingly looking for methods to lengthen the maintenance cycle of traction motors. The maintenance cycle of a traction motor is determined mainly by the lubrication life of the bearing. To extend the lubrication life, it is essential to limit heat generation within the bearing during operation. Railway manufacturers are also increasingly adopting fully-closed traction motors[1)], which typically expose the traction motor bearings to more severe temperatures than the standard open motor type.

In extending the maintenance cycle and developing applications for fully-closed traction motors, improving the heat dissipation of resin coatings is vital to achieve higher reliability.

(2) Features and specifications

- Improvement of heat dissipation of injection molded resin coating for outer rings
- Improved reliability and reduced maintenance costs

Table 6 Specification of resin-insulated bearing

Item	Specifications	
Bearing type	Cylindrical roller bearing	Deep groove ball bearing
Insulation specifications	Injection molded resin coating of outer ring	
Bearing dimensions	NU214 φ 70 × φ 125 mm	6311 φ 55 × φ 120 mm
Basic dynamic load rating	83.5 kN	71.5 kN
Basic static load rating	95 kN	45 kN
Insulation resistance	100 M Ω min. (DC500 V)	

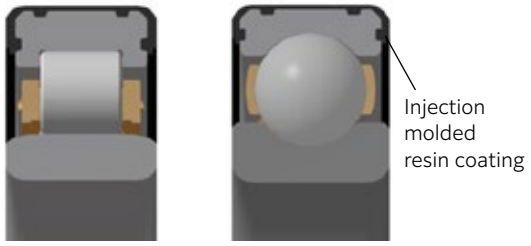

Fig. 7 Resin-insulated bearing

(3) Evaluation test

(3-1) Outer ring temperature

Evaluation was carried out by heating the raceway of the resin-insulated outer ring with a heater to simulate elevated temperatures during bearing use, and then measuring the outer ring base material outer surface temperature **(Table 7)**.

The test results showed that changes in the material of the resin coating resulted in a drop of about 5 ℃ in the outer ring base material outer surface temperature when compared to the conventional product **(Fig. 8)**.

Table 7 Test condition

Item	Conditions
Prototype	Resin-insulated outer ring (NU214)
Heating method	Heating of outer ring raceway using special-purpose jig with cartridge heater
Heating temperature	120 ℃ (special-purpose jig part)

(3-2) Change in bolt fastening force

The outer ring of the resin-insulated bearing is compressed in the axial direction due to the bolt fastening force of the traction motor's bearing box and end cap. Therefore, a drop in bolt fastening force occurs due to deformation in the film thickness of the resin coating on the outer ring.

We incorporated the developed resin-insulated outer ring and conventional product into a test jig, fastened the bolt of the test jig with the specified fastening force, and applied compressive force in the thickness direction to the resin coating width surface. The raceway was heated to 120 ℃ × 100 h, and cooled to room temperature, and the drop in bolt fastening force was evaluated **(Table 8)**.

The test results showed that the developed product was more effective at reducing change in bolt fastening force by roughly 20 % compared to the conventional product **(Fig. 9)**.

Table 8 Test condition

Item	Conditions
Prototype	Resin-insulated outer ring (NU214)
Bolt fastening	4-M10, axial force 18 kN/bolt
Heating method	Heating of outer ring raceway using special-purpose jig with cartridge heater
Heating temperature	120 ℃ (special-purpose jig part)
Test time	100 h

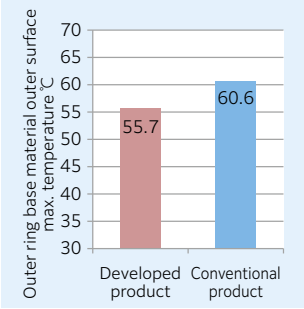

Fig. 8 Temperature of outer ring

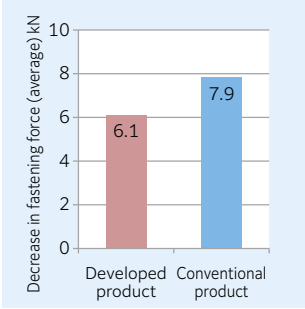

Fig. 9 Change in bolt fastening force

2.3 Improved seizure resistance performance of drive unit bearings

It is typical for tapered roller bearings to be arranged face-to-face in a parallel Cardan drive unit **(Fig. 10)**.

The pinion-side bearing supports the pinion axle weight, part of the coupler weight, and the gear engagement load. The gear bearing supports part of the gearbox weight and the gear engagement load.

In terms of main bearing dimensions, the outer diameters of the pinion bearing and gear bearing are, respectively, ϕ 150 – ϕ 180 mm and ϕ 280 – ϕ 330 mm, and lubricating oil is supplied to the bearing by gear rotation.

In recent years, drive units using cylindrical roller bearings have also been developed[2)-4)], but the major bearing type is still tapered roller bearings. With this type, an axial load acts on the tapered roller bearing, and seizure resistance performance of the pinion-side bearing is especially important.

The next section introduces efforts to improve the seizure resistance performance of the pinion-side tapered roller bearing in low temperature environments.

2.3.1 Improved seizure resistance performance of tapered roller bearings for drive units in low temperature environments

(1) Background

While some research has been done on the effects of the bearing axial clearance and surrounding temperature have on the rise in bearing temperature in connection with seizure of the pinion-side bearing in low temperature environments[5)], there have been no examples of observing the status inside a drive unit and measuring bearing load under low temperature conditions. Thus, we improved the product by observing the state inside the drive unit, and measuring the bearing load.

(2) Internal observation of drive unit

The upper cap of the drive unit was switched to one made of acrylic resin, and we took a video in order to observe the situation inside the drive unit at low temperature up to seizure of the pinion-side bearing **(Table 9)**.

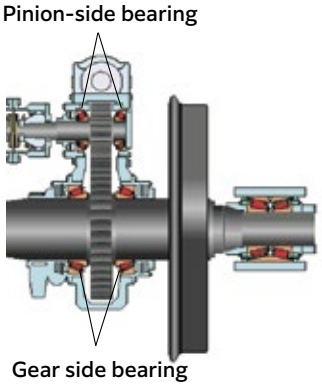

Fig. 10 Bearing arrangement in driving-unit

Table 9 Test condition

Item	Conditions
Test bearing	Drive unit pinion-side tapered roller bearing
Atmospheric temperature	-15 ℃
Maximum rotational speed	5,772 min^{-1}
Lubricating oil	Lubricating oil for drive unit
Axial gap	60 % of design value (to reproduce seizure)

[Results of observing situation inside the drive unit in a low-temperature environment **(Fig. 11)**]

① At startup, high-viscosity lubricating oil brought up by the gear is supplied to the pinion engagement section, and some of that is supplied to the pinion-side bearing.

② After that, viscosity of the lubricating oil decreases with rising temperature, and the lubricating oil deposited on the walls inside the drive unit flows along the inner walls due to the flow of air inside the unit.

③ Immediately before the pinion-side bearing seizes, the inside of the drive unit gradually clouds up due to lubricating oil and the pinion momentarily gives off sparks.

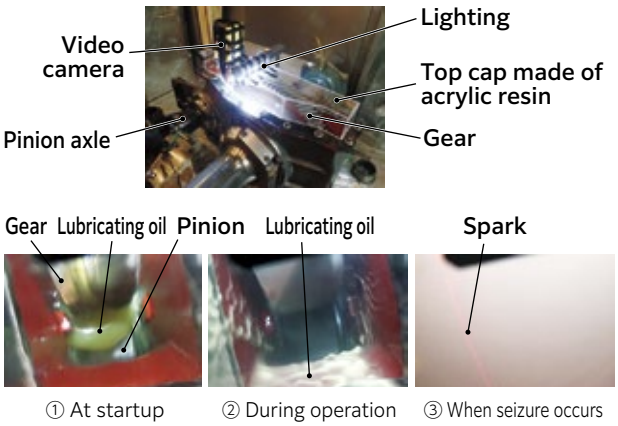

Fig. 11 Internal state of driving-unit in low-temp. environment

(3) Results of measuring axial load

The axial load of the pinion-side bearing was measured in order to understand the process up to seizure of the pinion-side bearing. The measurement results **(Fig. 12)** revealed a mechanism where, after starting from a low-temperature condition, the axial clearance disappeared before long due to the difference in thermal expansion of the bearing inner ring, pinion axle, and gearbox. After a few minutes of operation, the axial load increased, resulting in seizure. It was also confirmed that an axial load as high as 150–200 kN acts on the pinion-side gear when seizure occurs.

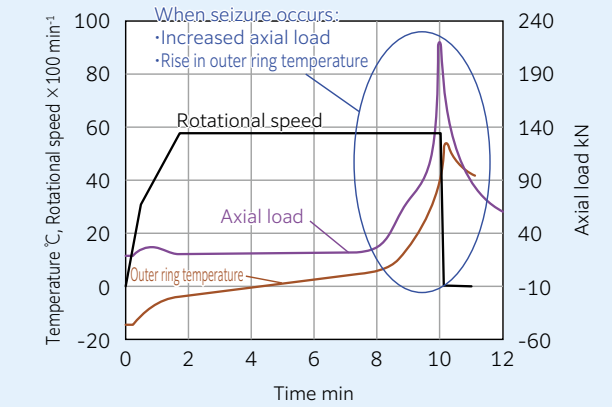

Fig. 12 Bearing temperature and axial load

(4) Effectiveness of countermeasure design

To improve seizure resistance performance of the tapered roller bearing for drive units in low-temperature environments, it is effective to improve seizure resistance strength of the roller large end face and the inner ring rib surface. Suppressing the rise in temperature is also important to limit the reduction in the axial clearance. An improvement effect was evident in comparative testing of the conventional product and the improved product by incorporating these countermeasures **(Fig. 13)**.

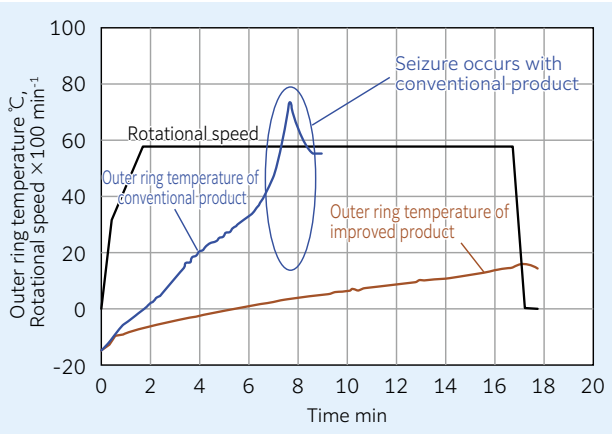

Fig. 13 Start-up test result in low-temp. environment

3. Summary

This article has introduced efforts to develop bearings for railway vehicles at **NTN**. Development of bearings for railway vehicles often proceeds in close collaboration with development of vehicles and equipment. The examples presented in this article are some of **NTN**'s development activities for railway vehicle bearings.

Contributing to society by developing and providing bearings for public transportation services such as railway transportation is significant as a corporate activity. Going forward, we will continue active efforts to develop technology and products.

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