Creepless Ball Bearing

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As housings and bearing rings are made thinner to accommodate downsizing or reduced weight transmissions for improved fuel consumption in automobiles, outer ring creep is more likely to occur.

NTN has developed a "Creepless ball bearing" capable of preventing creep during single direction load conditions. This article introduces the features and performance capabilities of the Creepless ball bearing.

1. Introduction

Deep groove ball bearings are frequently used as gear support bearings in automotive transmissions. These bearings are often configured with a loose fit between the outer ring and housing, which could result in the outer ring experiencing creep depending on factors such as bearing specifications, loose fit conditions or load conditions. Creep of the outer ring causes wear on the fitting surfaces of the outer ring and housing, and increases misalignment or inclination of the shaft which results in problems like abnormal noises or vibrations in the apparatus[1].

The growing demand for greater fuel efficiency in recent years has led to motors being developed with more gears or more compact and lightweight designs. To achieve this, housings and bearing raceways tend to be designed with thinner raceways; however, this can result in outer ring creep occurring more often. As such, there has been increasing demand for creep-resistant bearings in recent years.

The creepless ball bearing developed here is able to prevent creep when a load is applied from a specific direction as in the case of progressive wave type creep[2], where the outer ring slips in the same direction as the rotation of the inner ring.

This article provides an outline of a newly developed product that is easy to assemble as it features the same components as standard bearing types.

2. Features

The features of the developed Creepless Ball Bearing (hereafter, developed product) are as follows.

Superior creep resistance*	: prevents creep No creep wear (under **NTN** test conditions)
Ease of assembly	: equivalent to standard type
Durability	: equivalent to standard type (under **NTN** test conditions)

* Under conditions with load applied in a specific direction

3. Structure and Performance

3.1 Types of Bearing Creep[2]

There are two main types of bearing creep depending on the direction of rotation and phenomena. **Table 1** outlines the various types of outer ring creep. Outer ring creep in the opposite direction of rotation occurs when there is clearance between the outer ring and housing, or elastic deformation and slippage of the outer ring. Outer ring creep in the same direction as rotation occurs when there is outer ring distortion due to the rolling element load being applied in progressive waves. **NTN** calls this "progressive wave type creep" (which occurs when load is applied to the bearing in one specific direction).

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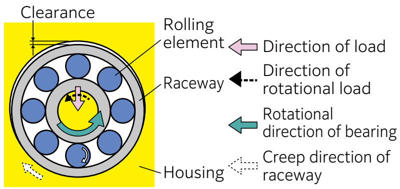
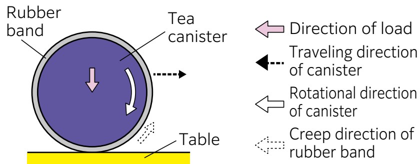
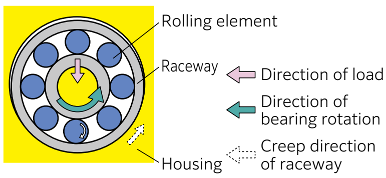
Table 1 Types of outer ring creep[2)]

Type	Illustration
Creep (opposite direction of rotation)	① Loose fit for outer ring and housing  · Occurs with rotating load · Caused by clearance between the outer ring outer diameter and housing inner diameter ② Interference fit for outer ring and housing (example of tea canister with rubber band around it)  · Occurs with rotating load · Caused by elastic deformation and slippage of the raceway
Creep (same direction as rotation) → Progressive wave type creep	 · Occurs when load is in one direction · Caused by outer ring distortion

3.2 Mechanism of Progressive Wave Type Creep[2)]

Details of the mechanism are shown below **(Fig. 1)**.

(1) Rolling element load acts on the outer ring

(2) Outer ring material immediately below is displaced

(3) Outer ring surface becomes wavy up to several microns depending on the magnitutde of the rolling element load

(4) When inner ring rotates, the rolling elements also move

(5) Surface waves become progressive waves and cause outer ring creep

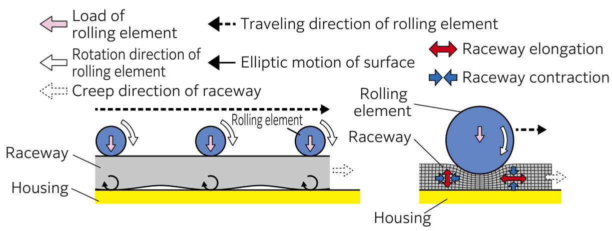


Fig. 1 Creep by strain

Progressive wave type creep only occurs when the load on the bearing is in one direction. By using the following formula, progressive waves can be prevented. However, extremely thick sections are required for standard bearings, which makes preventing progressive wave type creep difficult in reality **(Fig. 2)**.

Raceway thickness t / pitch interval between rolling elements w > 0.6

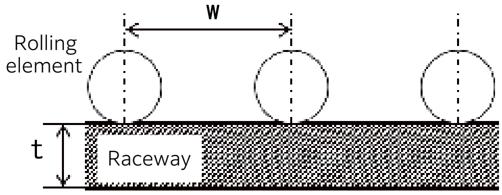


Fig. 2 Thickness of bearing ring and rolling elements

3.3 Overview of Developed Product

3.3.1 Aim of Design

The gear support sections of transmissions often suffer from progressive wave type creep due to the bearing fit and load conditions. By focusing on the mechanism of progressive wave type creep, **NTN** developed a product to stop creep by blocking progressive waves in the outer ring.

3.3.2 Appearance

The components are the same as the standard type bearing, but the developed product features an arc-shaped undercut across the full width of part of the outer diameter of the outer ring **(Fig. 3, 4)**.

The size of the new product is interchangeable with standard bearings, and does not impact assembly into the housing.

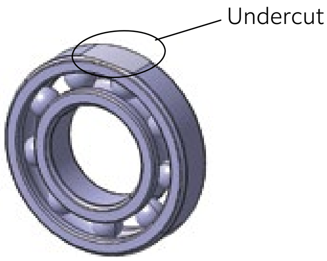


Fig. 3 Appearance of developed product

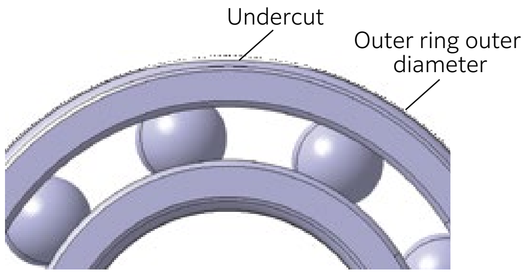


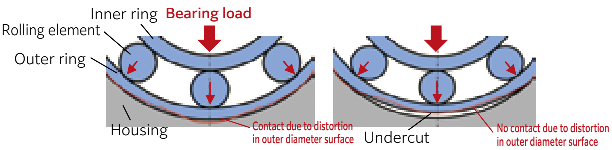
Fig. 4 Structure of developed product

3.3.3 Mechanism to Prevent Creep

Standard type bearings transmit progressive waves in the load region if the outer diameter surface of the outer ring deforms and makes contact with the housing, causing creep in the same direction. The developed product however, avoids contact with the housing in the region of the undercut, which blocks progressive waves and stops creep from occurring.

An image of the mechanism that prevents creep is described below and shown in **Fig. 5**.

(1) Bearing load acts on outer ring after passing through the inner ring and rolling elements
(2) Outer ring outer diameter surface deforms in the radial direction due to the load from the rolling elements
(3) Undercut used to avoid contact with the housing
(4) Progressive waves caused by distortion on outer ring outer diameter surface are blocked, which prevents creep



(a) Standard type (b) Developed product

Fig. 5 Mechanism image for creep stop

Outer ring creep is prevented when the undercut is positioned in the load zone; even when the undercut is positioned outside of the load zone, creep is prevented when the outer ring undercut enters the load region as a result of creeping. Accordingly, there is no need to factor in phase when installing the developed product into the housing.

3.3.4 Creep Speed

Tests were conducted to verify the speed at which the developed product would creep. The test conditions are shown in **Table 2** and test results shown in **Fig. 6**.

Four types of samples were tested alongside the developed product, including standard type bearings, **NTN**'s conventional creep prevention AC bearings[3], and bearings with coated outer ring outer diameters.

Creep speed in the standard type bearings and AC bearings increased as the load was increased. However, there was no creep in the developed product even with high loads verifying that progressive waves in the outer ring were blocked and creep was prevented by the new design.

Table 2 Test condition

Bearing number	6208
Load Fr (P/C)	4 standards from 0.1 to 0.4
Inner ring rotational speed min^{-1}	6,000
Lubricant	CVT fluid
Bearing outer ring temperature ℃	50

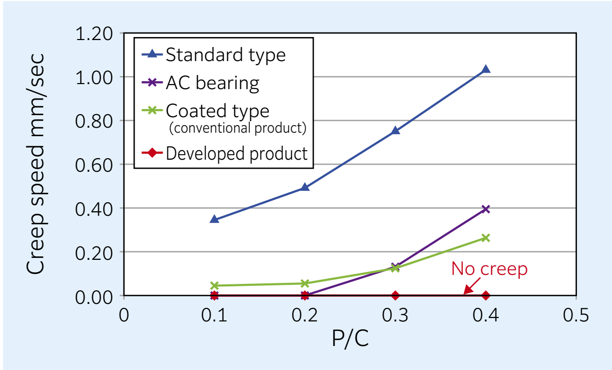


Fig. 6 Creep speed test results

The order of creep speed at high loads was as follows.

High ← Creep speed → Low

Conventional product ＞ AC bearing ＞ Coated type ＞ Developed product

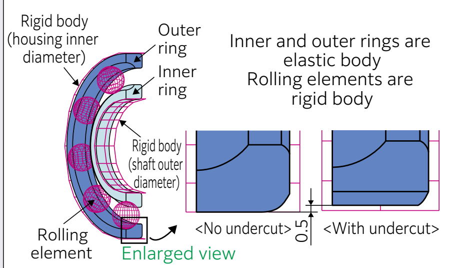
3.3.5 Impact on Outer Ring Undercut Strength

Tests were conducted using FEM analysis to verify the stress on the outer ring outer diameter surface of the developed product.

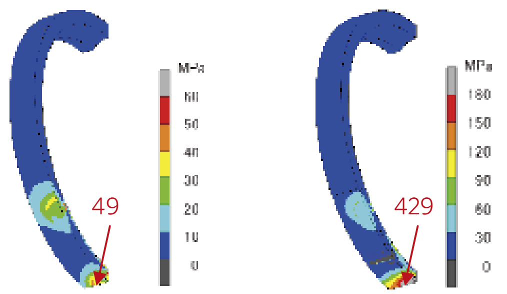
The analysis conditions are shown in **Table 3** and analysis results shown in **Fig. 7**.

While the developed product generated around 10-times the tensile stress compared to the standard type, this was not at a level that could cause failure and had several times the safety factor for allowable tensile stress of bearing steel (SUJ2).

Table 3 Strength analysis condition

	Standard Type	Developed Product
Bearing number	6208	
Undercut	No	Yes (immediately below load region)
Load Fr (P/C)	0.4 * (top of ball)	
Bearing fits	Clearance fit (outer ring outer diameter / housing inner diameter)	
Analysis model image		

* The rolling element load distribution of the developed product differs from the standard type due to the undercut.
As indicated in these analysis conditions, the maximum rolling element load of the developed product is lower than the standard type when the undercut is immediately below the load region. To consider the worst case scenario, the same rolling element load as the standard type has been used for the analysis.



(a) Standard type (b) Developed product

Fig. 7 Strength analysis result

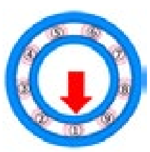
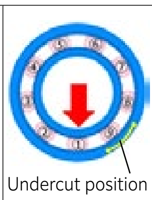
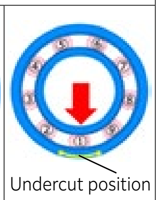
3.3.6 Impact on Operating Life

The load distribution on the rolling elements in the developed product differs from standard bearings due to the position of the undercut in relation to the load direction. As such, the impact on the rolling fatigue life was calculated theoretically.

To understand how the undercut affects the developed product, the balance of forces was calculated by factoring in both the elastic deformation of the outer ring and housing as well as the amount of elastic contact between the balls and raceway due to Hertzian contact.

Table 4 shows a list of the analysis results.

Table 4 Calculation result

	Standard Type	Developed Product	
		Undercut 45° position	Immediately below undercut
Bearing number	6208		
Undercut	No	Yes (45° position)	Yes (immediately below)
Load Fr (P/C)	0.4		
Illustration			
Rolling fatigue life L_{10} (compared to standard type)	1	0.95	1.06

When the undercut is at a 45° position with respect to the load direction, the rolling fatigue life decreases (around 5 %) compared to the standard type; however when the undercut is immediately below the load, it actually increases (around 6 %). This is due to the change in the maximum rolling element load as compared to the standard type. As such, the impact on the rolling fatigue life due to the undercut is small.

3.4 Evaluation Result of Developed Product

3.4.1 Outer Ring Crack Test (static)

A static crack test was conducted to verify the strength of the outer ring outer diameter surface undercut included in the developed product.

The test jig is shown in **Fig. 8**. The undercut of the developed product was simulated with a load using a special jig, with one rolling element positioned in the load region to concentrate the load at the undercut. A precision universal testing machine was used as the tester to apply a static load from the inner ring, with the cracking load deemed to be the point when the load decreased suddenly.

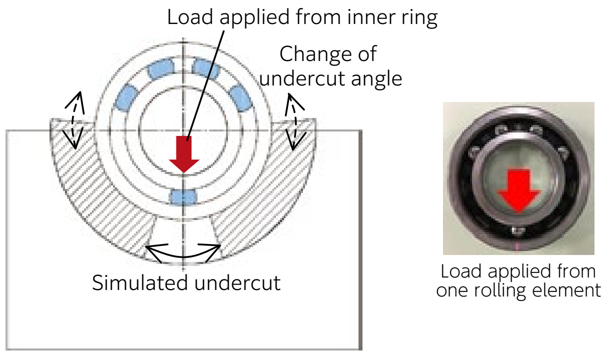


Fig. 8 Outer ring crack tester

The test results are shown in **Fig. 9**.

The cracking load was determined to have a safety factor of two times or more against the basic static load rating C_0, and as such was deemed acceptable with respect to static destruction.

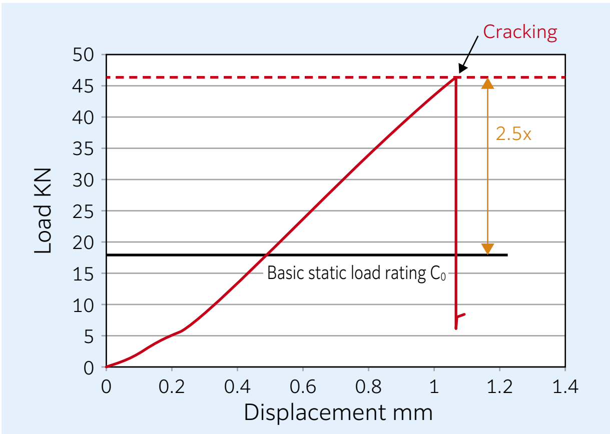


Fig. 9 Crack test results

3.4.2 Outer Ring Crack Test (dynamic)

A dynamic crack test was conducted to verify the strength of the outer ring outer diameter surface undercut included in the developed product.

To evaluate the fatigue strength, a load exceeding the basic dynamic load rating was applied for more than 10^7 cycles. The test conditions and results are shown in **Table 5**.

Table 5 Test condition and result

Test conditions	Bearing number	6208
	Load Fr (P/C)	1.2
	Inner ring rotational speed min^{-1}	2,500
	Lubricant	CVT fluid
	Bearing outer ring temperature ℃	Natural temperature rise
	Operating time	Suspended at double the 1×10^7 cycles passed by the rolling element (equivalent to 3-times or more the rolling fatigue life)
Test result		No failure in standard type or developed product

Under these conditions, the developed product was deemed acceptable with respect to dynamic destruction.

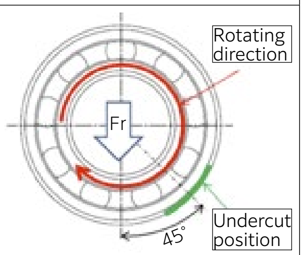
3.4.3 Durability Test

The rolling fatigue life was verified with a durability test. The test conditions are shown in **Table 6**. The undercut was positioned at 45° from the direction of the applied load where the rolling element load is the highest. The operating time was set to be suspended at 10-times the calculated operating life.

From the results shown in **Table 6**, the developed product was deemed acceptable with respect to rolling fatigue life under these conditions.

* This durability test used a high-rigidity housing to ensure that there was no creep.

Table 6 Test condition and result

Test conditions	Bearing number	6208
	Load Fr (P/C)	0.6
	Inner ring rotational speed min^{-1}	3,000
	Lubricant	CVT fluid
	Bearing outer ring temperature ℃	Natural temperature rise
	Operating time h	$L_{10h} \times 10$
	Undercut position	 Test configured at position with highest rolling element load
Test result		No failure in standard type or developed product (suspended at 10-times calculated operating life)

4. Conclusion

This article provided an outline of the Creepless Ball Bearing. The developed product features an undercut in part of the outer diameter surface of the outer ring to successfully prevent outer ring creep caused immediately below the load when the bearing rotates in a specific direction. Creep is traditionally restricted by using external parts or applying a coating; however the developed product completely prevents all creep by including a simple modification to the outer ring without any changes to the internal components or envelope dimensions of the standard type bearing and without affecting assembly to the housing.

The Creepless Ball Bearing is anticipated to contribute to making automotive transmissions smaller, more lightweight and more fuel efficient, and will be actively released in various markets. Efforts will also be made to promote product development with the aim of further increasing performance.

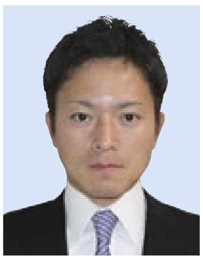
References

1) Takayuki Teramoto, Yutaka Sato, Prediction Method of Outer Ring Creep Phenomenon of Ball Bearing Under Bearing Load, Transactions of the Society of Automotive Engineers of Japan, Volume 46 Issue 2 March, (2015) 355.

2) Tsuyoshi Niwa, A Creep Mechanism of Rolling Bearings, NTN TECHNICAL REVIEW, No. 81, (2013) 100-103.

3) NTN “Ball and Roller Bearings Catalog” CAT. No. 2203/J, (2020) B-15.

Photo of authors



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