

High Speed Thrust Needle Roller Bearings

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NTN has developed a high-speed thrust needle roller bearing capable of 1.5-million $d_m n$ to meet the high-speed demand of high-powered electric motor units used in hybrid vehicles and multiple speed automatic transmissions.

In recent years, the demand for high-speed needle roller bearings has increased for high-powered electric motor units used in hybrid vehicles and multiple speed automatic transmissions in the pursuit of more fuel-efficient vehicles.

NTN's design features the following:

- Improved surface finish of the cage pocket contact with the roller end, while still maintaining a conventional cage configuration that has good oil flow.
- Special contact configuration of roller end and cage pocket which does not affect roller movement.
- Point contact of the roller end and cage pocket at the center point of the roller end with low circumferential velocity is made possible by the configuration of roller end curvature.

These features enable reduction of cage wear and seizure as well as improve the permissible rotational speed from the conventional 860,000 $d_m n$ to 1.5 million $d_m n$, which is the world's highest. In addition, the temperature rise at high-speed operation is reduced by 36% in comparison with conventional bearings while also improving lubrication reliability.

1. Introduction

Needs for vehicles that boast lower fuel consumption or better fuel economy have been ever increasing. As a result, smaller motors for use on hybrid vehicles and automatic transmission systems with increased number of gear speeds are more commonly being used in the automotive market, thus increasing the demand for thrust needle roller bearings capable of higher speeds.

NTN's newly developed high-speed thrust needle roller bearing (**Photo 1**) is based on the W-shaped NTN standard cage (**Photo 2**) that features better lubricant flow; and has been optimally designed. Thus, the new high-speed thrust needle roller bearing boasts an increased maximum allowable bearing speed, and has a $d_m n = 1.5$ million.

*1: $d_m n$ value = d_m (pitch circle dia. of bearing, mm) \times n (bearing speed, min^{-1})

Ex. : When a bearing of $d_m=100$ mm is run at $n=10,000 \text{ min}^{-1}$, the resultant $d_m n$ value is $100 \times 10,000 = 1$ million.

This paper hereunder describes the features and performance of this unique high-speed thrust needle roller bearing.

2. Structure of high-speed thrust needle roller bearing

By special treatment of the outside diameter of the pocket faces on the cage (**Table 2**) with which the roller end face contacts, we have improved the surface quality (surface roughness) of the contact surfaces of the NTN high-speed thrust needle roller bearing (**Tables 1 and 2**).

As a result of the special treatment, a larger contact surface occurs between the outer pocket face of the cage and the roller end face. Thus, a very stable cage pocket-roller end face contact state is maintained regardless of the motion of the cage or roller.

In addition, NTN employs special needle rollers each having a unique curved end face. Consequently, the center point of each needle roller, at which the roller circumferential velocity is low, can reliably keep a contact point relation with the cage pocket outside diameter resulting in an arrangement that has a lower

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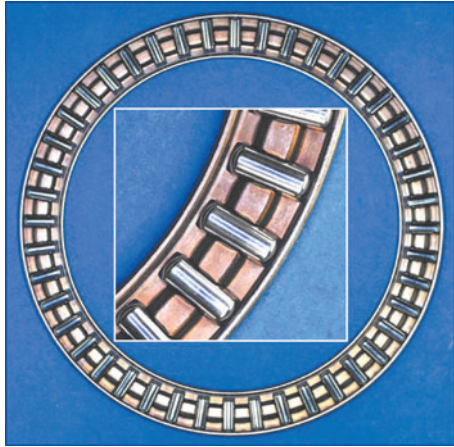


Photo 1 High-speed Thrust Needle Roller Bearings

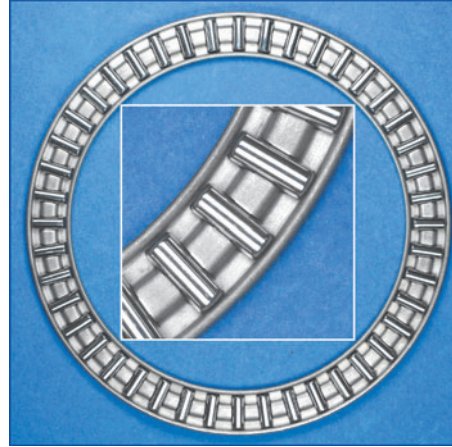


Photo 2 Current Bearings

Table 1 Diagrammatic illustration of development bearing and current bearing

Bearing specification	Cross section view
New design	<p>The cage pocket outside diameter is in contact with the curved roller end face.</p>
Conventional design	<p>The cage pocket outside diameter is in contact with a portion of the roller end face (flat face).</p>

Table 2 Enlarged illustration of development bearing and current bearing

Bearing specification	Cage pocket outside diameter
New design	<p>Contact surface (treated with new technique)</p>
Conventional design	<p>Contact surface</p>

PV value.

Furthermore, the cage riding clearance between the rollers and cage and also the riding position and the roller crowning form have all been optimized to provide a certain degree of freedom to the rollers, so that the cage least affects the behavior of each roller. Thus, we desire that each roller be independent of the motion of any other component. As a result of these efforts, premature wear and excessive temperature rise of the bearing have been minimized and the allowable running speed of the bearing has been increased, thereby attaining a d_{mN} value of 1.5 million.

3. Advantages of the new NTN high-speed thrust needle roller bearing

[1] Fastest in the world

d_{mN} value of 1.5 million (76% improvement over the conventional product)

[With a bearing that is run at a speed of 21,000 min⁻¹, where the bearing pitch circle diameter measures 72mm]

[2] Inhibition of temperature rise

36% decrease in bearing temperature rise (relative to the conventional design)

[Data obtained from the operation at an oil temperature of 80°C and a d_{mN} value of 86,000]

[3] Cage strength

1.3 times stronger (relative to the conventional design)

4. Performance evaluation

In evaluating the performance of the new NTN high-speed thrust needle roller bearing the conventional design was used as a benchmark. The conventional design and the new design have been subjected to a series of tests that included stress analysis, an allowable limiting speed test and a temperature rise test. A portion of the performance evaluation test result is presented below.

4.1 Technical data for test bearings

The test bearings used for performance evaluation measure 63mm in bore diameter, 80mm in outside diameter and 2.5mm in width.

The bearing technical data for the new design and conventional design are summarized in **Table 3**.

4.2 Analysis of cage stress

The cage stresses on the new design and conventional design have been analyzed through FEM analysis technique, and the resultant findings are summarized below.

(1) Analysis conditions

The analysis condition is summarized in **Fig. 1**.

For the analysis conditions, the outer circumference and bore circumference of the cage have been assumed to be fully constrained and a linear load has been assumed to be applied to the roller riding positions.

(2) Analysis result

The analysis result is summarized in **Table 4**.

The cage bar strength of the new design has been compared with that of the conventional design. As a result, it has been found that the ratio of the maximum

Table 3 Comparison of bearing specifications

Bearing specification	New design	Conventional design
Bearing size (mm)	Bore dia. 63×outside dia. 80×width 2.5	
Basic dynamic load rating C_a (N)	27800	
Basic static load rating C_{0a} (N)	143000	
Cage type	Cage of new form made of sheet steel	W-type cage made of sheet steel
PCD (mm)	72.0	71.5
Number of rollers	44	44

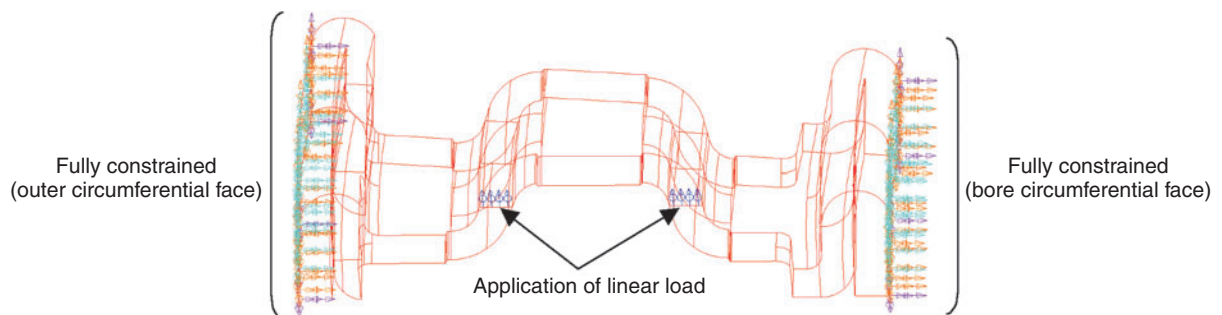
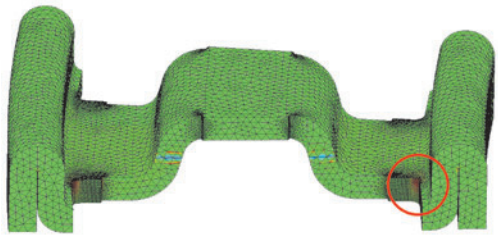
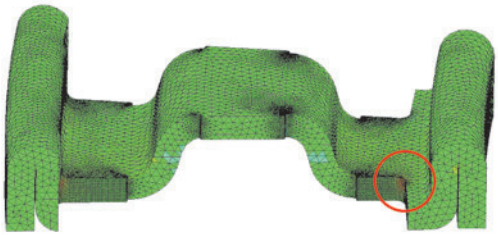


Fig 1 Analytical condition

Table 4 Analytical result

Bearing specification	Location of maximum principal stress occurrence/Corner R of the pocket inner diameter side	Maximum main stress ratio
New design		1
Conventional design		0.77

principal stress on the new design to that on the conventional design is 1:0.77. This in turn means that the cage bar strength of the new design is approximately 1.3 times stronger than that of the conventional design.

On the new design, the pocket position is closer to the outer circumference, as compared with that on the conventional design; thereby the cage bar width between the corner R portions at the inner diameter side of the neighboring cage pockets is greater, with each cage bar having greater strength. Furthermore, the width of the cage bar is again larger at the corner R area on the outside diameter side of the cage pocket, as not only the cage bars but also the cage outer circumference rib can be easily deformed. The resulting mechanical strength of the newly developed cage is approximately 1.5 times greater than that of the conventional design.

From these two facts, the newly developed NTN high-speed thrust needle roller bearing boasts a much-improved mechanical strength of the cage bars, compared with the conventional product.

4.3 Allowable limiting speed

For the allowable limiting speed test, an NTN horizontal-type thrust bearing test rig was used.

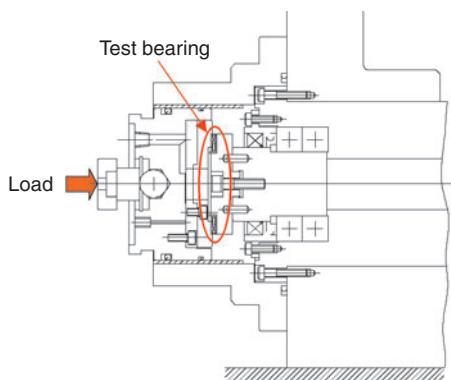


Fig. 2 Diagrammatic illustration of NTN horizontal type thrust bearing test rig

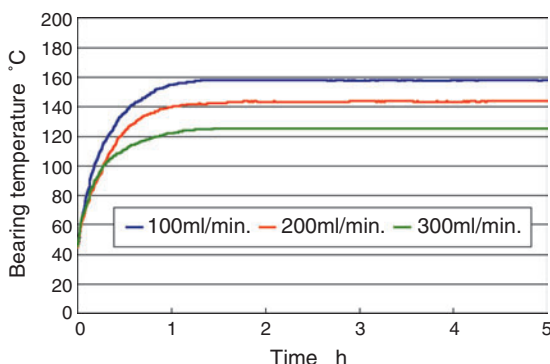


Fig. 3 Temperature-rise comparisons of each oil quantity

The NTN horizontal-type thrust bearing test rig used is schematically illustrated in Fig. 2.

(1) Test conditions

The conditions used for the allowable limiting speed test are summarized in Table 5.

(2) Test result

The bearing temperature on the new design is graphically plotted in Fig. 3. Table 6 provides appearances of the cage pocket outside diameter face and roller end face for the tested specimens.

The new design was tested at oil flow rates of 100 mL/min, 200 mL/min and 300 mL/min with no specimen developing a problem of roller drilling wear on the cage. Thus, it has been verified that our newly developed high-speed thrust needle roller bearing is capable of readily running at 21,000 min⁻¹ ($d_{m\Omega} = 1.51$ million), which is the maximum permissible speed of the test rig, regardless of the magnitude of oil flow rate. Thus, this speed was taken as the allowable limiting speed of this new bearing.

At an oil flow rate of 100 mL/min, the cage on the conventional design developed roller drilling wear and the end face of the roller exhibited wear when the conventional design was running at 13,000 min⁻¹ ($d_{m\Omega} = 93,000$). Therefore, the allowable limiting speed of the conventional design should be limited to 12,000

Table 5 Limiting speed test condition

Test rig	NTN horizontal-type thrust bearing test rig
Running speed	21000 rpm ($d_{m\Omega} = 1.51$ million)
Axial load	1961 N
Lubrication system	Apollo oil ATF-DX Circulating lubrication: 100, 200, 300 ml/min. Initial oil temperature: 80°C
Criteria for stopping the test	Detection of roller drilling wear ^{※2} , or occurrence of abnormal vibration
Run time	5 hours

※2 Roller Drilling Wear: The outer end face of each roller is forced into the outside diameter pocket face of the corresponding cage pocket owing to factors including the centrifugal force as well as roller rotation on its own axis. As a result, wear can occur on the cage pocket outside diameter face. This phenomenon is referred to as "roller drilling wear".

Table 6 Externals situation of cage and roller edge side

Oil flow rate	100ml/min.	200ml/min.	300ml/min.
Cage			
Roller			

min⁻¹ ($d_{m\Omega} = 86,000$).

The allowable limiting speeds of the new design and conventional design at an oil flow rate of 100 mL/min are graphically shown in Fig. 4.

The allowable limiting speed of the new design is at least approximately 1.7 times higher than that of the conventional design (76% improvement over the conventional design).

4. 4 Temperature rise test

For the temperature rise test, the NTN horizontal-type thrust bearing test rig shown in Fig. 2 was again used.

(1) Test conditions

The test conditions for the temperature rise test are summarized in Table 7.

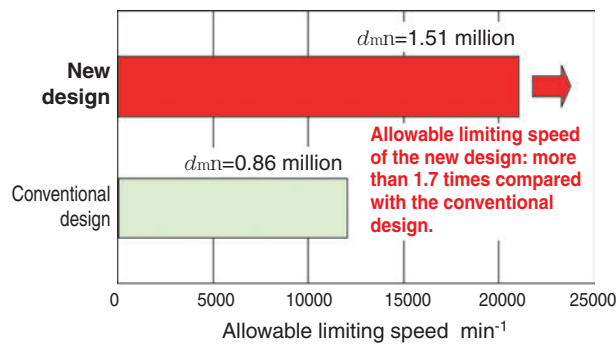


Fig. 4 Comparison of Limiting speed

Table 7 Temperature-rise test condition

Test rig	NTN horizontal-type thrust bearing test rig
Speed	Allowable limiting speed with the conventional design
Axial load	2780 N
Lubrication system	Apollo oil ATF-DX Circulating lubrication: 100, 200 ml/min. Initial oil temperature: 80°C
Criteria for stopping the test	At detection of occurrence of drilling wear, or occurrence of abnormal vibration
Run time	5 hours

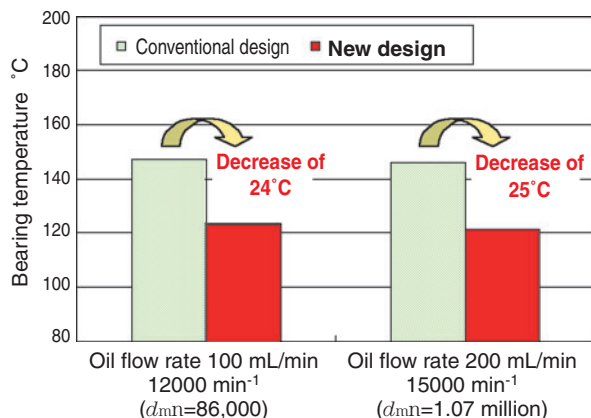


Fig. 5 Temperature-rise comparison between development bearing and current bearing by limiting speed for current bearing

(2) Test result

Under the test conditions in Table 7, the allowable limiting speeds of the new design are as follows: 12,000 min⁻¹ ($d_{m\Omega} = 86,000$) at oil flow rate of 100 mL/min; and 15000 min⁻¹ ($d_{m\Omega} = 1.07$ million) at oil flow rate of 200 mL/min.

In the temperature rise test, the bearing temperatures of the new design and conventional design were measured at the allowable limiting speed of the conventional design.

Fig. 5 illustrates the heat rise patterns for the new and conventional bearings at the allowable limiting speed of the conventional bearing.

The new and conventional bearings were run at a speed of 12,000 min⁻¹ ($d_{m\Omega} = 86,000$) at an oil flow rate of 100 mL/min. The temperature on the new design was approximately 24°C lower compared with the conventional design. In other words, the new design can limit the bearing temperature rise by 36%.

Also, the new and conventional bearings were run at a speed of 15,000 min⁻¹ ($d_{m\Omega} = 1.07$ million) at an oil flow rate of 200 mL/min. The temperature on the new design was approximately 25°C lower compared with the conventional design. In other words, the new design can limit the bearing temperature rise by 38%.

Compared with the conventional design, the newly developed high-speed thrust needle roller bearing can be characterized that the running temperature will be low, and its heat generation is limited.

5. Conclusion

The NTN innovative high-speed thrust needle roller bearing has been thus described.

This product will find a wide range of applications including motors for hybrid vehicles, automatic transmissions and CVT's on conventional vehicles, as well as general industrial machinery.

NTN's desire is to develop an optimized version of the new high-speed thrust needle roller bearing for each particular industrial field.

Photo of author



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