1. Introduction

Recently, further increases in productivity and reductions in energy consumption are demanded in industrial fields including machine tools, in view of social challenges such as the reduction of the labor pool due to decreasing birthrates and aging population, and environmental issues. To respond to these demands, higher output and higher efficiency are required.

Bearings are one of the key components of industrial machines, often referred to as "essential and indispensable in the industry." Many bearings are used in the rotational parts of machinery affecting heat dissipation, efficiency and output; therefore, improvement in performance of the bearings is the key to achieving improvement in performance of machinery.

Angular contact ball bearings have higher load carrying capacity and rigidity than deep groove ball bearings, and are used in many machines in broad industry fields.

NTN has increased performance of angular contact ball bearings of the "70" and "79" dimension series, which are broadly used as bearings for machine tool main spindles, and is already marketing them as 70U/79U Series in the line-up of high functional products under the name of "ULTAGE"※1, 2). Based on this successful outcome and the market trend, we have newly developed the 72U Series, which is the high-function angular contact ball bearing in the dimension series "72."

2. Features of developed product

The precision standard type angular contact ball bearings are superior in load carrying capacity and rigidity compared with the angular contact ball bearings of special high-speed specification, which use rolling elements of smaller diameter※3); however, their application was limited to lower speed.

In this development, the goal was set to expand the application range and further increase the load carrying capacity while ensuring both rigidity and high-speed capability, which are in a trade-off relationship, by reviewing the internal design of the 72 Series -- which intrinsically has a larger load carrying capacity and higher rigidity than the 70U/79U Series.

2.1 Load resistance

The newly developed product, 72U Series, achieved approximately 1.1 times greater basic dynamic load rating, approximately 1.2 times greater basic static load rating and approximately 1.3 times longer basic rating life compared to the conventional product (Fig. 1 and Fig. 2).
For machine tool main spindles and bearings, impact load (large axial load) may be applied due to unclamping load while exchanging tools during off-operation or unexpected collision of tool attached to the tip of the main spindle and the workpiece. When the impact load exceeds the design limit, indentation may occur on the raceway, impeding smooth and highly precise rotation. This axial load limit is called permissible axial load (stationary) and NTN defines it as the load leading to any of the following 4).

- The end of the contact ellipse produced between the rolling element and the raceway reaches the shoulder of either the inner ring or outer ring raceway. (Fig. 3).

The contact surface pressure of the raceway reaches 3,650 MPa\(^2\) on either the inner or outer ring.

\*2 Contact surface pressure 3,650 MPa\(^2\) is a value to produce permanent deformation of 0.00002 to 0.00005 times the rolling element diameter.
The newly developed 72U Series achieved approximately 2.5 times larger permissible axial load, significantly exceeding the conventional product, by reviewing the internal design such as the size of the height of shoulder (Fig. 4 and 5).

When grease lubrication is used, consideration for grease deterioration due to heat (namely, grease life) is important; therefore, an internal bearing design for grease retention is required. Even if the conventional product uses the cage made of polyamide resin, the newly developed product adopts the cage made of phenolic resin which has superior properties for high-speed operation with both air-oil lubrication and grease lubrication, and adopts a new shape designed for improved lubricating capability. The key points are described in the following section.

2.2.1 New-shape phenolic resin cage

The groove on the inner diameter surface of the new-shape phenolic resin cage (hereafter, new-shape cage) was deepened compared with the standard design to achieve the following two objectives (Fig. 6):

1. Stabilize cage behavior by improving the cage so that it is actively guided to the outer ring, arranging the contact position of the rolling elements and cage pockets.
2. Extend the grease life by improving the grease retention, expanding the space for holding the grease.

2.2 High-speed capability (lubricating capability)

For air-oil lubrication, not only the supply of lubricating oil into the bearing but also the drainage of lubricating oil out of the bearing is important. Without smooth supply and drainage, lubricating oil may remain inside the bearing without good heat transfer, resulting in a possible rise in temperature and potential seizure\(^\text{5, 6}\). To maintain a stable temperature under high speed operation, an optimum internal design of rolling elements and raceway shapes plus consideration of supply and drainage of lubricating oil are required.

Fig. 6 (a) Appearance of resin cage

Fig. 6 (b) Bore diameter shape of resin cage
**Fig. 7** and **8** show the results of high-speed operation test of the cages with standard shape and new shape. It was verified that the temperature of the bearing outer ring of the new-shape cage, newly adopted this time (○ in the graph) was equivalent to or below the standard shape cage (□ in the graph), both for air-oil lubrication and grease lubrication.

### 2.2.2 Modification of inner ring shape

Since the inner ring outer diameter (front side), which is the loaded side of the newly developed 72U Series, affects the permissible axial load, dimensions such as the shoulder height were reviewed. On the other hand, the inner ring outer diameter (back side), which is the anti-loaded side, was designed with lower height than the conventional product to make it easier to supply lubricating oil and grease injection between the cage and the inner ring raceway surface by combining it with the aforementioned new-shape cage.

Particularly in the case of air-oil lubrication, this allows supply of lubricating oil from the slanted direction (nozzle target), which was not possible with the conventional product, reducing the restriction of size for installing a spacer with nozzle between bearings, improving the degree of freedom for designing the peripheral structure of the bearings (**Fig. 9**).

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**Fig. 7** High-speed test of standard and new cage (air-oil lubrication)

**Fig. 8** High-speed test of standard and new cage (grease lubrication)

**Fig. 9** Section of ULTAGE precision standard angular contact ball bearing 72U series
2.3 Rigidity

In order to achieve both rigidity and high-speed capability of the newly developed 72U Series, which are in a trade-off relationship, we checked the impact of the internal bearing design of rolling elements and raceway shapes on rigidity, and when found to be significant, restricted the change to the minimum so that the rigidity can be maintained.

The comparison of the rigidity between the newly developed product and the conventional product is shown in Fig. 10 and 11. Although the rigidity of the developed product is slightly lower than the conventional product, it is almost at the same level.

3. Operation test results

The operation test results under a constant pressure preload of the newly developed 72U Series and the conventional product are shown in Fig. 12 and 13. It was verified that the temperature of the bearing outer ring of the developed product (○ in the graph) was equivalent to or below the conventional product (△ in the graph), both for air-oil lubrication and grease lubrication.

This developed product achieved improvement of load carrying capacity and permissible axial load. On the other hand, rigidity of this developed product is maintained at the same level as the conventional product, and by combining with the aforementioned new-shape cage, high-speed capability is also maintained at the stable temperature similar to or below that of the conventional product, achieving approximately 1.6 times larger $d_{mn}$ value $^{3}$ of 1.8 million for air-oil lubrication and approximately 1.1 times larger $d_{mn}$ value of 1 million (both with contact angle of 15˚ and use of steel balls).

$^{3}d_{mn}$ value expresses the rotational performance of bearings. $d_{mn}$ (diameter of rolling element (mm) x rotational speed (min$^{-1}$))

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**Fig. 10** Axial rigidity (7210CDB)

**Fig. 11** Axial rigidity (7220CDB)

**Fig. 12** Running test (air-oil lubrication)
ULTAGE Precision Standard Angular Contact Ball Bearing, 72U Series

5. Summary

The newly developed ULTAGE Precision Standard Angular Contact Ball Bearing 72U Series achieved improved load resistance and equivalent or better high-speed capability compared to the conventional products, while maintaining rigidity.

The developed product is one of the precision bearings that satisfies the market requirement for machine tools and other industrial machines with ongoing requirements for higher functionality.

We are poised to work on the improvement of the existing Series including the Standard Series and development of new Series for our precision angular contact ball bearings.

References