Precision Bearings "ULTAGE" Series for Machine Tools

1. Introduction

Machine tools, including machining centers, are looking for higher speed, higher efficiency and higher precision. In addition, as the development of dry machining technology that does not use oil during the machining process suggests, more attention is being paid to the working environment.

With regard to bearings designed for the main spindles of machine tools, NTN has been pursuing higher $d_{mn}$ values, higher precision and lower NRRO (Non-Repeatable RunOut). We are also paying attention to eco-consciousness.

This paper introduces the "ULTAGE Series", developed as ECO series for machine tools, with the concept of "harmony with the environment" in addition to high speed and high precision features. "ULTAGE" is a combination of the words "ULTIMATE" and "STAGE", to express the NTN's concept of pursuing the ultimate precision rolling bearings for machine tools.

2. ULTAGE Series

The ULTAGE Series offers a total of 10 types of bearings, including angular contact ball bearings and cylindrical roller bearings. (See Table 1)

For angular contact ball bearings, a total of eight types are available. They include "70U/79U" type developed from the standard angular contact ball bearings; "HSE" type with improved abrasion resistance and seizure resistance in addition to high speed capability; "HSF" type which achieves higher speed and limited temperature rise; two sealed types (BNS, 70/79AD, CD) designed for grease lubricated applications; the eco-conscious "HSL , HSFL" types designed for air-oil lubricated applications, with reduced noise level and low air/oil consumption; the ball screw support type "2A-BST", and the light contact sealed type "2A-BST LXL".

For cylindrical roller bearings, two types are available; "N10HSR type" featuring high-speed operation under both air-oil and grease lubrication, and the eco-conscious "N10HSL type" designed for...
Precision Bearings “ULTAGE” Series for Machine Tools

In this paper, five types (sealed and eco-conscious types) in the ULTAGE Series are introduced.

Table 1  ULTAGE series

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Features</th>
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</thead>
<tbody>
<tr>
<td>[Standard] 70U type, 79U type (Contact angle 15°, 20°, 30°)</td>
<td>Optimized interior structure and resin cage help positively inhibit temperature rise.</td>
<td></td>
</tr>
<tr>
<td>[High-speed] 5S-2LA-HSE type (Contact angle 15°, 20°, 25°)</td>
<td>Adoption of special material and surface treatment, with drastically improved abrasion resistance and seizure resistance. Features improved rigidity and reliability in addition to the high speed of the conventional “HSB0CAEX1” ultra high-speed angular contact ball bearing.</td>
<td></td>
</tr>
<tr>
<td>[Super high-speed] 5S-2LA-HSF type (Contact angle 25°)</td>
<td>Maintaining the advantages of HSE type, this type has small diameter ceramic balls to achieve higher speed and limited temperature rise.</td>
<td></td>
</tr>
<tr>
<td>[Eco-conscious] 5S-2LA-HSL type (Contact angle 15°, 20°, 25°) 5S-2LA-HSFL type (Contact angle 25°)</td>
<td>Adoption of special material and surface modification, with drastically improved abrasion resistance and seizure resistance. Designed only for air-oil lubrication, with circumferential grooves on the inner ring of the HSE type and eco-conscious nozzle. Features reduced noise and air/oil consumption in addition to the high speed of the HSE type. It is applicable also to HSF type.</td>
<td></td>
</tr>
<tr>
<td>[High-speed] 5S-2LA-BNS type (Contact angle 15°, 20°, 25°)</td>
<td>Adoption of special material and surface heat treatment, with drastically improved abrasion resistance and seizure resistance. Designed only for grease lubrication, with optimized internal design, grease reservoirs, special grease and non-contact seals.</td>
<td></td>
</tr>
<tr>
<td>[Standard] 70CD type, 79CD type (Contact angle 15°) 70AD type, 79AD type (Contact angle 25°)</td>
<td>Angular contact ball bearing with optimized internal structure, non-contact rubber seals on both sides, and long-life special grease. Bearing with ceramic balls is also available.</td>
<td></td>
</tr>
<tr>
<td>[Open] 2A-BST type (Contact angle 60°)</td>
<td>Open type bearing with longer rolling contact fatigue life by additional surface heat treated rings.</td>
<td></td>
</tr>
<tr>
<td>[Light contact sealed] 2A-BST LXL type (Contact angle 60°)</td>
<td>Features longer rolling contact fatigue life by additional surface heat treated rings and drastically reduced fretting wear by employing special grease. Provides improved dust resistance and grease-retaining capability by low-torque and light contact seals.</td>
<td></td>
</tr>
<tr>
<td>N10HSR type</td>
<td>Features optimized internal structure for high speed capability with low temperature rise. Provides higher limiting speed than the conventional “N10HS” high-speed cylindrical roller bearing.</td>
<td></td>
</tr>
<tr>
<td>N10HSL type</td>
<td>Designed only for air-oil lubricated applications, with circumferential grooves on the inner ring of the N10HSR type and an eco-conscious nozzle. Features reduced noise and low air/oil consumption in addition to the high speed capability of the N10HSR type.</td>
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2.1 Bearings for Main Spindles
2.1.1 Grease-lubricated Sealed Angular Contact Ball Bearing (BNS Type)

From the viewpoint of environmental issues, grease is the most suitable lubrication method for bearings used for main spindles. When using bearings under grease lubrication, no external lubrication unit is required, therefore assembly and maintenance are easy. Additionally, because the bearings are pre-lubricated with a suitable amount of grease, the amount of oil mist is very low.

However, when using high-speed angular contact ball bearings, the lubrication life will be a major factor. NTN evaluated the long life grease from various viewpoints, and developed "Grease-lubricated Sealed Angular Contact Ball Bearing (BNS Type)" (Fig. 1) to be used for high-speed spindles of ø 50 or larger diameter. Then, NTN introduced at JIMTOF2000 (Japan International Machine Tool Fair).

For the BNS type, special material and surface heat treatment are adopted for rings to extend the rolling contact fatigue life. Grease is retained and supplied to the raceway surface by the seals provided on both sides of the bearing. Grease reservoirs set directly adjacent to the outer ring raceway, in order to extend the grease life during high-speed operation. Fig. 2 illustrates the effect of grease reservoirs for bearing life, and Table 2 shows the results of endurance test.

From the test results shown in Fig. 2, it was found that the life of the grease-lubricated sealed angular contact ball bearing is 7.4 times longer than the conventional type.

The endurance test was conducted on the BNS type (5S-2LA-BNS020: ø 100 × ø 150 × 24) with seals on both sides, and HSE type (5S-2LA-HSE020C without seals: ø 100 × ø 150 × 24), with "0N" fixed position.

![Fig. 1 Grease-lubricated Sealed Angular Contact Ball Bearing](image)

![Fig. 2 Effect of grease reservoirs on bearing life](image)

<table>
<thead>
<tr>
<th>Bearing Type</th>
<th>Spindle Direction</th>
<th>Spindle Size</th>
<th>Duration, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSE type (Without seal)</td>
<td>Horizontal</td>
<td>ø 100 × ø 150 × 24</td>
<td>650h</td>
</tr>
<tr>
<td>BNS type</td>
<td>Horizontal</td>
<td>ø 100 × ø 150 × 24</td>
<td>20000h</td>
</tr>
<tr>
<td>BNS type</td>
<td>Vertical</td>
<td>ø 100 × ø 150 × 24</td>
<td>20000h</td>
</tr>
</tbody>
</table>

**Table 2** Endurance test results

<table>
<thead>
<tr>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>[HSE type]</strong></td>
</tr>
<tr>
<td>5S-2LA-HSE020C (ø 100 × ø 150 × 24)</td>
</tr>
<tr>
<td><strong>[BNS type]</strong></td>
</tr>
<tr>
<td>5S-2LA-BNS020LLB (ø 100 × ø 150 × 24)</td>
</tr>
<tr>
<td>Grease</td>
</tr>
<tr>
<td>Rotating speed</td>
</tr>
<tr>
<td>Preload amount</td>
</tr>
<tr>
<td>Jacket cooling</td>
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</tbody>
</table>
preload (after mounted) and at a rotating speed of 11,000 min\(^{-1}\) (\(d_{mn}\) value: 1,400,000). The HSE type showed a life of 1,000 hours or shorter, while the BNS type showed a life of 20,000 hours (the test was suspended after 20,000 hours).

This result suggests that air-oil lubricated spindles can be replaced by grease-lubricated spindles in the high-speed range up to 1,400,000 (\(d_{mn}\) value).

In addition, since the BNS type is a pre-lubricated sealed type, there is no need to fill grease and to clean the bearings during spindle assembly. This may not only simplify handling procedure and reduce assembly labor, but also improve the working environment (e.g. elimination of cleaning oil disposal).

Furthermore, an improvement was made on the seal after JIMTOF2000. Seal on the back side was replaced by the orange seals (previously, black seals were used on both sides). This facilitates confirmation of bearing direction during assembly work: for DB mounting, the orange seals face each other, and for DF mounting, the black seals face each other.

### 2. 1. 2 Grease-lubricated Sealed Angular Contact Ball Bearing (70/79 AD, CD Type)

For spindles of \(\phi 50\) or less inner diameter, such as rotating tool spindles and small-size spindles, which are used in low to medium speed ranges, we developed the "Grease-lubricated Sealed Angular Contact Ball Bearing (70/79 AD, CD Type)" (Fig. 3) and introduced at JIMTOF2002.

This bearing has a load capacity equal to the standard angular contact ball bearing, and offers two types: CD type (contact angle 15\(^{\circ}\)) and AD type (contact angle 25\(^{\circ}\)). It is developed based on the design concept of the BNS type, which features non-contact seals on both sides, long-life special grease and optimized internal structure for reduction of heat generation. Bearing with ceramic balls is also available.

**Fig 4** shows the results of high-speed operation test. The test was conducted on the 70CD (7006CD: \(\phi 30 \times 55 \times 13\)) and 70AD type (7006AD: \(\phi 30 \times 55 \times 13\)), with mounted preload of 180N and 250N, respectively. The bearings were mounted with DB arrangement. Both 70CD and 70AD types ran stable at rotating speeds of up to 25,000 min\(^{-1}\) (\(d_{mn}\) value: 1,100,000).

With 70/79 AD and CD types, black and orange seals were provided at the front and rear sides respectively, like the BNS type, to facilitate confirmation of bearing mounting orientation during assembly work.

#### Table 3 Bearing arrangement aided by seal color

<table>
<thead>
<tr>
<th>DB set [Rear-side]</th>
<th>Orange seal + Orange seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange seal</td>
<td>Orange seal</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>DF set [Front-side]</td>
<td>Black seal + Black seal</td>
</tr>
<tr>
<td>Black seal</td>
<td>Black seal</td>
</tr>
</tbody>
</table>

**Fig 3** Grease-lubricated Sealed Angular Contact Ball Bearing

**Fig 4** High-speed test results
2.1.3 Eco-conscious Air-Oil Lubricated Angular Contact Ball Bearing (HSL , HSFL Type)

Advantages of grease lubrication with regard to environmental issues were discussed previously. However, sufficient supply of lubricating oil to the raceway is difficult in high-speed operation, thereby, the life of lubricating oil becomes an issue. Because of this, air and oil lubrication is normally used in high-speed applications. However, reduction of air/oil consumption and noise level are constant requirements.

Based on the "Low-Noise Angular Contact Ball Bearing (SF Type)" [1], which was introduced at JIMTOF2000, we continued to make further improvements and have eventually developed the "Eco-conscious Air-Oil Lubricated Angular Contact Ball Bearing (HSL , HSFL Type)" [3], featuring not only high-speed capability and low noise, but also reduced air and oil consumption, which was then introduced at JIMTOF2002.

Even with the SF type (low-noise angular contact ball bearing), oil was supplied efficiently to the inside of the bearing and reduction of air and oil consumption was possible. However, it was found that as the air supply rate is reduced, oil begins to collect in the circumferential groove at the exit of the nozzle, and when collected oil enters the inner section of the bearing at once, it causes the bearing temperature to fluctuate. This issue was solved by removing the circumferential groove from the nozzle and instead providing circumferential groove on the outer face of the bearing inner ring. [4] [5]

Fig. 5 shows the bearing design of HSE(HSF) type, SF type, and HSL(HSFL) type.

Fig. 6 shows the correlation between air supply rate and outer ring temperature measured for the HSF type, SF type and HSFL type (5S-2LA-HSFL020: \( \phi 100 \times \phi 150 \times 24 \)), with a constant spring preload (2.5kN). The test was carried out under fixed conditions: rotating speed of 21,000 min\(^{-1}\) (\(d_m\) value: 2,650,000) and oil supply rate of 0.03mL/5min.

With the HSF and SF types, the outer ring temperature rose suddenly at an air supply rate of 22.5NL/min and 15NL/min respectively. However, with the HSFL type, operation was still possible at much lower air supply rate of 10NL/min.

Fig. 7 shows change of outer ring temperature at a fixed rotating speed (21,000 min\(^{-1}\)) and at different oil supply intervals (oil supply rate: 0.03mL/shot). With the HSFL type, stable operation was possible in the oil supply interval range of 2 to 21 min. With the HSF type ...

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**Fig. 5** Bearing design

**Fig. 6** Air supply rate on outer ring temperature

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**[Test Conditions]**

**[HSFL type]**

5S-2LA-HSFL020 (\( \phi 100 \times \phi 150 \times 24 \))

**[SF type]**

5S-SF10XX (\( \phi 100 \times \phi 150 \times 24 \))

**[HSF type]**

5S-SLA-HSF020 (\( \phi 100 \times \phi 150 \times 24 \))

- Rotating speed : 21000 min\(^{-1}\)
- Preload amount : 2.5 kN (Constant preload)
- Oil supply rate : 0.03mL/5min
- Jacket cooling : Provided
type, maximum reduction of oil consumption to 1/10 is possible, since an oil supply interval of 2 min is normally recommended for dmns value: 2,650,000.

Fig. 8 shows noise level change at different rotating speeds of up to 20,000 min\(^{-1}\). It is demonstrated that noise level can be reduced by approximately 10dBA.

Fig. 9 shows operation results of the HSL type (5S-2LA-HSL020: \( \phi 100 \times 150 \times 24 \)) when operated with a fixed position preload (mounted preload: 0N). With the HSE type, the outer ring temperature becomes unstable when the rotating speed increases over than 16,000 min\(^{-1}\), but the HSL type can achieve stable operation at rotating speeds of up to 19000 min\(^{-1}\) (dmn value: 2,400,000), at 10NL/min (air supply rate) and at 0.03mL/10min (oil supply rate).
2.1.4 Eco-conscious Air-Oil Lubricated Cylindrical Roller Bearing (N10HSL Type)

Conventionally, the allowed dmn value of air-oil lubricated cylindrical roller bearings is approximately 1,500,000, therefore, angular contact ball bearings are used for the rear side of spindles that exceed dmn 1,500,000. In this case, a slide mechanism equipped with a ball bushing is used to compensate spindle extension for complicating the spindle structure (Fig. 10). To improve this structure, NTN developed the "Eco-conscious Air-Oil Lubricated Cylindrical Roller Bearing (N10HSL Type)".

This bearing enables high-speed operation by optimizing the internal structure and using a special resin cage which is lighter than brass cage.

The lubrication system, like the eco-conscious angular contact ball bearing, is constructed in such a way that air cutting noise caused by the rolling elements is reduced and oil is supplied inside of the bearing by supplying air and oil to the tapered portion of the inner ring, not directly to the rolling element. This enables reduction of air and oil supply rates as well as noise level.

Fig. 11 shows the bearing design of standard bearing (N10HS type) and eco-conscious bearing (N10HSL type).

Fig. 12 shows the test results of outer ring temperature rise for the N10HS and N10HSL types. The N10HS type shows an acute temperature rise of outer ring temperature at 20,000 min⁻¹ under conditions of 40NL/min (air supply rate), 0.02mL/5min (oil supply rate) and 0.2 m (clearance after mounted).

With the N10HSL type (N1014HSL: 70 × 110 × 20), operation is possible under conditions of 20NL/min (air supply rate) and 0.02mL/10min (oil supply rate), which are 1/2 of the conventional figures. High-speed operation at 26,000 min⁻¹ (clmax value: 2,300,000) is possible. From comparison of the outer
Precision Bearings “ULTAGE” Series for Machine Tools

ring temperature between N10HS and N10HSL, it is obvious that the N10HSL type has a lower temperature rise, which is because of the low temperature rise effect by smaller rolling elements. A rise of outer ring temperature is shown at low speeds for both types. This caused by the excessive supply of oil which is suitable for the high-speed operation.

Fig. 13 shows the measurement results of noise level. The eco-conscious type shows a lower noise level by approximately 6dBA than the standard type at 15,000 min⁻¹.

![Fig. 12 Outer ring temperature rise](image1)

![Fig. 13 Noise level](image2)

![Test Conditions](table1)

![Test Conditions](table2)
2.2 Ball Screw Support Bearing (2A-BST LXL Type)

To improve efficiency of machine tools, the speed of the feeder also needs to be improved in addition to the main spindle. Ball screw support bearings used for feeders sometimes cause fretting on the raceway due to the oscillation generated by slight feed movement and vibration generated during cutting operation. In addition, deterioration of grease due to entry of cutting oil and shortened life due to entry of contaminants (e.g., ball screw grease, cutting chips) are also present.

The ball screw support thrust angular contact ball bearing (2A-BST LXL type) (Fig. 14) has been developed to solve these problems, with the intention of improving resistance to fretting by applying surface heat treatment and pre-lubricating with special grease (the oscillation test results show the improvement in fretting resistance by 10 times). The results are shown in Fig. 15.

Unlike the BST type standard bearing (open design), the 2A-BST LXL type that has low-torque, light-contact seals, which not only prevents entry of contaminants but also facilitates assembly work since the greasing process is not required. Furthermore, confirmation of bearing orientation during assembly is also made easier by changing the seal colors between sides, like the sealed angular contact ball bearing developed for main spindles.

![Fig. 14 Thrust angular contact ball bearing for ball screw support](image)

![Fig. 15 Oscillation test results](image)
3. Conclusion

Machine tools in the future are expected to feature eco-consciousness in addition to conventional functional requirements such as high speed, high efficiency and high precision. Eco-conscious technologies, including reduction of air/oil consumption, oil mist and noise level with power saving will play more important roles.

For machine tool bearings, including those for spindles and feeders, eco-consciousness will be a key issue in addition to the quest for higher dmn value and lower NRRO.

A wide range of requirements is expected from customers. However, NTN will continue to work on improvement and development of ultimate precision bearings keeping its motto "be friendly to the earth and its people" in mind.

References
5) K.Fujii , JSME Division of Manufacturing and Machine Tools

Photo of the author

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