

$d_{mn}170 \times 10^4$ Sealed High-Speed Angular Contact Bearing “New BNS Type”

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The limiting d_{mn} value of the BNS type sealed high-speed angular contact bearing is $d_{mn} 140 \times 10^4$.

A new limiting speed of $d_{mn} 170 \times 10^4$ (the world's highest speed level) was enabled by optimized internal design and a new grease. New grease improves the running-in operation for main spindle bearings. It corresponds to the small machining center and tapping machine by making it to the series up to the small diameter size of $\phi 20\text{mm}$ bore.

1. Introduction

Four years have already passed since the ULTAGE Series of products were presented at JIMTOF 2002. The main purpose for developing the ULTAGE Series was to provide bearing products that can handle higher speeds and advanced functions in machine tool main spindles. The need for higher main spindle speeds has posed new challenges for bearings that support machine tool main spindles. That is, higher main spindle speeds have led to higher bearing speeds, and main spindle bearings must handle the increased heat generation that results from the adoption of built-in spindle motors capable of rapid acceleration and deceleration. Main spindle bearings must also accommodate shorter bearing lengths in order to help increase critical bearing speeds. Greater centrifugal force, higher ambient temperatures, and shorter bearing spans have led to increased internal bearing preloads, making operating conditions for main spindle bearings much more demanding. To address this problem, NTN has developed and marketed the ULTAGE Series of standard angular contact ball bearings (HSE type) that are capable of high-speed operation under high bearing stress conditions.

The ULTAGE Series consists of 12 product types capable of meeting various customer needs for higher speeds and difficult environmental considerations. It includes an eco-friendly bearing product line and a

sealed angular contact ball bearing product line.

This report describes NTN's product development efforts for the “New BNS Type” sealed angular contact ball bearing product, which is capable of the world's highest d_{mn} limiting speed, at 170×10^4 , with a definite position preloading system. Based on the conventional BNS type, this product has been developed through optimization of the internal design, introduction of the new SE-1 grease and employment of a special carburized steel for the inner and outer rings.

2. Development of the "New BNS Type" Sealed Super High-Speed Angular Contact Ball Bearing Featuring the World's Highest d_{mn} of 170×10^4

2.1 Highlights of development

For machine tool main spindle bearings, higher speed and greater stiffness are required to shorten machining time, while inhibition of excessive temperature increases and higher running accuracy are also needed to improve machining accuracy. Furthermore, reduction in the amount of lubricating oil and employment of grease lubrication are necessary to ensure eco-friendliness. Among these requirements, the most outstanding market need is the adoption of a grease lubrication system because of its friendliness to the environment and ease of

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handling. In this context, the ULTAGE Series grease-lubricated, sealed angular contact ball bearing products are highly favored in the market.

However, demand is strong for higher speeds in excess of the $140 \times 10^4 d_{mn}$ limit of conventional grease-lubricated, sealed angular contact ball bearings. The proposed arrangements for coping with this trend are a starvation lubrication unit that is intended to extend lubrication life, as well as a grease lubrication system for bearing spacers (NTN's new grease lubrication system).

The most critical performance characteristic associated with employment of grease lubrication is long-term durability, and a bearing life of longer than 20,000 hours is usually required. To achieve long-term durability for grease-lubricated main spindle bearings, it is necessary to inhibit excessive heat increases with the bearings, retain the grease and supply the base oil around the rolling surface. It is also necessary to maintain the durability of the bearings against heat buildup from built-in motors situated near the bearings. In addition, the reduction of main spindle costs is also an important consideration.

To address these challenges and satisfy the need for super high speed, the author has developed the New BNS Type, which is capable of the world's fastest level of running speed. This new product line retains the bore diameters, single outside diameters and widths of conventional grease-lubricated, sealed angular contact ball bearings. The New BNS Type bearing products allow high-speed main spindles, which previously needed oil lubrication arrangements including air-oil lubrication, to be actively lubricated with grease. This advantage can help decrease costs for main spindles. Compared with the conventional

BNS type bearings, the New BNS Type products feature an improved internal design optimized for higher speed, thereby achieving stable operation at the world's highest d_{mn} , 170×10^4 , a 20% increase over conventional BNS type products. Furthermore, temperature increases on main spindles are limited to the same level as conventional BNS type bearings.

The author believes that adoption of the new grease leads to simplification of bearing running-in operation and inhibition of adverse effects from heat generated by built-in motors. Thus, the author's new bearing product line can withstand long periods of operation, in excess of 20,000 hours.

The New BNS Type product series will also include bearings with bore diameters measuring 20 to 100 mm so that the products can be used on small-sized machining centers and tapping centers.

2.2 Optimized design

Beginning with the conventional grease-lubricated BNS type, the author first redesigned the internal structure to achieve a higher bearing speed while maintaining a grease-lubrication arrangement. The author reached a design with an optimal combination of diameter, number of balls, groove curvature, and other factors. This combination helped prevent heat buildup in the bearing, inhibit increases in internal bearing pressure and minimize loss in bearing rigidity (**Fig. 1**). In addition, the author adopted grease pockets identical to those used on conventional BNS type products so that grease is kept nearest to the rolling elements running at higher speeds in order to optimize the lubricating performance of the grease (**Fig. 2**).

Furthermore, since hoop stress can pose a problem

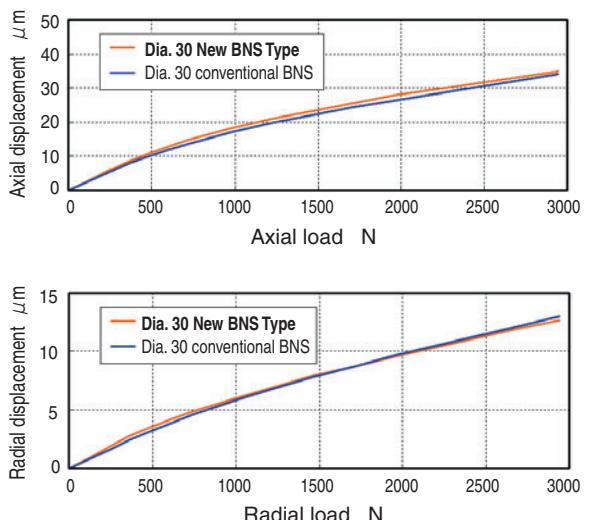
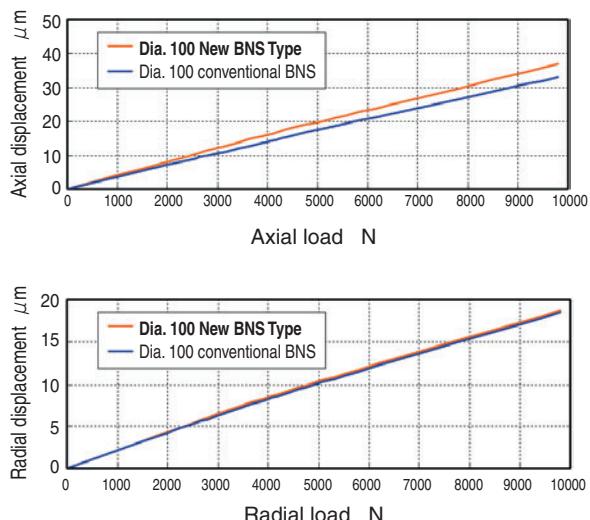
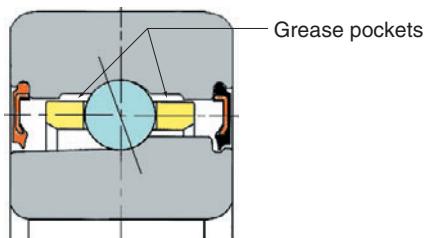


Fig. 1 Rigidity graph

**Fig. 2** New design

when a bearing is used at a higher speed range, the bearing ring of the author's bearing is made of a special carburized steel that has an optimized alloy composition.

In bearing performance test, the newly developed bearing was run at a maximum speed of $190 \times 10^4 d_{mn}$ (150 $\times 10^4 dn$), exceeding the target of the development effort of $170 \times 10^4 d_{mn}$ (135 $\times 10^4 dn$). Thus, the author proved that the newly developed bearing design features limited temperature increase in comparison with the conventional BNS type (**Fig. 3**).

Note that, at same d_{mn} values, the temperature

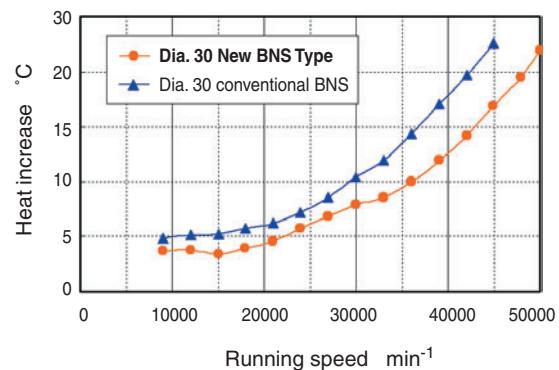
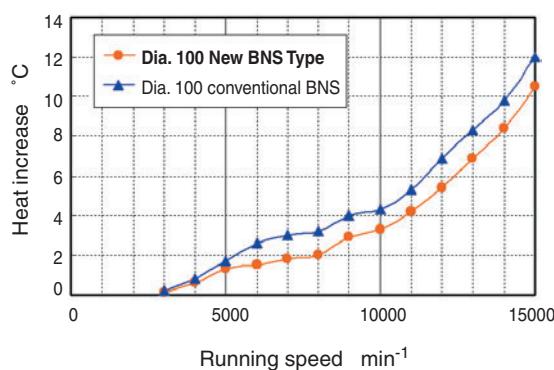
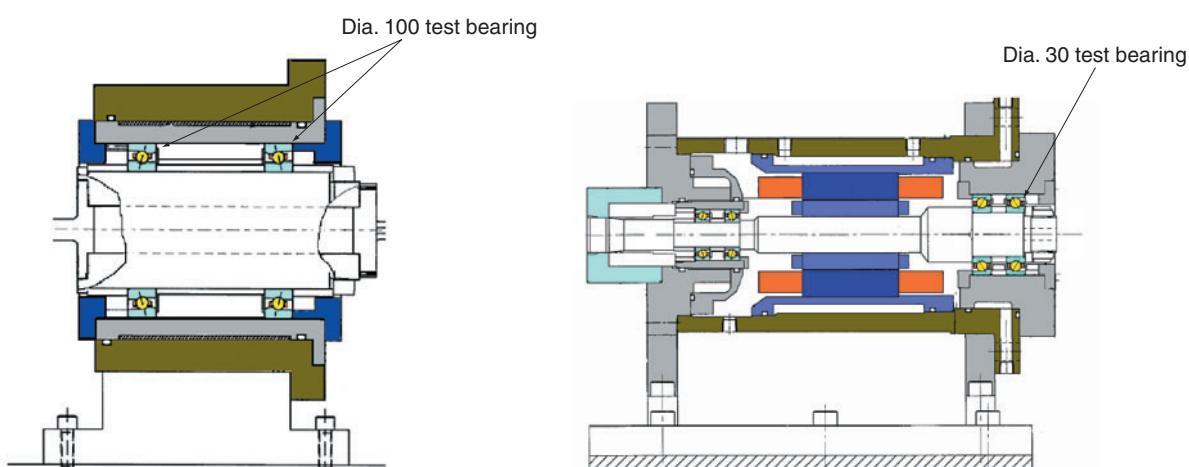
increase in the 100 mm bore diameter bearings differ from those of the 30 mm bore diameter bearings. This is because of the difference in the construction of the test rigs (**Fig. 4**).

2.3 Grease life (lubrication life)

One important consideration in determining the lubrication specifications for a main spindle bearing is grease life (lubrication life). The useful life of any grease greatly varies depending on its operating environment. The typical factors that greatly affect grease life include the operating temperature, bearing load (preload) and ingress of foreign matter (chips, etc.).

Unlike the main spindles used on the test rigs, main spindles used on real machine tools feature better sealing performance in order to avoid ingress of coolant during machining operation. This means that heat buildup tends to occur inside machine tool main spindles.

In addition, main spindles that are more compact mean smaller bearing-to-bearing distances, which hinders heat dissipation. Poor heat dissipation causes

**Fig. 3** Temperature rise test results**Fig. 4** Test machine

accelerated heat buildup in main spindles. Furthermore, when a machining load works on a main spindle, heat buildup is further promoted, leading to shorter grease life. This trend is more apparent with machine tool main spindle bearings that lack the provision of jacket cooling.

Provision of a cooling arrangement on a main spindle such as jacket cooling greatly affects the temperature profile of a given machine tool main spindle, and significantly influences the useful life of the grease used on the bearings on that main spindle.

The newly developed bearing employs a novel grease. In developing this grease, a test rig arrangement was developed that incorporated a main spindle configuration without jacket cooling to simulate operation on real machine tool. Thus, the author attempted to obtain more reliable grease endurance data.

Note that the main role of the seals on a sealed bearing is to retain grease, and due to the limitations of their function, these seals are not intended to prevent coolant ingress.

Ingress of foreign matter (chips, etc.) into main spindles on actual machine tools rarely occurs. However, coolant entering a bearing on a main spindle bearing can cause the consistency of grease in it to vary, possibly allowing the grease to flow out or to become hardened. If this situation occurs, the grease will fail to develop its designed performance and the bearing will no longer run smoothly. Therefore, this situation must be actively avoided.

2.4 Development of the new SE-1 grease

The conventional BNS type is lubricated with

prefilled MP-1 (urea-based thickener and synthetic oil) as a standard grease. This grease had been performing well in high-speed electric motors and in the CRC grease high-temperature life test conducted according to ASTM D 3336, exhibiting longer life. For this reason, this grease was applied to the BNS type. In addition, it has been performing very well as a grease for machine tool main spindles.

Immediately after adoption by the author, the MP-1 was subjected to a durability test with an angular contact ball bearing. It exhibited a high degree of lubrication performance as it withstood 20,000 hours of operation at $140 \times 10^4 d_{mn}$ (bore diameter $100 \times 11000 \text{ min}^{-1}$, with jacket cooling) (Fig. 5).

The downside, however, is that the viscosity of the base oil in MP-1 is relatively high ($40.6 \text{ mm}^2/\text{s}$ at 40°C) compared with general-purpose greases for main spindle bearings that are commonly used by machine tool manufacturers (Fig. 6). When jacket cooling is not provided, the outer ring temperature sometimes (though rarely) exceeds 60°C during the running-in period. In other words, MP-1 needs improvement to achieve easy running-in operation.

As previously mentioned, the durability test was executed at a high-speed condition of $140 \times 10^4 d_{mn}$, and therefore, jacket cooling was provided. However, there has been demand for main spindles that perform reliably even when no jacket cooling is provided. A portion of the data from durability test is given in Fig. 7.

SE-1 grease has been developed to address two challenges: easy running-in operation and durability without jacket cooling.

Employing diurea as a thickener of excellent shear

Bearing type	Attitude	10000h	20000h	Test conditions
BNS	Vertical	:	Discontinued	BNS type 5S-2LA-BNS020LLB · Grease: MP-1 · Running speed: $1,1000 \text{ min}^{-1}$ · Preload: 0 N as mounted (definite position preloading) · Jacket cooling: Yes
	Horizontal	:	Discontinued	

Fig. 5 Durability test results of BNS type

Grease brand	General purpose grease for main spindle bearing	MP-1	SE-1
Thickener	Barium complex soap	Urea-based	Urea-based
Base oil	Ester oil	Synthetic oil	Ester oil
Base oil viscosity ($40^\circ\text{C} \text{ mm}^2/\text{S}$)	20	40.6	22
Operating temperature ($^\circ\text{C}$) range (for reference)	$-60 \sim +130$	$-40 \sim +150$	$-50 \sim +120$

Fig. 6 Grease properties

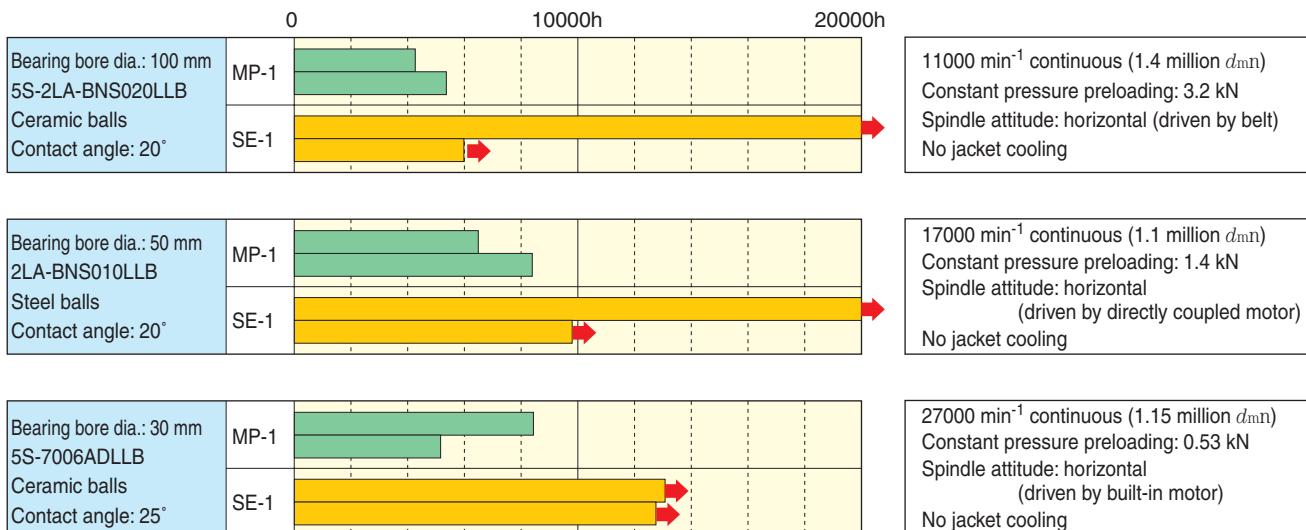


Fig. 7 Durability test results (no jacket cooling)

<Test conditions>
5S-2LA-BNS010LLBDB
0-20000 min⁻¹
Preload as mounted: 98 N
Jacket cooling: No

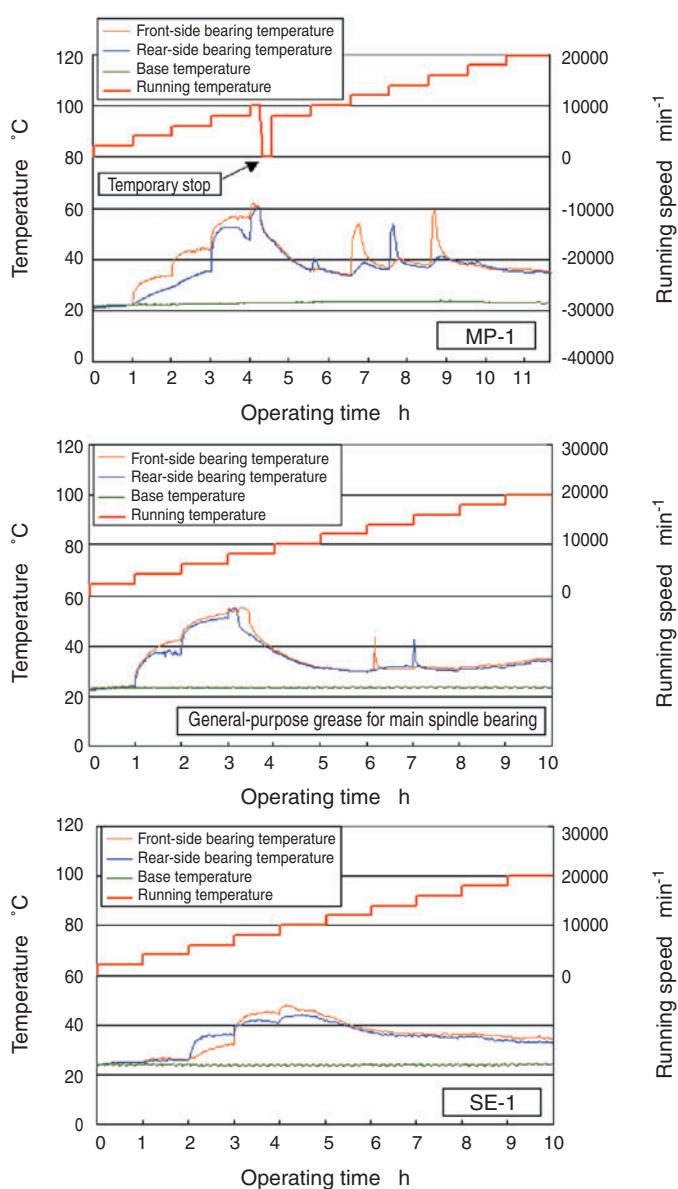


Fig. 8 Running in operation

Bearing type	Attitude	10000h
$\phi 100\text{mm}$	Horizontal 1	Still running after 9719 hours 

Test conditions

- Dia. 100 externally driven test rig
- Grease: SE-1
- Running speed: 13500 min^{-1}
- Preload: 0 N as mounted (definite position preloading)
- Jacket cooling: Yes

Bearing type	Attitude	5000h
$\phi 30\text{mm}$	Vertical	Still running after 2922h hours 
$\phi 30\text{mm}$	Horizontal	Still running after 2491 hours 

Test conditions

- Dia. 30 built-in motor test rig
- Grease: SE-1
- Running speed: 40000 min^{-1}
- Preload: 0 N as mounted (definite position preloading)
- Jacket cooling: Yes

Fig. 9 Durability test results

stability, SE-1 is capable of lubrication in a wide speed range, from very low speeds to higher speeds. The base oil used in SE-1 is an ester oil that excels in heat resistance and oxidation stability, helping extend grease life.

The viscosity of the base oil is $22 \text{ mm}^2/\text{s}$ (40°C), which contributes to achieving easy running-in operation (**Fig. 8**).

Currently, the author is performing high-speed durability testing with the newly developed bearing type that is configured in a back-to-back duplex arrangement (DB arrangement), with each of the paired bearings being prefilled with SE-1 (**Fig. 9**). The running speed is $13,500 \text{ min}^{-1}$ for the 100 mm bore diameter bearing and $40,000 \text{ min}^{-1}$ for the 30 mm bore diameter bearing. The main spindle speed corresponding with $170 \times 10^4 d_{mn}$ falls in a sufficiently

high-speed range and requires the provision of jacket cooling. Therefore, the author's durability test rigs incorporate jacket cooling. During testing, the bearing temperatures have been stable.

3. Conclusion

The process for developing the New BNS Type bearing has been described above. The most important considerations in developing a high-speed lubrication arrangement are how to inhibit heat increase in the bearing and how to feed lubricant to the rolling surface.

The author is now conducting a durability test at $170 \times 10^4 d_{mn}$, and will remain committed to the development of a grease that is capable of much greater bearing speed.

Photo of author



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