[New Product]

Machine Tool Main Spindle Bearings with Air Cooling Spacer for Grease Lubrication

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Recently, machine tools are required multitasking for various processes and works. Though high speed and high rigidity of spindle bearings are trade-off relationship each others, they are demanded to achieve higher level performance cointanstaneously. And the application of grease lubricated spindle bearings has been increasing in the last years because of the strongly trend of the simplification of devices and systems and environmental concerning. **NTN** has been developing the application of the air cooling spacer to the grease-lubricated spindle bearings to meet the above mentioned two requirements.

1. Introduction

The required properties of main spindles vary depending on the machining needed. High rigidity and accuracy spindle are required when working difficult-to machine material or partial processing of complex shapes. On the other hand, high-speed and highly precise rotation is required for machining molds for machine components and components used in the medical field. Therefore, demand for 5-axis machine tools with multiple machining capabilities and complex machine tools, which require bearings for main spindles, to offer both high speed and high rigidity are increasing [2).

Demand for bearings in the main spindles with grease lubrication is increasing for simplification of facilities and reduction of environmental burden. One concern of grease lubricated bearing is that heat accelerates degradation of grease thus significantly impact the lubrication life [3). Therefore, it is critical to reduce heat during the operation of the bearings. There have been several measures taken to meet this challenge. For example, grease with superior high-speed properties, and heat resistance and optimization of internal design [4) In this development we have attempted to apply air cooling spacers to tool main spindle bearing [1) to grease lubrication as a new approach.

Machine tool main spindle bearings with air cooling spacers are the proprietary technology that **NTN** developed and is used in products with air oil lubrication.

In this article, functional evaluation of the cooling effect, in particular, when air cooling spacers are applied to grease lubrication and the arrangement for commercialization are described.

2. Structure and cooling mechanism of air oil lubrication air cooling spacer

In the following, we will describe the basic structure and cooling mechanism of the "machine tool main spindle bearings with air cooling spacers," by using actual application example..

Air nozzles are created in the outer ring spacer which is inserted between two back to back angular contact ball bearings (**Fig. 1**). These nozzles are at offset positions from the axial center and the cooling air in normal temperature injected from these nozzles goes through the space between the inner and outer spacers, as well as inside the bearings, swirling in the rotational direction of the inner ring. The cooling air removes heat from the surface of the inner ring spacer to cool it down.

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As shown in the fluid analysis result of **Fig. 2**, when cooling air is injected vertically to the inner ring spacer (left figure), the cooling air immediately spreads out in the axial direction, which minimize the cooling effect. On the other hand, when the air nozzles of the cooling air are offset (right figure), the cooling air stays around the surface of the inner ring spacer longer to extend the time for the cooling air to remove heat from the inner ring spacer surface, which increases the cooling effect of the inner ring spacer.

As inner ring spacer cooled down, the adjacent bearing inner ring also cooled down. Usually, when bearings rotate, the inner ring is more heated than the outer ring. Therefore, the preload increases by the difference in thermal expansion. In this cooling technology, the difference of temperature between the bearing inner ring and outer ring can be reduced by cooling the inner ring. As a result, preload and contact surface pressure on the raceway can be reduced to achieve both high speed and high rigidity at a high level. **Table 1** and **Fig. 3** show an example of test results of the machine tool main spindle bearing with air cooling spacer [1].

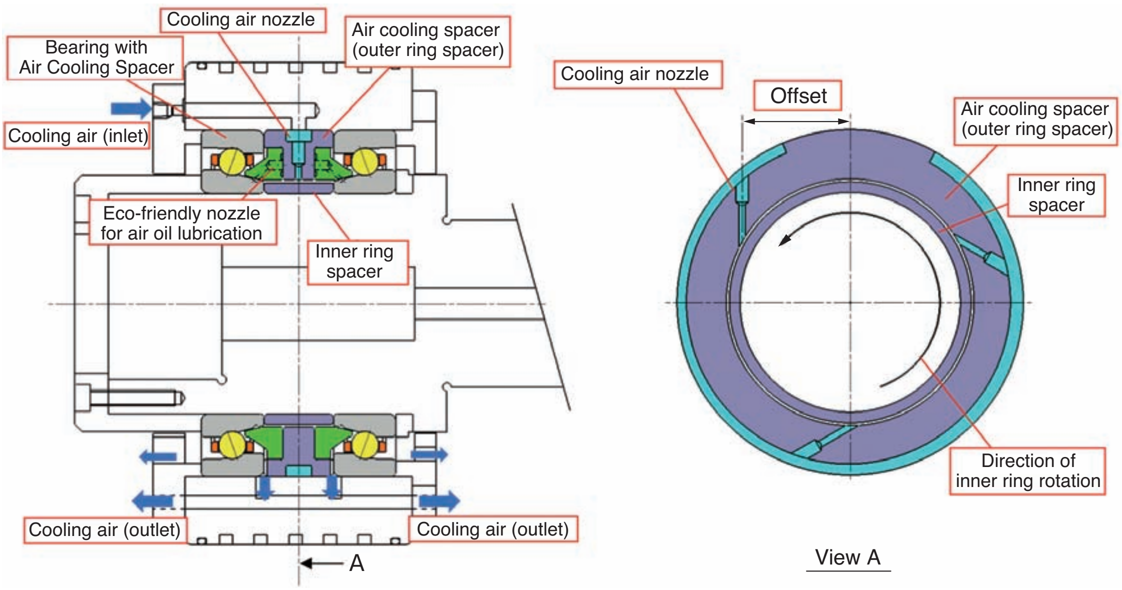
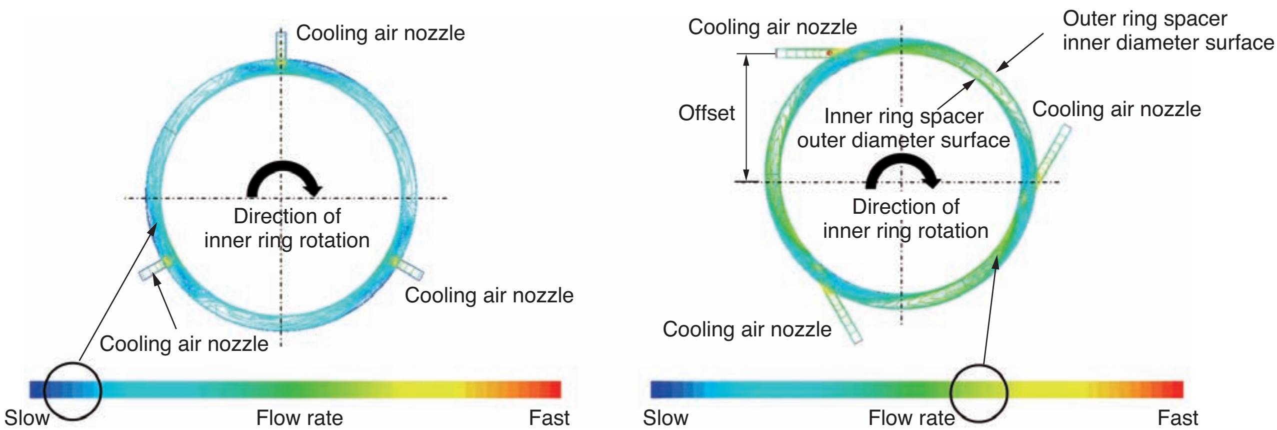


Fig. 1 Machine tool main spindle bearings with air cooling spacer (for air oil lubrication) [1]



When cooling nozzle is not offset

Cooling air collides to inner ring spacer vertically immediately after injected from air cooling nozzle and spreads to axial direction. Therefore, the cooling air only stays on the surface of the inner ring spacer for a short time, with insufficient cooling effect.

When cooling nozzle is offset

Having the air cooling nozzle in an offset position from the center of the shaft, the cooling air swirls in the inner ring radial direction and stays on the surface of the inner ring space for a long time. Therefore, the cooling air can remover more heat from the surface of the inner ring spacer, increasing the cooling effect of the inner ring spacer and inner ring.

Fig. 2 Cooling air flow between inner and outer spacers (Fluid analysis results) [1]

Table 1 Test conditions for high speed running test of the machine tool main spindle bearings with air cooling spacer (air oil lubrication)

Test bearing	φ70×φ110×20 Equivalent to 5S-2LA-HSL014 (Eco-friendly air-oil lubrication angular contact ball bearing with ceramic balls)
Preload method	Fixed position preload (preload of 0N after incorporation)
Rotational speed	0 - 23,000min^{-1}
Lubrication method	Air oil lubrication
Supply oil amount	0.03mL/10min
Lubricating oil	ISO VG32
Lubricating air flow	30NL/min
Outer cylinder cooling	Yes, thermal tuning to room temperature (21±1˚C)
Attitude of axis	Horizontal axis

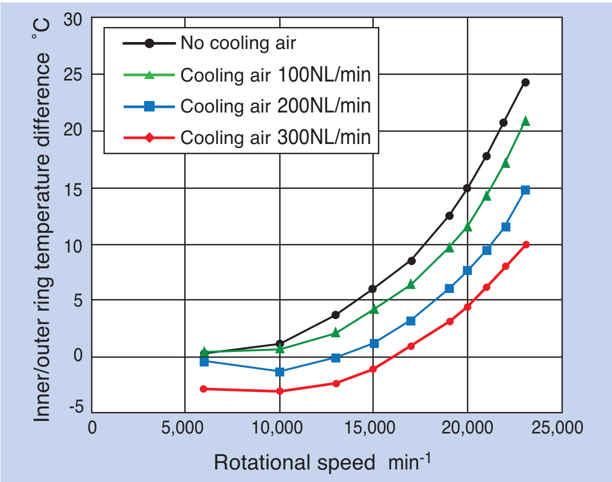


Fig. 3 Result of high speed running test of the machine tool main spindle bearings with air cooling spacer (air oil lubrication)

From the test results in **Fig. 3**, we verified the cooling effect of the "air-oil lubrication bearings with air cooling spacers" by cooling air from low-speed to high-speed rotation, as well as the fact that the cooling effect is greater as the cooling air supply is larger.

3. Structure of grease lubrication air cooling spacer

Fig. 4 shows the structure of the "machine tool main spindle bearing with air cooling spacer" when it is applied to grease lubrication. The cooling air nozzles are formed in the outer ring spacer. It is then inserted between the back to back angular contact ball bearings with grease lubrication seals.

4. Cooling effect of grease lubrication air cooling spacer

A high-speed operation test was conducted to verify the cooling effect of the "machine tool main spindle bearing with air cooling spacer" when it is applied to grease lubrication. The test condition is shown in **Table 2** and the structure of the tester is shown in **Fig. 5**.

In this test, the upper limit of the cooling air supply was set to 150 NL/min. considering the commercialized version. The offset amount of the nozzles was set to 80% of the radius of the inner ring spacer outer diameter, based on previous test results [5].

Fig. 6 shows the test results of the high-speed operation test. It was verified that the inner/outer ring

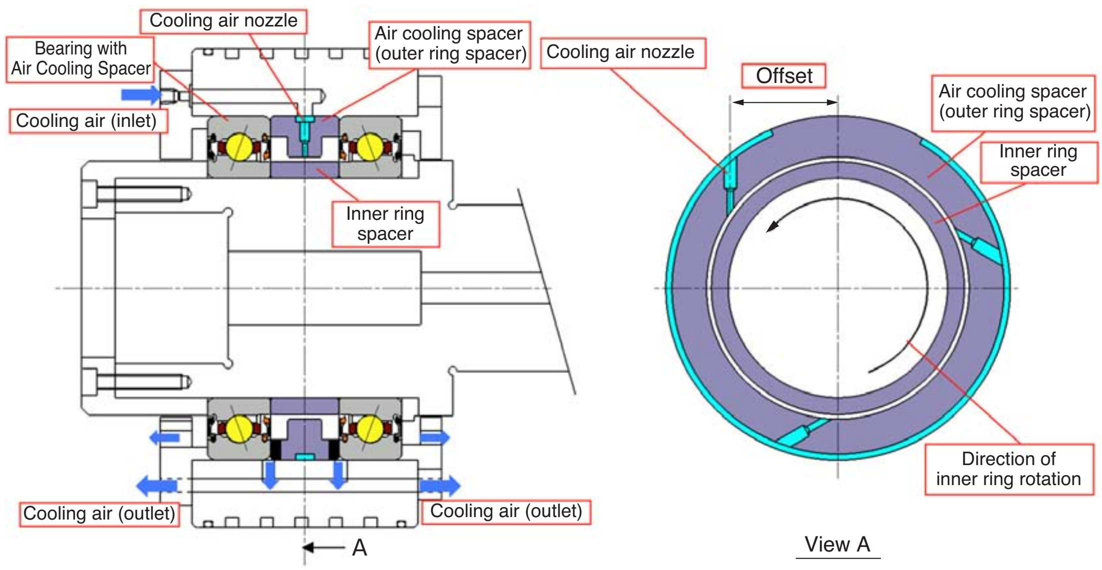


Fig. 4 Machine tool main spindle bearings with air cooling spacer (for grease lubrication)

temperature difference at 20,000 min^{-1} ($d_m n$ value 1.8 million) decreases approx. 2.5˚C with 150 NL/min of cooling air supply compared to no supply. Because of this decrease of inner/outer ring temperature difference, the maximum contact stress on the raceway surface at 20,000 min^{-1} can be reduced by approx. 10%. These results bring about the following effect. (1) The temperature at 18,000 min^{-1} with no cooling air supply and the temperature at 20,000 min^{-1} with supply of 150 NL/min cooling air are equivalent, which enables higher speed by approx. 10%. (2) Preload of the bearings after incorporation into the main spindle can be increased, which enables increase of main spindle axial rigidity by approx. 10% (**Fig. 7**). In addition, improvement of lubrication durability can be expected. This point will be further verified.

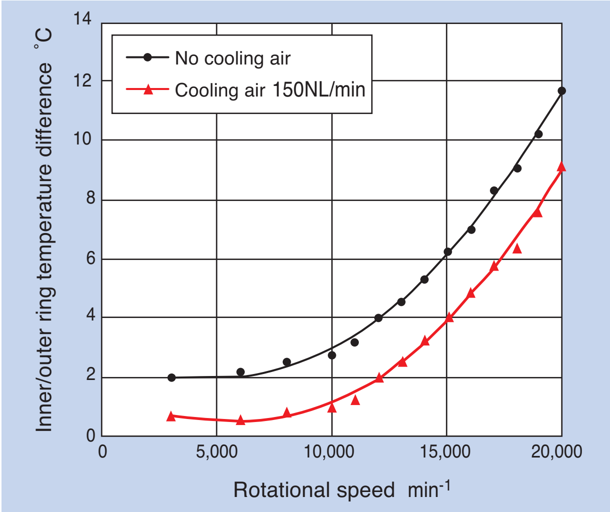


Fig. 6 Result of high speed running test of the machine tool main spindle bearings with air cooling spacer (grease lubrication)

Table 2 Test conditions for high speed running test of the machine tool main spindle bearings with air cooling spacer (grease lubrication)

Test bearing	ϕ70×ϕ110×20 Equivalent to 5S-2LA-BNS014LLB (High speed angular contact ball bearing with grease lubrication seals and ceramic balls)
Preload method	Fixed position preload (preload of 40N after incorporation)
Rotational speed	0～20,000min^{-1}
Lubrication method	Grease lubrication
Grease	SE-1
Outer cylinder cooling	Yes, thermal tuning to room temperature (21±1˚C)
Attitude of axis	Horizontal axis

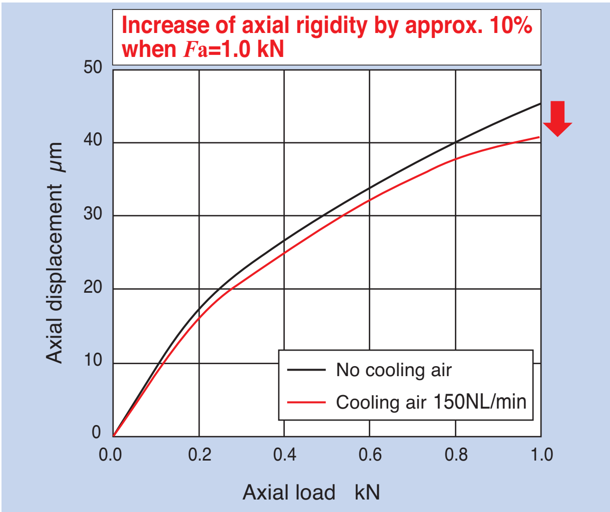


Fig. 7 Relation between cooling air amount and axial rigidity (grease lubricated air cooling spacer)

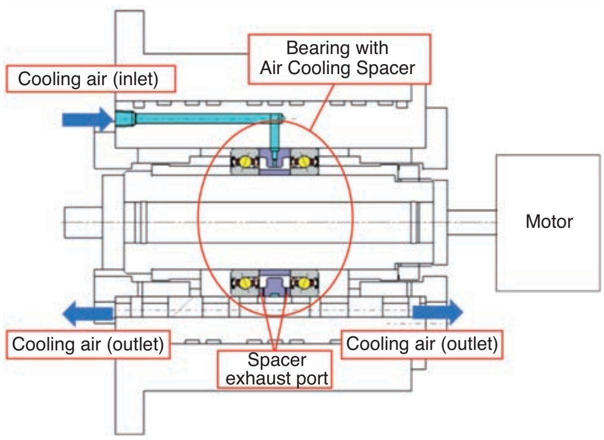


Fig. 5 Structure of test spindle (grease lubricated air cooling spacer)

5. Challenges for commercialization of grease lubrication air cooling spacer

From the results of the previous Section, it was verified that the machine tool main spindle bearing with air cooling spacer has cooling effect for grease lubrication, as well. On the other hand, by observing the bearing after the high-speed operation test, grease was found attached in the seal gap of the bearing with cooling air supply, as shown in **Fig. 8** . A small amount of grease was observed leaking from the width surface of the bearing.

In order to increase lubrication durability of the bearings, it is desirable to hold as much grease as possible inside the bearings. Therefore, it is necessary to reduce the leakage of grease from the width surface

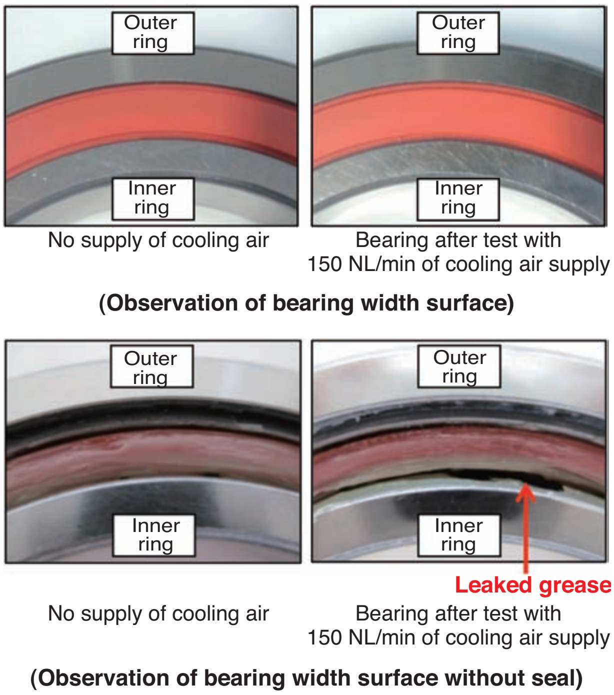


Fig. 8 Grease status inside the bearing after the high speed running test

of the bearings to a minimum. A possible cause of the grease leakage was the flow of cooling air into the bearings. Thus, a change of the spacer shape was studied to let the air exhaust from the exhaust port created on the air cooling spacer, so that the air does not flow into the bearings.

The cooling air flow was simulated under the fluid analysis condition shown in **Table 3**.

Fig. 9 (a) shows the enlarged view of the standard spacer shape evaluated with **Fig. 5**. **Fig. 9 (b)** shows the result of the analysis. When cooling air is supplied to the nozzles of the standard spacer, the cooling air collides with the inner ring spacer and then spreads out to the axial direction with a fast flow rate while maintaining a fast flow rate in the radial direction. A part of the injected cooling air reaches the exhaust port placed on the outer ring spacer; however, a part flows into the bearings. It was estimated that the grease leaked, affected by the air flow into the bearings.

The cooling air flow in the axial direction can be controlled by increasing the gap between the nozzle and the inner ring spacer. By securing sufficient space at the opening of the nozzle, air can flow adhering to the inner ring, maintaining the flow rate toward the tangential direction, which is the direction of injection.

In addition, by creating a slope with large inclination on each side of the inner spacer, the air flow into the bearings can be reduced by guiding the air to the exhaust port, not in the axial direction. The inner ring spacer was divided into two along with the introduction of the slope for ease of assembly.

The improved spacer with these changes in specification is shown in **Fig. 10 (a)**. The improved spacer is expected to provide better cooling effect as the amount and time of adhesion of air to the inner ring are increased from the standard spacer. As shown in the result of the analysis of **Fig. 10 (b)**, a smooth flow in the tangential direction of the inner ring was verified with reduction of flow into the bearings.

Table 4 shows the percentage of cooling air flown to the bearings and exhaust port, and the ratio of heat transfer between the standard spacer and the improved spacer. With the standard spacer, 50% of the supplied air flows through the bearings; however, it is reduced to approximately 10% with the improved spacer. The heat transfer also shows improvement of 50%. Improvement of cooling effect can be expected with grease lubrication, while preventing grease leakage by using the improved spacer.

Table 3 Fluid analysis conditions

Inner ring rotational speed	19,100min^{-1}
Air pressure	0.2MPa (Equivalent to 150 NL/min of air supply)
Temperature	Inner ring 50˚C; other 27˚C

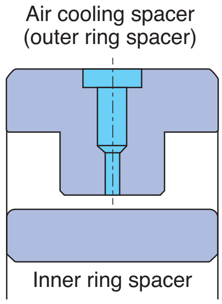


Fig. 9 (a) Standard designed spacer shape

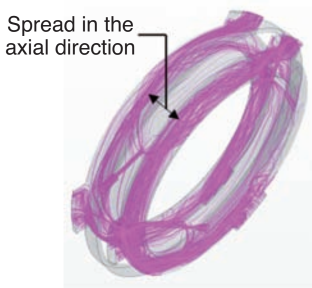


Fig. 9 (b) Cooling air flow of Standard designed spacer (Fluid analysis results)

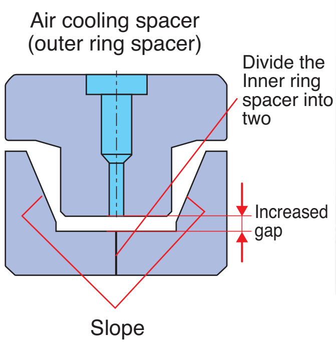


Fig. 10 (a) Development designed spacer

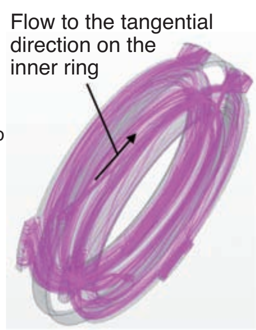


Fig. 10 (b) Cooling air flow of development designed spacer (Fluid analysis results) varies significantly and the cooling air flow can change depending on the drive methods and exhaust methods. Therefore, we will develop prototypes and continue verifying the superiority of the improved spacer.

Table 4 Fluid analysis results of standard spacer and development spacer

		Standard spacer	**Improved spacer**
Flow rate of the cooling air	Exhaust port	41%	87%
	Inside bearing	59%	13%
Heat transfer ratio		1	1.5

6. Summary

Demand of bearings for main spindles using grease lubrication is expected to grow for higher functionality and reduced environmental burden of machine tools. At **NTN,** we have attempted to apply the "machine tool main spindle bearing with air cooling spacer," which uses **NTN**'s proprietary air cooling technology to grease lubrication as a new approach and verified its effect. We will continue to work on improving the performance and refinement of the product, such as ensuring grease retention, toward commercialization.

References

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