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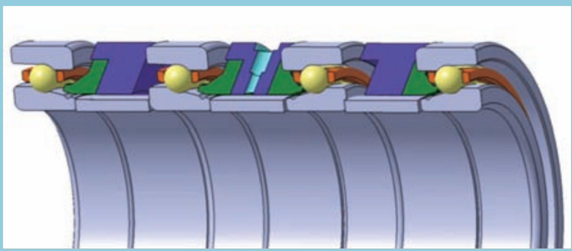
[Technical Article]

Machine Tool Main Spindle Bearings with Air Cooling Spacer



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NTN developed “Machine Tool Main Spindle Bearing with Air Cooling Spacer” which can perform high-speed and high-rigidity at the same time with higher level than ever, through the original air cooling technology. We carried out the performance tests of the cooling technology in various practical applications of machine tool spindles. In this paper, the results of the above mentioned tests and fluid analysis regarding the cooling technology are introduced as follows.

1. Introduction

The main spindles of machine tools are required to have both high rigidity and high precision when machining difficult-to machine materials or components with complex shapes. Additionally, high speeds and highly precise rotation are required to machine molds for machine components and medical field components. Although the requirements for the main spindles of machine tools vary depending on the machining method and the products to be machined, there has recently been increased demand for 5-axis machine tools with multiple machining capabilities, as well as complex machine tools which require spindles and bearings that offer both high speed and high rigidity at a high level [1]. To that end, it is important to keep the temperature of the bearings low during operation, and **NTN** has developed "machine tool main spindle bearings with air cooling spacers", and applied its proprietary air-cooling technology to the bearings [2].

In this development, we demonstrated the cooling of the bearings as well as noise reductions by improving the shape of the outer ring spacer. This time, in order to demonstrate its practicality, we implemented this technology with bearings and operating conditions which are commonly found in machine tool main spindles and verified the cooling effects.

2. Structure and cooling mechanism

The structure of bearings with air cooling spacers is shown in **Fig. 1** and the fluid analysis results are shown in **Fig. 2**. **NTN**'s proprietary eco-friendly air-oil lubrication nozzle [3, 4] is applied to outer ring spacers between the angular contact ball bearings in a back-to-back arrangement (DB arrangement) for reductions in air-oil and noise. Additionally, a separate air cooling nozzle is included.

The air cooling nozzles are at offset positions about the center axis. The compressed room temperature air injected from these nozzles (hereinafter cooling air) goes through the space between the inner and outer spacers as well as the inside of the bearings, revolving 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.

The air nozzles of the cooling air are offset so that the cooling air remains near the surface of the inner ring spacer longer, allowing more time for the cooling air to remove the heat from the inner ring spacer surface, thereby increasing the cooling effects of the inner ring spacer.

When the inner ring spacer is cooled down, the adjacent bearing inner ring is also cooled. As a result, the difference in temperature between the bearing inner ring and outer ring (hereinafter, inner/outer ring

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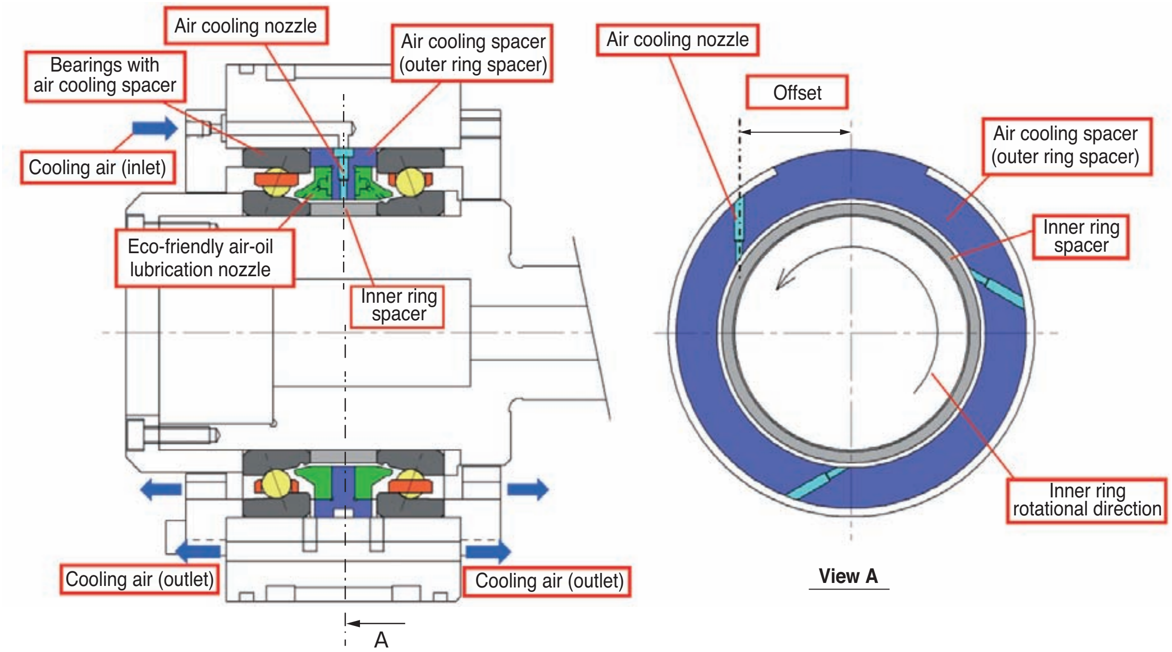

Fig. 1 Structure of the bearing with air cooling spacer

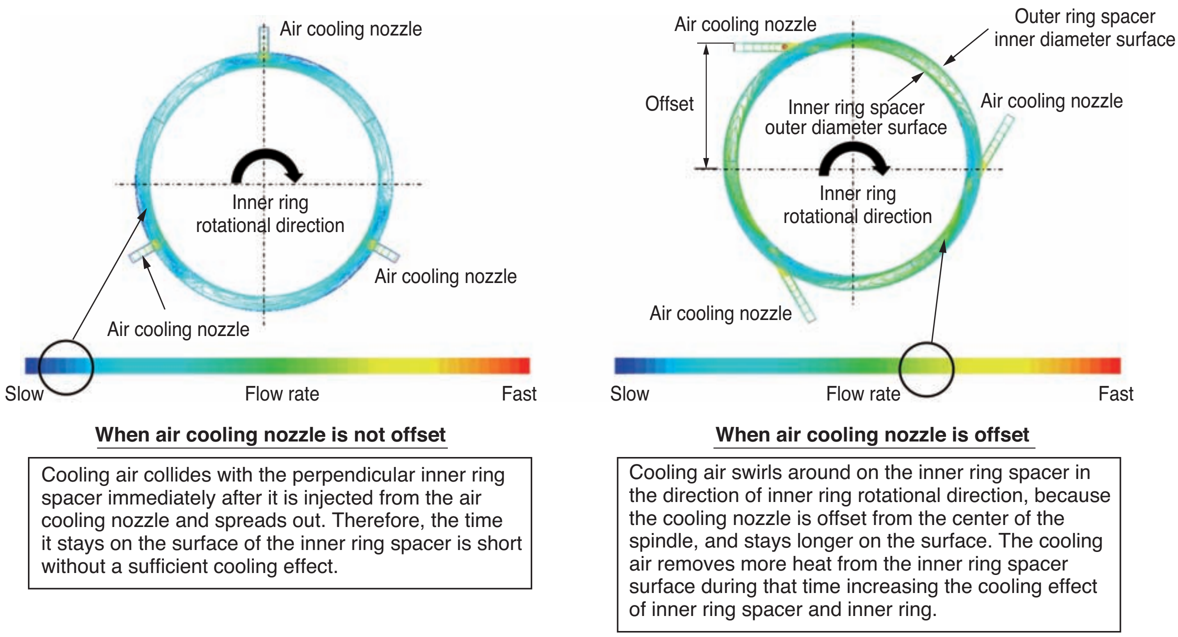

Fig. 2 Cooling air flow between inner and outer spacers (Fluid analysis results)

temperature difference) is reduced, and the contact stress on the raceway surface decreases to allow for both high speed and high rigidity at a high level.

3. Cooling effects

In order to verify the cooling effects with bearings and operating conditions which are commonly found in machine tool main spindles, high speed operation testing was conducted under the four conditions shown in **Table 1**.

The nozzle offset was set to 80% of the radius of the inner ring spacer outer diameter [2].

Table 1 Test conditions

Bearing arrangement	Main spindle drive method	
DB (Back-to-back)	[Test 1] Motor direct	[Test 2] Built-in motor
DTBT (Tandem back-to-back)	[Test 3] Motor direct	[Test 4] Built-in motor

3. 1 Cooling effects of back-to-back arrangement (DB arrangement)

Cooling effects of the bearings with air cooling spacers under DB arrangement was confirmed with the high speed operation testing. The test conditions are shown in **Table 2**, the structure of the tester is shown in **Fig. 3**, and the test results are shown in **Fig. 4**. This test was conducted with a DB spacer width of 22mm, almost the same width as the bearing, a condition where heat is not easily released because the bearings (which are heat sources) are close to each other.

In the case of a direct motor drive, inner/outer ring temperature difference at 17,000 min^{-1} ($d_m n$ value 1,530,000) was confirmed to decrease by approx. 2˚C with cooling air of 100NL/min, approx. 5.5˚C with 200NL/min, and approx. 7.5˚C with 300 NL/min compared with no cooling air conditions. Due to these decreases in inner/outer ring temperature difference, the maximum contact stress on the bearing raceway surface at 17,000 min^{-1} is reduced by approx. 10% at 100NL/min, approx. 15% at 200NL/min, and approx. 20% at 300NL/min.

As a result, the stress at 17,000 min^{-1} with no cooling air supply and the stress at 21,000 min^{-1} with a supply of 300NL/min cooling air are equivalent, which allows for a 25% increase in speed.

In the case of the built-in motor drive, the inner/outer ring temperature difference at 17,000 min^{-1} ($d_m n$ value 1,530,000) was confirmed to decrease by approx. 5˚C with cooling air of 100NL/min, approx. 8˚C with 200NL/min, and approx. 11˚C with 300 NL/min

Table 2 Test conditions for DB arrangement

Test bearings	φ70 x φ110 x 20 5S-2LA-HSL014 equivalent (Eco-friendly air-oil lubricated angular contact ball bearings with ceramic balls)
Pre-load method	Fixed position pre-loading (Pre-loading ON after built-in)
Rotational speed	0～23,000min^{-1}
Lubrication method	Air-oil lubrication
Amount of lubricant	0.03mL/10min
Lubricant	ISO VG32
Lubrication air flow rate	30NL/min
Cylinder cooling	Yes, Sync w/room temperature
Spindle position	Horizontal spindle

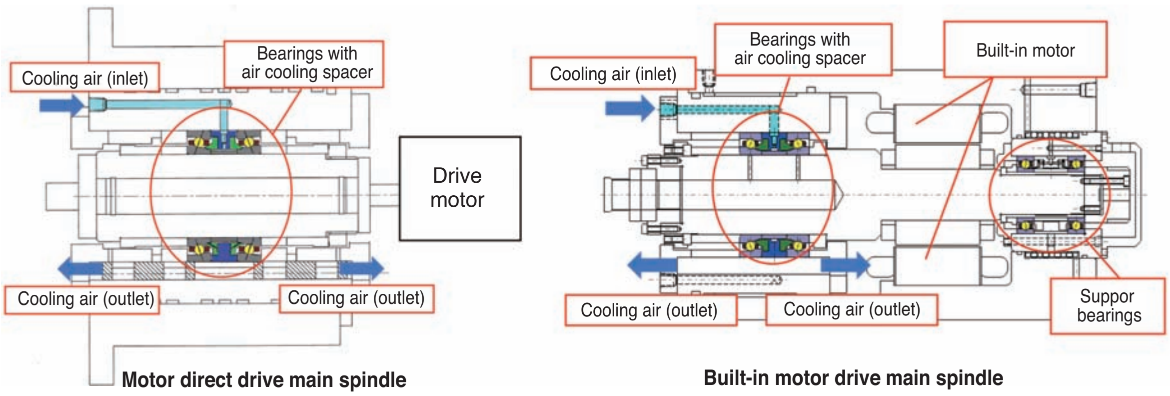

Fig. 3 Test spindles for DB arrangment

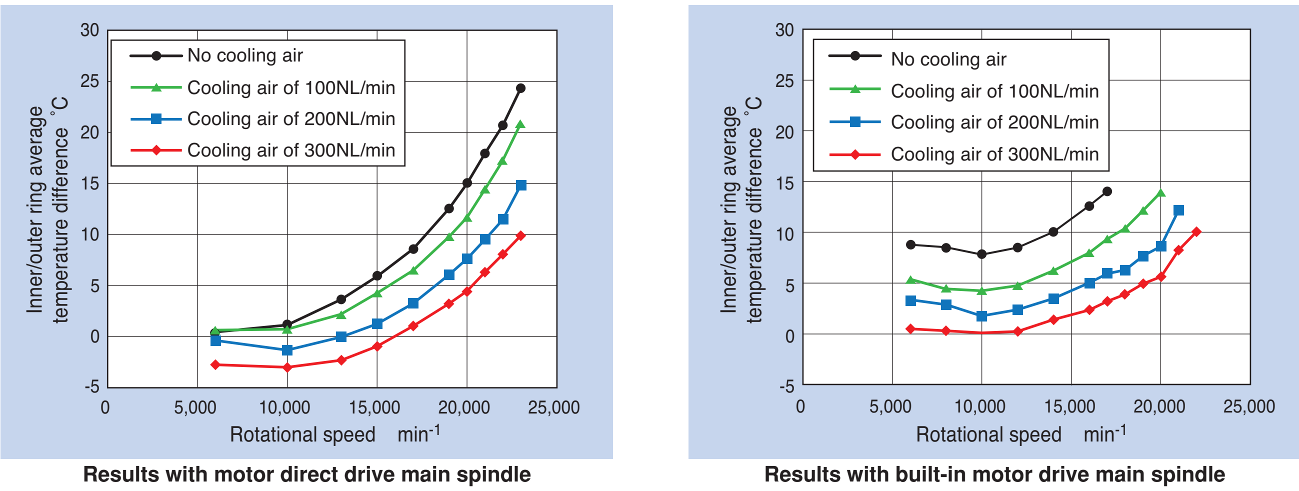

Fig. 4 Relation between cooling air amount and temperature difference between inner ring and outer ring (In case of DB arrangment)

compared with no cooling air conditions. Due to these decreases in inner/outer ring temperature difference, the maximum contact stress on the bearing raceway surface at 17,000 min^{-1} is reduced by approx. 15% at 100NL/min, approx. 20% at 200NL/min, and approx. 25% at 300NL/min. As a result, the contact pressure at 17,000 min^{-1} with no cooling air supply and the contact pressure at 22,000min^{-1} with a supply of 300NL/min cooling air are equivalent, which allows for a 30% increase in speed.

In either main spindle drive method, the cooling effects of bearings with air cooling spacers were verified.

In addition to the test with a spacer width of 22mm as described earlier, a test with a spacer width of 66mm was also conducted, verifying the cooling effects [2].

3 .2 Cooling effects of tandem back-to-back arrangement (DTBT arrangement)

Following the evaluation test with DB arrangement in the previous chapter, cooling effects of the bearings with air cooling spacers under DTBT arrangement was confirmed with a high speed operation test. The configuration of the tester is shown in **Fig. 5** and test conditions are shown in **Table 3**. This test was also conducted with a DB spacer width of 22mm, similar to the test with DB arrangement in the previous chapter.

The results for the direct motor drive are shown in **Fig. 6**. The inner/outer ring temperature difference at 17,000 min^{-1} (d_mn value 1,530,000) was confirmed to decrease by approx. 6˚C with 300NL/min compared with no cooling air conditions. Due to this decrease of inner/outer ring temperature difference, the maximum contact stress on the raceway surface at 17,000 min^{-1} is reduced by approx. 15%, allowing for a 17% increase in speed.

Subsequently, a test with a built-in motor drive was conducted. With this drive method, the bearing temperature is bound to be affected by the heat from the motor as the built-in motor is close to the bearings.

To verify this effect, a high-speed test was first conducted without cooling air. The inner/outer ring temperature difference at 17,000 min^{-1} (d_mn value 1,530,000) is shown in **Fig. 7**. In this test, larger inner/outer ring temperature differences were

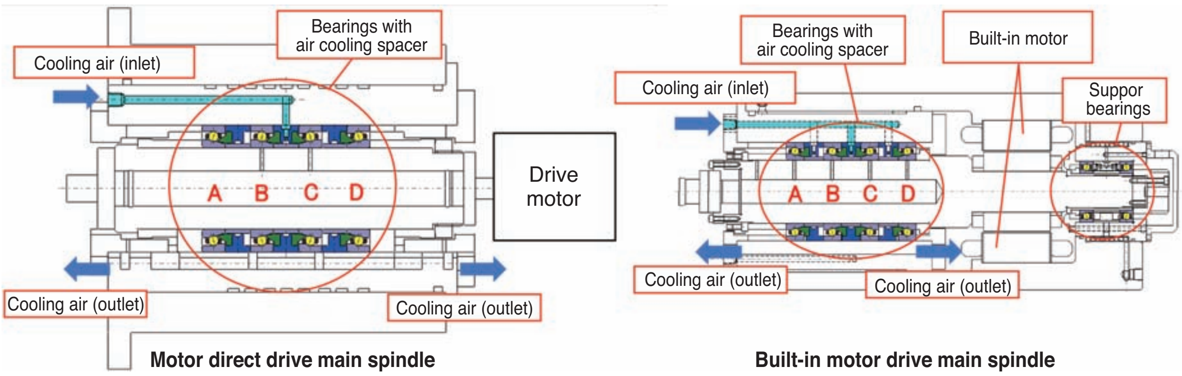

Fig. 5 Test machines for DTBT arrangment

Table 3 Test conditions for DTBT arrangement

Test bearings	ϕ70 x ϕ110 x 20 5S-2LA-HSL014 equivalent (Eco-friendly air-oil lubricated angular contact ball bearings with ceramic balls)
Pre-load method	Fixed position pre-loading (Pre-loading ON after built-in)
Rotational speed	0～23,000min^{-1}
Lubrication method	Air-oil lubrication
Amount of lubricant	0.03mL/10min
Lubricant	ISO VG32
Lubrication air flow rate	30NL/min
Cylinder cooling	Yes, Sync w/room temperature (21 ± 1°C)
Spindle position	Horizontal spindle

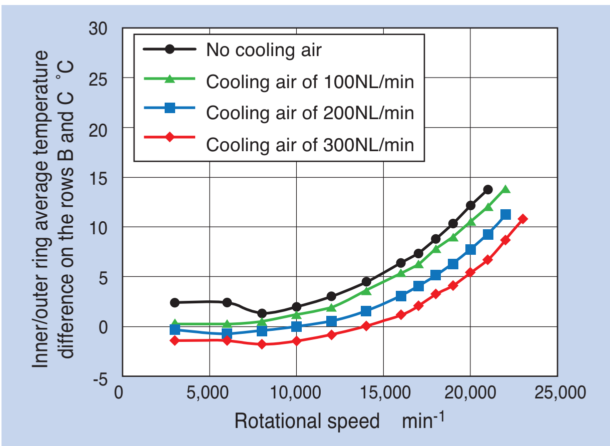

Fig. 6 Relation between cooling air amount and temperature difference between inner ring and outer ring (Coupling direct motor system, in case of DTBT arrangment)

observed on bearings closer to the motor. Therefore, methods to cool down row C and row D, which showed larger inner/outer ring temperature differences and higher maximum contact stress on the raceway surface, were considered.

The relationships between the supply point of cooling air, supply amount, and inner/outer ring temperature difference are shown in **Fig. 8**. When cooling air was supplied at 300NL/min between DB (**Fig. 8. (1)**), the inner/outer ring temperature difference at 17,000min^{-1} (d_{mn} value 1,530,000) decreased by approx. 7˚C at row C and approx. 3˚C at row D as compared to the case where no cooling air was supplied. When cooling air of 300NL/min was supplied between DT (**Fig. 8 (2)**), the inner/outer ring temperature difference at 17,000min^{-1} (d_{mn} value

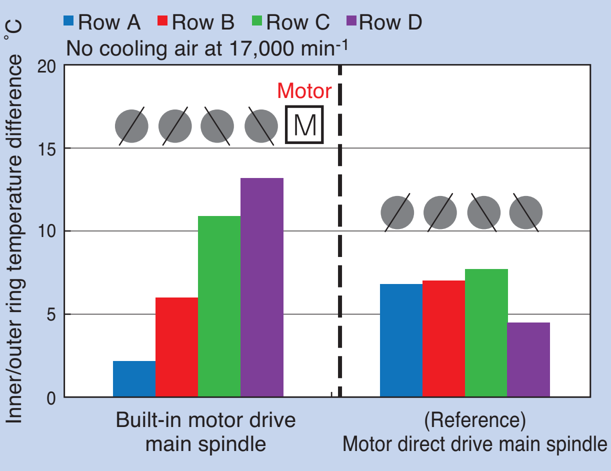

Fig. 7 Temperature difference between inner ring and outer ring without cooling air (Coupling direct motor system and built-in motor drive system, in case of DTBT arrangment)

1,530,000) decreased by approx. 7˚C at rows C and D. When cooling air of 150NL/min was supplied between both DB and DT for a total of 300NL/min (**Fig. 8 (3)**), the inner/outer ring temperature difference at 17,000 min^{-1} (d_{mn} value 1,530,000) was verified to decrease by approx. 5.5˚C at row C and approx. 5˚C at row D.

From the above, this test has verified that rows C and D, which are mostly affected by the heat produced by the built-in motor, can be intensively cooled down by concentrating the supply of cooling air between DT, closer to the built-in motor.

4. Fluid analysis result

In the DTBT arrangement of the built-in motor drive main spindles described in the previous chapter, when cooling air is supplied between DT closer to the built-in motor, the cooling air is supplied to the space on the front side of row C and to the space on the back side of row D. We simulated how the air oil and cooling air would flow through those spaces with fluid analysis. Results are shown in **Fig. 9**.

The cooling air injected from the air cooling nozzle revolves along the surface of the inner ring spacer in the direction of spindle rotation, then flows to row D, which has a larger exhaust space, and finally exhausts in the spindle’s direction.

Additionally, **Fig. 9** also shows the streamline of air oil injected from the air-oil lubrication nozzle with a red line. We have verified that the streamline of air oil reached the bearing raceway surface on all four rows, including rows C and D, which are closer to the air flow nozzle.

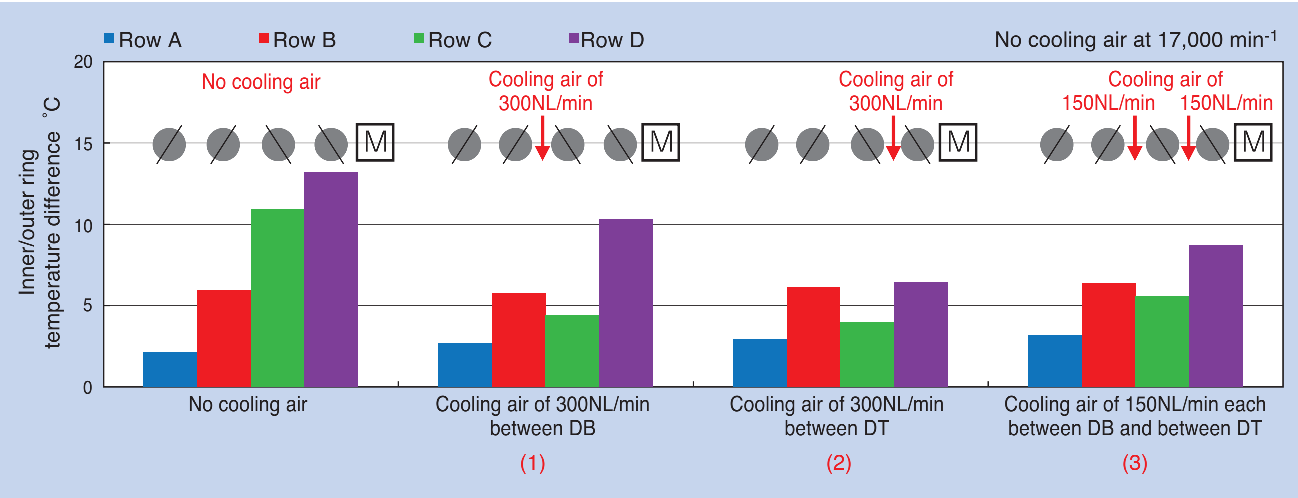

Fig. 8 Relation between cooling air point and each bearings temperature difference between inner ring and outer ring (In case of DTBT arrangment)

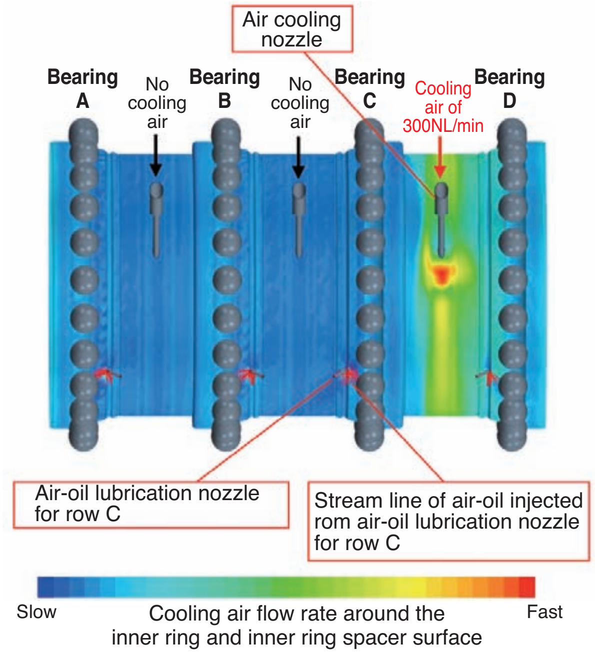

Fig. 9 Cooling air flow on inner ring and inner spacer surface (Fluid analysis results)

5. Summary

NTN has developed "machine tool main spindle bearings with air cooling spacers" with air cooling technology. In order to demonstrate its practicality, we verified the cooling effects by applying this technology on bearings and operating conditions which are commonly found in machine tool main spindles, and confirmed achievement of high speed and high rigidity at a high level.

This development can contribute to the advancement of machine tools in any application with regard to higher speed, higher rigidity, and higher reliability. We will continue working on enhancements and contributing to performance improvements of machine tools.

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