Air Oil Lubrication Bearings with Re-lubricating Hole on the Outer Ring for Machine Tool

1. Introduction

Air-oil lubrication systems are often used to lubricate machine tool main spindle bearings, wherein the lubricating oil is traditionally fed into the interior of each bearing through a ring spacer having re-lubricating holes. There are also some present-day European machine tools featuring machine tool bearings where oil penetrates more directly into the bearing interior through outer ring re-lubricating holes. Lubricant oil flow in this manner will lead to various benefits including improved lubrication efficiency and eliminating the need of a separate ring spacer component. This article describes NTN's unique version of “air-oil lubricated machine tool main spindle bearings with outer ring re-lubricating holes” including the basic design concept and performance test results.

2. Bearing design details – machine tool bearing design with outer ring re-lubricating holes

Fig. 1 illustrates the comparison between NTN's new design concept and the traditional bearing/spacer system used now. The traditional system requires oil to flow through the separate spacer.

The NTN design also includes an O-ring on each side of the outer ring to prevent oil leakage out the sides, while oil is fed into the bearing via the circumferential oil groove and holes.

3. Basic advantage for the bearing to have an outer ring with re-lubricating holes

We checked heat and noise generation between NTN's new design idea with the traditional bearing/spacer system.

Fig. 2 schematically illustrates the test rig (main spindle type test rig) for this test. Table 1 summarizes the test conditions.

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*Industrial Business HQ. Industrial Engineering Dept.
Fig. 3 provides outer ring temperature data for speeds up to up to 13,000 min⁻¹ using fixed position preload bearing samples. Notice that the temperature increase profile using the traditional standard bearing / ring spacer system (oil hole bore dia. 1.2 mm, air flow rate 40 NL/min) was virtually same as the bearing sample using outer ring re-lubrication holes (bore dia. 0.8 mm, air flow rate 25 NL/min).

The data shown in Fig. 3 shows the temperature rise results while running at 13,000 min⁻¹, but varying the oil and air flow rate. Fig. 4 gives temperature rise result after fixing the air flow rate at 15 NL/min, but the lubrication injection intervals at 0.03 mL/shot were varied. When the re-lubrication interval was set at 1 shot per minute for the bearing with outer ring re-lubricating holes, over-lubrication occurred and the bearing temperature actually rose significantly (heat buildup). When re-lubrication intervals were reduced to once every 25 minutes, the traditional bearing / ring spacer system exhibited only minor heat rise. We believe that, even though the total oil flow rate into bearing is decreased, the standard bearing / ring spacer system becomes under-lubricated as it is readily affected by an “air-curtain” effect created by

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**Table 1** Test conditions

<table>
<thead>
<tr>
<th>Test bearing</th>
<th>φ100×φ150×24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Bearing ring: special bearing steel Rollling elements: ceramic material</td>
</tr>
<tr>
<td>Contact angle</td>
<td>25˚</td>
</tr>
<tr>
<td>Type of preload</td>
<td>Fixed position preload (preload on mounted bearing: 98 N)</td>
</tr>
<tr>
<td>Oil feed rate</td>
<td>0.03 mL/10min</td>
</tr>
<tr>
<td>Lubrication system</td>
<td>Air-oil</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>VG32</td>
</tr>
<tr>
<td>Number of relubricating holes</td>
<td>One/bearing</td>
</tr>
<tr>
<td>Jacket cooling</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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**Fig. 2** Test spindle

**Fig. 3** Bearing temperature

**Fig. 4** Amount of oil and bearing temperature

**Fig. 5** Volume of air flow and bearing temperature
the high speed movement of rolling elements around the bearing center.

Fig. 5 is a graphic that illustrates test results when the oil flow rate was fixed at 0.03 mL/10 min and the air flow rate was varied. When the air flow rate is reduced, temperature fluctuation occurs with the bearing / ring spacer system. This phenomenon seems to be the result of an "air-curtain" effect that keeps lubricating oil flow from remaining smooth, and the bearing becomes under-lubricated.

From these results, we can see that the oil and air flow rates for a non-traditional bearing that uses an outer ring with re-lubricating holes (bore dia. 0.8 mm) can be reduced, and this bearing type can operate with an air flow rate of 10 - 20 NL/min and oil feed rate ranging from 0.03 mL/5 min to 0.03 mL/25 min.

Fig. 6 is a graph showing the noise levels measured of bearing test samples. Bearings with both the non-traditional outer ring with re-lubricating hole system (bore diameter either 0.8 mm or 1.2 mm) and the traditional bearing / ring spacer system (spacer re-lubricating holes of bore dia. 1.2 mm) were compared. The traditional bearing with a ring spacer / re-lubricating hole (bore diameter 1.2 mm) exposed to an air flow rate of 40 NL/min had a noise level generally less than the non-traditional bearing with an outer ring re-lubricating hole (bore dia. 0.8 mm or 1.2 mm). However, when the air flow rate is reduced to 15 NL/min, the bearing with the non-traditional bearing using an outer ring re-lubricating hole running faster actually generated a lower noise level. These noise level differences seem to result of an air condition created when the air is injected through each re-lubricating hole configuration.

Fig. 7 shows measurement results and the relationships between the re-lubricating hole bore size, air pressure, and air flow rate. When the air pressure is constant, air flow rate is dependent on the re-lubricating hole diameter. Naturally, the smaller the hole, the lower the air flow rate with constant air pressure. Similarly, when the re-lubrication hole size is constant, a lower air flow rate results with a reduced air pressure.

Fig. 8 illustrates the relationship between the re-lubricating hole diameter and air flow velocity (air jet speed) for various air flow rates (calculated values are based on assumption of no loss).

When the re-lubricating hole diameter is constant, the air flow velocity becomes lower as the air flow rate becomes lower. When the air flow rate is constant, the air flow velocity becomes lower as the nozzle diameter becomes larger.
In the case of non-traditional bearings with outer ring re-lubricating holes, high-pressure air is injected through the re-lubricating holes and directly reaches the rolling elements. Also, the distance that the injected air travels is much shorter as compared to using the traditional bearing / spacer system. The reason why the noise level is greater with the non-traditional, outer ring-lubrication system is that the injected high-pressure air reaches the rolling elements with less velocity loss causing the rolling elements to develop a whistling sound (Fig. 9). Information shown in Fig. 6 shows that the noise level of the non-traditional bearing with outer ring re-lubricating holes (bore dia. 0.8 mm) and an air flow rate of 15 NL/min is lower when compared to the same bearing experiencing an air flow rate of 25 NL/min. The noise level is also lower when the re-lubricating hole bore diameter is 1.2 mm (25 NL/min). It is believed that this is due to the difference in air flow velocity. Air flow velocity in the traditional ring spacer system is limited to only 600 m/s. It seems that the "air curtain" effect helps reduce the air flow velocity before air reaches actually the rolling elements.

4. Improved bearing having outer ring with re-lubricating holes

Sec. 3 provides information showing that the noise level (whistling noise) of a bearing with the non-traditional outer ring re-lubricating system is less than the traditional bearing / ring spacer system even with improved oil flow efficiency. It seems that a reduction in air flow rate and air flow velocity will reduce noise level.

Method of reducing air flow rate:
Lower the air supply pressure and use a smaller re-lubricating hole bore diameter

Method to decrease air flow velocity:
Reduced air flow rate and use a larger re-lubricating hole diameters

However, because a reduced air flow rate will affect lubrication oil capacity in the supply line tube to the nozzle\(^1\), the flow rate needs to be at least 20 NL/min. In a real-life commercial operation it would probably be appropriate to set air pressure between 0.3 to 0.5 MPa; the re-lubricating hole bore diameter should be 1.2 to 1.5 mm to reduce the air flow velocity while maintaining an air flow supply rate of 20 NL/min. In our investigation, we adjusted the air flow velocity to 400 m/s or lower. We then investigated the nozzle parameters to satisfying all of the above-mentioned requirements.

As a result of our investigation, we have developed a special bearing specification capable of reducing air flow velocity, but maintaining air pressure at approximately 0.3 MPa and also supply a air flow rate of at least 20 NL/min: as illustrated in Fig. 10. The non-traditional outer ring design has two equally spaced re-lubricating holes measuring 1.5 mm diameter as well as a circumferential groove with a cross-sectional area equivalent to a 0.8 mm diameter re-lubricating hole.

Usually, when an outer ring is fed with an air pressure of 0.3 MPa and has two bore 1.5 mm diameter re-lubricating holes, the air flow rate per hole is about 40 NL/min, and the air flow velocity is around 400 m/s. Therefore, we decided to adopt a bearing specification that helps limit the supply air flow rate to approximately 20 NL/min relative to an air pressure of 0.3 MPa (see Fig. 11). We also used a smaller outer ring circumferential groove than usual to help control the air flow rate. Furthermore, using of a two-hole design helps cut the air flow rate in half and limit the air flow velocity to 400 m/s or lower.

Fig. 12 compares phase differences of re-lubricating holes on the housing and outer ring with air flow rates. The air flow rate reduction created by the circumferential groove is particularly apparent when...
the hole diameter is 1.5 mm. When the two re-lube holes are more than 90 degrees apart, this apparently does not significantly affect the overall air flow rate. A maximum flow rate reduction per outer ring re-lubrication hole is achieved by using “axisymmetrically situating” (equally spaced) holes each with a 1.5 mm diameter and situating the housing relube holes exactly at the midpoint between the holes on the bearing outer ring.

**Fig. 12** graphically illustrates the result of assessing our improved bearing design. Noise level of our new, non-traditional design outer ring hole system with the hole geometry and distribution mentioned above is lower compared to using a non-traditional bearing with outer ring oil holes a 0.8 mm diameter or a traditional bearing / spacer system.

5. Conclusion

We have tested bearing samples designed with a non-traditional, outer ring re-lubricating hole system and evaluated the results to adjust the details to an optimal bearing design. Heat generation of our improved, non-traditional bearing design concept is equivalent to the traditional bearing / ring spacer system where oil is injection nozzle while its noise remains the same. Consequently, redesigning to incorporate a re-lubrication nozzle to the new design onto the ring spacer is needed, but allows the bearing system to be smaller by eliminating the ring spacer. This helps to create an overall more compact machine tool main spindle design that has increased tool rigidity when re-locating the bearing more towards the outer end of tool than when using a traditional bearing / spacer system. In addition, tests results prove that our improved, non-traditional bearing design using outer ring re-lubricating holes is reliably lubricated, and we learned that the air flow rate and oil consumption can be reduced compared to that of the traditional bearing system that uses a separate spacer / re-lubricating hole. At the same time, we have clarified that changing a re-lubricating hole bore diameter size affects bearing noise generation. We plan to continue our efforts to improve bearing lubricating systems and conditions to allow even greater machine tool main spindles speeds. It is encouraging to see how our lower-noise, air-oil lubricated bearing helps improve the functionality of machine tool main spindles.

References