Minimum Quantity and Cooling Jet Lubrication
Single-row Cylindrical Roller Bearings

1. Introduction

Compared with conventional jet lubrication systems, our MQCJ lubrication system boasts much decreased power loss. In the 23rd Japan International Machine Tool Fair held in 2006 (JIMTOF 2006), an actual example of a MQCJ lubrication angular contact ball bearing was installed on a machining center main spindle and its performance was demonstrated in machining operation. Recently, we have adopted the MQCJ lubrication system to cylindrical roller bearings, thereby realizing super high-speed operation with maximum $d_{mn}$ of 3.35 million (practical $d_{mn}$ of 3 million) with oil lubrication. By utilizing MQCJ lubrication, a cylindrical roller bearing can be incorporated into the rear side (free side) of a main spindle, helping simplify the main spindle structure.

This paper hereunder presents the features of the "Minimum Quantity and Cooling Jet (MQCJ) lubrication single-row cylindrical roller bearings" and the result of evaluation testing for these bearings.

2. Features of MQCJ lubrication

2.1 System overview

To our Minimum Quantity and Cooling Jet (MQCJ) lubrication single-row cylindrical roller bearings, a lubrication system identical to that for MQCJ lubrication angular contact ball bearings can be applied. Fig. 1 schematically illustrates such a lubrication system.\(^1\), \(^2\)

With this lubrication mechanism, one common oil supply device supplies oil to the bearing section and the jacket cooling section, and the used oil is recovered with a scavenge pump. Since the jacket cooling oil also functions as the bearing lubricating oil, auxiliary equipment to the bearing system is simplified.

2.2 Specifications of MQCJ lubrication cylindrical roller bearings

The MQCJ lubrication system is a jet lubrication system that is capable of cooling the inner race and has a minimum quantity lubrication mechanism for the rolling surface. On our MQCJ lubrication angular contact ball bearings (Fig. 2), a jet of lubricating oil is directed to the inner race scoop and lubricating oil adheres to the inside surface of scoop, and is then transferred to the conical surface outside of the inner race by centrifugal force and surface tension, with the result that only a small quantity of lubricating oil is fed into the bearing.

Since the lubrication space defined by the conical surface and the outer race spacer limits the quantity of lubricating oil fed into the bearing, a larger portion of lubricating oil takes part in cooling of the inner race and only a small portion of lubricating oil flows through...
Incidentally, our cylindrical roller bearings are basically intended for use on the rear side: therefore, we should remember that when a main spindle is running, the shaft elongates to the rear side (free side) owing to heat generated.

Lubrication space may be defined by the inner race conical surface and the outer race spacer (as in cases with angular contact ball bearings). However, depending on the installation orientation of the nozzle spacer, the lubrication space can vary while the bearing runs: as a result, the lubrication space can get narrower (Fig. 3) or wider (Fig. 4) owing to elongation on the shaft.

Because variation in the size of lubrication space can affect the quantity of oil passing through the space, we have invented a horizontal space design (Fig. 5) to prevent variation in the size of lubrication space owing to elongation of the shaft. By adopting the horizontal space design, we can avoid adverse effects from variation in the size of lubrication space that results from bidirectional shaft elongation.

Though based on ULTAGE Series single-row cylindrical roller bearings (roller guided cage), our MQCJ lubrication single-row cylindrical roller bearings adopt an inner race guided cage to stabilize rotation of the cage in order to run at a higher speed range. With a conventional design, lubricating oil was supplied from one side only; as a result, lubrication on the roller end faces and inner race ribs on the side opposite to oil supply can be unstable. In contrast, with our new bearings, lubricating oil is supplied from both sides: as a result, all the areas between the roller end faces and

**Fig. 1** MQCJ lubrication system

**Fig. 2** MQCJ lubrication angular contact ball bearing

**Fig. 3** change of lubrication space

**Fig. 4** change of lubrication space

Gap between inner race and spacer will shrink.

Gap between inner race and spacer will expand.
inner race ribs are smoothly lubricated and the inner race is more effectively cooled, thereby increase of preload is inhibited and stable high-speed operation is ensured.

2.3 Test data

Table 1 summarizes the test conditions applied, and Fig. 6 schematically illustrates the test spindle used.

The test bearing was based on the N1011HSR (bore diameter 55 mm) belonging to the ULTAGE Series high-speed cylindrical roller bearing family. This bearing size was based on the assumption that the front main spindle bearings were comprised of dia. 70 mm MQCJ lubrication angular contact ball bearings in definite position preloading configuration. The test spindle used was a vertical test rig driven by a built-in motor.

The support bearing unit consisted of a pair of angular contact ball bearings in DB configuration and was air-oil lubricated. Figs. 7 and 8 plot the test results based on samples with a single-sided lubrication nozzle, and Figs. 9 and 10 are plotted based on a double-sided lubrication nozzle configuration. On both single-sided and double-sided lubrication nozzle configurations, temperature increase is small and power loss is low (including power loss at rear bearing) with MQCJ lubrication compared with conventional jet lubrication. This is due to the effectiveness of the MQCJ lubrication system that positively cools the bearing (inner race) and supplies a minimum quantity of lubricating oil into the bearing.

Compared with the single-sided lubrication nozzle configuration, the double-sided lubrication nozzle configuration is capable of much higher bearing speed (maximum \( d_{max} \) 3.35 million).

Incidentally, in tests with air-oil lubrication and a single-sided lubrication nozzle configuration, lubricating oil (VG32) was fed at a rate of 0.02 mL/10 min, thereby it has been learned that both temperature increase and power loss are more significant with MQCJ lubrication. This is because the quantity of oil fed into both bearings is greater with MQCJ lubrication, and the effect of stirring resistance in the bearings is greater.

Fig. 11 graphically plots the results of passing oil flow measurements on bearings with conventional jet lubrication and MQCJ lubrication, Fig. 12 illustrates measurement positions for passing flow and non-passing flow relative to quantity of lubricating oil supplied. With conventional jet lubrication scheme, the horizontally situated lubrication nozzle aims at a location between the cage and bearing ring, with approximately 50% of lubricating oil passing through the bearing. On the other hand, with MQCJ lubrication, lubricating oil is injected to the scoops on the inner race and the horizontal gap is regulated by the spacer and stepped inner race, thereby the quantity of passing lubricating oil at higher bearing speed is as low as approximately 10%.

Results for air-oil lubrication with a double-sided

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<table>
<thead>
<tr>
<th>Item</th>
<th>Content</th>
</tr>
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<tbody>
<tr>
<td>Test bearing</td>
<td>N1011HSR basis (Φ55 mm × Φ90 mm × 18 mm)</td>
</tr>
<tr>
<td>Support bearing</td>
<td>5S-2LA-HSL007DB (air-oil lubrication)</td>
</tr>
<tr>
<td>Main spindle attitude</td>
<td>Vertical</td>
</tr>
<tr>
<td>Target assembly gap</td>
<td>0 μm</td>
</tr>
<tr>
<td>Spacer nozzle</td>
<td>Nozzle diameter Φ1 mm, two positions (180-degrees spacing)</td>
</tr>
<tr>
<td>Oil flow rate</td>
<td>1~5L/ min</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>VG1.5 (VG32)</td>
</tr>
<tr>
<td>Temperature of lubricating oil supplied</td>
<td>23~24°C (setting: 20°C)</td>
</tr>
<tr>
<td>Jacket cooling</td>
<td>Yes (5 L/min)</td>
</tr>
</tbody>
</table>
nozzle configuration are shown in Figs. 9 and 10; wherein like in the case of MQCJ lubrication, the test was performed while lubricating oil (VG 1.5) was fed into the bearing at a rate of 0.5 mL/min (maximum feed rate for air-oil lubrication unit).

The oil feed rate with air-oil lubrication is significantly low compared with MQCJ lubrication; however, temperature increase at lower speed range is very high with air-oil lubrication. This seems to result from stirring of lubricating oil. Note, additionally, that there is temperature drop at the middle-speed range. This appears to be because that the rollers and cage generate an air curtain, and, as a result, a proportion of lubricating oil not fed into the bearing increases and the centrifugal force helps increase the quantity of lubricating oil released from inside the bearing, thereby the stirring resistance decreases.

Note also that the temperature at lower speed range is low with MQCJ lubrication and jet lubrication, each involving greater oil feed rate compared with air-oil lubrication. This appears to be because a large quantity of oil cooled by MQCJ lubrication or jet

Fig. 7 Outer race temperature

Fig. 8 Power loss

Fig. 9 Outer race temperature

Fig. 10 Power loss

Fig. 11 Amount of oil that passes in bearing

Lubricating oil (one side only)

Fig. 12 Measurement position
3. Conclusion

Our MQCJ lubrication single-row cylindrical roller bearings can be used as a rear-side bearing on machine tool main spindles whose front-side bearing comprises a MQCJ lubrication angular contact ball bearing in definite position preloading mode.

NTN has already developed an angular contact bearing arrangement that achieves high-speed operation of 40,000 min\(^{-1}\) with MQCJ lubrication, using bearings with bore diameter of 70 mm -which are arranged in DB set configuration and are provided with definite position preload. Since our newly developed bearings are intended for use on the rear-side of this bearing arrangement, the maximum speed of our new bearing design is as high as 40,000 min\(^{-1}\); thus our new bearing design is capable of commercial high-speed operation of \(d_{mn}\) 3 million.

Note that our MQCJ lubrication system is essentially a jet-lubricated system, and that main spindle construction involving an MQCJ lubrication system requires a much enhanced labyrinthine structure in addition to the system configuration described previously in the system overview section. Notwithstanding, we believe that our new development helps increase possible options for selecting bearing and lubrication arrangement for bearings that support super high-speed machine tool main spindles. We hope that NTN’s new lubrication system helps assist in realizing further sophistication of machine tool main spindles.

References