Development of Next Generation Low Friction Torque Tapered Roller Bearing (LFT-IV)

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We JTEKT have been developing low friction torque bearings from the viewpoint of environmental issues such as global warming. In particular, we are more advanced than competitor companies regarding the development of low friction tapered roller bearings (TRB), which at JTEKT are called our "LFT series". Furthermore, we have engaged in the development of the new TRB, known as the "LFT-IV", and have achieved a 50 percent reduction in friction torque compared with the previous product ("LFT-II") by utilizing CAE tools.

***Key Words**: low friction torque, tapered roller bearing, cage, resin, CFD, LFT-IV*

1. Introduction

In response to environmental issues such as global warming, needs such as reduced friction loss, higher efficiency and lower energy consumption are growing stronger year after year. Particularly in regards to automobiles, the CO_2 emission regulations of each country are becoming stricter every year and there are expectations of low friction technology for rolling bearings. JTEKT has been engaging in ongoing initiatives to advance the low torque specifications of tapered roller bearings (LFT series) contributing to the downsizing and weight reduction of units with compact and high load capacity designs. As a result, the LFT-III[1)] was developed in 2006, which provided 50% less torque loss than the standard bearing (40% less than LFT-II[2)]). However, in order to meet market requirements, which grow tougher year after year, JTEKT has developed a new product (LFT-IV) with even less friction loss, achieving a reduction of up to 50% compared with the LFT-II. This report discusses the results of this development.

2. Development Aims

Three main factors leading to friction loss in a tapered roller bearing are ①rolling viscosity resistance, ② lubricant agitating resistance and ③sliding resistance between the inner ring back face rib and roller end face (**Fig. 1**)[3)]. **Figure 2** shows the contribution ratio of each.

Factor 3 has been reduced in the LFT-I, factor 1 in the LFT-II and factors 1 and 2 in the LFT-III (**Table 1**).

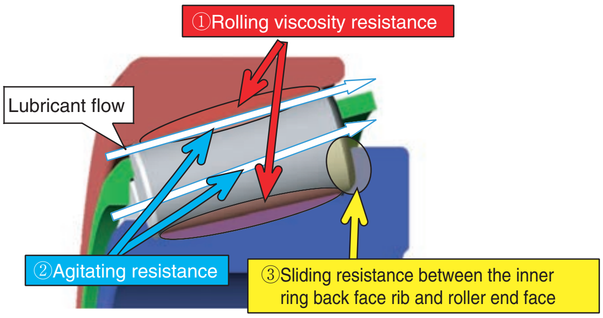

Fig. 1 Elements of tapered roller bearing torque

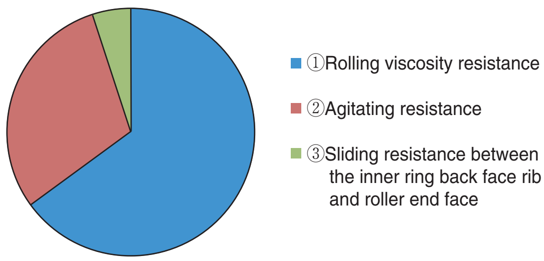

Fig. 2 Factors contributing to friction torque and their contribution ratio

Table 1 Low friction torque tapered roller bearings

Applied technology	Reduction factor*1	Applied/not applied*2			
		LFT-Ⅰ	LFT-Ⅱ	LFT-Ⅲ	LFT-Ⅳ
Optimization of roughness and profile for large rib and roller end face	③	○	←	←	←
Raceway crowning	①	–	○	◎	←
Optimization of internal geometry	①②	–	–	○	←
Inflow control of lubricating oil	②	---	---	○	◎

＊1 ①Rolling viscosity resistance
②Agitating resistance of lubricant
③Sliding resistance between the inner ring back face rib and roller end face
＊2 ○：Applied ◎ Further improved

For the LFT-III, in order to reduce lubricant agitating resistance (factor 2), the amount of lubricant which flows into the bearing (lubricant inflow) from the cage is suppressed. In order to suppress the amount of lubricant inflow further, it is necessary to reduce the clearances between the inner ring and cage and the outer ring and the cage at the small end of the cage, as these are the locations where lubricant enters. However, if the clearance becomes too small, there is a risk that lubricant becomes blocked off entirely considering temperature change and dimensional variance, therefore it is necessary to reduce flow while maintaining clearance to a certain extent. For this development project, JTEKT investigated whether or not it was possible to achieve both a clearance which did not become blocked and suppress lubricant inflow by changing the shape of the small end face of the cage and altering the flow of lubricant near the inlet. Also, resin with a high degree of freedom in regards to shape was adopted as material for the cage.

3. Shape Optimization Utilizing CAE

In recent years, systems and equipment have become increasingly high-function, therefore the components used in them are becoming more sophisticated and complex. This means products with even higher reliability than in the past are being sought by consumers. Meanwhile, there is a need to shorten the time taken for design and evaluation, therefore utilization of CAE technology early on in the development process is essential. For this development project, CAE technology was used to optimize the cage shape.

The concept for the newly developed LFT-IV was to reduce the amount of lubricant inflow through being innovative with the shape of the cage's small end face. To achieve this, it is important to understand the dynamic characteristics of the lubricant when it flows into the bearing. However, it is difficult to obtain sufficient data with experiments alone, therefore by using fluid analysis technology to make the flow visible and quantify characteristics, it became possible to evaluate changes in characteristics due to shape improvement cost-effectively and with better speed.

The analysis conditions are shown in **Table 2**. A parameter study was conducted for the dimensions shown in **Fig. 3** and the shape for which lubricant inflow is minimum was found. **Figure 4** shows the results of a fluid analysis on the clearance between the outer ring and cage.

Table 2 Simulation conditions

Item	Conditions
Rotational speed	5 000 min^{-1}
Lubricant	Gear oil
Temperature	80℃
Other	Uncompressed, constant temperature, turbulent, steady

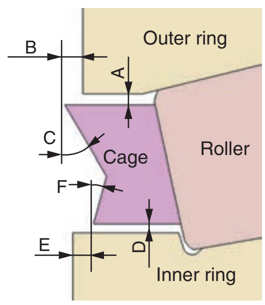

Fig. 3 Parameter study of tapered roller bearing

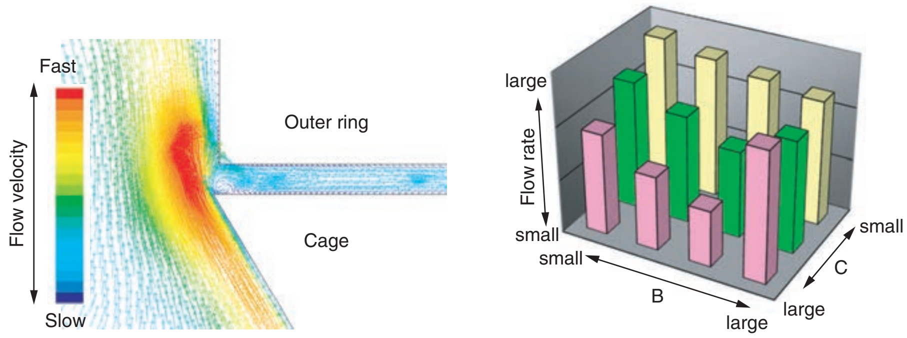

Fig. 4 Simulated results of velocity vector and flow rate

The results of this analysis showed the following types of shapes would be advantageous in reducing the amount of lubricant inflow.

- Regarding the positional relationship of the inner ring and cage, the cage end face is towards the inside
- Regarding the positional relationship of the outer ring and cage, the cage end face is towards the outside
- An incision is made in the side of the cage so that the cross-section looks like a less-than sign (<)
- Reciprocal interaction was recognized with the dimension parameters. Also, there is a max./min. value and if these are exceeded or not reached, the effectiveness will be diminished.

Based on the above knowledge, the final shape for the cage small end was determined (**Fig. 5**).

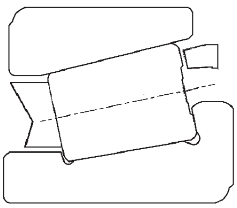

Fig. 5 Optimized shape of LFT-IV by utilizing oil flow simulation

In order to confirm the effect of controlling lubricant inflow, we created a model simulating a oil flow rate testing machine (details discussed later), and analyzed the behavior of lubricant oil for gas-liquid two-phase flow. The results of this analysis are shown in **Fig. 6**. With the LFT-IV, there is less lubricant inside the bearing, therefore it is obvious that the amount of lubricant inflow is limited. Our analysis showed that oil flow rate is reduced by approximately 95% (3 000 min^{-1}).

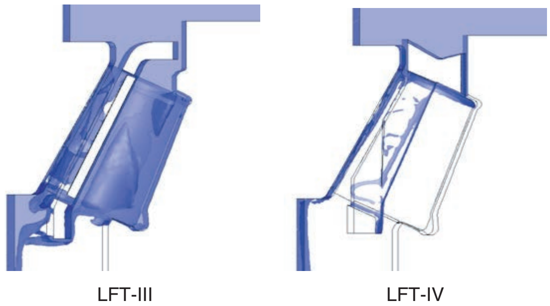

Fig. 6 Simulated results of dynamic oil flow

4. LFT-IV Performance

4. 1 Oil Flow Rate to the Bearing

The amount of oil flow through to the bearing was measured on the LFT-IV, which featured an optimized-design cage based on fluid analysis. The result was compared with the model's predecessor, the LFT-III. **Table 3** shows the test conditions, while **Fig. 7** shows the testing equipment and **Fig. 8** shows the results of the amount of oil flow rate measurement. When rotational speed is between 1 000 and 4 000 min^{-1}, the reduction ratio of the oil flow rate is between 87 and 92% less for the LFT-IV in comparison with the LFT-III (**Fig. 8**), while at 3 000 min^{-1}, the test result is a reduction of 91%, which is in good agreement with the fluid analysis result of 95%, therefore it can be said that it is possible to accurately predict oil flow rate using fluid analysis.

Table 3 Test conditions

Rotational speed	1 000～4 000 min^{-1}
Lubricant	Gear oil
Temperature	50℃
Oil Supply method	Circulating lublication

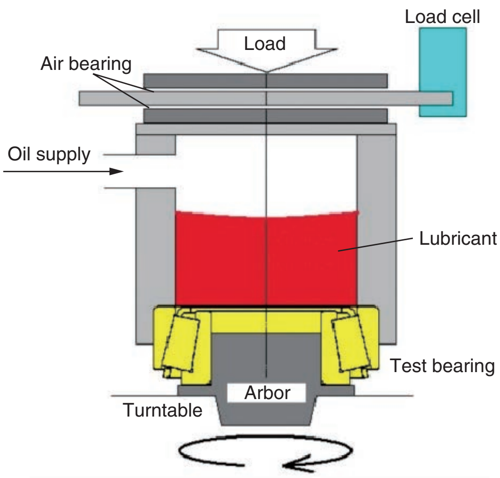

Fig. 7 Testing equipment

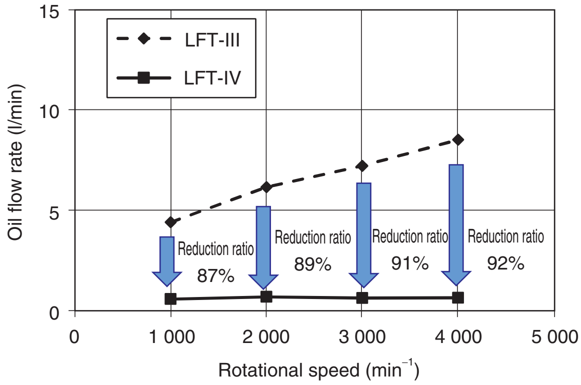

Fig. 8 Results of measurement of penetrated lubricant

4. 2 Bearing Individual Torque

We confirmed the effect on reducing rotational torque for the LFT-IV (test conditions and testing equipment were identical to when oil flow rate was measured). The results of measuring the bearing's individual rotational torque are shown in **Fig. 9**. Results confirm that, for the LFT-IV, rotational torque has been reduced by up to 50% compared with the conventional type (LFT-II) and up to 30% compared with the LFT-III. Therefore, the LFT-IV has the ability to suppress the amount of lubricant that oil flow rate to the bearing, and achieves low torque by reducing the agitating resistance of lubricant.

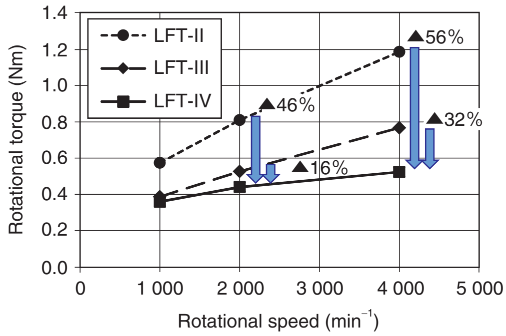

Fig. 9 Results of torque measurement

4. 3 Effectiveness on an Actual Vehicle

Next, in order to verify effectiveness on an actual vehicle, we assembled the LFT-IV on a rear differential for a passenger vehicle and measured the amount of torque necessary to rotate the pinion shaft. The test conditions are shown in **Table 4**, while the testing equipment is shown in **Fig. 10**. After running in the test bearing, it was assembled on the pinion shaft support portion with a preload of 3 kN. We measured the torque of the pinion shaft in isolation, making sure the pinion gear and ring gear did not mesh. Also, we used another motor to rotate the ring gear at a speed which corresponded with the rotational speed of the pinion, thus making the lubricant flow inside the differential the same as that of an actual vehicle. **Figure 11** shows the results of this rotational torque measurement. By adopting the LFT-IV, loss can be reduced by around 50% compared with the conventional type (LFT-II).

Table 4 Test conditions

Rotational speed	2 000 min^{-1}
Load	No-load (preload 3.0 kN)
Lubricant	Gear oil
Temperature	50℃

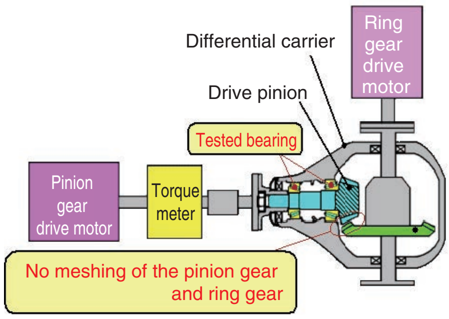

Fig. 10 Testing equipment

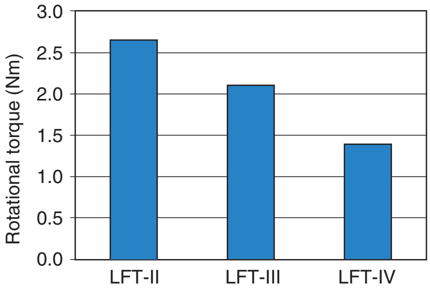

Fig. 11 Results of pinion torque measurement

5. Conclusion

For the LFT-IV, by using resin for the cage material and controlling lubricant flow at the small end face of the cage, the amount of lubricant which oil flow rate to the bearing was reduced, resulting in a reduction of bearing friction torque of up to 50% compared to the conventional type (LFT-II) and up to 30% compared to the LFT-III. During development, a parameter study using fluid analysis was conducted to efficiently determine the optimal shape of the cage.

If the LFT-IV is used as a support bearing for the pinion shaft of a differential, where a particularly large amount of highly viscous lubricant is used, an even greater effect is had on reducing friction loss. JTEKT will continue to develop highly efficient products, which will serve an increasingly important role for their contribution to alleviating environmental issues.

*1 LFT is a registered trademark of JTEKT Corporation.

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