Super-low Friction Torque Technology of Tapered Roller Bearings for Reduction of Environmental Burdens

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We developed a tapered roller bearing that has super-low friction torque that is up to 80% less than the friction torque of standard tapered roller bearings. It has been confirmed through application on drive pinion bearings in passenger car rear axle differentials that this technology achieves torque and temperature rise levels as low as those of ball bearings. The developed bearings are expected to contribute to higher axle differential efficiency and improved vehicle fuel efficiency, which will result in reduced burdens on the global environment.

Key Words*: tapered roller bearing, low friction torque, high efficiency, axle differential, fuel economy*

1. Introduction

Energy demand in the world has been increasing year by year, and the problem of global warming caused by mass consumption of fossil fuels, etc. has confronted human beings with more and more critical realities. While international efforts have been made toward global environmental conservation, automobile-related environmental regulations are getting stricter and stricter. Especially, efforts for improved fuel and energy efficiency to reduce the emission of carbon dioxide (CO_2) have become one of the most important issues. Under these circumstances, higher bearing efficiency is strongly expected since more than one hundred rolling bearings are used in one vehicle.

Rolling bearings are used for supporting rotating shafts of automobiles and various industrial machines, contributing to the reduction of energy loss or heat generation caused by friction. Focusing on tapered roller bearings widely used in automobiles, JTEKT has developed a new technology[1), 2)] for drastically reducing friction torque while maintaining the features of compactness, long life and high rigidity of tapered roller bearings. Super-low friction torque tapered roller bearing, LFT-Ⅲ (3rd Generation Low Friction Torque Tapered Roller Bearing) has low friction torque, 80% less than that of standard tapered roller bearings, and contributes to the reduction of CO_2 emissions thanks to improved fuel efficiency, which will result in a reduced burden on the global environment. Hereafter are described the points aimed at in this development, the outline of the developed bearing and of basic technologies, and the effects of the bearing when mounted in a rear axle differential.

2. Factors Contributing to Friction Torque in Tapered Roller Bearing and Contribution Ratio

Rolling bearings are classified into ball bearings and roller bearings based on rolling element types. As tapered roller bearings have high rigidity as well as about 2 to 2.5 times larger load carrying capacity than that of ball bearings, they can support the rotating shaft more compactly than ball bearings. However, tapered roller bearings have larger friction torque and higher heat generation than those of ball bearings. We have tackled these weak points with the technology development for reducing the torque of tapered roller bearings to the same level as that of ball bearings without increasing the bearing size.

JTEKT has provided low friction torque tapered roller bearings (LFT bearings) to the market for over 20 years[3), 4)]. In the conventional method for reducing the torque, the raceway profiles and the surface roughness profile of the inner rib were optimized by paying attention to viscous rolling resistance and sliding resistance. The resulting torque reduction ratio was around 20%, which was still higher than that of ball bearings. Then, we again directed our attention to agitating resistance of lubricating oil. Factors contributing to friction torque in tapered roller bearings and each contribution ratio have been obtained by experiment and calculation for tapered roller bearings used in automobile rear axle differential (hereinafter referred to as differential) as a representative application[1)]. As shown in **Fig. 1**, the contribution ratio of viscous rolling resistance was the largest and that of agitating resistance was the second largest. Based on the result, our efforts have been made not only for further reduction of viscous rolling resistance, but also for reduction of agitating resistance which had not been studied before.

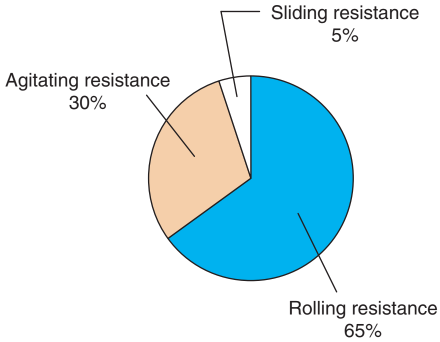


Fig. 1 Factors contributing to friction torque and each contribution ratio

3. Features and Performance of Super-low Friction Torque Tapered Roller Bearing[1), 2)]

Figure 2 shows the features of super-low friction torque tapered roller bearing, LFT-Ⅲ (hereinafter referred to as the developed bearing). The developed bearing is based on three basic technologies described hereunder.

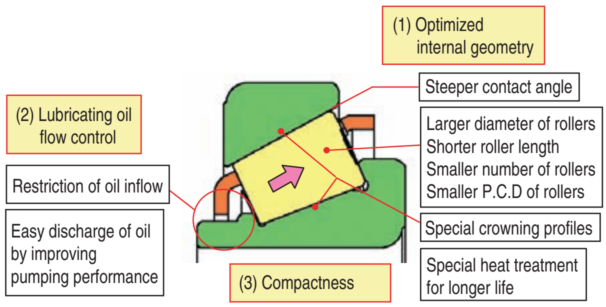


Fig. 2 Features of super-low friction torque tapered roller bearing

3. 1 Reduction of Viscous Rolling Resistance by Optimization of Internal Geometry

The first technology is the optimization of internal geometry considering various performance characteristics. Although it is effective to reduce the contact areas between rollers and raceways by reducing the number of rollers and shortening the roller effective length for reducing the viscous rolling resistance, simply reducing the contact area results in shorter fatigue life and lower rigidity. Therefore, reduction of the life and the rigidity has been suppressed by increasing the roller diameter and contact angle as well as reducing the contact area. Moreover, providing special crowning profiles on the raceways has achieved both lower torque and longer life.

3. 2 Reduction of Agitating Resistance by Lubricating Oil Flow Control

The second technology is the reduction of agitating resistance by lubricating oil flow control. As a result of investigating the influence of inflow and outflow routes of the oil on the torque, it has been found, as shown in **Fig. 3**, that while the torque is reduced by reduction of oil flow rate when the inflow route is closed, the torque is increased when the outflow route is closed. Based on this information, the lubricating oil is considered as one of the bearing components, and the oil flow has been designed. That is, in order to reduce the oil flow through the bearing, the inner diameter of the cage has been made smaller, and a special shape has been provided on the small rib of inner ring so as to form a labyrinth structure between the cage and the small rib of inner ring. Moreover, in order to restrain the oil stagnation inside the bearing and quickly discharge the oil outside the bearing, the oil pumping performance of the bearing has been improved by a steeper contact angle, a reduced number of rollers and an increased roller diameter. **Figure 4** shows a comparison of agitated states inside the bearing with and without inflow oil control, indicating that inflow oil control has restrained bubble generation and reduced oil agitation.

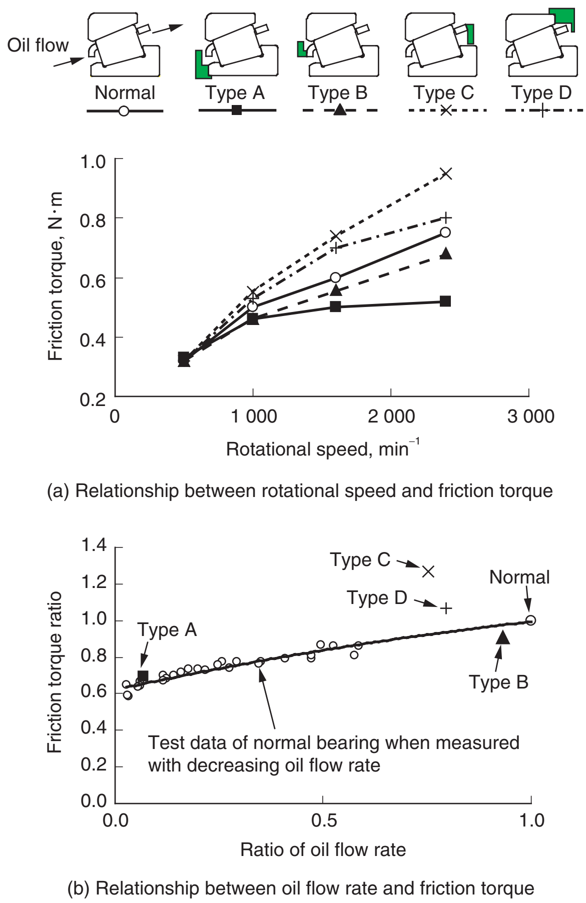
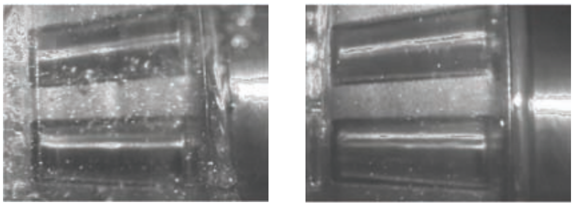


Fig. 3 Effect of oil flow control on friction torque



(a) Without inflow oil control (b) With inflow oil control

Fig. 4 Comparison of agitated state in bearing

3. 3 Compactness by Application of Heat Treatment Technology for Longer Life

The third technology is the compactness by applying heat treatment technology for longer life. By applying our original carburizing heat treatment[5] for longer fatigue life to raceways and rollers, which increases the surface hardness and optimizes the residual austenite content, bearing life in contaminated oil mixed with wear particles of gears etc., can be drastically increased. As the bearing size can be reduced while maintaining the same bearing life, the pitch circle diameter whose influence on the torque is the largest can be made smaller, and thus this technology is effective for reduction of viscous rolling resistance and agitating resistance.

3. 4 Performance of Developed Bearing

In addition to these basic technologies, the large rib surface of the developed bearing's inner ring has been provided with the same special surface roughness profile[3] as conventional LFT bearings. This profile is approximate to surface roughness profile as inner large rib after running-in, has lower contact pressure than that of normal profile, and is favorable for oil film formation. Also, the profile is superior for anti-wear and anti-seizure performance and restraints reduction of support rigidity due to the decrease of preload.

Figure 5 shows a comparison of friction torque measurement results among the developed bearing, a conventional low friction torque tapered roller bearing (hereinafter referred to as conventional bearing) and a double-row angular contact ball bearing (hereinafter referred to as ball bearing), which have been designed so as to have the same calculating life. The developed bearing has realized 75% lower torque compared with that of a conventional bearing, and the torque is lower than that of a ball bearing. As shown in **Table 1**, when a standard tapered roller bearing (hereinafter referred to as standard bearing) for automobile rear axle differentials is set to be the standard, the developed bearing has achieved 80% lower torque and 40% lighter weight while maintaining the basic bearing performance.

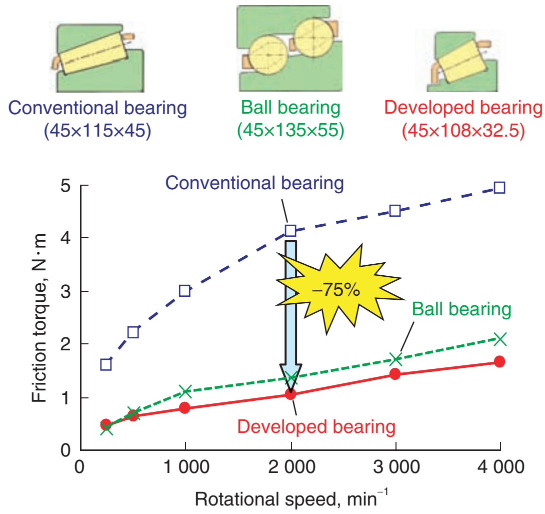
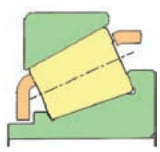
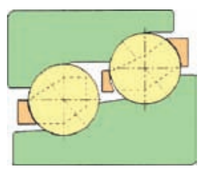


Fig. 5 Friction torque comparison between developed bearing, conventional bearing and ball bearing

Table 1 Performance of developed bearing (when standard bearing performance is set as 1)

Bearing type		Standard bearing	Developed bearing	Ball bearing
Structure				
Boundary dimensions (ID × OD × Width, mm)		45 × 115 × 45	45 × 108 × 32.5	45 × 135 × 55
Friction torque		1	0.2	0.3
Life	Clean oil	1	1	1
	Contaminated oil	1	1	1
Rigidity		1	1	1
Anti-seizure		1	1	–
Ease of assembly		1	1	0.3
Size		1	0.6	1.8

4. Application to Automobile Rear Axle Differential[6)]

4. 1 New Concept of Drive Pinion Support

Super-low friction torque technology of tapered roller bearings described above has been applied to the bearings supporting the drive pinion of automobile rear axle differential of a passenger car. A typical structure of the differential is shown in **Fig. 6**. A large quantity of lubricating oil is supplied to the pinion bearing by splash accompanied by ring gear rotation, and the space between the head and tail bearings will be filled with oil. In a fuel consumption measurement mode which is presumed to be urban drive cycle such as NEDC (New European Driving Cycle), friction loss of pinion bearings accounts for about 50% of whole power loss at the differential. Therefore, reduction of friction loss of pinion bearings can improve the differential efficiency, thereby contributing to improved fuel efficiency of automobiles.

Figure 7 shows the structure of drive pinion support to which the developed bearings is applied. The labyrinth structure for inflow oil control is provided only for the head bearing, not for the tail bearing. By this structure, the supplied oil to the head bearing in which the conventional support structure excessively increases the lubricating oil amount can be decreased to reduce the agitating resistance. On the other hand, the supplied oil to the tail bearing, which runs the risk of seizure in case of low temperature start or high-speed turning, can be increased to improve the anti-seizure performance.

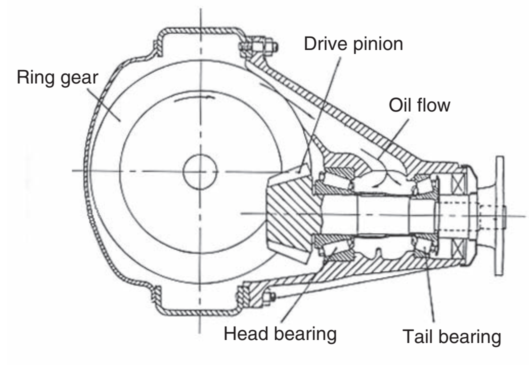


Fig. 6 Rear axle differential

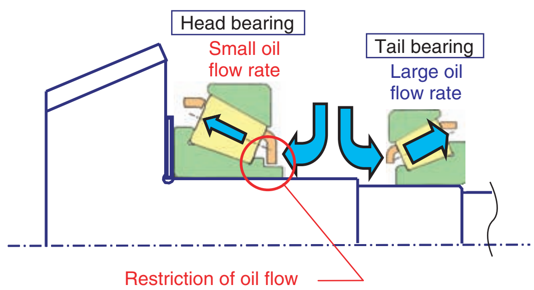
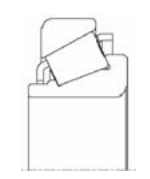
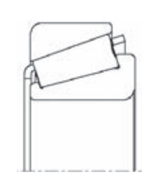
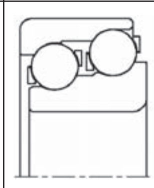
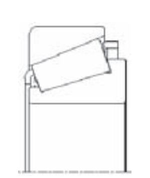
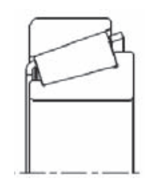
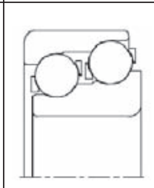


Fig. 7 New concept of drive pinion support

Table 2 Test bearings

	Developed bearings	Conventional bearings	Ball bearings
Pinion head			
ID×OD×W (mm)	34.9×72.2×20.5	34.9×72.2×25.4	34.9×79×31
Pinion tail			
ID×OD×W (mm)	30.2×64.3×21.4	30.2×64.3×21.4	30.2×64.3×23

4. 2 Friction Torque of Bearings under Combined Load Simulating Operating Conditions

Friction torque of the developed bearings alone was measured under combined load simulating operating conditions and compared with the results of the conventional bearings and the ball bearings. Test bearings are shown in **Table 2**. These bearings were designed to have the same bearing life, shaft support rigidity and static safety factor. The main part structure of test equipment is shown in **Fig. 8**. Combined loads calculated based on the input torque from the propeller shaft was imposed on the bearing, and the torque required for rotating the main shaft at the predetermined speed was measured. Friction torque of support bearings alone was measured beforehand, and the torque per one bearing set was obtained from the difference between the two measurement results. A circulation lubrication system was applied with SAE 75W-90 gear oil, and the supplied oil quantity was adjusted so that the front of the test bearing's inner ring was filled with oil. The oil temperature was kept at 50℃.

The sum of measured torque of the head bearing and the tail bearing was supposed to be the measured value of the pinion bearing's torque. **Figure 9** (a) shows the relationship between friction torque and rotational speed at input torque of 20 N·m. The torque of the developed bearings is approximately equal to that of ball bearings and is 50% lower than that of conventional bearings at the rotational speed of 2 000 min^{-1}. Next, **Fig. 9** (b) shows the relationship between friction torque and input torque at the rotational speed of 2 000 min^{-1}. While the torque of ball bearings remarkably increases with the load increasing and a difference with that of the conventional bearings is almost eliminated, the developed bearings can maintain low friction torque performance even under these high loaded conditions. This is because the effect of the load on the torque of ball bearings with point contacts is larger than that of tapered roller bearings with line contacts.

In addition, **Fig. 10** shows the torque comparison of the developed bearings with the ball bearings under various combinations of the input torque and the rotational speed. The vertical axis in **Fig. 10** shows the torque ratio when the torque of the conventional bearings is set to be 1. The torque ratio of the developed bearings is less than 0.6 at the input torque of less than 300 N·m and the rotational speed of more than 1 000 min^{-1}. On the other hand, the torque ratio of the ball bearings is close to that of the developed bearings at the input torque of less than 100 N·m, but is larger than that of the developed bearings at the input torque of more than 200 N·m. The torque ratio of the ball bearings is increased with the input torque increasing and is close to 1 at the input torque of 600 N·m. As mentioned above, regardless of the input torque and rotational speed, the developed bearings show the super-low friction performance over the par with the ball bearings.

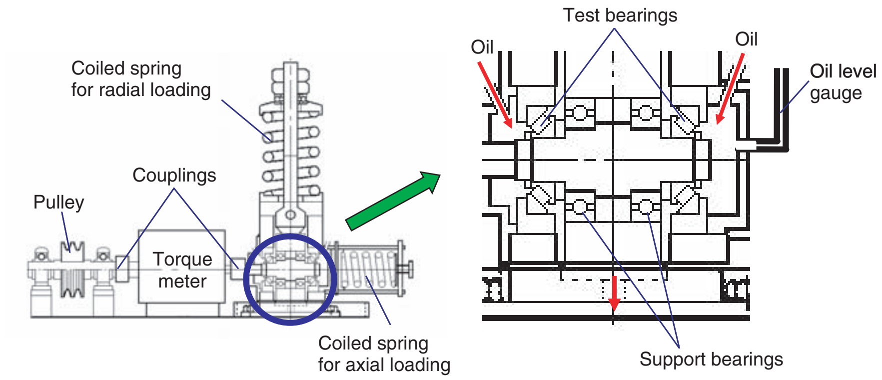


Fig. 8 Schematic diagram of bearing friction torque test equipment

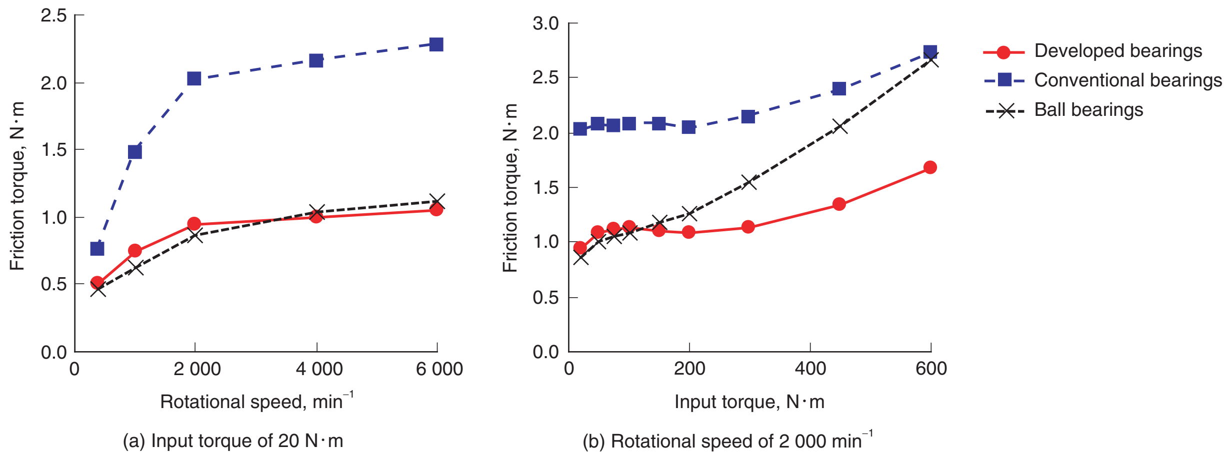


Fig. 9 Friction torque measurement results for pinion bearings under combined load

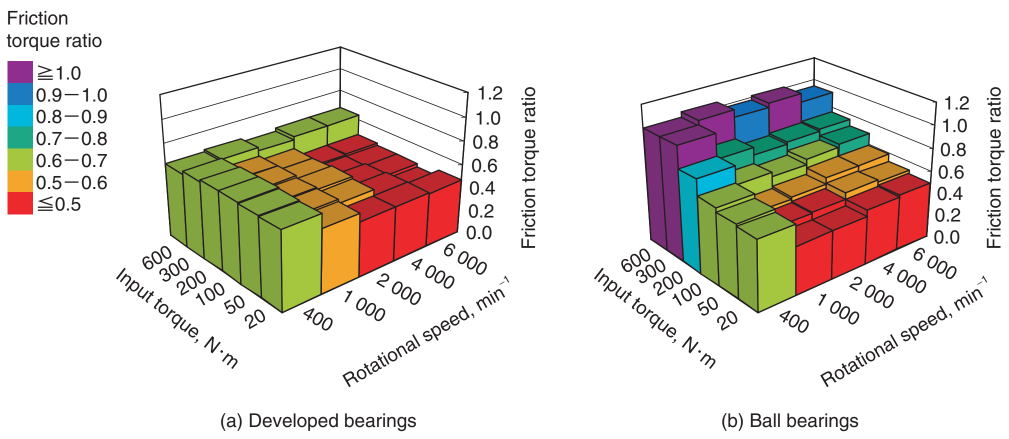


Fig. 10 Friction torque comparison between developed bearings and ball bearings

4. 3 Pinion Torque and Oil Temperature in Rear Axle Differential

The developed bearings were mounted in the drive pinion support of the differential, and the torque required for rotating the pinion shaft and the oil temperature at the bottom of the differential carrier were measured. In order to mount the test bearings shown in **Table 2** to the same differential, the outer diameter and the width of the developed and the conventional bearings are united with the ball bearings. **Figure 11** shows a schematic diagram of the test equipment. The test bearings were mounted in the drive pinion support with a preload of 5 kN, after they were made to be running in. To measure the pinion bearing torque only, the pinion shaft was modified so that the pinion gear was not in mesh with the ring gear. The ring gear was driven by a separate motor at its appropriate speed to simulate the oil flow in the axle differential. This test was conducted under no load. However, it is considered that the bearing load at low-loaded conditions as the NEDC is not very different from the case only of preload. SAE75W-90 gear oil was used as lubricating oil.

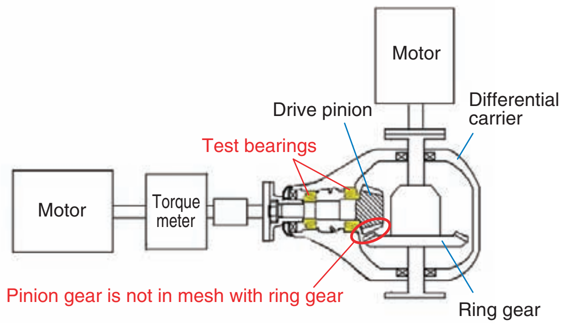


Fig. 11 Schematic diagram of axle differential test equipment

Figure 12 (a) shows the measurement result of pinion torque at oil temperature of 80℃. The torque of the developed bearings is approximately equal to that of ball bearings in the whole rotational speed range tested and is 40% lower than that of conventional bearings. Next, the measurement result of oil temperature inside the differential is shown in **Fig. 12** (b). The oil temperature of the developed bearings is approximately equal to that of ball bearings in the whole rotational speed range tested. At the pinion rotational speed of 7 000 min^{-1} (equivalent to about vehicle speed of 220 km/h), the developed bearings can restrain the oil temperature rise to about 20℃ compared with conventional bearings.

4. 4 Effect for Reduction of Environmental Burdens

As described above, it has been confirmed that the developed bearing has a low friction torque equal to or lower and low temperature rise performance equal to lower than those of ball bearings in the axle differential test. As the developed bearing has been designed to have 50% or more low friction torque compared with the standard bearing, the application of the developed bearings can reduce power loss of the differential up to 25 to 35%, supposing that half of the power loss of the differential results from the pinion support part. When a trial calculation of the developed bearing effect is performed, improved vehicle fuel efficiency of up to 1.5 to 2% and reduction of CO_2 emission of up to 3.5 to 4.5 g/km can be expected. This effect is equivalent to reducing CO_2 emissions by 400 000 tons when calculated only for Japan. As mentioned, rolling bearings, which are usually working behind the scenes, can significantly contribute to the reduction of the environmental burdens. Moreover, the restraining effect of the temperature rise of the developed bearing is considered to contribute not only to the prevention of lubricating oil deterioration and to higher rotational speed, but also to cost reduction of units by the elimination of cooling fins, etc.

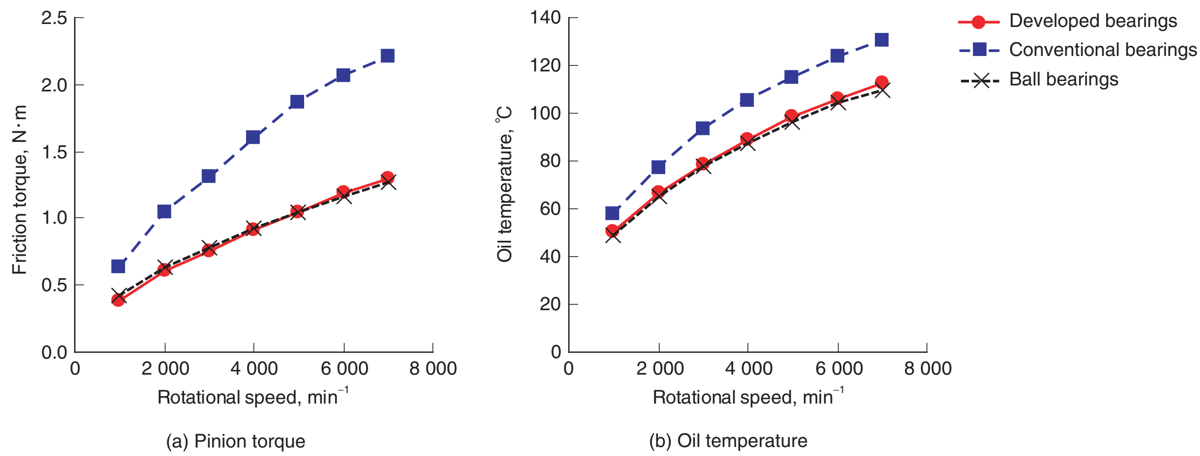


Fig. 12 Pinion torque and oil temperature measurement results

5. Conclusion

Super-low friction torque tapered roller bearing, LFT-Ⅲ developed by JTEKT can realize friction torque reduction of up to 50% for the same size bearing and 80%, given the compactness effect. Since the energy saving effect of the developed bearing is remarkable, and since its superiority in originality and economical aspect has been highly evaluated, JTEKT received the Minister of Economy, Trade and Industry's Award for Excellent Energy-Conserving Equipment from the Japan Machinery Federation. Each basic technology developed for higher efficiency of tapered roller bearings can be widely applied to other rolling bearings used in each industrial machine field for the 21st century-oriented environmental protection technology.

(LFT is a registered trademark of JTEKT.)

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