Low Friction Torque Bearings for Differential Pinion

H. OOSHIMA

JTEKT has succeeded in the practical application of two types of low friction torque bearings which have 40% to 50% less friction torque than that of the conventional low friction torque tapered roller bearing (LFT-Ⅱ) in automobile differential pinion. One is the super-low friction torque tapered roller bearing (LFT-Ⅲ), which has achieved lower friction torque with an optimized internal geometry and lubricating oil inflow control. The other is the tandem angular contact ball bearing, which has achieved lower friction torque by changing bearing types from tapered roller bearings to ball bearings. These bearings are expected to reduce CO_2 emissions by improving automobile fuel efficiency.

Key Words: *tapered roller bearing, tandem ac, low friction torque, high efficiency, differential pinion*

1. Introduction

The differential as one part of power transmission systems transmits power transferred from the engine to driving wheels and compensates for the difference in the rotational speed of the right and left side wheels. Generally, tapered roller bearings which have high load carrying capacity and high stiffness are used for supporting the drive pinion (pinion) and the ring gear. However, on the other hand, when compared with ball bearings tapered roller bearings have higher friction torque and higher heat generation.

To achieve reduction of CO_2 emissions through improvement of automobile fuel efficiency, movement towards greater effciency in differential and other power transmission systems has been accelerating. And, as one such measure, reduction of bearing friction torque (torque) has been studied.

This report introduces two types of low friction torque bearings which have been put into actual use for automobile differential pinions. One is the super-low friction torque tapered roller bearing (LFT-Ⅲ), which has achieved lower friction torque through optimized internal geometry and lubricating oil inflow control in addition to the low friction torque technology of LFT (low friction torque tapered roller bearing)-Ⅰ[1] and LFT-Ⅱ[2]. The other is the tandem angular contact ball bearing (Tandem AC) which has realized lower friction torque by changing the bearing type from tapered roller bearing to ball bearing. Actual use of these bearings has enabled 40% to 50% torque reduction compared with conventional LFT-Ⅱ. JTEKT can also supply combinations of LFT-Ⅲ and Tandem AC in response to customers' needs.

2. LFT-Ⅲ [3), 4)]

2. 1 Causes of Friction Torque of Tapered Roller Bearings and Their Contribution Ratios

The structure of a typical rear differential is shown in **Fig. 1**. A large quantity of lubricating oil is supplied by the splash that accompanies ring gear rotation to both the head-side and tail-side tapered roller bearings for the supporting pinion. Observation of the oil flow around the bearings in a transparent resin carrier has revealed that both the head-side and the tail-side bearings are completely filled with oil at rotational speeds from 600 to 900 min^{-1} (equivalent to vehicle speed 20 to 30 km/h). That is, pinion bearings are excessively lubricated in the speed ranges of practical use, and it has been considered that torque due to agitating resistance of oil cannot be negligible.

The main causes of friction torque and their contribution ratios were calculated based on experimental results under driving conditions that are representative of NEDC (New European Driving Cycle, European fuel efficiency measurement mode-Axial load 4 kN,

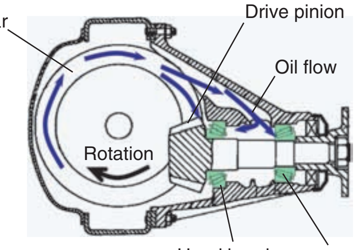


Fig. 1 Structure of typical rear axle differential

Rotational speed 2 000 min^{-1}, gear oil, oil temperature 50℃). The calculation results are shown in **Fig. 2**. It can be seen that the contribution ratio of rolling viscosity resistance between rollers and raceways is the highest and that of agitating resistance of lubricating oil is second. On the other hand, the contribution ratio of sliding resistance between the large rib of the inner ring and large end of the rollers is small. This is considered to be due to sufficient EHL (elastohydrodynamic lubrication) oil film formation between the large rib of the inner ring and the large end of the rollers as the bearing is lubricated with high viscosity gear oil.

Based on the above results, in order to further reduce the torque of existing tapered roller bearings (LFT-Ⅰ, LFT-Ⅱ), we have made efforts to realize optimization of internal geometry for further reduction of rolling viscosity resistance and inflow control of lubricating oil for reducing agitating resistance.

2. 2 Features of LFT-Ⅲ

Features of LFT-Ⅲ are shown in **Fig. 3**.

The first technology is the optimization of internal geometry considering the balance of performance required for bearings. Deterioration of bearing life and stiffness has been restrained by reducing the number of rollers, shortening the length of rollers, reducing the contact area between rollers and raceways, and at the same time, increasing roller diameter and contact angle.

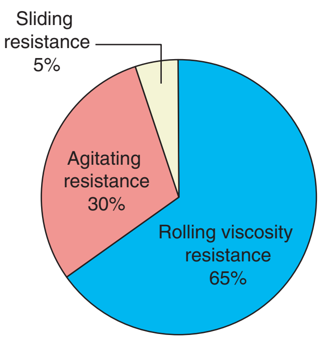


Fig. 2 Causes of friction torque and their contribution ratios

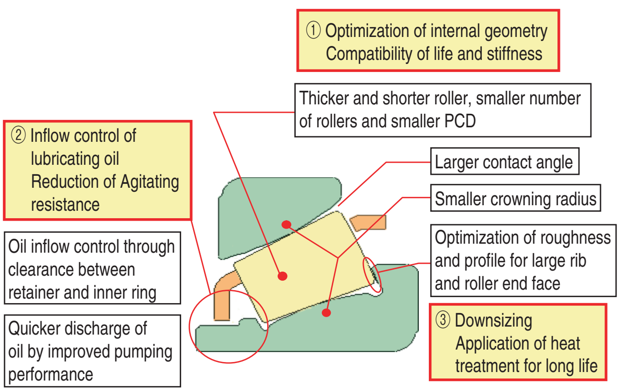


Fig. 3 Features of LFT-Ⅲ

Moreover, by applying a special crowning on the raceway, longer life has been balanced with lower torque.

The second technology is the reduction of agitating resistance by inflow control of lubricating oil. To reduce the quantity of oil flowing into the bearing, the inner diameter of the retainer was reduced, the small rib of the inner ring was given a special shape, and a labyrinth was formed between the retainer and small rib of the inner ring. To inhibit the accumulation of inflow oil in the bearing and discharge it quickly to the exterior, bearing pumping performance was increased by enlarging the contact angle, reducing the number of rollers, and enlarging roller diameter.

Along with the above two elemental technologies, lower torque can be realized through downsizing of bearings by applying long-life heat treatment technology. Bearing life in contaminated oils especially with wear debris of gear, etc. can be remarkably improved when special carbonitriding heat treatment technology[5], which increases surface hardness of bearings and optimizes residual austenite for longer life, is applied to rollers and raceways. Since this technology can improve the load carrying capacity and the static strength of the bearings, downsizing is possible while maintaining bearing life. This enables PCD which has the largest influence on bearing torque to be downsized and, as a result, it becomes possible to reduce both rolling viscosity resistance and agitating resistance.

Moreover, in addition to these technologies, a special surface roughness profile[1] has been provided for the large rib surface of the inner ring of LFT-Ⅲ in the same way as LFT-Ⅰ. This profile approximates the roughness profile of a large rib surface after being broken-in and is more advantageous in oil film formation due to contact pressure lower than a normal profile. As a result, LFT-Ⅲ is superior for anti-wear and anti-seizure and can inhibit the decrease of support stiffness from preload decrease.

The lineup of JTEKT's low friction torque tapered roller bearings is shown in **Table 1**, for reference.

Table 1 Low friction torque tapered roller bearings

Applied technology	Standard	LFT-Ⅰ	LFT-Ⅱ	LFT-Ⅲ
Optimization of roughness and profile for large rib and roller end face	–	○	○	○
Raceway crowning	–	–	○	○
Optimization of internal geometry	–	–	–	○
Inflow control of lubricating oil	–	–	–	○

○: Applied

3. Tandem AC

3. 1 Features of Tandem AC

Although conventionally, tapered roller bearings with high load carrying capacity and high stiffness have been used as bearings for pinions, using the specifications below, it has become possible to take advantage of the lower friction torque performance of ball bearings as compared to conventional tapered roller bearings.

Features of Tandem AC are shown in **Fig. 4**.

(1) Two row arrangement of balls in the same contact angle attains improvement in bearing life and stiffness which are inferior to conventional tapered roller bearings.

(2) By arranging balls with different PCDs in the same contact angle direction, the type where the assembly of the inner and outer rings is the same as conventional tapered roller bearings has been changed to a separate type bearing, which leads to an easy assembly into the differential.

(3) Application of carbonitriding heat treatment to inner rings realizes longer life through higher hardness of raceway surface, formation of compressive stress layer and optimization of residual austenite.

(4) Uses a resin retainer with superior oil resistance

3. 2 Precautions in Tandem AC Application

The following precautions need to be taken for application of Tandem AC.

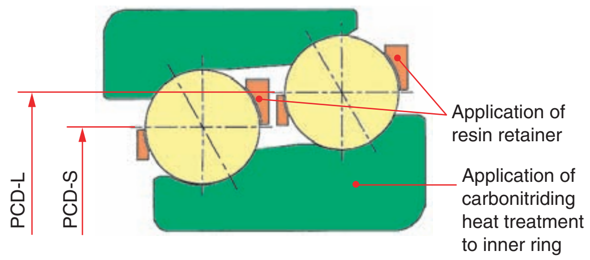


Fig. 4 Features of tandem AC

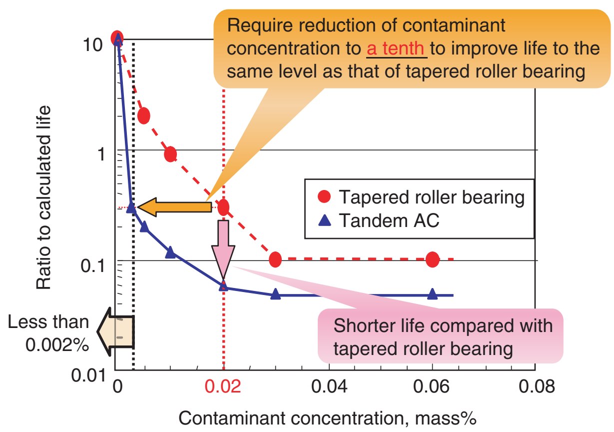


Fig. 5 Relationship between contaminant concentration and bearing life (bearing test)

3. 2. 1 Reduction in Contaminant Resistance

Tandem AC is inferior in contaminant resistance compared with conventional tapered roller bearings. **Figure 5** shows the relationship between contaminant concentration and bearing life based on a parameter study of contaminant concentration. Since bearing life of Tandem AC decreases to less than a tenth compared to that of tapered roller bearings, it is essential to reduce the contaminant concentration in the differential. It is presumed that one of the reasons for shorter life is, because of differences in the internal geometry, there is a difference in the flow of oil through the bearing, and thus the adverse influence of contaminants clogging the bearing internally becomes greater due to insufficient agitation.

3. 2. 2 Review of Preload Control in Assembling

In general, the differential pinion assembling process preload is controlled by the torque value at rotational speeds of 50 to 60 min^{-1}. Preload control of Tandem AC becomes difficult because, in order to set the same preload range of 4 to 6 kN as that of conventional tapered roller bearings, the rotational torque of Tandem AC needs to be controlled in a fifth of the torque range compared to conventional tapered roller bearings. **Figure 6** shows a comparative example of assembling preload control.

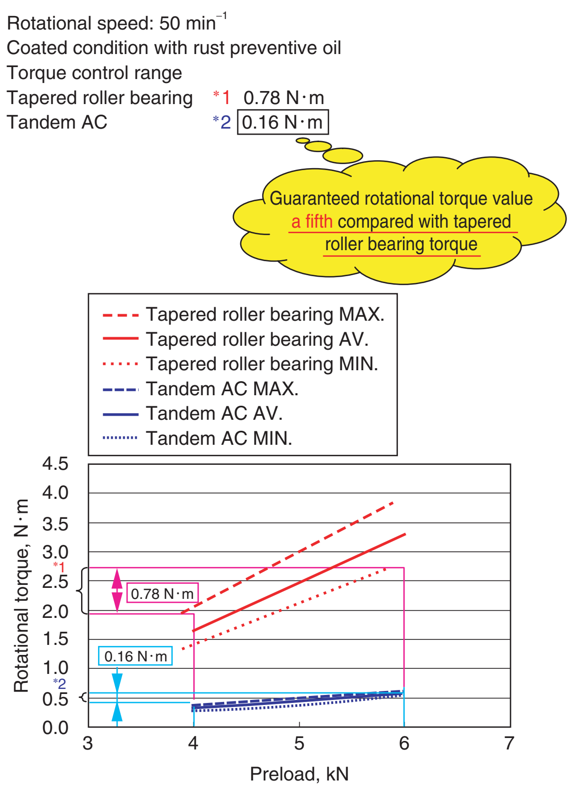


Fig. 6 Comparative example of assembling preload control

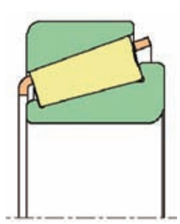
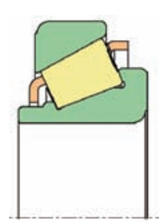
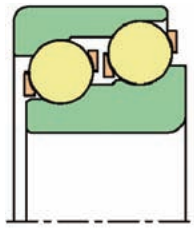
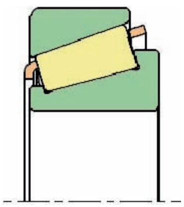
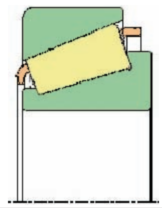
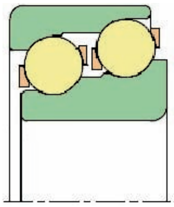
4. Performance of LFT-Ⅲ and Tandem AC[6)]

4. 1 Torque of Bearing Itself under Assumed Load Conditions of an Actual Vehicle

Torque of the bearing itself was measured under a combined load assuming actual vehicle operating conditions and the results were compared to conventional LFT-Ⅱ, the LFT-Ⅲ that was developed, and the Tandem AC that has been put into actual use. Test bearings are shown in **Table 2**. These bearings are designed to have the same life, the same shaft support stiffness and the same static strength. The core structure of the test equipment is shown in **Fig. 7**. Torque required to rotate the main shaft at the predetermined rotational speed was measured under the combined load on bearings, which was calculated based on the input torque from the propeller shaft. Torque of the support bearing itself was measured beforehand and torque for one set of test bearings was obtained from the difference between measurement results of both bearings. For lubrication the circulation feed system of SAE75W-90 gear oil was used and the inner ring front face of the test bearing was filled with oil by adjusting the quantity of supplied oil. Oil temperature was set to be constantly at 50℃.

The relationship between rotational torque and rotational speed under input torque 20 N·m is shown in **Fig. 8** (a). Torque of LFT-Ⅲ is nearly the same as that of Tandem AC and, under rotational speed 2 000 min^{-1}, it is 50% smaller compared to that of conventional LFT-Ⅱ. Next, the relationship between rotational torque and input torque under rotational speed of 2 000 min^{-1} is shown in **Fig. 8** (b). Although torque of Tandem AC increases in accordance with increased load and the difference between Tandem AC and conventional LFT-Ⅱ becomes almost zero, LFT-Ⅲ can maintain low torque performance even under these heavy load conditions. This is considered to be because of larger influence of load on the torque of point-contact ball bearings than that of line-contact tapered roller bearings. However, as seen from the relationship between rotational torque and input torque during running in **Fig. 8** (b), compared with the conventional LFT-Ⅱ at

Table 2 Test bearings

	LFT-Ⅱ (Conventional)	LFT-Ⅲ	Tandem AC
Head bearing			
Inner diameter × outer diameter × assembled width (mm)	34.9 × 72.2 × 25.4	34.9 × 72.2 × 20.5	34.9 × 79 × 31
∗3 Tail bearing			
Inner diameter × outer diameter × assembled width (mm)	30.2 × 64.3 × 21.4	30.2 × 64.3 × 21.4	30.2 × 64.3 × 23

∗3 Tail bearing (LFT-Ⅲ) has no labyrinth structure to control inflow oil quantity.
Concern about seizure at low-temperature starting and high speed rotation is taken into account.

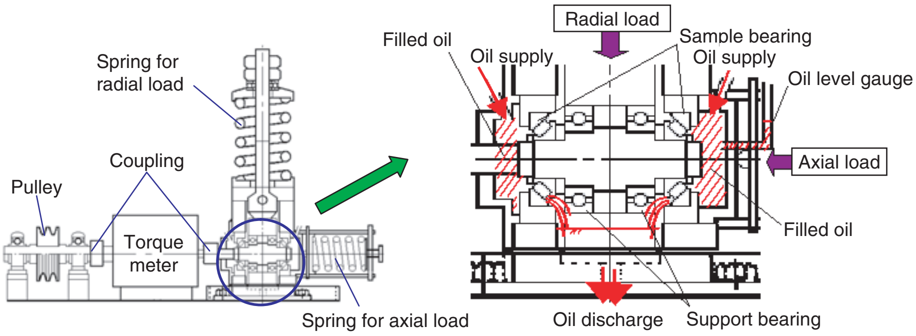


Fig. 7 Schematic diagram of bearing friction torque test equipment

input torque of 200 N·m, the rotational torque of LFT-Ⅲ is 50% lower and that of Tandem AC is 40% lower, which shows that both bearings can contribute to high efficiency under normal running range.

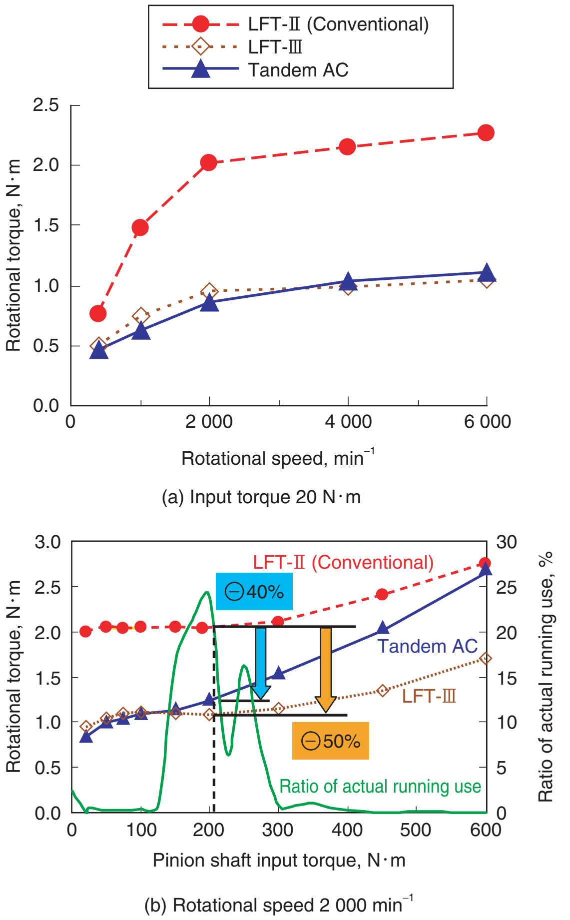


Fig. 8 Friction torque measurement results of bearings themselves

4. 2 Pinion Torque and Oil Temperature in Actual Machine

Torque required to rotate the pinion shaft and oil temperature in the bottom portion of the differential carrier were measured by mounting in the pinion portion of a passenger car rear differential bearings that have been put into actual use. The outer diameter and width of conventional and actual use bearings was changed to have the same dimensions of outer diameter and assembled bearing width as those of the Tandem AC which is the largest in size among them. A schematic diagram of the test equipment is shown in **Fig. 9**. Test bearings after breaking-in were mounted in the pinion support portion with a 5 kN preload. By changing the pinion profile so that the ring gear did not engage with the pinion, only pinion torque was measured. Also the ring gear was rotated by another motor at a speed equivalent to rotational speed of the pinion, so that oil flow in the differential was the same as real conditions. This test was done under no load; however, under low load condition like NEDC, influence of load on bearings is considered to be almost the same as in the case of preload only. SAE75W-90 was used as a lubricating oil.

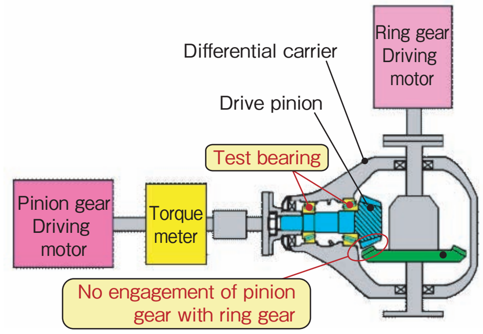


Fig. 9 Schematic diagram of axle differential test equipment

Figure 10(a) shows the measurement results of torque in the pinion portion at oil temperature of 80℃ and rotational speed 2 000 min^{-1}. Torque values of LFT-Ⅲ and Tandem AC are about 40% smaller compared to that of the conventional LFT-Ⅱ. Next, measurement results of oil temperature inside the differential at rotational speed of 7 000 min^{-1} (equivalent to vehicle speed of about 220 km/h) are shown in **Fig. 10** (b). Oil temperature rise of LFT-Ⅲ and Tandem AC can be reduced as much as about 20℃ compared to that of conventional LFT-Ⅱ. As mentioned above, it has been confirmed by the actual machine test that both LFT-Ⅲ and Tandem AC have superior torque and low temperature rise performance compared to conventional LFT-Ⅱ.

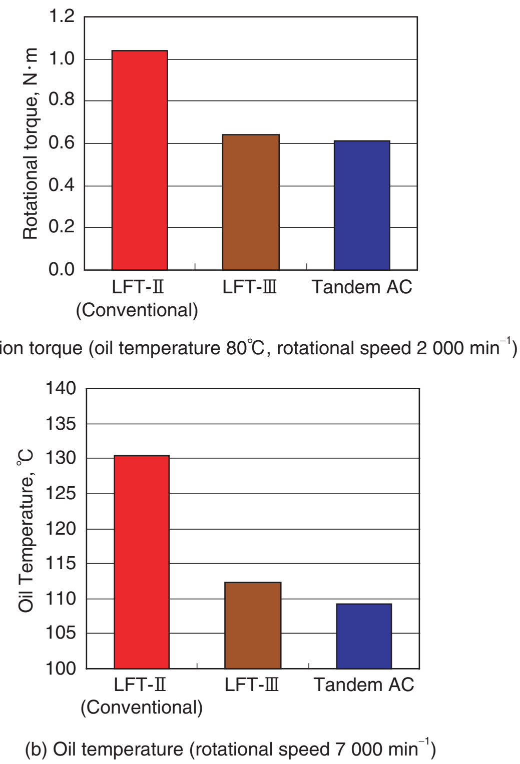
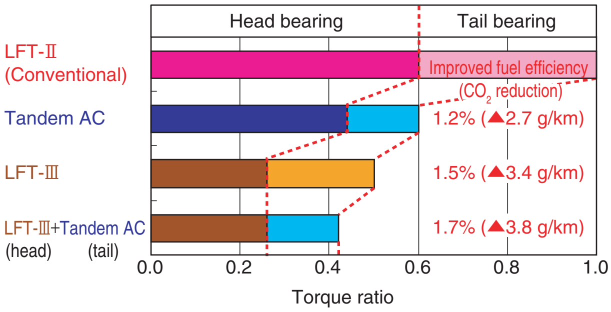


Fig. 10 Measurement results of pinion torque and oil temperature

POWER TRAIN

4. 3 Effect on Reduction of Environmental Load

A calculation example of contribution ratio to environment under pinion input torque of 200 N･m in **Fig 8**(b) is shown below. LFT-Ⅲ, for example, has achieved 50% lower torque compared to conventional LFT-Ⅱ, so if it is presumed that half of the differential's power loss comes from the pinion bearing, 25% of the power loss of the differential could be reduced by applying LFT-Ⅲ. From trial calculations of the effect of the bearings evaluated here, 1.5% improvement in vehicle fuel efficiency and 3.4 g/km reduction of CO_2 emissions can be expected. **Figure 11** shows the calculation results of contribution ratio to environment by a combination of pinion bearings [classification of passenger car: C segment (1.5 to 2 L class compact car)].



<Conditions>
・Input torque: 200 N･m ・Rotational speed: 2 000 min^{-1}
・Lubricant: SAE75W-90 gear oil ・Oil temperature: 50℃

Fig. 11 Contribution ratio to environment

4. 4 Application Example of Low Torque Bearing for Differential Pinion

Although Tandem AC is slightly advantageous for low torque performance under low load conditions like NEDC's fuel efficiency measurement condition, LFT-Ⅲ is advantageous for low torque performance in all ranges of load, from light to heavy. From the above results, by using LFT-Ⅲ in the head-side to which heavy load is applied and Tandem AC in the tail-side in which there is a fear of seizure, quantity of oil in the differential can be reduced and further low torque performance can be realized. In the future, we think combinations of LFT-Ⅲ and Tandem AC will increase.

4. 5 Lineup of Low Torque Bearings for Differential Pinion

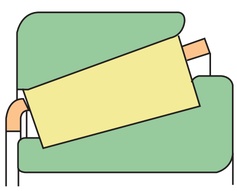
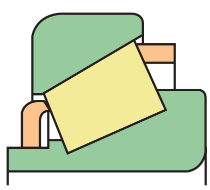
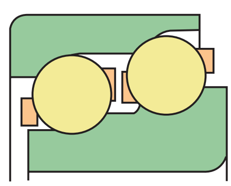
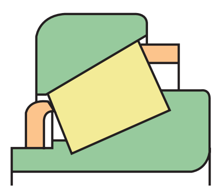
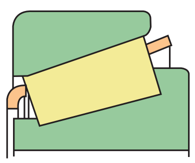
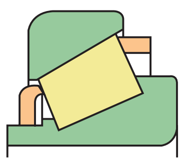
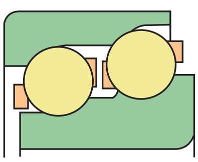
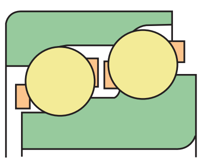
Table 3 shows a lineup of low torque bearings for differential pinion. JTEKT can propose a combination of pinion bearings appropriate for customers' required performance, operating conditions and structure of differential carriers.

5. Conclusion

Super low torque technology of tapered roller bearings and ball bearing substitution technology have been applied to pinion bearings of passenger car differentials. As a result, it has been confirmed that low friction torque bearings can give sufficient low torque and low temperature rise performance compared to conventional tapered roller bearings. Each elemental technology comprising these bearings can also be applied to transmissions and a wide range of other automobile applications besides differentials and can contribute to a reduction in global environmental load.

＊1 LFT is a registered trademark of JTEKT Corporation.

Table 3 Lineup of low torque bearings for differential pinion

Type	LFT-Ⅱ	LFT-Ⅲ	Tandem AC	LFT-Ⅲ + Tandem AC
Head side				
Tail side				

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