High Efficiency and Lightweight Technology of Automotive Parts for Energy Saving*1

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High efficiency and lightweight of automotive parts such as rolling bearings, steering systems and driveline units is a significant contribution to reduction of CO_2 emissions by vehicle fuel efficiency. JTEKT has introduced a "JTEKT Ecology Package" for 2.5 L class AWD vehicles for the purpose of achieving energy saving in vehicles. The paradigms of ecologically friendly products which constitute the "JTEKT Ecology Package", in particular rolling bearings and their fundamental technologies, have been presented for their high efficiency and lightweight quality. It is expected that the total fuel efficiency improvement from the "Ecology Package" is 10.7 percent.

Key Words: *rolling bearings, automobiles, tribology, low friction, high efficiency, lightweight, energy saving*

1. Introduction

The demands on vehicles are changing significantly. Conventionally, vehicle development focused on the three aspects of “safety”, “comfort” and “environment”, but now many new demands have emerged, including responses to the following:

1) environmental issues such as the prevention of global warming,
2) energy issues made apparent by soaring oil prices,
3) resource issues such as rare metal
4) competing on a global market in line with market expansion in emerging countries.

In particular, the response of automobiles to environmental and energy issues is an important theme which will have impact upon the fate of the automotive industry moving forward. It would not be an overstatement to say that improving fuel efficiency and reducing CO_2 emissions are the most important issues related to global warming and energy conservation.

In this situation, JTEKT proposes a total package for improving fuel efficiency, we call “JTEKT Ecology Package”, which comprises of automotive parts such as rolling bearings, steering systems, driveline units etc., which contribute to energy-saving of vehicles, or in other words, the reduction of CO_2 emissions through improved fuel efficiency. In this paper, we introduce the ecologically-friendly products and their respective element technologies, which have developed to realize high-efficiency and lightweight of vehicles.

2. Response to Environmental and Energy Issues

It is common knowledge that Japan, Europe and the U.S. alike are becoming more stringent in regards to vehicle fuel efficiency (CO_2 emissions) regulations in response to global warming and in line with the rapid industrial development of emerging countries. In July 2015, the Japanese government finalized a draft proposal of Japan’s commitment to achieve a 26% reduction in greenhouse gases from a 2013 baseline by the year 2030 and submitted this draft to the United Nations Framework Convention on Climate Change. CO_2 emissions originating from energy constitute 90% of Japan’s greenhouse gas emissions, and the transportation sector, which produces around 20% of all CO_2 emissions, is required to achieve a reduction of 28% compared to 2013 results. In order to meet such a requirement, there is a need to promote energy-saving initiatives for vehicles, which occupy the majority of the transportation sector. If attempts to curb vehicle energy consumption focused on the vehicle in isolation, it would only be a matter of the extent to which fossil fuel consumption could be minimized during a vehicle’s operation, that is, improving fuel efficiency.

Figure 1 shows the percentages of energy loss when a U.S. gasoline-driven vehicle is travelling[1)]. The Japanese Society of Tribologists have also conducted a similar investigation[2)] and obtained loss distribution percentages

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for each element roughly the same as **Fig. 1**. Aside from reducing vehicle weight, many technologies have been developed for the improvement of fuel economy. Effective areas of focus are:

1) Improving engine efficiency
2) Reducing idling loss
3) Improving power transmission efficiency
4) Reducing travel resistance
5) Reducing auxiliary device loss

JTEKT engages in the development of technologies to achieve the above outcomes and satisfy demands for high-efficiency and lightweight needs[3].

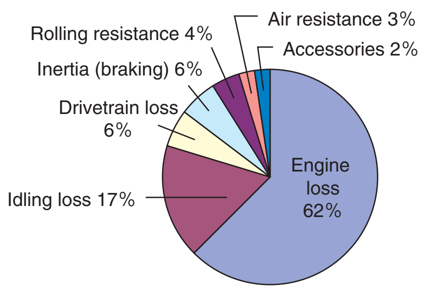


Fig. 1 Percentages of energy loss in traveling gasoline engine vehicles

3. JTEKT Ecology Package

Figure 2 shows the JTEKT Ecology Package assuming a 2.5 L-class AWD vehicle. The percentage values shown in this figure represent the fuel efficiency improvement rate as a result of increased efficiency and weight reduction. In the following, the representative ecologically-friendly products and their respective element technologies to configure them in chassis, powertrain and drivetrain systems, have been presented.

4. Chassis

4. 1 Steering

In 1988, JTEKT was the first in the world to begin mass production of column type electric power steering (EPS). With the conventional hydraulic power steering (HPS), there was a need to constantly run a hydraulic pump with engine driving force. In contrast, an EPS system only requires the motor to be operated when the vehicle is being steered, therefore energy consumption is small, at a mere one-sixth compared to HPS, which translates to a fuel efficiency improvement of 2.5% (**Fig. 3**)[4, 5]. Looking at overall global vehicle production by steering type, HPS

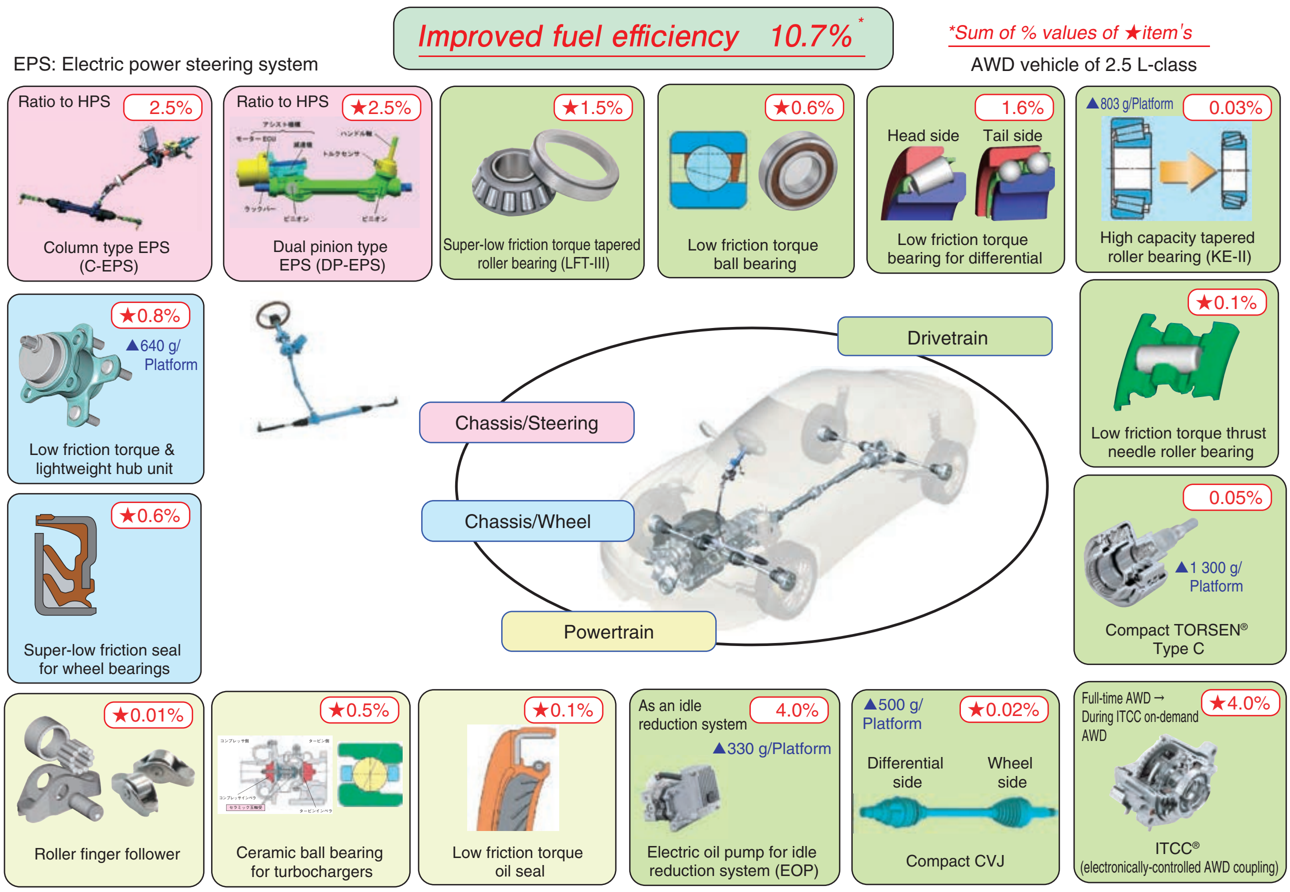


Fig. 2 JTEKT Ecology Package

was used on the majority of vehicles produced around the 2000s, however by 2014, EPS was used on half, demonstrating the rapidly accelerating shift to EPS[6].

Due to being adopting on a higher number and broader range of vehicles, various types of EPS have been produced, and the system has become high-output and high-functionality. The dual pinion type EPS (DP-EPS) has an assist mechanism in the engine chamber to simultaneously achieve higher output and improvement of vehicle mountability. In recent years, the developed column type EPS (C-EPS) has achieved a weight reduction of 15% (2.7 kg) compared to the conventional model due to motor/ECU integration[7], a smaller brushless motor and other measures.

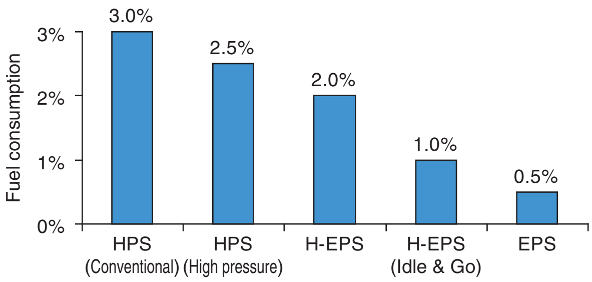


Fig. 3 Comparison of energy consumption in steering systems

Fig. 4 Worm gear for EPS motor reducer

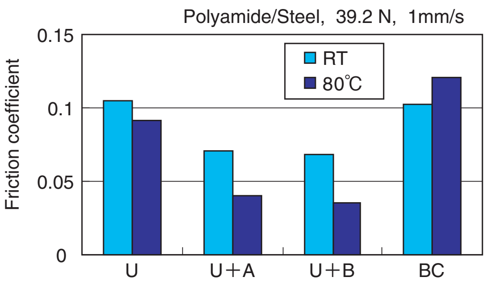


Fig. 5 Comparison of friction characteristics between lubricating greases with different thickeners and additives

The worm gears used in EPS motor reducers are made from resin worm wheels and steel worm shafts, and the sliding portions of these (**Fig. 4**) are lubricated with grease. In recent years, a new grease low-friction technology[8] has been developed with optimized additives and improvement of influx to sliding portions. As shown in **Fig. 5**[9], by adding stearate-based additives to enhance oiliness (A, B) to an aliphatic diurea grease (U), it would be possible to reduce friction compared to conventional Ba complex soap grease (BC). This is also effective in minimizing any change to resin material properties caused by high temperatures. By adopting this technology, it is possible to achieve low temperature rising of the worm shaft, improved resin gear durability and enhanced reducer efficiency.

4. 2 Wheel

As **Fig. 6** shows, the hub unit comprises of peripheral components such as the wheel bearing and hub shaft, all integrated into one. This has significantly contributed to reducing components and weight. Currently, the 3rd generation hub unit is mainstream and is characterized by integrating one inner ring with the hub shaft. For the 3rd generation hub unit, JTEKT utilized a lightweight design and "monozukuri" technology using CAE analysis which included the configuration of surrounding sections to achieve a 25% weight reduction while securing strength and rigidity (**Fig. 7**)[3]. Moreover, a total friction torque reduction of 55% was achieved by reducing seal sliding resistance, which accounts for half of the hub unit's overall friction torque, in addition to reducing rolling resistance through minimizing preload and improving dimensional/assembly accuracy.

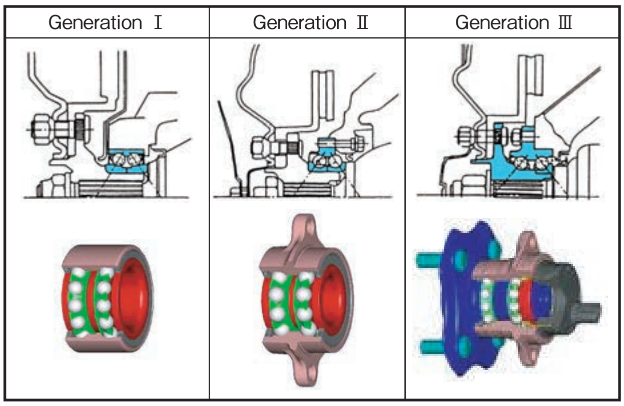


Fig. 6 Transition of hub units

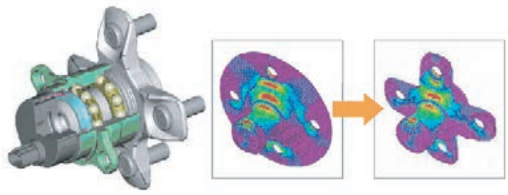


Fig. 7 Example of CAE analysis of hub unit flange

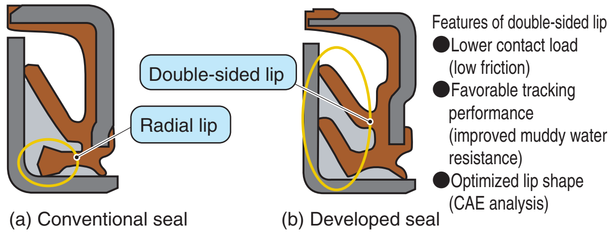


Fig. 8 Super-low friction seal

In the super-low friction torque seal used in hub units and wheel bearings, a double-sided lip was adopted to achieve both good muddy water resistance and low friction torque[10]. As shown in **Fig. 8**, the radial lip, which largely contributes to contact load, particularly friction torque, has been abolished on the developed seal, and two axial lips, which help to improve muddy water resistance, were adopted. This has reduced the friction torque by 50% compared to the conventional low friction torque seal, and 70% compared to the standard seal, at the same time as doubling muddy water resistance.

5. Powertrain

In order to reduce engine loss, which accounts for around 60% of total vehicle energy loss, the technology is being developed to replace the bearing from widely used sliding type to rolling type. In regards to the rocker arm, a major component of the valve system, low-speed friction torque, which has particularly large friction loss, has been reduced through adoption of a rolling type rocker arm, meaning that the roller finger follower uses needle rollers as the rolling elements. As **Fig. 9** shows, by applying a special barreling treatment (Tetratekt) to harden only the topmost layer of the roller's outer surface, which contacts by rolling while sliding with the camshaft, at the same time as suppressing surface roughness, it has been possible to reduce the aggressiveness on the camshaft, as well as reduce friction torque.

In regards to the turbocharger, which is an effective means in reducing engine size, studies are being carried out to enhance efficiency and acceleration response through using a rolling bearing for turbine support. To handle this issue, the ceramic ball bearing[3] has been adopted due to having low friction torque at high-speed conditions, good heat resistance, high-speed ability and improved durability (**Fig. 10**). As **Fig. 11** shows, by switching to a rolling type for the developed bearing, friction loss has been reduced, the use of low viscosity lubricant has been made possible, less lubricant is required and acceleration response has been improved.

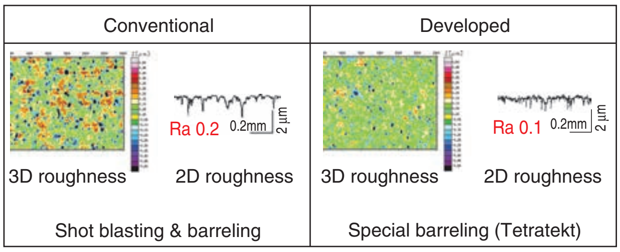


Fig. 9 Special barreling (Tetratekt)

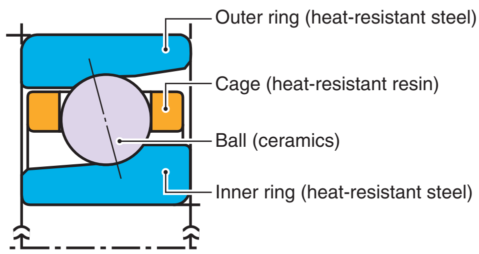


Fig. 10 Ceramic ball bearing for turbocharger

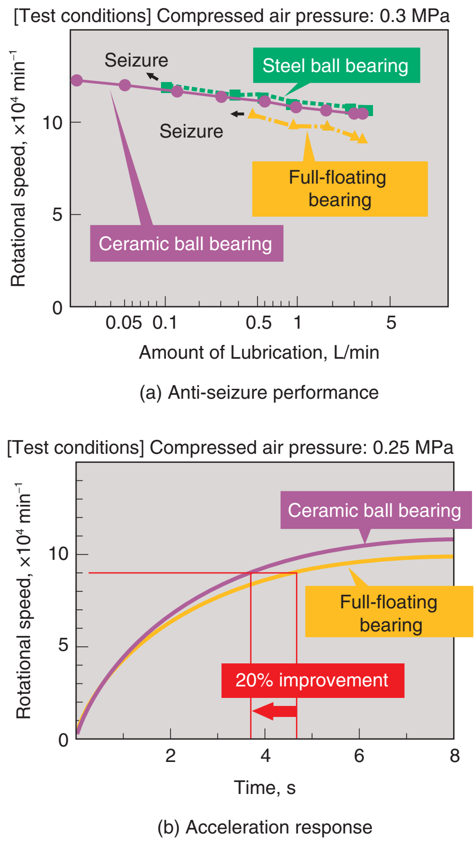


Fig. 11 Performance of developed bearing

Furthermore, a low friction torque oil seal with optimized tension design and a coating on its sliding surfaces has also been effective.

6. Drivetrain

6. 1 Bearings

Drivetrain units such as transmissions and differentials utilize many different types of rolling bearing. In order to increase the power transmission efficiency of each unit, reducing the friction torque of rolling bearings is considered as important as extending bearing service life. As a leading company in tapered roller bearings, JTEKT has been offering a low friction torque tapered roller bearing (LFT) on the market for over thirty years. **Figure 12** shows the transition of LFT bearings. LFT-I[11] has reduced sliding resistance between the cone rib and the roller end faces, while LFT-II[12] has reduced rolling resistance between the rollers and the raceway. For the super-low friction torque tapered roller bearing, LFT-III[13], rolling resistance has been reduced through the optimization of internal geometry, including the number of rollers, roller length, roller diameter and contact angle and so on. Furthermore, as shown in **Fig. 13**[14], lubricating oil has been considered as another bearing component and its flow controlled to reduce agitating resistance. In addition, rolling fatigue life has been maintained by applying long-life technology based on special carburizing heat treatment, while the bearing has been made more compact, thus reducing both rolling and agitating resistance. LFT-III has 50% less friction torque than a standard bearing of identical size, and 80% less friction torque when the effects of size reduction are incorporated, thereby surpassing the ball bearing. A 1.5% improvement in fuel efficiency can be expected if the LFT-III is used on a rear axle differential.

For ball bearings, the design concept of LFT-III was applied to achieve optimization of internal geometry, including ball configuration (number of balls, ball diameter, pitch circle diameter of balls), raceway curve radius and raceway surface roughness, and a resin cage has been adopted to control the lubricating oil flow, as shown in **Table 1**, thus ultimately reducing friction torque by 40% compared to the conventional ball bearing[15]. The profile of the developed cage was optimized to suppress the influx of oil into the bearing and make it easier for oil inside the bearing to be discharged. Moreover, a different pitch circle diameter was adopted on the double row angular contact ball bearing, which has the same contact angle direction, to produce the tandem-type angular contact ball bearing (Tandem AC)[16] with enhanced load capacity and rigidity. As **Fig. 14** shows, by using LFT-III and Tandem AC in combination, the differential can be expected to achieve even higher efficiency.

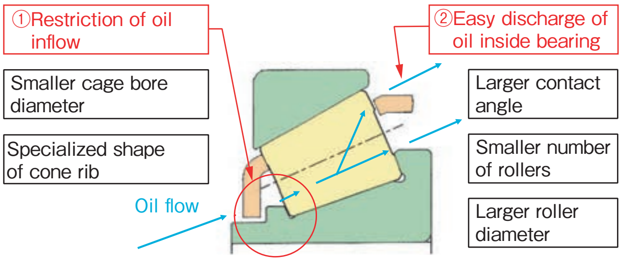
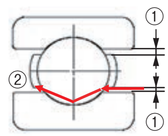
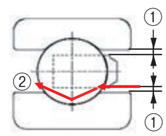
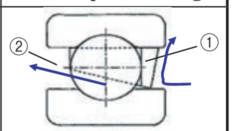


Fig. 13 Lubricating oil flow control for reducing agitating resistance

Table 1 Cage shape of low friction torque ball bearing

Current cage		Developed cage
Steel cage	Resin snap cage	Low-torque resin cage
		 Ideas for the cage guide surface, back face angle and I.D. form
①Oil influx easily increasing the amount of oil inside the bearing ②Small amount discharged from inside the bearing		①Suppress oil influx ②Encourage discharge of oil from inside bearing

← ← : Oil flow

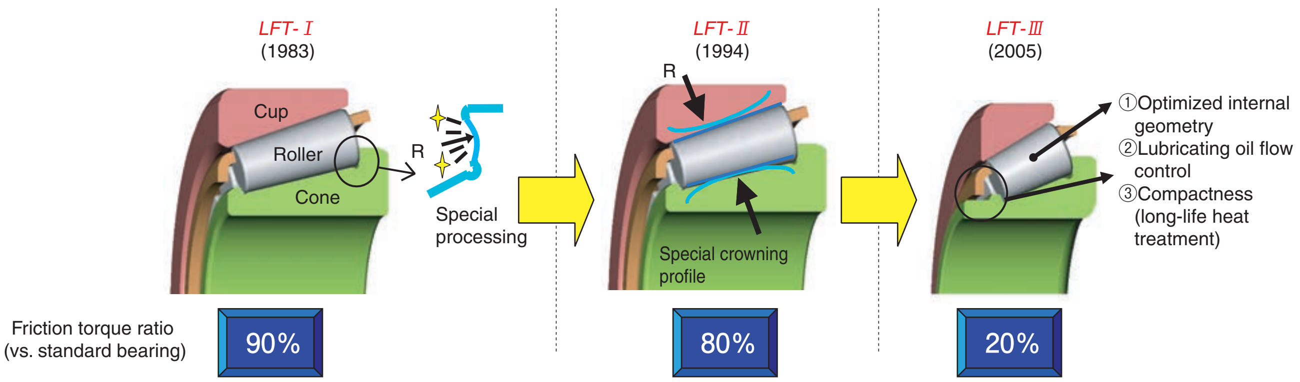


Fig. 12 Transition of LFT bearings

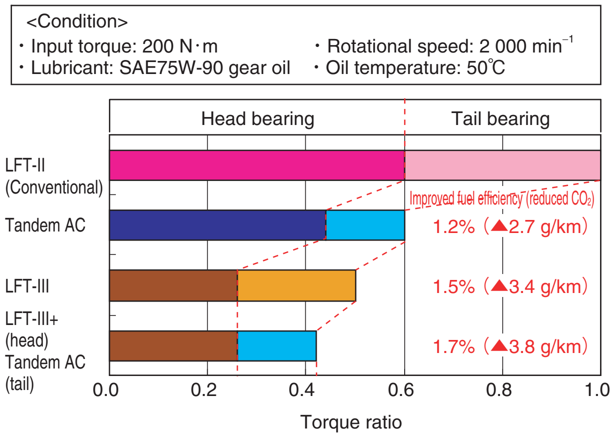


Fig. 14 Degree of environmental contribution with combination of drive pinion bearings

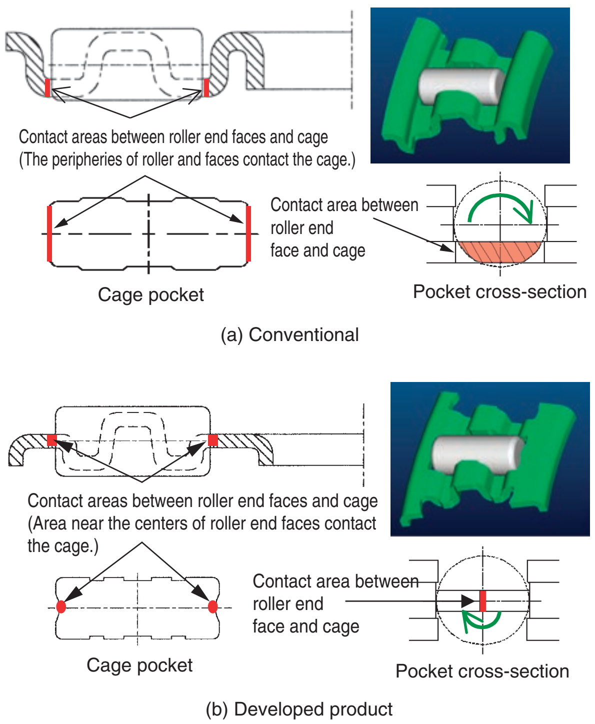


Fig. 15 Low friction torque thrust needle roller bearing

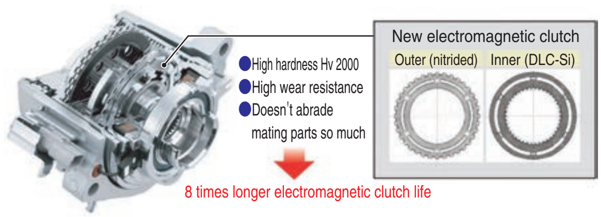


Fig. 16 Electronically controlled AWD coupling

A high number of thrust needle roller bearings are used particularly in regards to automatic transmissions, needs for friction torque reduction are particularly high. JTEKT has optimized cage design to reduce the sliding resistance between the rollers and the cage, achieving 50% less torque without compromising on life, high-speed performance and wear resistance (**Fig. 15**)[17].

Increasing load carrying capacity of the bearing by applying heat treatment technology allows the bearing to be made more compactness whilst maintaining the life, thereby contributing not only to weight reduction but also higher efficiency due to lower friction torque and a more compact drive unit. On the high-capacity tapered roller bearing (KE-II)[18], a higher load carrying capacity has been obtained by refining and evenly distributing carbides through carbide dispersion carburizing technique, improving the bearing life by 4 times in clean oil and 15 times in contaminated oil as compared with the conventional bearings.

6. 2 Driveline Unit

With attention focused on highly fuel efficient, environmentally-friendly vehicles, there is a demand for driving stability, safety and enhanced fuel efficiency on the powerful and popular AWD. In order to satisfy such demands, JTEKT was quick to develop the Intelligent Torque Controlled Coupling (ITCC®) as an electronically-controlled AWD coupling. The ITCC suppresses power loss when travelling in 2WD mode under normal conditions, while providing the optimal torque distribution necessary as an AWD when starting the vehicle in snow, or other slippery road surfaces. This means that both torque transmission frequency and power loss are reduced, thus enabling driveline units such as the propeller shaft and rear differential to be made lighter and more compactness, as well as improving fuel efficiency.

Two issues which arose from the outset of ITCC development were the wear resistance and durability of the electromagnetic clutch inside the coupling. As such, JTEKT developed a high-performance electromagnetic clutch with a coating made from Silicon Containing Diamond-Like Carbon (DLC-Si) (**Fig. 16**)[19]. This DLC-Si coating had the effect of significantly improving durability by 8 times and enabling the coupling to be made smaller and lighter. JTEKT then developed the 3rd generation coupling (Gen3)[20] on which increases in drag torque and transmission torque at low temperature had been reduced by modifying the surface texture of the electromagnetic clutch, hence allowing the driveline to be made even smaller and lighter (**Fig. 17**). Driveline units such as the compact, lightweight constant velocity joint (CVJ) and planetary gear-type torque sensitive LSD (Torsen® Type C) also contributed to size and weight reduction.

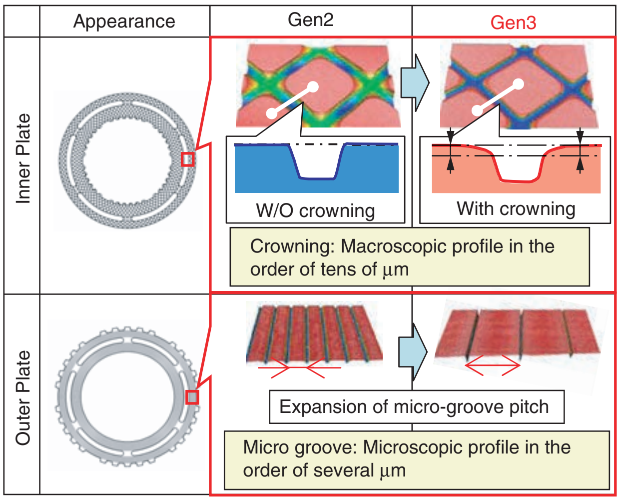


Fig. 17 Comparison of surface profiles in magnetic clutch

6. 3 Electric Oil Pump

The idle reduction system that stops the engine when the car is stationary at traffic lights, etc. is one form of technology to reduce fuel consumption, however the instantaneous engagement of the transmission clutch is necessary to ensure a smooth takeoff when the engine restarts. For this purpose, an electrical oil pump (EOP) to supply hydraulic pressure to the transmission when the engine is stopped is necessary. The electric oil pump for idle reduction system developed by JTEKT (**Fig. 18**)[21, 22] adopts a compact brushless motor and reduces the length of the bearing inside the motor rotor to achieve 30% size reduction compared with the conventional pump. Motor power consumption has also been reduced by up to 47%. This product will facilitate the popularization and expansion of vehicles with the idle reduction system and contribute to 4% improvement in fuel efficiency.

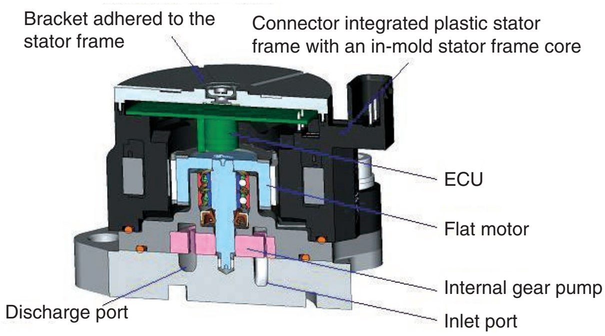


Fig. 18 Structure of electric oil pump for idle reduction system

7. Conclusion

Applying tribological technology to vehicle components does not only increases the efficiency of components due to reduced friction of sliding surfaces, but also contributes to reducing the size and weight of components and units through enhanced durability, anti-seizure performance and wear resistance, thus significantly contributing to energy saving. If the reductions in fuel consumption achieved by the JTEKT Ecology Package shown in **Fig. 2** are simply summed up, an overall improvement of 10.7% is obtained, which is equivalent to reducing CO_2 emissions by 25.4 g/km. A tentative calculation based on the number of vehicles produced in the world's major countries shows that CO_2 emissions would be reduced by 11 million tons per year. Electric vehicles and fuel cell vehicles are already being introduced as a measure to reduce CO_2 emissions, and it can be predicted that by the year 2020, technologies to improve the fuel efficiency of conventional, fuel-driven vehicles will be of extreme importance. JTEKT wishes to continue developing technology able to contribute to energy saving, hence alleviate the environmental burdens.

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