Technological Trends and Outlook of Automotive Bearings

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Global awareness of environmental improvement has been growing in recent years, and therefore it is necessary to continue responding to environmental issues on an industry-wide scale. To achieve this, it is important to understand the evolution and transformation of motor vehicles precisely, as well as assess bearing technological trends that respond to this evolution and transformation, and advance the development of fundamental technology.

This paper presents the trends of automotive bearings and introduces the evolution of technologies for powertrain bearings, drivetrain bearings and chassis bearings which respond to these trends.

***Key Words**: automotive bearing, trends, bearing technology, tribology*

1. Introduction

Due to increasing global awareness about environmental conservation in recent years, further efforts for environmental response are necessary in the future in all industries. In particular, extremely stringent environmental regulations are placed upon the automotive industry, and requirements for low friction torque in bearings used within automobiles are rising as this greatly contributes to CO_2 reduction by improving efficiency within automobiles. Furthermore, power units (HV, EV, FCV, diesel, and engine downsizing + turbocharger) have been diversified by automakers, so that it is essential to develop bearings and bearing unit products that support the function and performance of those power units (**Fig. 1**)

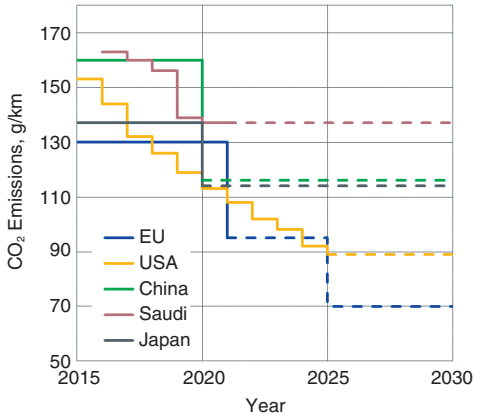


Fig. 1 Transition of CO_2 restrictions for cars

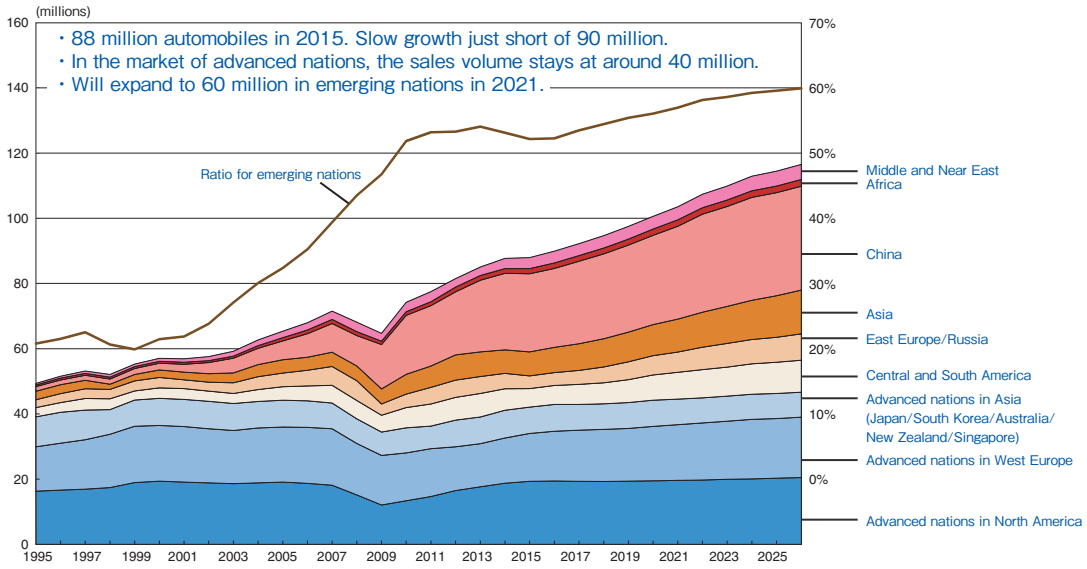


Fig. 2 Global trend in automobile market[1)]

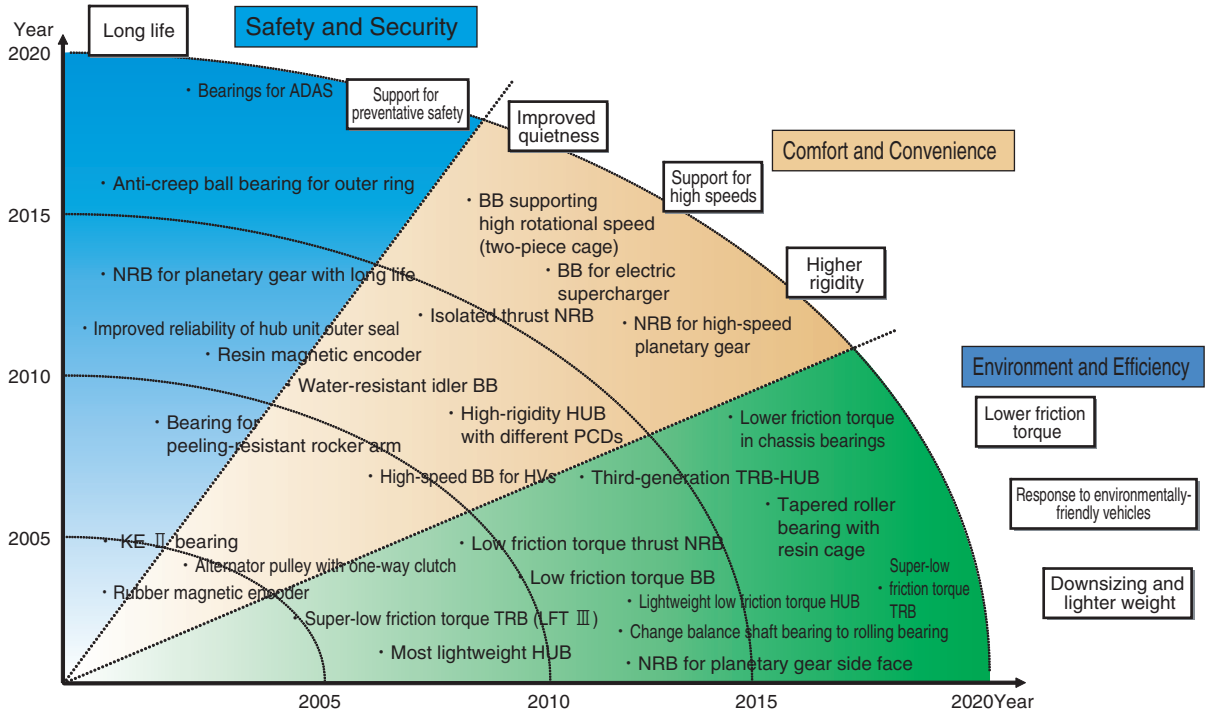


Fig. 3 Technical trends of automotive bearings

On the other hand, automobile sales will increase in the global automobile market due to market expansion following the spread of automobiles in emerging nations. Automobile sales are not forecasted to increase very much in advanced nations, however. Requirements for automobiles vary greatly depending on the market: In emerging nations requirements focus on reliability in harsh outside environments, and in advanced nations requirements center on low fuel consumption and light weight, as well as the expansion of electronization, integrated controls, and the Advanced Driving Assist System (ADAS). The polarization of these markets is expected to continue (**Fig. 2**).

This paper will introduce the trends of development of automotive bearings in the aforementioned environment, as well as JTEKT bearing products and evaluation technologies which satisfy required functions and performances, by their respective applications.

2. Trends of automotive bearings and bearing units

Although the duties required of automobiles are largely divided into “Safety and Security”, “Comfort and Convenience”, and “Environment and Efficiency”, technical trends of automotive bearings differ according to their applications. This paper introduces the technical trends and responding technologies for powertrains, drivetrains and chassis applications starting in **Chapter 3** (**Fig. 3**). Furthermore, as for evaluation and verification methods during bearing development, technical innovations in simulation have progressed recently, allowing simulation to be utilized for more detailed and diverse verification. In particular, the flow of lubricant, which is difficult to measure, has been visualized through fluid simulation, and effects caused by the differences in shape, fluid properties, and boundary conditions have been quantified, which have contributed to lower friction torque and longer life of bearings. In the next-generation super-low friction torque tapered roller bearing (LFT-IV), the optimal shape has been determined through the application of fluid simulation technology, reducing development time and enhancing reliability (**Fig. 4**).

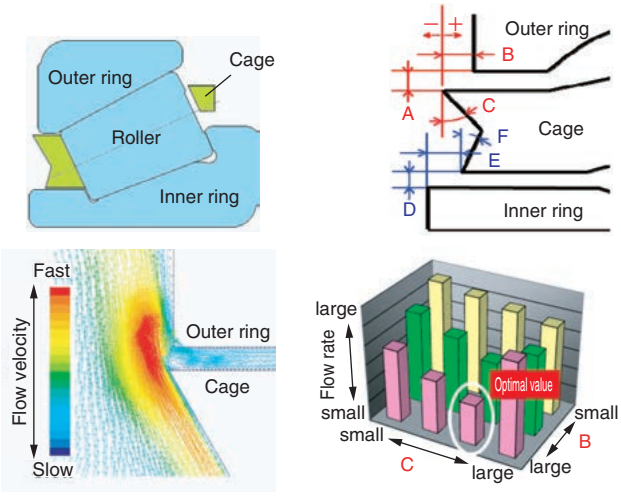


Fig. 4 Shape optimization using fluid simulation

3. Powertrain bearings

To respond to fuel economy and emissions regulations, initiatives are being taken by automakers towards the downsizing and high efficiency of engines, and the expansion of HVs. With this comes the necessity of responding to further low friction torque and high speeds for powertrain bearings.

The downsizing of the gasoline engine, which began in Europe, has been progressing recently within Japan as well, and downsized engines are already being mass-produced. For downsizing, supercharger technology utilizing a turbocharger is necessary in order to compensate for insufficient output. Turbochargers have been used for diesel engines since the past; however it is necessary to improve turbocharger efficiency as a measure for fuel economy and emissions regulations. The adoption of rolling bearings to support the turbine shaft is therefore expanding to facilitate this improvement.

In the past, sliding bearings were used for turbochargers; however the large amount of frictional resistance during acceleration caused a time lag (turbo lag) until the boost pressure rose, creating an uncomfortable response felt by the driver and worsening fuel economy. Changing from sliding bearings to ball bearings, which have smaller frictional resistance, drastically reduced turbo lag and improved fuel economy. Bearings for turbochargers are used under extremely harsh conditions, such as ultra-high speeds (max. 200 000 min^{-1}) and high temperatures (max. 350℃). JTEKT is the first bearing manufacturer that put ball bearings with ceramic balls into practical use for turbochargers after providing optimal internal design and improving the heat resistance of bearing ring and cage materials. JTEKT is currently developing a ball bearing unit which unitizes the bearing, housing and spacer, improving installability and stabilizing bearing performance (**Fig. 5**). In addition, with the recent ongoing development of motor-driven superchargers in order to improve turbocharger efficiency, JTEKT is promoting the development of bearings able to endure sudden acceleration into high rotational speeds.

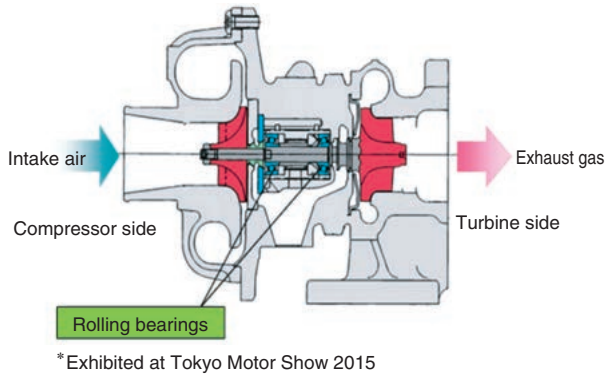


Fig. 5 Example of turbocharger structure with rolling bearing

Another initiative for achieving high engine efficiency is a variable valve system. There are two types of variable valve system: variable valve timing type and variable valve lift type. Both systems have become electronized. Ball bearings are used for the spindle of the electric actuator as well as the reduction gear, which require low friction torque, fretting resistance, and high rigidity. To respond to these requirements, JTEKT has developed and is currently mass-producing specially heat-treated bearings whose internal design features low friction torque and high rigidity, and which use long-life materials that improve cleanliness and grease with excellent fretting resistance, among other features (**Fig. 6**).

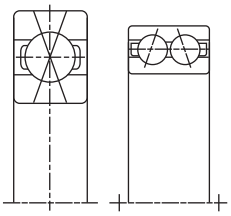


Fig. 6 Example of bearings for variable valve controlled by ectric motor

The ISG (Integrated Starter Generator) for startup, electricity generation, and power assist is currently mass-produced as a means for achieving high efficiency through auxiliary equipment. Ball bearings are used to support the spindle of this generator. The required bearing performance for this application includes the high-temperature and high-speed durability and vibration and spalling resistance required of bearings for alternators, as well as water resistance, low friction torque, frequent startup for the start-stop function, and long-term durability. It is necessary to consider all of these factors in the design of this bearing. JTEKT contributes to better ISG performance through the development of an original high-performance grease, low friction torque seal with high sealing capability, and low friction torque cage (**Fig. 7**).

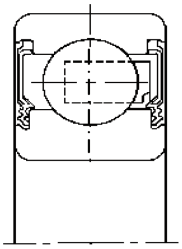


Fig. 7 Bearing for ISG

Motor speed is being increased to achieve HVs with low fuel consumption, low cost, high output, and compact drive unit. With this comes increasing requirements for higher speeds for bearings as well, and thus JTEKT has developed a bearing that endures high rotational speeds (**Fig. 8**) with a $d_m n$ value[*1] of over two million when used with oil lubrication. This bearing employs a newly-developed high-rigidity resin cage. The conventional single-support shape of this cage has been changed to a dual-support shape to increase rigidity. This new cage has been designed to prevent interference between the cage and balls from occurring due to cage deformation caused by centrifugal force during high-speed rotation. In addition, the cage is assembled from two identically-shaped parts, in consideration of productivity.

*1 $d_m n$ value: bearing P.C.D. (mm) × rotational speed (min^{-1})

Fig. 8 High rotational speed ball bearing

As a means of reducing fuel consumption to combat the environmental problems that have come forth in recent years, there are rising demands for change from sliding bearings to rolling bearings. Automobile engines in particular employ a relatively high number of sliding bearings, an example of which is on the balance shaft. Due to the application of sliding bearings, it is necessary to supply lubrication oil to the bearing part by generating high oil pressure in the oil pump. However, this pressure will not rise to a high level in the low-speed rotation zone. This prevents sufficient lubrication oil supply, creating the problem of large sliding frictional resistance. JTEKT therefore proposes initiatives to reduce sliding frictional resistance. **Figure 9** shows a measurement example of running torque.

Changing from sliding bearings to rolling bearings eliminates the need for high oil pressure, and thus, reduces the oil pump volume, which enables the pump to be downsized. Furthermore, the start-stop function is easier to employ with rolling bearings as these allow startup with low friction torque. This allows the engine to stop, which contributes to a dramatic reduction in fuel consumption.

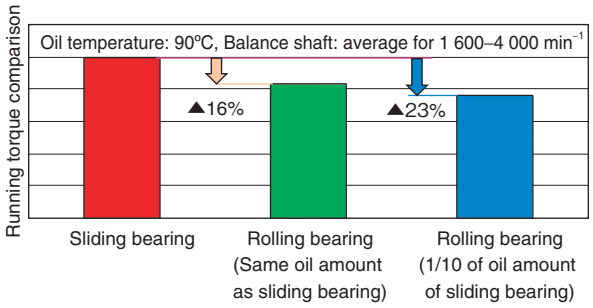


Fig. 9 Example of torque reduction

4. Drivetrain bearings

In the trend of electronization nowadays, it is the transmission mechanism in the drivetrain which is most affected. There are numerous transmission mechanisms used, ranging from the conventional manual transmission (MT) and automatic transmission (AT) to transmissions for HVs and FCVs, all of which are currently being improved. There are also many performance requirements for the bearings which are utilized within transmissions; however, the primary requirement is smooth support for the gear shaft which transfers rotation and torque from the engine and motor. The reduction of running torque remains the issue with the topmost priority for drivetrain bearings.

Tapered roller bearings (TRB), which are a main product of JTEKT, are used in great numbers for transmission mechanisms. This is because TRBs have a high load carrying capacity against both radial and axial loads which occur at gear meshing, and allow a combination of high rigidity and space-saving. On the other hand, TRBs have relatively high torque loss, and therefore JTEKT has worked for long time towards the reduction of friction torque in order to overcome this disadvantage, and commercialized this technology as the Ⅰ, Ⅱ and Ⅲ of the LFT (Low Friction Torque) series.

The "super-low friction torque TRB (LFT-Ⅲ)" was developed with a focus on reducing lubrication oil churning loss, and dramatically reduces bearing losses by suppressing the amount of lubrication oil that flows into the bearing, thereby contributing to better fuel economy of the automobile. JTEKT pursued the reduction of churning loss thoroughly and developed the "next-generation super-low friction torque TRB (LFT-IV)" (**Fig. 10**) by evolving this technology in order to respond to CO_2 regulations which will continue to increase in stringency. This bearing employs a resign cage with a high level of design freedom, achieving a maximum of over 50 percent reduction in losses compared with the JTEKT "standard low friction torque TRB" of the same size, by optimizing the cage shape using oil flow analysis via CAE.

*Presented at Tokyo Motor Show 2015

Fig. 10 Next-generation super-low friction torque tapered roller bearing (LFT-IV)

Additionally, JTEKT has developed the tandem angular contact ball bearing (**Fig. 11**) and high axial load-compatible ball bearing (**Fig. 12**) as a means of achieving low friction torque by changing from roller bearings to ball bearings. The tandem angular contact ball bearing has the structure of a double-row ball bearing with different pitch circle diameters and the same direction of contact angle, and in particular can operate with smaller running torque in low load ranges. This bearing has both high load capacity and rigidity, and is used mainly to support differential drive pinion shafts. Combining this bearing with the aforementioned low friction torque tapered roller bearing enables the achievement of a shaft support mechanism suited for the characteristics of the differential. The high axial load-compatible ball bearing has improved axial load capacity obtained by raising the height of diagonally opposite inner and outer ring shoulders of a deep groove ball bearing, and can be used in parts of the transmission that receive high axial loads.

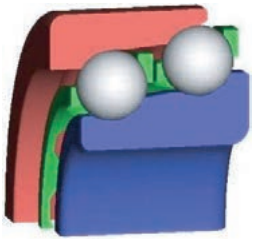
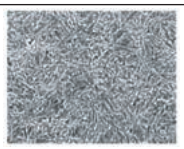
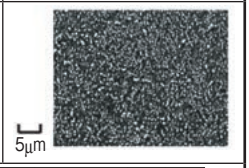
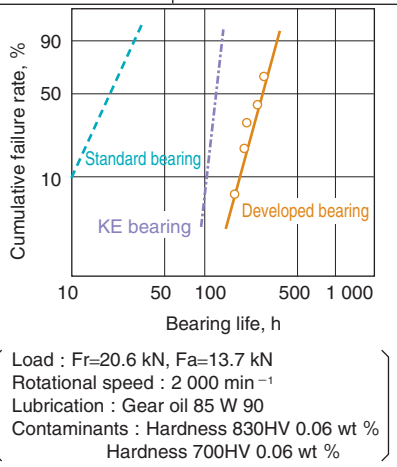


Fig. 11 Tandem angular contact ball bearing

Fig. 12 High axial load-compatible ball bearing

Another large technical issue in bearings for drivetrains is the improvement of contamination resistance. These bearings are used with oil lubrication that contains hard contaminants such as powder created from material wear during gear meshing of the transmission. A bearing failure mode under this environmental condition is a surface spalling originated from a ridge at the edge of an indentation caused by the entry of foreign matter or surface layer spalling accompanied by wear, which shortens the bearing life to one half to one tenth of that of a standard bearing with clean lubrication oil. In response to these issues, JTEKT has developed a new material and heat treatment technology to achieve the development of long-life tapered roller bearings (KE, KE-Ⅱ) (**Table 1**). These bearings have high contaminant resistance, which enables downsizing of bearings used with contaminated lubrication oil.

Table 1 Comparison of standard and long life (KE-Ⅱ) bearings

		Standard bearing	Long-life (KE-Ⅱ) bearing
Material		SAE5120	KCr620: Optimization of silicon/manganese/chromium
Heat treatment		Carburized quenching/tempering	Super carburized quenching/tempering
Structure	Fine carbide	None	Average 0.2 μm, approx. 10% in area ratio
	Outer appearance		
Life in contaminated oil		 Load : Fr=20.6 kN, Fa=13.7 kN Rotational speed : 2 000 min⁻¹ Lubrication : Gear oil 85 W 90 Contaminants : Hardness 830HV 0.06 wt % Hardness 700HV 0.06 wt %	

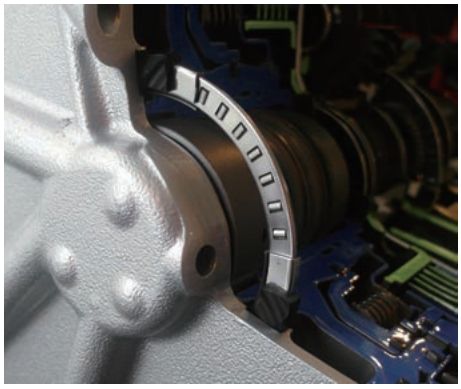


Fig. 13 Thrust needle roller bearing isolator for automatic transmission (AT)

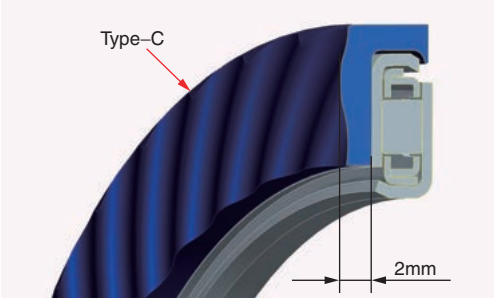


Fig. 14 Isolated needle roller bearing

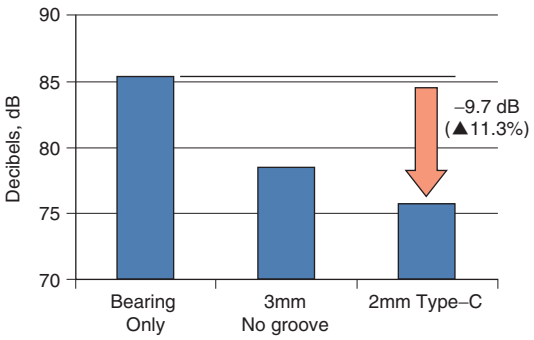


Fig. 15 NV-related benefits

Amidst rising automobile requirements for passenger comfort in recent years, the automobile, which is a complex assembly of many parts, contains numerous sources of noise and vibration (NV) which hinder comfort. Rolling bearings used in drivetrains are one of the parts which impacts NV, as well as thrust needle roller bearings (**Fig. 13**) used in ATs.

JTEKT worked to develop the isolated thrust needle roller bearing with a focus on the transfer of vibration within the AT, with the goal of improving NV characteristics by reducing vibration transfer within the bearing alone. This bearing utilizes a high-polymeric material with excellent damping characteristics between the bearing and the housing, and is able to contribute to passenger comfort in automobiles by enabling the improvement of NV characteristics (**Fig. 15**) through the installation of an isolator with a thickness and a groove shape designed to have a large damping effect on vibration transfer (**Fig. 14**).

5. Chassis bearings

As shown in **Fig. 16**, wheel bearings have evolved from the first generation with an integrated outer ring which can withstand radial load and bidirectional axial load by combining two angular contact ball bearings to the third-generation hub unit which incorporates a mounting flange and other peripheral components. The third-generation hub unit in particular is a bearing unit that can contribute to omitting the time and effort taken by troublesome preload and gap adjustment within the assembly lines of automakers through shaft clinching and a built-in ABS sensor.

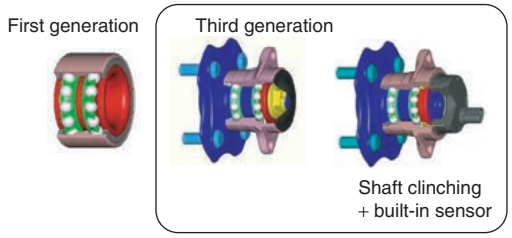


Fig. 16 Evolution of wheel bearing

It is known that the reduction of automobile weight is effective in improving fuel economy, and thus there are still heavy demands to downsize and reduce the weight of the hub unit as well. Reduced weight and strength/rigidity are contravening design elements for the hub unit. A simply lightweight design may lower strength and rigidity. The third-generation hub unit has an integrated mounting flange for the knuckle and that for the brake rotor and wheel. Using a model that includes the knuckle and the brake rotor, coupling analysis is conducted by high-accuracy CAE to promote the optimal design from all aspects of strength, rigidity, and weight reduction.

As with weight reduction, reduction of rolling loss in tires is also an essential technology for fuel economy improvement in automobiles, and it is also necessary to reduce running torque in wheel bearings, which is one of the factors of rolling loss in tires. The running torque of the hub unit is divided into seal torque for maintaining bearing function against mud and muddy water on the suspension of the car, and torque from the bearing part. For the seal part, JTEKT has developed a double-axial seal (**Fig. 17**) with reduced lip friction torque by examining the optimal seal shape through analysis of super-flexibility that imitates the characteristics of rubber materials. Furthermore, to reduce running torque

maintaining reliability in the harsh environments (such as muddy roads and cold regions) of Asia and Russia, where automobile demands are increasing significantly, we JTEKT utilized our Iga Proving Ground to analyze the water exposure state of the hub unit when muddy water splashes up from the tires, and developed a deflector structure based on these results. By conducting improvements for the water exposure environment surrounding the seal, JTEKT has achieved simplification of the seal lip (**Fig. 18**) as well as a reduction in seal torque.

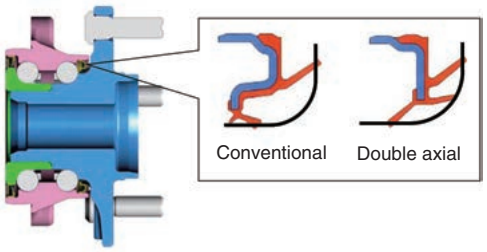


Fig. 17 Structure of seal for hub unit

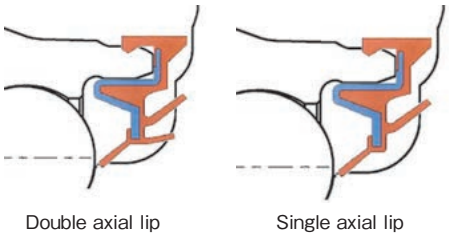


Fig. 18 Structure of deflector

For torque loss in the bearing part, JTEKT focused on lubrication as well as optimization of preload of the bearing part, and developed a hub unit with extremely low friction torque performance utilizing a synthetic oil with low viscosity as the grease base oil.

Hub units introduced so far are mainly ball bearing types for passenger vehicles. However, a TRB type hub unit, which evolved from wheel support utilizing two conventional TRBs is also employed for the wheels of pickup trucks.

SUVs and pickup trucks are often driven on unpaved roads, and are used in harsher environments compared with passenger vehicles, and thus are required to have extremely long life and high durability, as well as sealing ability. In addition, like passenger vehicles, there are strong demands for weight reduction and lower friction torque to improve fuel economy. To respond to such needs, we JTEKT also produce the third-generation TRB hub unit (**Fig. 19**) that employs raceway crowning and LFT technology able to reduce torque loss at the inner ring rib, both of which have been fostered in our tapered roller bearings, as well as a long-life seal with high

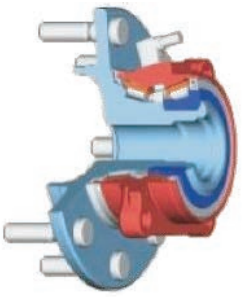


Fig. 19 Third-generation TRB hub unit

sealing capability and weight reduction technology.

Furthermore, automatic operation has developed remarkably as a next-generation technology, transitioning from Levels 1 and 2 where the driver monitors the driving environment to automated monitoring of the driving environment in Levels 3 and 4. Within this field as well, JTEKT has developed a sensing system that monitors road surface conditions utilizing the characteristic of the hub unit that it has a stationary outer ring and is located closest to the tire, and is steadily progressing with the development of new technologies which respond to technical development trends in automobiles, such as in the development of in-wheel motors that allow rotational speed control of each of four tires independently.

6. Conclusion

JTEKT has been promoting technological development to enable both automobile convenience and global environmental conservation for the future. It is believed that vehicles with ordinary gasoline and diesel engines will continue to account for the majority of those within emerging nations, and it is vital to reduce CO_2 emitted from these automobiles. Therefore, JTEKT will further deepen and pursue tribology technology. On the other hand, in advanced nations, technologies responding to the transition to steer-by-wire due to the spread of HVs, EVs and similar automobiles will be introduced into the market. In addition, with the forecast of rapid sophistication of automobile functions through ADAS and related technology, we JTEKT will aim to develop No. 1 & Only One technologies combined with our bearing technology, steering technology and driveline-related technology. Through the development of bearing products, we JTEKT will continue to contribute to the creation of, even a part of it, a future vision of an automobile society where all users can safely travel to their destinations and where more comfortable driving can be achieved through the latest technologies.

*1 LFT is a registered trademark of JTEKT Corporation.

References

1) Y. Tanaka: New Trend of Global Automotive Market and Technologies, FOURIN, Inc. No. 2 (2016) 3. (in Japanese)
2) M. Kawamura: Latest Technological Trend of Automotive Bearings, Kikai Sekkei, Vol. 60 No. 1 (2016) (in Japanese)
3) K. Kouda: CO_2 Reduction Technology through Downsizing and Torque Reduction of Tapered Roller Bearings for Automotive Drive Line, THE TRIBOLOGY, No. 338 (2015) (in Japanese)
4) Y. Sankai, K.Yoshizaki, T. Ogimoto: Achieving Low Torque by Applying Low Viscosity Synthetic Grease to Hub-unit Bearing, International Tribology Conference, Tokyo 2015
5) M. Murakami, Y. Takahashi, D. Okamoto: JTEKT ENGINEERING JOURNAL, No. 1011 (2013) 39
6) J. BRUBAKER: JTEKT ENGINEERING JOURNAL, No. 1011 (2013) 45
7) T. Wakisaka, H. Shibata, S. Nakajima, Y. Takada: JTEKT ENGINEERING JOURNAL, No. 1011 (2013) 49

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