Bearing Technology Trends and Prospects with the Electrification of Automobiles

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The increasing trend toward the electrification of automobiles is due to heightened environmental awareness which has resulted in efforts to create a sustainable global society.

In automotive bearings, technological developments have been carried out to reduce friction loss, size, and weight. Also, development is underway to address future needs due to the changes in vehicles brought about by electrification.

***Key Words**: BEV (Battery Electric Vehicle), HEV (Hybrid Electric Vehicle), PHEV (Plug-in Hybrid Electric Vehicle), FCEV (Fuel Cell Electric Vehicle)*

1. Introduction

Responding to worldwide environmental regulations is an urgent issue and it is believed that electric vehicles classified into BEV, HEV, PHEV or FCEV will continue to increase in number in the future due to regulations to push zero-emission vehicle shift in several countries and New Energy Vehicle mandate of China with accompanying sales promotion measures for those.

This electrification brings structural changes to automobiles and is a keyword that has the greatest impact on JTEKT's line of bearing products. For example, for bearings for electric vehicle powertrains, improvement of performance such as lower torque and size/weight reduction are required like for conventional bearings. In addition, however, those bearings are also required to endure significantly higher rotational speeds than bearings used on vehicles with conventional engines, as well as to have technology for improving reliability in order to respond to any new issues that may arise due to the change of driving patterns (**Fig. 1**).

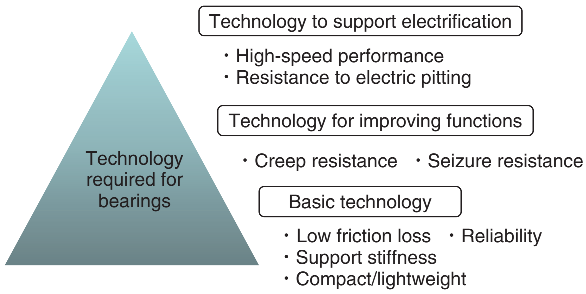


Fig. 1 Required bearing performance

This paper specifically introduces the technologies required for this electrification by looking at bearings for three different applications: 1) powertrain bearings, 2) drivetrain bearings, and 3) chassis bearings. As a product related to bearings, this paper will also introduce oil seals for high-speed rotation and touch upon the technologies that support the development of these products. Finally, this paper will present an outlook for the future of bearing development.

2. Bearing Technology for Supporting Electrification

2. 1 Powertrain Bearings

<Bearings for high-speed rotation>

Being able to accommodate high-speed rotation is the most important requirement for bearings caused by the change of vehicle power sources. For speed settings, it is not uncommon that the maximum rotational speed ratio between the motor and the engine, which is a conventional power source, exceeds three. Motors, which are relatively more capable of rotating at higher speeds than engines, are able to keep torque low and can be made smaller than engines with the same output.

It is getting common that motor bearings require $d_m n$ values approximately 1.5 times larger than that for bearings for engine accessories (alternators), which conventionally rotate at relatively high speeds, and there is a possibility that they will be increased in the future. (A $d_m n$ value is a bearing high-speed performance index calculated by multiplying the rolling element pitch diameter (d_m) and the bearing rotational speed (n).)

There are two types of motors: wet type motors in which oil circulates inside, and dry type motors which have no oil inside.

One problem with operating wet type motors at high rotational speeds is that they suffer cage deformation due to centrifugal force. In the case of standard resin cages, deformation of cage pockets occurs due to centrifugal force when the speed limit is exceeded. It causes interference between the cage pockets and rolling elements, and then, abnormal heat generation due to increased rotational resistance, which results in bearing seizure.

This makes the suppression of cage deformation an issue, which we have attempted to solve by developing a two-piece cage capable of minimizing such deformation[1]. By combining two resin parts of the same shape to create a structure that suppresses deformation, we were able to ensure a performance of 2 million $d_m n$ or more, which greatly exceeds the limit (1.5 million $d_m n$) required by the current electric vehicle market (**Figs. 2-1** and **2-2**).

Fig. 2-1 Two-piece cage shape

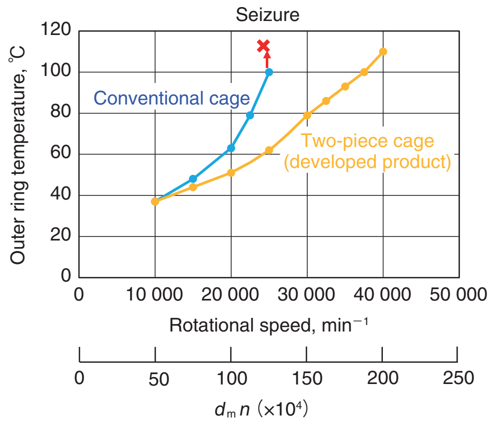


Fig. 2-2 Two-piece cage bearing performance under increased temperature

For dry type motors, sealed bearings pre-lubricated with grease are used. Although the above-mentioned two-piece cage eliminates concerns about cage deformation at high rotation speeds, its low ability to supply oil of grease to the rolling area and only limited space available for grease cause concerns about grease leakage and reduction of bearing life. To address this, we have newly developed a cage with a new shape focusing on the feasibility in sealed bearings pre-lubricated with grease (**Fig. 3-1**). By employing a single-support structure, we have improved the ability to supply oil of grease to the rolling area while increasing the volume of the free space for grease.

Moreover, we were able to reduce deformation by making the cage more lightweight in order to reduce centrifugal force, and succeeded in avoiding interference between the cage and rolling elements caused when deformation does occur by changing the cage guiding system from the rolling element guide to the raceway guide. By doing so, a high speed of 1.85 million $d_m n$ was achieved even with grease lubrication, which normally has lower high-speed and lubrication performances than oil lubrication (**Fig. 3-2**).

Fig. 3-1 Newly developed bearing shape (Cage with new shape)

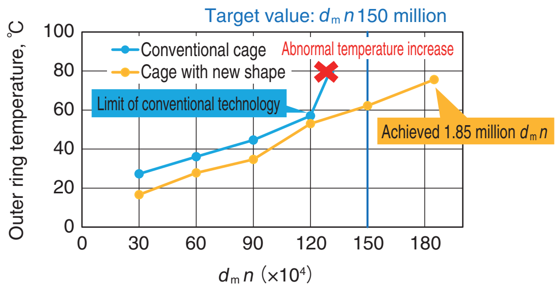


Fig. 3-2 Performance of newly developed bearing under increased temperature of outer ring

Furthermore, improving the performance of the packed grease itself is also an important factor in achieving high-speed rotation. By adopting a base oil with a high viscosity index and optimizing the thickener, we aimed to improve the supply of oil to the rolling area while suppressing bearing temperature rise under high-speed rotation conditions. By doing so, we succeeded in improving bearing life, torque at low temperatures, and acoustic performance.

<Electric pitting preventive bearings>

In the case of bearings used for motors, especially those used for motors driven by an inverter, a magnetic flux imbalance inside the motor may cause a potential difference between the inner and outer rings of the bearing. It is known that this potential difference causes sparking in contact areas between the rolling elements and raceways, which in turn causes corrugation-shaped damage to the raceways (**Fig. 4-1**).

Until now, we have created products such as bearings with resin-coated outer rings and bearings with ceramic balls in which sparking has been prevented by increasing insulation against such potential differences[2]. However, because resin coating and ceramic balls are expensive to use in automobiles and because their mass production also presents issues, we have developed a new low-cost insulated bearing with a special coating (**Fig. 4-2**).

On the other hand, electric pitting can be prevented by bypassing the electric potential between raceways using a separate circuit in parallel with the raceway in order to suppress the potential difference that occurs between the rolling elements and the raceways. We call these "conductive bearings" and their development is currently underway.

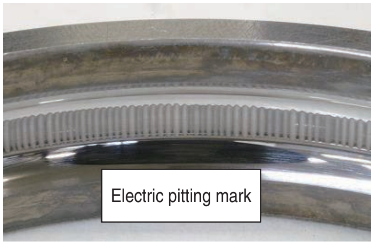


Fig. 4-1 Electric pitting

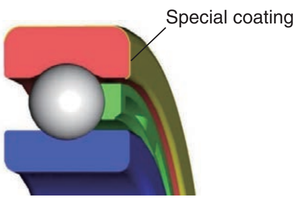


Fig. 4-2 Insulated bearing structure

<Hydrogen circulation pump bearing>

Some electric vehicles use hydrogen as an energy source and employ a hydrogen circulation pump as an auxiliary device for fuel cells for obtaining electric power directly from hydrogen.

Although concerns exist regarding corrosion to hydrogen circulation pump bearings caused by water made through chemical reaction, as well as regarding hydrogen embrittlement, we are addressing these concerns by developing heat treatments and using highly corrosion-resistant and hydrogen-resistant steel to develop bearings that provide the required level of performance (**Fig. 5**).

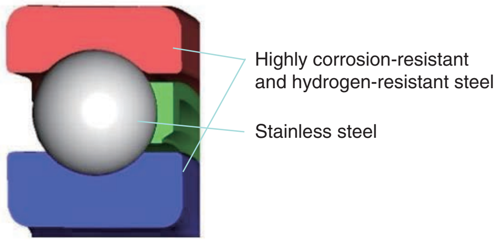


Fig. 5 Hydrogen circulation pump bearing

Moreover, in order to evaluate hydrogen resistance performance during the development stage, we have developed equipment on our own that enables bearings to be evaluated in a hydrogen atmosphere (described later in **Fig. 12**)[3].

2. 2 Drivetrain Bearings

In addition to the conventional basic requirements for drivetrain bearings, electrification has brought about the need to address bearing creep caused by increased opportunities for regenerative driving. Other necessary improvements include reductions in thickness and width to enable bearings to be made smaller and lighter, as well as improvements in seizure resistance to enable high-speed rotation.

<Creep-resistant bearing>

Bearing creep induces housing wear, shaft misalignment, and shaft inclination, which can lead to abnormal noise and early flaking. Two types of bearing creep exist (**Fig. 6-1**).

The first type is creep caused by strain, which occurs when the outer ring becomes slightly strained each time a ball passes through the area subjected to the rolling element load on the outer ring, and the repeated seizure and relative sliding between the outer ring and housing cause the outer ring to rotate relative to the housing. Conventionally, the thickness of the outer ring has been increased as a measure for improving rigidity, but this prevents bearings from being made smaller and lighter. To resolve this problem, JTEKT created a circumferential groove on the bearing outside surface after quantifying the above-mentioned mechanism using MBD (model-based development). As a result, creep caused by strain has been prevented by suppressing seizure and relative sliding at the fitting surface caused by outer ring strain without changing the outer ring thickness (**Fig. 6-2**)[4].

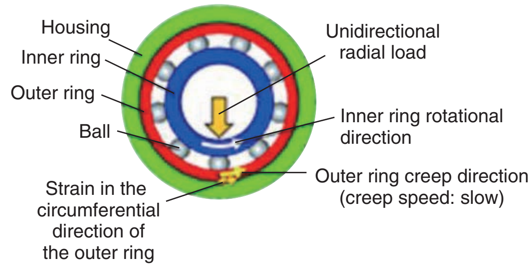
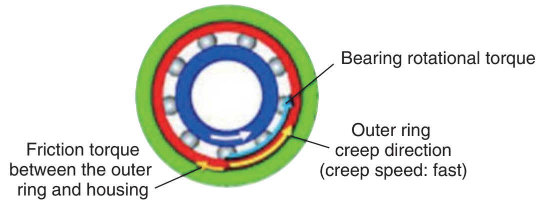
<table>
<tr><th>Creep type</th><th>Creep caused by strain</th><th>Creep caused by drag</th></tr>
<tr><td>Cause of creep occurrence</td><td>Outer ring circumferential strain caused by large unidirectional radial load</td><td>Bearing rotational torque (force to rotate the outer ring) > Friction torque between the outer ring and housing (force to stop the outer ring rotation)
Occurs when no load or light load</td></tr>
<tr><td>Schematic</td><td>
</td><td>
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Fig. 6-1 Bearing creep

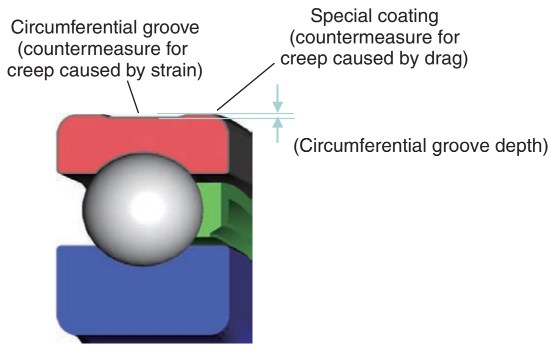

Fig. 6-2 Creep-resistant bearing

The second type is creep caused by drag, which occurs due to outer ring sliding that takes place when the bearing load is removed at the moment when power running and regenerative driving are switched. In this type of creep, the outer ring rotates (creeps) when the bearing load is removed. Then, the moment the load is restored, frictional sliding causes housing wear. Improving the lubricating ability of the fitting surface is an effective countermeasure for this. By applying a special oxide coating to the outer ring outside surface (fitting contact surface), oil is retained within the microscopic shape pattern of the coating, enabling creep wear to be reduced by ensuring the lubricating ability of the fitting surface.

<Slim bearings>

Restrictions on unit mounting space brought about by increase in gear width caused by increase in transmitted torque have created an increased need for slimmer bearings. Normally, bearing width dimensions are set in consideration of cage width dimensions in order to prevent the cage from protruding and interfering with surrounding parts. We have developed a bearing whose width has been reduced to almost the same size as the ball diameter by minimizing the cage width dimensions while ensuring the strength of the cage. Bearing performance is determined by the minimum thickness dimension of the cage and the strength of that portion, and we have succeeded in securing cage strength by optimizing both the cage mold and molding conditions (**Figs. 7-1** and **7-2**).

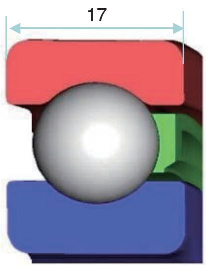

Fig. 7-1 Conventional bearing (Bearing no. 6207)

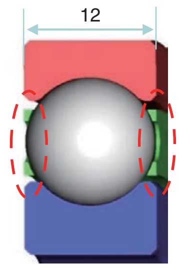

Fig. 7-2 Slim bearing

Fig. 7-3 Appearance comparison

<Tapered roller bearing with improved seizure resistance>

Although deep groove ball bearings are normally used for the first axes (motor shafts) of eAxles (electric axle units), tapered roller bearings are often used for the second axes to make them smaller and lighter.

Because the lubrication of bearings inside reduction gears is sometimes performed by oil splashing by the gears, not by using a pump, there are concerns that poor lubrication conditions may occur temporarily.

Lubrication conditions also tend to worsen because low-viscosity lubricants are used to reduce unit friction loss. Furthermore, the tapered roller bearings used for the second axis are required to have higher seizure resistance for high-speed rotation.

Seizure resistance is greatly affected by the amount of oil supplied to the area of contact between the inner ring rib and roller. To ensure a sufficient amount of this oil supply, and in turn, improve seizure resistance, we have devised a shape that enables a specially shaped resin cage to actively guide a small amount of oil flowing along the outer ring raceway from the large end face of the roller to the area of contact with the inner ring rib (**Fig. 8**).

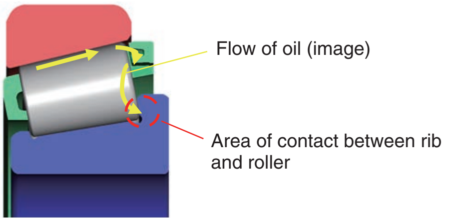

Fig. 8 Tapered roller bearing with improved seizure resistance

2. 3 Chassis Bearings

<Needle roller bearings for electric brakes>

Electric brakes are one type of unit that is increasingly being electrified. Electric brakes generate braking force by using motor power to press the brake pads against the rotor. A slide screw or ball screw is used as the mechanism for converting the rotary motion of the motor into linear motion, while a needle roller thrust bearing is used to support the generated axial force (**Fig. 9-1**)[5].

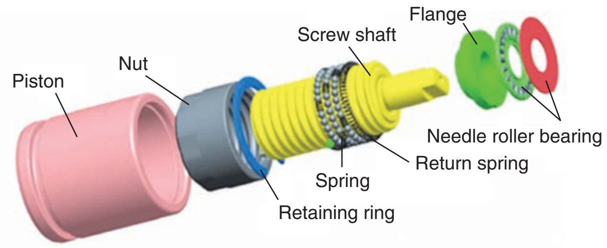

Fig. 9-1 Linear conversion section of electric brake

In order to make brake units smaller, the conversion efficiency from rotation to linear motion is emphasized, and an efficiency of 80% or more is required. For this reason, approximately 25% friction loss reduction is required of this needle roller bearing compared to a conventional one. Because the needle roller thrust bearings for these piston units tend to have a relatively small roller pitch circle diameter compared to the roller length, slip between the rollers and raceways increases when the bearing rotates, which tends to increase friction loss. To reduce such slip, rollers are split into two in order to decrease the roller length/pitch circle diameter ratio and thereby solve the above-mentioned issue (**Figs. 9-2** and **9-3**).

By using split needle rollers, we have reduced friction loss by more than 40% and are working towards further friction loss reductions.

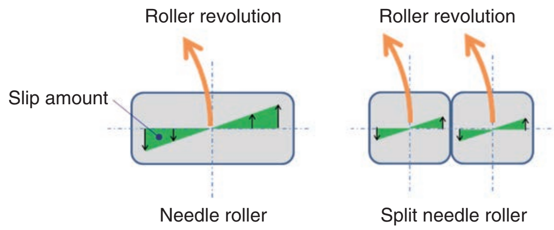

Fig. 9-2 Roller slip amount

Fig. 9-3 Needle roller thrust bearing (cage assembly)

2. 4 Bearing-related Products

<Oil seals for high-speed rotation>

As we have already mentioned above, electrification requires bearings to accommodate high-speed rotation. Then, oil seals installed between the dry type motor and the gearbox are also required to respond to high-speed rotation.

Oil seals generally have a circumferential speed limit of around 30 m/s. However, circumferential speed limits exceeding 50 m/s are beginning to be required of seals for motor shafts.

At high-speed rotation, the oil supply to the seal lip sliding portion decreases due to factors such as centrifugal force and the surrounding airflow, creating concerns regarding lip burning and wear. The key to avoiding these is supplying oil to the tip of the lip. For this reason, we designed a surface shape for the seal lip side face that actively utilizes the airflow around the seal lip to ensure oil is supplied to the seal lip. Doing so has enabled us to maintain seal functions at high-speed rotation (**Fig. 10**).

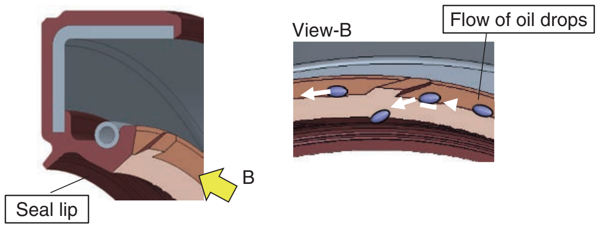

Fig. 10 High-speed oil seal

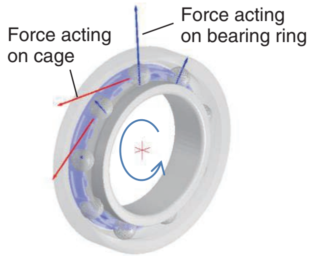

Fig. 11-1 Example of dynamic analysis of bearing

Fig. 11-2 Example of lubricant flow analysis

2. 5 Analysis and Evaluation Technology

JTEKT is working on improvement of analysis and evaluation technology in order to shorten development periods and to improve the performance of products in development and developed products.

For example, when bearings are used at high rotational speeds, large centrifugal force and inertial force act on each part, resulting in much harsher operating conditions than during rotation at normal speeds. This means that understanding and predicting the operating conditions of each part are essential for product development. However, because it is sometimes difficult to predict such operating conditions using conventional analysis tools, it became urgent for us to acquire analysis tools capable of adapting to new conditions.

In developing technology to support high-speed rotation, it is important to utilize technologies such as bearing dynamic analysis capable of predicting the dynamic force acting on each part, lubricant flow analysis capable of predicting the flow of lubricant by considering the effects of the surrounding airflow, and bearing thermal analysis. JTEKT has developed these types of analysis based on experimental results and is utilizing them to analyze the behavior of cages in the above-mentioned bearings for high-speed rotation, as well as lubricant distribution inside of bearings (**Figs. 11-1** and **11-2**)[6].

We have also developed a high-speed testing machine capable of rapid acceleration/deceleration for use in experimental evaluations. Furthermore, we are now able to conduct more reliable development of bearings for FCEV-related equipment since we are now capable of conducting evaluations under new conditions such as those by using hydrogen environment testing equipment (**Fig. 12**).

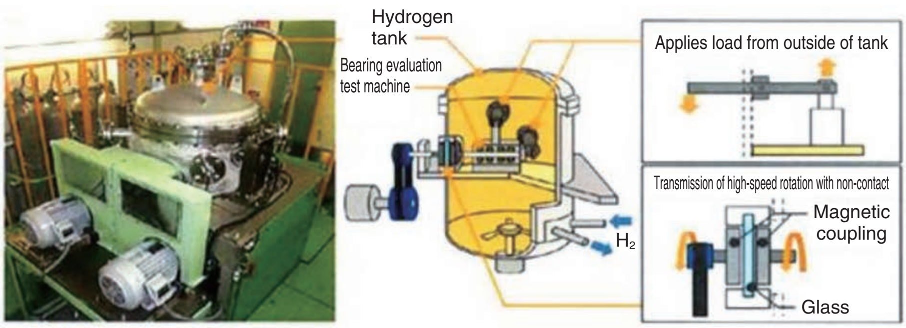

Fig. 12 Hydrogen atmosphere testing (case study)

3. Outlook for the Future

The development trends of various bearings for electrification have been mentioned in the above sections. It is expected that electrification will bring about a significant reduction in the number of bearings used on vehicles due to the elimination of engine accessories and the shift from multi-speed transmissions to fixed-speed reduction gears.

Under such circumstances, JTEKT feels it is necessary to prioritize quality over quantity while providing enhanced levels of added value. In particular, we consider it essential to promote factors that directly affect environmental friendliness, which is the reason for initiating electrification in the first place, such as lower friction loss, smaller and lighter products, and the development of recyclable materials. We have hitherto accumulated technologies for supporting electrification based on basic technology and technology for improving functions. We will contribute to society not only by promoting size/weight reduction by integrating bearings with surrounding parts but also from a perspective of the product life cycle, by responding to a wide range of environmental needs in the stages of materials, production, (use), and disposal (**Fig. 13**) as well as those during bearing operation (during use).

Furthermore, by utilizing the automobile electrification technology we have cultivated thus far, we are actively seeking to expand beyond land mobility represented by automobiles, and into the aerospace field represented by air mobility (flying cars/drones).

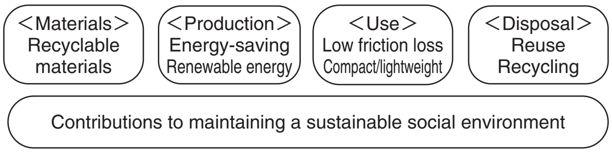

Fig. 13 Future bearing development keywords

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