# Trends and Future Views on Rolling Bearing Technology

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*In line with recent trends toward diversified technical development, JTEKT has promoted the development of bearings not only by further developing its fundamental technology in areas such as material, heat treatment and tribology, but also by developing units and modules through combining bearing technology with technology in such other areas as sensing or control. Concerning automotive bearings, new devices and functions for integrated vehicle control and technology for more efficient engine systems and drivetrain systems have been developed. Concerning industrial bearings, compact bearings for windmill power generators, high-speed bearings for machine tools and other bearings have been developed.*

*JTEKT will continue efforts to contribute to people and industries around the world by further developing bearing fundamental technologies and quickly providing new products that meet the needs of customers in such vital areas as environment, safety, comfort, productivity, and maintenance.*

***Key Words**: automotive bearing, industrial bearing, trend, bearing technology*

## 1. Introduction

In recent years, atmosphere surrounding technology development has increasingly diversified, e.g. needs for unique and creative new product development, development of world-class high quality products, innovation in manufacturing to secure cost competitiveness, including the development of technologies for global environment protection as typified by those for energy-saving and reduction of substances of environmental concern.

Amidst such circumstances, JTEKT's rolling bearing technology development covers not only the development of basic technologies such as materials, heat treatment, tribology and precision machining but also the fusion of bearing technologies and technologies in other fields such as sensor technology and control technology, including unitization, modularization, and CAE to develop these technologies effectively. Furthermore, we are improving our engineering planning ability to forecast and evaluate the future more accurately, cultivating human resources able to pursue innovation and exercise leadership, and reforming workplace atmospheres to fully utilize such human resources.

This paper presents an overview of technological trends in the automobile and industrial (non-automotive) fields and explains JTEKT's direction of bearing technology development in response to these trends.

## 2. Trends and Outlook of Automobile Bearings and Units

Technological trends of automobiles and bearings are shown in **Fig. 1** classified in the three basic areas: safety, environment, and comfort.

### 2. 1 Technology for Safety

As the importance of preventive safety technology is being increasingly emphasized in order to prevent car accidents, a system that integrates and controls "running," "turning" and "braking" has been mass-produced and is evolving further. This system includes ABS and traction control designed to control braking and driving performance to enhance vehicle safety, and so-called integrated vehicle motion control that integrally controls vehicle's motion including motion by steering systems.

JTEKT has been working on development of various technologies that can be applied to this integrated vehicle control system, some examples of which are shown in **Fig. 2**. They include an actuator for active steering that can change the relationship (gear ratio) between revolution of the steering wheel and linear motion of the rack, an ITCC (Intelligent Torque Controlled Coupling) that controls the torque distribution between the front and rear wheels, a lateral torque distribution mechanism for controlling the torque distribution between the right and left wheels, and in relation to bearing technology, a hub unit that can sense the forces acting on the tires and the tire gripping force on a real time basis. By these technology developments, it will be possible to secure

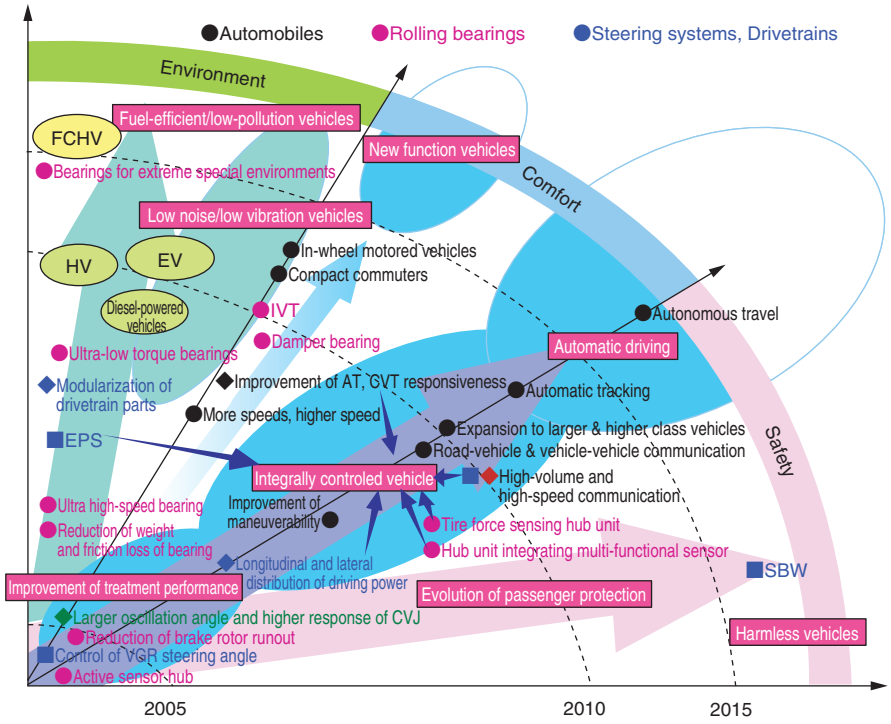


**Fig. 1** Automobile technical trends

the necessary element technologies for integrated control of vehicle, allowing us to offer customers devices and functions that satisfy their needs in mind in terms of vehicles before such needs are actually released from them.

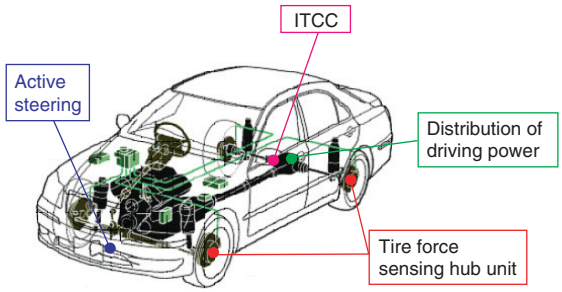


**Fig. 2** Examples of integrated vehicle control technology

## 2. 2 Technology for the Environment

In pursuing the basic theme of environment protection, automobile manufacturers have been developing technologies for fuel-efficient and low-pollution vehicles such as diesel-powered vehicles, HVs, EVs and FCHVs. In the future, there will be demands for further improvement in fuel efficiency corresponding to heightening awareness of the need to tackle environmental problems. The current status and outlook of JTEKT's bearing technology in these areas are described below.

### 2. 2. 1 Power Train

First, some examples of bearings developed for diesel engines with less $CO_2$ emissions are presented below. Concerning direct injection type diesel engines, which have greater rotational speed variation than gasoline engines, there are problems of auxiliary belt slip noise and belt life shortening. In order to resolve such problems for alternators whose inertia moments are large among auxiliary devices, one-way clutch pulleys, which are pulleys with built-in one-way clutches to reduce rotational speed variation, have been developed for alternators and mass-produced[1] (**Fig. 3**). Another such example is related to turbochargers, which must be used with small-sized diesel engines to supplement their low output. In order to improve efficiency and acceleration response, there is a trend to replace the plain bearings supporting the turbine rotor with rolling bearings. JTEKT has developed and commercialized ceramic ball bearings for gasoline engine turbochargers (**Fig. 4**)[2], and it continues to pursue improvements to enable application to diesel engine turbochargers, which are used under severer conditions.

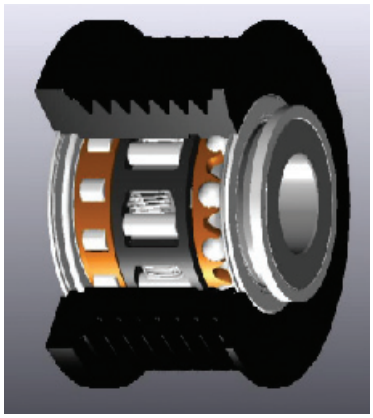

**Fig. 3** One-way clutch pulley for alternator

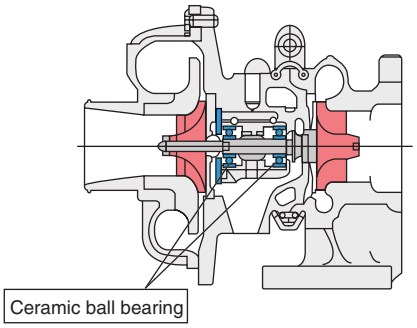


**Fig. 4** Ceramic ball bearings for turbochargers

Regarding gasoline engines, such valve mechanisms as variable valve timing and variable lift setting have been developed and improved to meet the demands for higher fuel efficiency and higher output. Rocker arm is one of the main valve components. To change plain bearings in rocker arms to rolling bearings, we developed a roller follower utilizing needle rollers as its rolling elements (**Fig. 5**). By optimization of this part's internal geometry[2], the rotational torque at low speeds, where friction loss is particularly large, has been reduced. We will continue to develop technologies that enable us to change plain bearings in gasoline engines to rolling bearings.

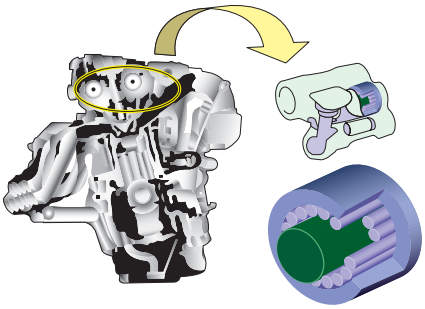

**Fig. 5** Roller follower

### 2. 2. 2 Drivetrains

The development of drivetrain bearings with higher efficiency, smaller size and lighter weight along with bearings particularly for hybrid vehicle drivetrains has been progressing.

Regarding higher efficiency, JTEKT over the years has made steady progress lowering the torque of tapered roller bearings, thrust needle roller bearings, etc.

Tapered roller bearings, which can bear high radial and axial loads compared to other types of bearings, have been successfully used in drivetrains. Although they are effective in making units more compact, their large torque loss has been a drawback. In response to that need, JTEKT developed its LFT–I and LFT–II bearings, which have improved sliding contact between the rib and roller, optimized raceway configurations and reduced rolling viscous resistance, but in addition JTEKT focused attention on agitating resistance of lubricant, contact angles, roller design (diameter, length, number), etc. and succeeded in developing the LFT–III (**Fig. 6**), the world's top-level tapered roller bearing whose torque is lower even than that of general ball bearings of comparable size. It can be expected that the fuel efficiency of a vehicle using LFT–III in the rear differential gear will be improved by 2% in EC mode.

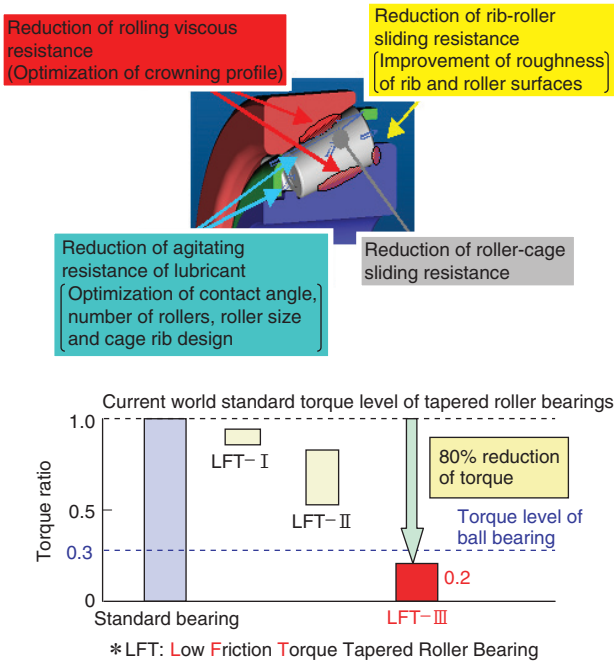


**Fig. 6** Low-torque tapered roller bearing and its benefits

Because of the structure of thrust needle roller bearings, sliding occurs between the race and rollers, and rotational torque is relatively high. Analyzing the bearing interior factors contributing to that rotational torque, we understand the largest of these is sliding resistance between the rollers and the cage (**Fig. 7**). To reduce this sliding resistance, JTEKT designed a cage configuration that reduces the amount of sliding with the rollers and developed pressing technology to enable manufacture thereof, enabling development of a low-torque thrust needle roller bearing without losing life, speed or wear resistance (**Fig. 8**). Although the load on each bearing is relatively small, in the case of application in automatic transmissions, which use many bearings, a total improvement of 0.3% in fuel efficiency can be expected.

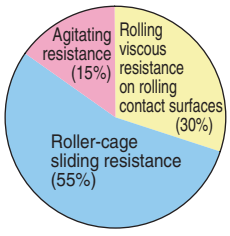


**Fig. 7** Rotational torque loss factors for thrust needle roller bearings

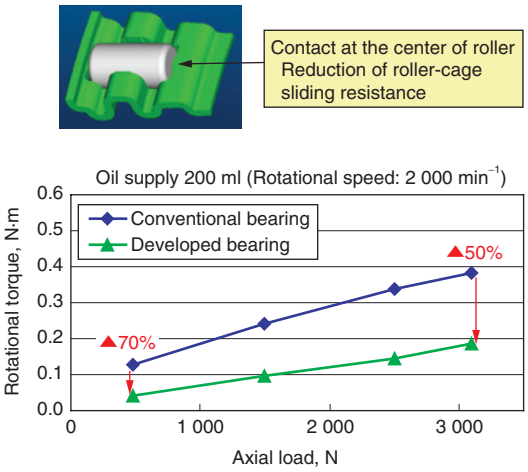


**Fig. 8** Developed bearing's features and rotational torque reduction effect

In the future, it is expected that demands for higher efficiency will increase not only regarding bearings alone but also regarding the unit products that house bearings. For instance, there is a trend toward using lighter housing materials (e.g. aluminum and magnesium), and the dimensional changes occurring as a result of temperature changes in the case of these materials cause problems for the bearings. These dimensional changes cause bearing preload to change, which leads to excessive preload and high torque loss. As an example of a countermeasure to this problem, JTEKT developed and has mass-produced pinion unit bearings (**Fig. 9**) that support pinion shafts in the pinion units. Along with such unitization of bearings, development is being carried out to create such products as an automatic preload-compensating bearing in which preload on the bearing is held constant.

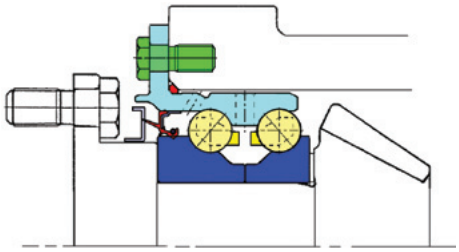

**Fig. 9** Pinion unit bearing

Concerning reduction of size and weight, such reduction is being pursued by lengthening the life of the individual bearings, but in the future, it is expected that the reduction of size and weight will be pursued by utilizing CAE for drive unit assemblies.

As an example of JTEKT's efforts, I will introduce a stiffness analysis of multi-shaft system that takes into account the stiffness not only of the bearings and parts in contact with the bearing but also of the shafts and housing surrounding the bearings. In this analysis, the bearing internal load conditions (rolling element load, contact angle, differential sliding, spin, etc.) are examined, and then such performance features as bearing life and friction torque are analyzed.

**Figure 10** shows a three-shaft analysis model for the 5-speed variable manual transmission of a passenger car. As examples of analysis results, the shaft center deflection curve at 1st speed loading is shown in **Fig. 11**, and the average bearing life is shown in **Fig. 12**. Based on the data of **Fig. 12**, etc., it is possible to select appropriate bearing specifications and optimum size without excessive quality.

Furthermore, this stiffness analysis was extended to an analysis of bearing friction torque under the condition of there being bearing mounting position error in the transmission case (example of center dislocation is shown in **Fig. 13**), taking lubricant viscosity and lubricant supply into account, with the result being as shown in **Fig. 14**. Based on this analysis, it is possible to propose transmission case designs and bearing internal designs that minimize bearing torque loss.

In the future, JTEKT will apply this method to more unit products through design-in activities*, and will propose optimal peripheral structures and bearings.

*) Design-in activity is to participate in customer's design activity from initial designing stage.

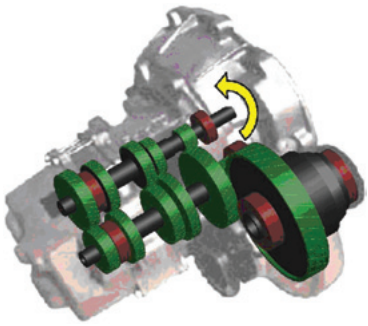

**Fig. 10** Analysis model

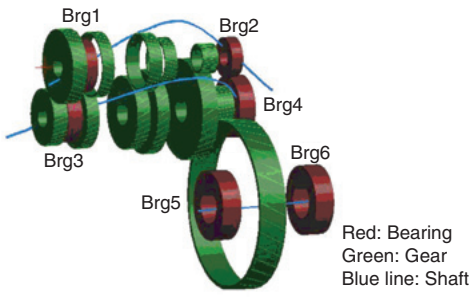


**Fig. 11** Deflection curve of shaft center

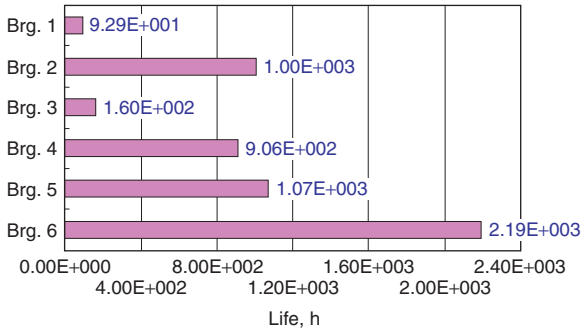


**Fig. 12** Average life of bearing

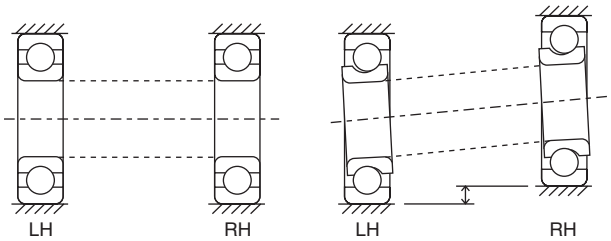


**Fig. 13** Schematic view of bearing assembly error (center dislocation)

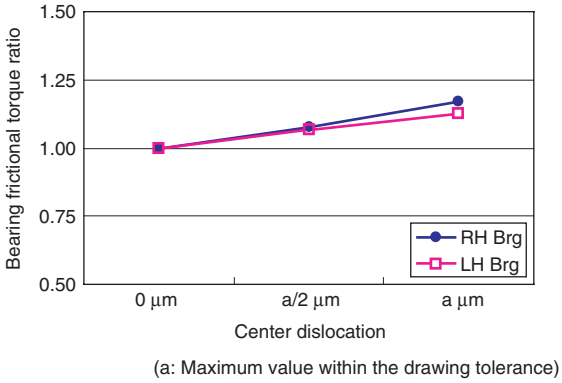


**Fig. 14** Relation between center dislocation and bearing friction torque

Lastly, I will present some comments on the bearing requirements for hybrid vehicles (HV). In order to realize drive units that are fuel-efficient, low-cost, high-power and compact, higher-speed motors have been developed and applied. Along with this, the need for high-speed motor-support bearings (ball bearings) has increased. When a ball bearing operates at high speed, its resin cage is liable to be deformed around the pockets due to the centrifugal force and heat generation, which may result in seizure between the cage and balls. To solve this problem, a completely new type matched resin cage that takes productivity into account has been developed based on CAE cage deformation analysis at the time of high-speed rotation and experimental analysis of lubricant flow. This new cage has enabled realization of high-speed capability while restraining cost increase (**Fig. 15**).

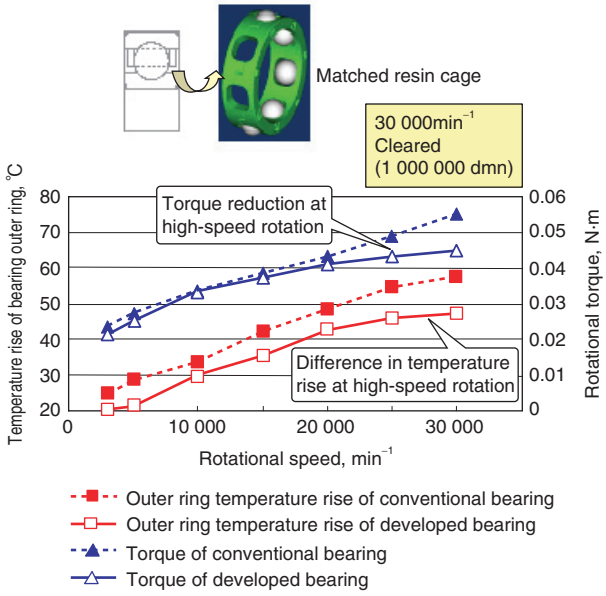


**Fig. 15** Matched resin cage and benefit of use in a ball bearing

## 2. 3 Technology for Comfort

Concerning vibration and noise, noise quality has come to be seen as an important automobile product feature along with quietness in recent years, and its improvement in conjunction with improvement of fuel efficiency is being sought.

Examples of bearing-related contributions to vehicle's comfort are the above-mentioned one-way clutch pulleys for alternators developed to minimize noise from the auxiliary belts of diesel engines and the design for wheel hub units to prevent stick-slip noise from being generated on the flange mating surface as described below.

Stick-slip noise is known to be a phenomenon generated on the mating surface between the hub unit flange and the brake rotor through the following process. First, microscopic relative sliding between these mating surfaces takes place because of the difference in stiffness distribution on these parts. Then, wear (fretting corrosion) due to such sliding progresses to such an extent that the coefficient of friction becomes low enough to cause stick-slip. Therefore, a design to prevent the fretting corrosion by calculating the amount of work in these mating areas was found. Since the FEM analysis results were found to be consistent with experimental results, it has been established as an effective means to prevent stick-slip in the design study stage (**Fig. 16**)[3].

In the future, we will propose technologies to improve noise and vehicle's comfort by improving not only bearings alone but also above type of peripheral parts through broad-view analysis work.

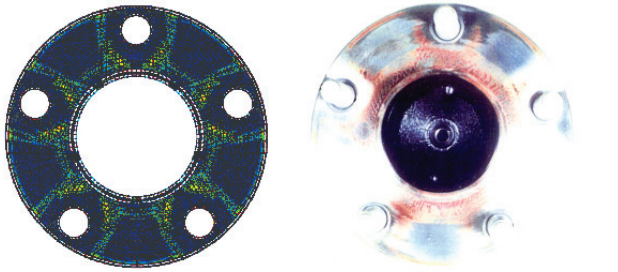


**Fig. 16** Fretting analysis results by FEM

## 3. Trends and Outlook of Industrial Bearings

Here, the technical trends and outlook regarding bearings for industrial (non-automotive) applications are described. Bearings for industrial applications are quite diverse. For example they range in size from ultra-large bearings for tunnel borers over 7 m in OD to small ball bearings less than 1mm in bore diameter for electric motors. The rotational speed exceeds 4 million dmn at high speeds. They are used in a wide variety of environments, such as ordinary life environment, super clean environment for semi-conductor manufacturing equipment, and high temperature environment in aircraft jet engines.

Technical trends in non-automotive industries are summarized in **Fig. 17**, centering on the steel mill, wind turbine generator, and machine tool industries. For industrial bearings, the three basic themes are "Environment," "Productivity" and "Safety and Maintenance."

### 3. 1 Technology for the Environment

Also in industries other than automobile, recent environment-oriented technological innovations have been remarkable, including power generation utilizing natural energy such as wind power and solar power, fuel cells without exhaust gas, energy-saving type machine tools, etc.

In the case of each of these innovations, all kinds of technical demand are imposed on the bearings, and JTEKT endeavors to respond to each of these needs. In this section, bearings for wind turbine generators, for which market demand is expanding in recent years, are introduced.

Along with the growing utilization of natural energy as a means of preventing global warming, power generation by highly efficient wind turbine generators has increased, and development of a wind turbine generator with over 2 MW capacity is being pursued.

The main spindle bearing for this wind turbine is required to have compactness and improved stiffness, and the work load for installation is required to be reduced. Thus a super large size bearing (with OD larger than 1 000mm) that has the largest dynamic and static strength in compact space was developed taking into account housing stiffness (**Fig. 18**). For the generator, JTEKT proposed a ceramic bearing with excellent insulating capability so that the bearing may not be damaged by electric corrosion (a phenomenon of local melting of the rolling contact surface due to electric current passing through the bearing) and to improve reliability of the generator[4].

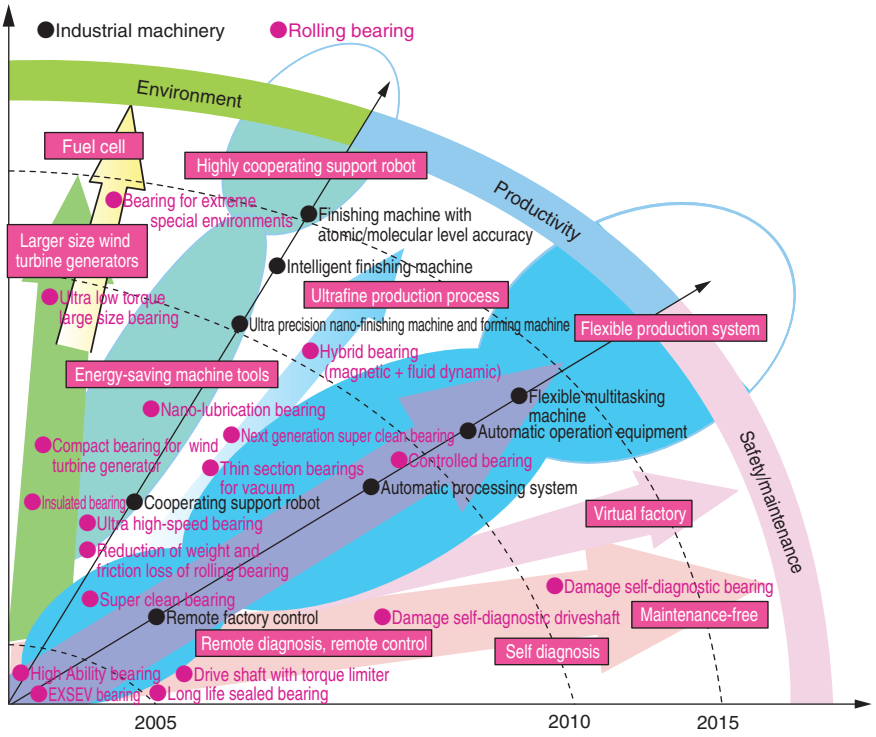


**Fig. 17** Technical trends of other industries

We will continue to develop more compact bearings with higher stiffness in response to larger wind turbines and more diverse installation places including off-shore.

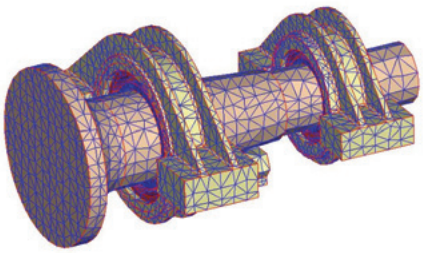

**Fig. 18** Stiffness analysis of housing

### 3. 2 Technology for Productivity

In every industry, productivity improvement has been an important theme that has driven the evolution of production systems from the automated manufacturing to automatic operation systems and flexible production systems. It has also urged the progress of individual production equipment concerning higher speed, accuracy and efficiency.

In this section, I would like to introduce technology for productivity with the bearings in machine tools, wherein bearings are used in diverse applications.

For machine tools, it is very important to improve the performance of the main spindle bearing as it has direct influence on machining accuracy and manufacturing efficiency. Particularly in a machining center that involves diverse machining operation ranging from heavy cutting at low speeds to light cutting at high speeds, the spindle bearing is required to have both high stiffness and high-speed capability. Also, more priority has been placed on reduction of environmental burdens such as control of oil dispersion, low noise and energy saving.

In order to satisfy these requirements, JTEKT has developed a High Ability angular contact ball bearing (**Fig. 19**), which enables to replace oil-air lubrication for main spindle by grease lubrication, which has also contributed to cost saving through elimination of the lubricant circulation system and simplified structure of the main spindle. In the meantime, there has been increasing demand for bearings with high-speed capability that can be handled in a similar manner to grease-lubricated bearings. To meet such demand, JTEKT has been developing a nano-lubrication bearing integrating a lubricating device so that a very small amount of lubricant may be supplied only to necessary areas only when it is required (**Fig. 20**)[5].

On top of these innovations, development of bearings with higher precision and longer life will be continued in response to the machine tool trends for higher speeds and heavier loading capability.

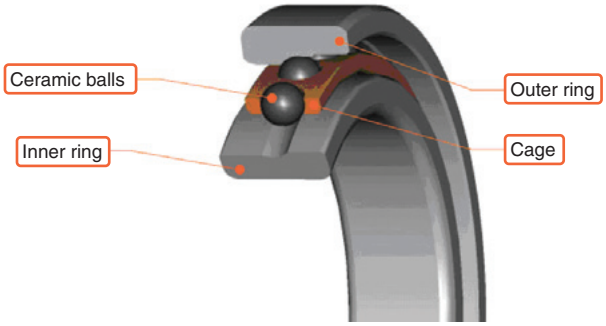


**Fig. 19** HIGH ABILITY angular contact ball bearing

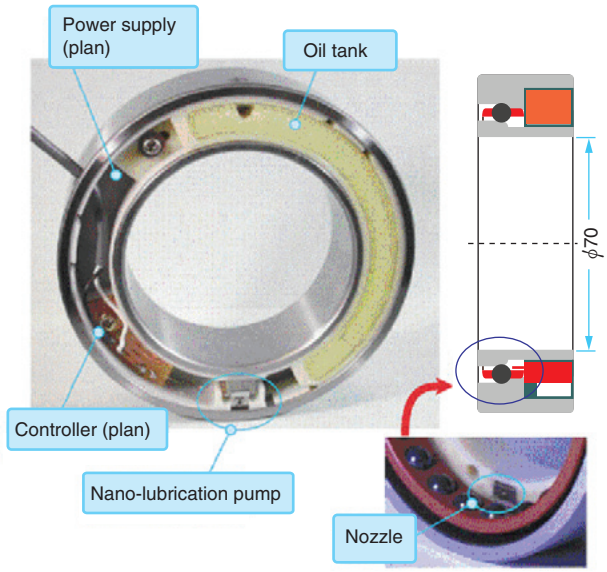


**Fig. 20** Nano lubrication bearing

### 3. 3 Technology for Safety & Maintenance

In the area of safety and maintenance of production equipment, technology has evolved from remote diagnosis and remote control to self-diagnosis and is now advancing further to maintenance-free capability. In steel mills in particular, where equipment maintenance has significant influence on production, the needs for maintenance-free capability is great.

Here, therefore, I present the latest bearing technology for steel mill equipment.

Steel product is used extremely widely, and its market still grows by several percent every year. In order to improve productivity, steel mill equipment has been used under increasingly severe operating conditions (higher speeds and heavier loads), while needing to have higher reliability for a better rate of utilization. Moreover, there has been increasing demands for simplified maintenance and reduction of maintenance costs.

Since the bearings in rolling mills are exposed to lots of cooling water, it is important to protect the bearing from permeation of water that can generate rust, which can be the starting point of bearing failure. To this end, JTEKT has developed a high load capacity sealed type roll neck

bearing (**Fig. 21**)[6], which contributes to extension of the maintenance intervals. Another example is thermal spraying of tungsten carbide (WC) on the keyways on driveshaft yokes (**Fig. 22**) to improve corrosion resistance, so that the increase of keyway clearance can be prevented. This treatment actually reduces the damage of bolts[7].

Our development for further improvement of productivity and cost reduction will be continued.

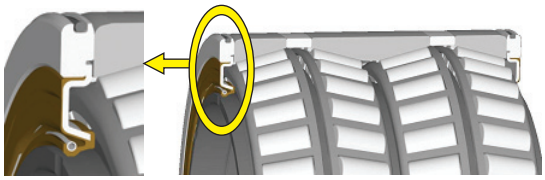

**Fig. 21** High load capacity sealed type roll neck bearing

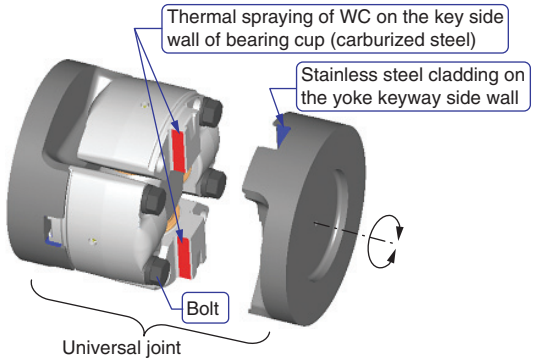


**Fig. 22** Improved corrosion resistance of yoke keyway of driveshaft

## 4. Conclusion

Rolling bearings, used in every industry and hence benefiting everyone in the world, are familiar products readily available and relatively inexpensive.

Behind this familiarity, however, there lies the state-of-the-art tribological technology that concerns friction, wear and lubrication as well as the most advanced manufacturing technology that enables machining with sub-micron accuracy at reasonable cost.

Thanks to these basic technologies, we have been able to develop new products as introduced herein that contain not only bearing technologies but also technologies created by fusing bearing technologies and peripheral technologies, unitization technology, sensor technology, control technology, etc.

While continuing to deepen our basic bearing technology with untiring diligence and humbleness, we will continue to carefully observe the future technical trend of each industry so that we can deliver new products that satisfy customers' needs as promptly as required. In this way we will continue to serve industries around the world.

## References

1) M. Kitamura: Koyo Engineering Journal, 161E (2002) 8.
2) S. Murao: Gekkan Tribology (Journal of the Tribology), 10 (2003) 44.
3) K. Kajihara: Koyo Engineering Journal, 167E (2005) 35.
4) Y. Kurashita: Gekkan Tribology (Journal of the Tribology), **20**, 4 (2006) 28.
5) O. Higashimoto: JTEKT Engineering Journal, 1001E (2006) 89.
6) K. Sameshima: Koyo Engineering Journal, 163E (2003) 17.
7) A. Nagayama: Koyo Engineering Journal, 166E (2005) 7.

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