Technical Trends and R&D Efforts Regarding Industrial Rolling Bearings

K. SAMESHIMA

Rolling bearings are important machine elements that support almost all rotating parts of industrial machines. In recent years the demand for compact, lightweight, maintenance-free industrial machines with improved reliability has increased, and bearings that are not only suitable for such machines but also high-quality, environmentally friendly and usable on a global basis are being required. By utilizing advanced analysis and measurement technology to understand rolling bearing behavior, wear and lubrication on a microscopic scale and utilizing submicron-precision machining technology, JTEKT has created rolling bearings able to improve the performance of a wide array of industrial machines. This paper presents technical trends and R&D efforts of JTEKT regarding rolling bearings used in major nonautomotive industrial fields.

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

1. Introduction

Rolling bearings are used as important machine elements to support the rotating parts of machines in the fields of automobiles, electrical machinery and equipment, information equipment, steel mill equipment, rolling stock, construction equipment, machine tools, aircraft, and virtually all other manufacturing industries.

In recent years, performance requirements for rolling bearings have diversified along with the general trends of machines and devices toward compact size, lighter weight, higher reliability and maintenance-free performance.

Moreover, technology for safety, energy-savings, and such global environmental needs as reducing the use of substances placing a load on the environment as well as higher quality and lower price to cope with globalization have become important.

In such circumstances, JTEKT has promoted product development based on R&D efforts in such fundamental technology areas as materials, heat treatment, tribology and precision machining, emphasizing synthesis with the sensing technology, unitization and modularization[1].

This paper presents technical trends and examples of JTEKT's R&D efforts regarding rolling bearings used in major industrial fields (herein meaning non-automotive fields).

2. Characteristics and Required Performance for Industrial Rolling Bearings

Industrial rolling bearings are used for a much broader range of applications than automotive rolling bearings. In terms of the size, they range from bearings 1mm in bore diameter for small motor bearings to bearings 7 m in outside diameter (OD) for tunnel boring machines. Viewed from the standpoint of operating conditions, bearing rotational speeds range from the ultra-low region of 1 min^{-1} to the high-speed region of dmn value (bearing P.C.D. mm × rotational speed min^{-1}) of 4 million, and bearing loads range from the light-load region of a few percent of the dynamic load rating to the heavy-load region of more than 80% of the dynamic load rating.

Operating environments also vary widely, from the ultraclean environments of semiconductor manufacturing equipment to the high-temperature, dusty, and corrosive gas environment existing in places such as steel mills.

Furthermore, demands for rolling bearings that contribute to the reduction of environmental load, enhanced productivity and improved safety and maintainability have intensified in recent years.

In such circumstances, JTEKT has promoted product development from the standpoint of combining bearings with sensing technology and forming bearing unit products based on R&D efforts in such basic technology areas as materials, heat treatment, tribology and precision machining as shown in **Fig. 1**.

Regarding the development of industrial rolling bearings, in many cases the bearing size or operating environment makes it difficult to produce and evaluate

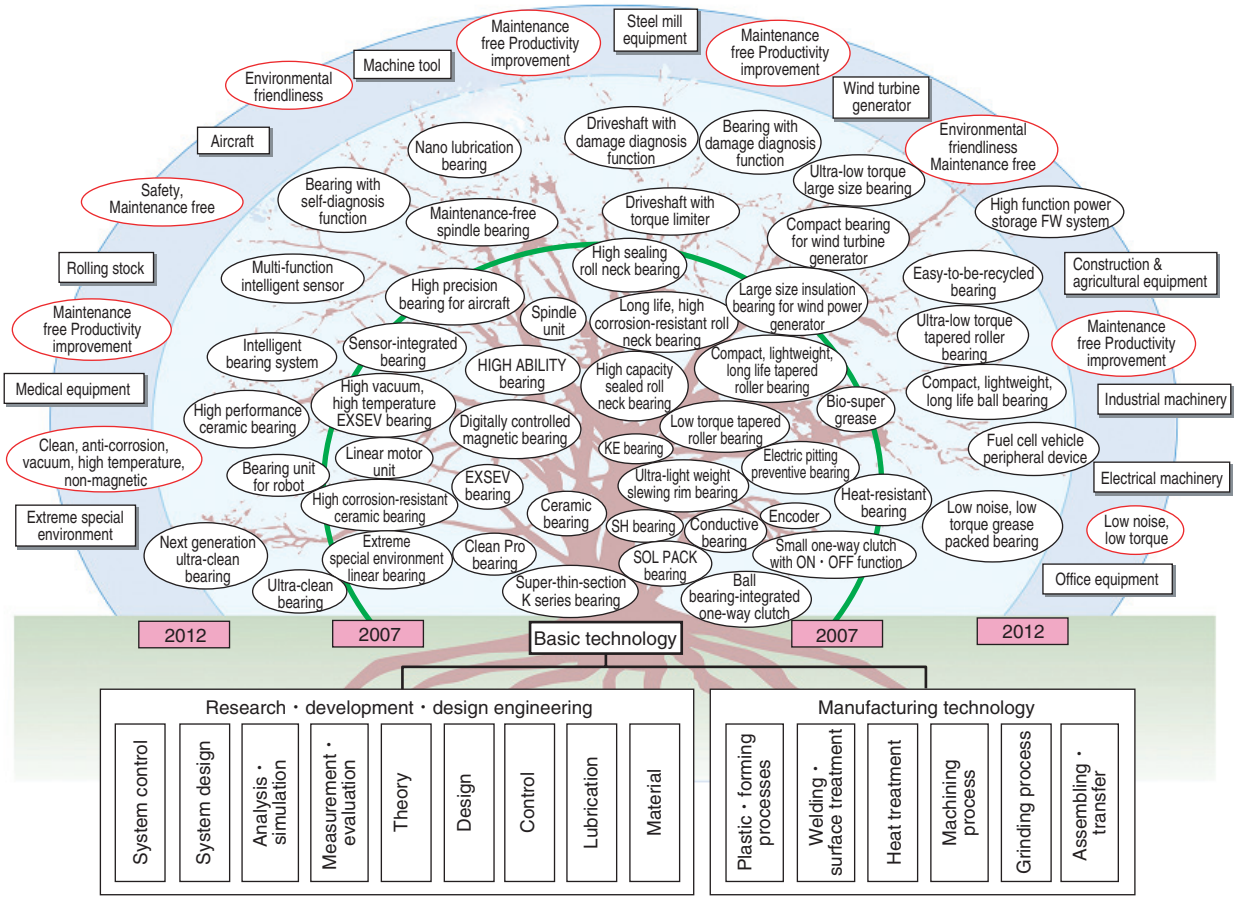

Fig. 1 R&D tree for industrial bearings

prototypes beforehand. Therefore, JTEKT has utilized CAE to develop products that meet customers' performance requirements for machines.

2. 1 Steel Mill Equipment

JTEKT developed its first rolling bearing for steel rolling mills in 1942, and since that time it has developed a wide variety of rolling bearings and driveshafts for steel mill equipment based on the rolling bearing technology it cultivated.

Japan's steel industry began efforts at an early stage to improve product quality. In 1972, a rolling bearing was first installed on the back-up rolls of a cold rolling mill in place of the conventional oil film bearing. Since then, it has become standard practice in Japan to use rolling bearings on the back-up rolls of all new cold rolling mills, which has made a remarkable contribution to the improvement in gauge accuracy of rolled steel products[2].

In the 1990s, global steel production declined substantially, and a number of steel production facilities were reduced.

Since 2000, however, steel demand has rebounded strongly, and steelmakers have needed to expand production drastically.

In today's Japanese steel industry, it has become very important to deliver products in a timely manner in response to increasing customer demands while also carrying out a shift toward high-grade steel products such as steel sheets for automobiles. Consequently, steel mills have strongly desired to improve both the productivity and reliability of steel mill equipment and reduce their maintenance costs. JTEKT has developed products that meet such needs.

Examples of developed products for rolling mills, an important part of the steel making process, are shown in **Fig. 2**.

Rolling bearings and driveshafts for rolling mills must be operated in severe environments, where there are large amounts of rolling oil, water vapor, dust and high temperatures. Therefore it is extremely important to prevent bearing and driveshaft performance from deteriorating due to the high temperatures or the ingression of rolling oil or dust. Such prevention can greatly contribute to the improvement of equipment reliability as well as operation stability over long periods of time.

For rolling mills, JTEKT has developed a new roller bearing incorporating new material and heat treatment technology that features long fatigue life and high corrosion resistance as well as a seal structure designed

Developed product	Long life high corrosion-resistant bearing	High-sealing roll neck bearing	Driveshaft with torque limiter
Targets	Extension of bearing life Extension of maintenance interval Reduction of maintenance work hours	Extension of bearing life Extension of maintenance interval Reduction of maintenance work hours	Protection of surrounding equipment in case of excessive torque during mill operation Avoiding long-term interruption of rolling operation
Description	<Material composition> Optimized composition by addition of Ni, Cr and Mo <Improved corrosion resistance> Adoption of special carbonitriding heat treatment Developed material Conventional carburized material Cumulative failure probability, % 90 50 10 1 5 10 50 100 Number of stress cycles, $\times 10^7$ cycles	Seal cover Oil seal Plate Locking pin O ring	Shear valve Coupler Bearing Oil seal Hydraulic expansion chamber Bearing Oil seal Torque transmission surface For roll driving

Fig. 2 Examples of products developed for rolling mills

to reduce ingression of rolling oil and dust. Thanks to this development, customers have successfully extended the maintenance interval of rolling bearings, which has contributed to improved equipment operation ratio and reduced maintenance costs and enabled stable operation for extended periods of time[3), 4)]. Moreover, substantial reduction of lubricant (grease) consumption has also been achieved.

When multiple in-take of rolled material happens during rolling operation, an excessive inertia moment due to sudden stopping of the roll rotation acts instantaneously on the entire transmission system, which may damage the driveshaft universal joints or other machine parts and in the worst case stop the rolling operation. JTEKT has developed a driveshaft with a torque limiter possessing a mechanism that instantaneously releases the excessive torque acting on the universal joint[5)]. This development prevents equipment damage from an accident during rolling operation and remarkably contributes to the improvement of productivity.

Furthermore, a new system that incorporates a sensing function in the driveshaft to enable diagnosis for damage during operation is under development[6)]. This system is expected to drastically improve the preventive maintenance of the equipment.

In the development of such products for steel mill equipment, in many cases the large size or severe operating environment makes it difficult to produce and evaluate prototypes beforehand in the development stage. Therefore, JTEKT has utilized CAE to develop products that meet the performance required by customers (**Fig. 3**).

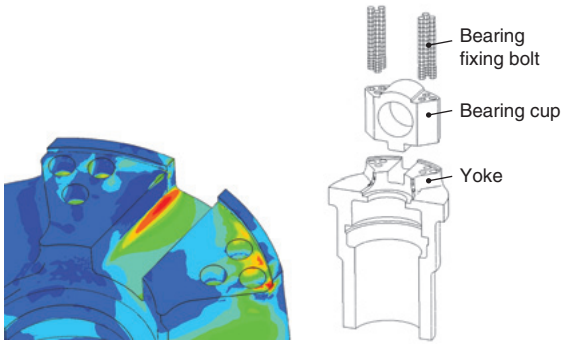

Fig. 3 Study of rolling mill driveshaft yoke strength

2. 2 Windmill Power Generator Equipment

Since the latter half of the 1990s, the number of windmill power generators has increased significantly as a result of the rising need to utilize natural energy in order to prevent global warming. Recently, to further increase the amount of power generation, a very large windmill power generator with a capacity of more than 2 MW has been under development, and large bearings with large load carrying capacity are required for the main shaft of the wind turbine. However, as it is very important to reduce the installation cost of large windmill power generators, large bearings with high stiffness that are as compact as possible are required.

The main shaft bearings of windmill power generators are subject to widely varying loads and changes of rotational speed depending on wind velocity and direction.

JTEKT has developed a compact and high-stiffness extra-large bearing exceeding 1 m in OD for the main shaft of windmill power generators (**Fig. 4**) by numerical processing of varying bearing rotational speeds and loads and analyzing housing stiffness.

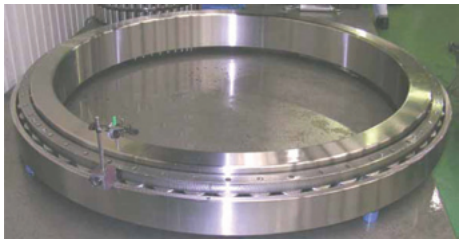

Fig. 4 Extra-large bearing for main shaft of windmill power generator

Furthermore, with the increased application of windmill power generators, the rolling bearings used therein have been required to improve reliability. Rolling bearings used in these generators are susceptible in particular to electric pitting (the phenomenon that a spark occurs through a very thin oil film on the rolling contact area and the surface partially melts when an electric current passes through the inside of the bearing during rotation), a major cause of failure. To prevent damage from electric pitting, JTEKT has developed a hybrid ceramic bearing (**Fig. 5**) with excellent insulation performance, which contributes to improved generator reliability[7].

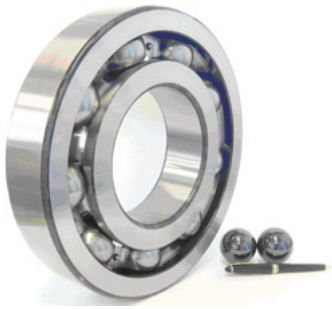

Fig. 5 Insulated hybrid ceramic bearing for windmill power generator

2. 3 Machine Tools

In manufacturing industries, demands for improved productivity and product manufacturing accuracy have intensified, driving endless efforts to increase the speed and efficiency of machine tools. Consequently, rolling bearings for machine tool spindles are required to have ultra-high-speed rotational performance to reduce processing time and high stiffness and low temperature-rise properties to enable precision machining.

At the same time, recently more priority is being placed on environmental aspects. In this respect, more attention is being paid to the grease lubrication that can maintain a clean environment without oil scattering for use in the place of oil-air lubrication or oil mist lubrication conventionally used in high-speed spindles. In response to these needs, JTEKT has developed its HIGH ABILITY sealed type angular contact ball bearing packed with grease, which has excellent high-speed performance (**Fig. 6**)[8]. As this bearing doesn't require a lubrication system, it contributes to cost reduction of the spindle by simplification of the spindle structure.

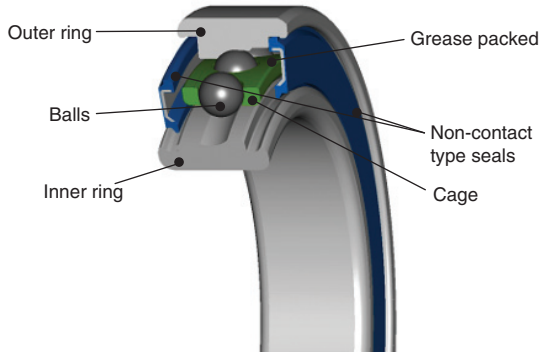

Fig. 6 HIGH ABILITY sealed-type angular contact ball bearing

Requirements for machining center spindle bearings to have both high stiffness and high-speed performance to enable broad machining capability ranging from heavy cutting at low speeds to light cutting at high speeds have increased. In response to such needs, JTEKT has provided high-speed and high-stiffness bearings and also has been developing a bearing preload control system to maximize bearing performance.

2. 4 Motors

In recent years, demands regarding motors have been increasing in various industrial fields. Motors for household electric appliances are required to have low noise, improved durability, and high efficiency. Accordingly, the rolling bearings for such motors are required to have improved quietness, high-temperature and high-speed durability, low torque, and anti-fretting properties. Also, many motors are necessitated by the growth of electronic control in automobiles, and bearings for these motors are required to have low-temperature startability in addition to the above properties.

Since the performance of motor bearings is significantly influenced by grease performance, JTEKT has developed various new greases as shown in **Table 1**, which contribute to the improved performance of various motors[9].

Demands for higher reliability of the equipment in which motors are used have caused more attention to be paid to the prevention of bearing failure due to electric pitting. For that purpose, JTEKT has developed various types of non-conductive rolling bearings.

Table 1 Greases for motor bearings

	KVC grease	KAM5 grease	ES804 grease
Thickener	Diurea	Lithium soap	PTFE
Base oil	Poly α olefin, ester	Ester, ether	Perfluoro-polyether
Base oil kinematic viscosity, mm^2/S (40℃)	47	53	68
Worked penetration	250	265	333
Dropping point, ℃	260 or over	186	–
Evaporation loss, mass %	0.17 (99℃, 22 h)	0.2 (99℃, 22 h)	1.3 (200℃, 24 h)
Oil separation, mass %	0.2 (100℃, 24 h)	1.3 (100℃, 24 h)	12.2 (200℃, 24 h)
Operating temperature range, ℃	−40～150	−30～140	−40～200
Low noise	–	Excellent	Excellent
High-temperature durability	Excellent	Excellent	Excellent
High-speed durability	Excellent	–	–
Low torque	Excellent	–	Excellent
Anti-fretting performance	Excellent	–	Excellent
Applications	High-temperature motor, vacuum cleaner motor	Multi-purpose motor, air conditioner motor	Vehicle mounted stepping motor

It is expected that demands for equipment quietness, low power consumption, improved reliability, and longer operating time will continue to strengthen and that likewise the bearings for such equipment will also be required to display improvement in the areas of quietness, low torque and longer life. To meet such requirements, JTEKT has been developing higher performance rolling bearings for motors making use of its wealth of technology in regard not only to grease but also to heat treatment and sealing.

2. 5 Rolling Bearings for Extreme Special Environments in High-Technology Fields

For such extreme special environments as vacuums and clean, high-temperature and corrosive environments wherein use of conventional rolling bearings is extremely difficult, JTEKT has developed extreme special environment rolling bearings and contributed to high-technology fields.

JTEKT was the first to develop a ceramic bearing in 1984, and since then it has developed various extreme special environment rolling bearings that satisfy performance requirements for diverse applications. These rolling bearings have been commercialized as the EXSEV (Extreme Special Environment) bearing series[10].

Examples of extreme special environment rolling bearings for semiconductor manufacturing equipment and medical equipment are described as follows.

2. 5. 1 Semiconductor Manufacturing Equipment

In accordance with the progress of integration of semiconductor products, requirements for cleanliness in semiconductor manufacturing equipment has become increasingly severe, leading to requirements for reduce particle and gas emission from roller bearings. To satisfy this requirement, JTEKT developed the Clean Pro PRZ bearing (**Fig. 7**).

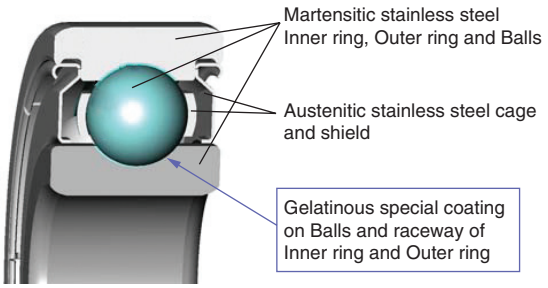

Fig. 7 Clean Pro PRZ bearing

The rolling surfaces of this bearing are coated with a gel type special polymer film containing lubricants suitable for a clean environment, enabling it to display significantly reduced particle and gas emissions in high vacuum conditions.

Transfer robots used in semiconductor manufacturing equipment also require compact, long-life bearings with low particle emissions.

JTEKT has responded to this requirement by developing and supplying a super-thin section ceramic ball bearing (**Fig. 8**).

To meet the needs of today's increasingly information-based society, JTEKT continues to develop products for use in clean environments by making the best use of its technology concerning materials, surface treatment, and lubrication.

Fig. 8 Super-thin section ceramic ball bearings

2. 5. 2 Medical Equipment

Great advances are being made in preventive medicine, and the use of various diagnostic machines for the early detection of diseases inside the human body and therapeutic treatment thereof has been spreading rapidly. Among these are X-ray CT (computer tomography) scanners, for which JTEKT supplies EXSEV bearings.

X-ray devices, which are covered with a hard glass tube, etc. and operate under high vacuums (10^{-6} Pa), irradiate electrons on the surface of the target, which is accompanied by much heat generation. To prevent the target surface from being damaged by the heat, rolling bearings to support and rotate the target at very high speed (approx. 10 000 min^{-1}) are required. In addition, as the X-ray device is orbited around the patient at high speed, the bearings are subjected to centrifugal force due to orbiting.

JTEKT has supplied compact spindle units for X-ray tubes (**Fig. 9**) that make use of excellent heat-resistant material and a solid lubricant that is effective in high vacuums, thereby contributing to the improved reliability of diagnostic equipment.

Fig. 9 Spindle units for X-ray tubes

The demand for advanced diagnostic equipment is increasing, and diagnostic equipment that can provide high-quality dynamic information in a short time is expected. In an attempt to meet such needs, JTEKT has developed bearings and units making the best use of its expertise in such areas as materials, surface treatment, lubrication, and design optimization.

3. Conclusion

Rolling bearings have been steadily improved over the years as a basic industrial product, following the same path of progress as the industrial revolution and the automotive industry. They have firmly established their position as a critical mechanical element in a wide variety of machines and equipment.

From macroscopic viewpoint, the basic construction of a rolling bearing, which composes an inner ring, outer ring, cage and rolling elements, has not changed significantly.

Nevertheless, JTEKT has carried out rigorous studies to clarify rolling bearing's microscopic behavior, friction, wear and lubrication characteristics, making the best use of measurement and analysis technology that also has continued to evolve. Based on the insight thus obtained and on the development of manufacturing technology enabling submicron levels of precision, JTEKT has developed and supplied various rolling bearings to satisfy the requirements for improved performance in various types of machines.

Based on further R&D efforts related to basic technology in such conventional areas as materials, heat treatment, tribology, and precision processing and giving full consideration to bearing peripheral technology and environmental needs, JTEKT will aim to continue developing new products to meet the needs of customers.

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