Rolling Bearing Development for the Future of Industrial Machinery

Etsu HARIMA*

NTN supplies many bearing sizes based on the needs of various applications in the industrial machinery market. These range from ultra-small bearings with outer diameters of a few millimeters for electronic devices, to ultra-large bearings with outer diameters of several meters for wind turbines and large mining machinery. In addition to existing customers for "core" industrial markets such as construction machinery, agricultural machinery, and machine tools, business from customers relating to social infrastructure is increasing. Activity with customers in the aircraft, railway vehicle, and wind turbine markets is growing with changes in social structure and increased awareness of environmental issues. Therefore, **NTN** has developed related engineering and production systems accordingly. Due to advancements in Internet of Things (IoT) and development of artificial intelligence (AI) technology, it is expected that the current environment will change significantly. This report introduces advancements in **NTN**'s analysis and evaluation technology, as well as **NTN**'s approach to higher bearing performance and reliability.

1. Introduction

In Egyptian pictures drawn thousands of years ago, people are transporting rocks by pulling them on rollers placed underneath the rocks. This is the origin of rolling bearings (hereafter, "bearings").

It is also believed that Leonardo da Vinci, an artist in the Renaissance era, invented the basic principle and structure of modern day bearings. Da Vinci had drawings of bearings with almost the same structure as the ones used today.

It has been about 100 years since **NTN** started manufacturing bearings. The appearance and components are almost the same as back then. However, the performance of the components has significantly improved thanks to the progress of materials, lubricants, and processing technologies. Bearings are now indispensable machine components for equipment.

In this paper, the evolution of bearings in areas such as steel manufacturing methods, manufacturing technologies, and design technologies is reviewed. Additionally, **NTN**'s progress of analytical technologies and evaluation technologies, as well as its initiatives for improvement of reliability are introduced.

This paper also introduces an approach for modular and intelligent components by integrating forward-looking bearing technology, sensing technology, and precise control technology, as well as new products and services leveraged by fault detection, condition monitoring system (CMS), and IoT.

2. Past technology development[1)]

Looking at the **NTN** company history, there are numberous revolutionary years showing excellence in technology.

In 1934, **NTN** developed bearings for aircrafts and its products were adopted in the engine and body of 100% domestically-produced aircraft, "Kamikaze." This aircraft set a world record of 94 hours 17 minutes and 56 seconds of flight between Tokyo and London.

Double-row cylindrical roller bearings and single-row deep groove ball bearings were adopted in 1964 as journal bearings of the 0-series Shinkansen (bullet train), which made its debut on the newly opened Tokaido Shinkansen line. Components of the materials, heat treatment, and inspection conditions were rigorously examined and standardized by the then Japan National Railways (currently, Japan Railways) and only **NTN** and other designated companies were allowed to deliver the products.

Later, the H-1 rocket, which made a successful launch of its first test vehicle in 1986, was the first rocket with 100% domestically-produced liquid oxygen/liquid hydrogen engine in the second stage. Almost all of the bearings[2)] used in the rocket were produced by **NTN**. In 2002, **NTN** developed bearings capable of ultra-high-speed rotation of 3 million in dn[*1] value in liquid hydrogen (-253 ℃) for the first time in the world together with the National Aerospace Laboratory of Japan (currently, JAXA)[3)].

*1 dn value: d=ID (mm) × n= shaft rotation speed (min^{-1})
In general, dn value exceeding 1 million is called "high-speed" and a dn value exceeding 2 million is called "ultra-high-speed".

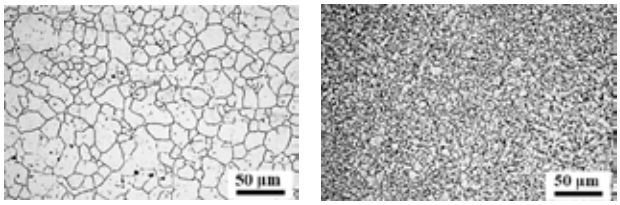
* Operating Officer, Corporate General Manager, Industrial Business Headquarters

As such, **NTN** has been accumulating product technologies and manufacturing technologies so that **NTN** can respond to the needs of its customers such as “long operating life” and “high speed.” These features are required by all industrial machines.

2.1 Long operating life

The evolution of the steel making method has significantly contributed to “long operating life.” As cleanliness of modern bearings has increased, internal origin flaking due to rolling contact fatigue caused by non-metallic inclusions is reduced under proper lubricating conditions. Operating life of bearings made of bearing steel with standard heat treatment (immersion quenching) are said to be semi-permanent if used under the fatigue limit load[4]. Conversely, since operating conditions of the actual bearings are severe and they are used under higher temperature, higher speed, and higher load, the expectation of the market is longer life with thinner lubrication and contamination.

Past research achievements[5] revealed that improvement of steel chemical components (alloy element) and heat treatment characteristics (toughness, hardness, etc.) can increase bearing life. As such, **NTN** has provided many long-life bearings on the market using these technologies. **NTN** has recently developed the “ETFA bearing.”[6] This bearing provides twice the bearing life of the conventional long-life “ETA bearing” and 6 times longer than the **NTN** standard “4 Top” series with contaminated lubrication. Resistance to foreign objects was increased thanks to special heat treatment technology (enhanced grain refinement) of case-hardened steel (carburized steel) **(Fig. 1)**.



Conventional product (ETA bearing) ETFA bearing

Fig. 1 Prior austenite grain under surface of bearing raceway

2.2 High speed

Another critical performance characteristic required for the bearings is “high speed.” Particularly, main shafts of machine tools, such as machining centers, are operated at significantly higher speed to improve machining efficiency and accuracy. **NTN** has been working on development and improvement of its products to respond to the requirement of high-speed operation[7].

As a result, **NTN** has achieved ultra-high-speed operation by adoption of ceramic balls which are lighter than steel balls and adapt well to high-speed operation with high contact pressure, adoption of smaller roller elements to reduce centrifugal force of high-speed operation, and adoption of air-oil lubrication and air-cooling technology[8]. The last two developments increase lubrication reliability by reducing heat caused by agitating resistance of lubricant **(Fig. 2)**.

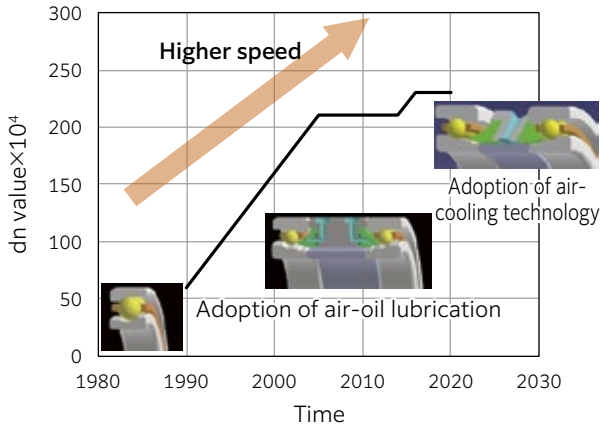


Fig. 2 Transition into higher speed machine tool bearings

Recently, demand for bearings for main shafts that use grease lubrication has increased for ease of use and reduced environmental impact. With grease lubrication, heat can cause degradation of the grease, and have a significant impact on bearing life. Therefore, reduction of heat during operation is an important factor. **NTN** developed “Machine Tool Spindle Bearing with Air Cooling Space for Grease Lubrication”[8] with its unique air-cooling technology. This technology introduces bearing cooling through air-cooling nozzles on outer ring spacers between bearings to cool the inner rings via inner ring spacers **(Fig. 3)**.

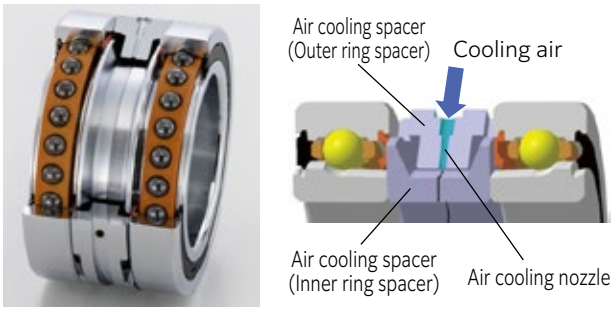


Fig. 3 Machine Tool Spindle Bearing with Air Cooling Spacer for Grease Lubrication

3. Evolution of rolling bearings

As mentioned earlier, the required function for bearings was to rotate smoothly under a large load for a long time. However, current bearings are not limited to that and **NTN** is now putting bearings with several more functions on the market.

New products are being developed to respond to demand, such as wind turbines and railway vehicles in growing markets, robots, aircrafts and machine tools. All of these industries require state-of-the-art technology.

3.1 Bearings for large wind turbines and CAE*2 analysis technology

Large wind turbines have rapidly evolved as an application area of bearings over the last 20 years. In addition to the requirement of a design life of over 20 years, highly reliable large-scale bearings are in high demand for offshore wind turbines. These bearing have outer diameters of over 2 m.

The magnitude and direction of load on bearings can vary depending on the wind conditions, and there are up to several millions of directional load combinations. Also, because of the size of the bearings, tests using the actual products are extremely difficult. Therefore, CAE analysis technology for deformation of bearings and their mating shafts and housings is indispensable **(Fig. 4)**.

*2 Abbreviation of Computer Aided Engineering

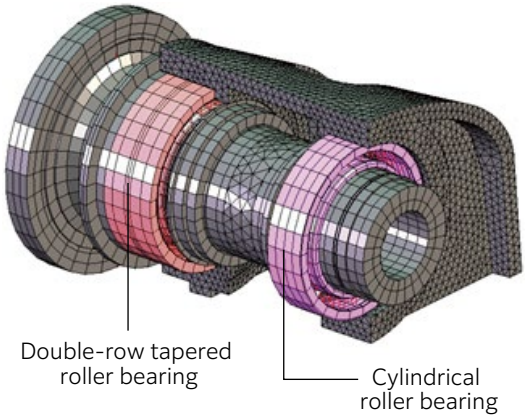


Fig. 4 Analysis model of wind turbine main shaft system

NTN also develops unique products contributing to long operating life. For main bearings, self-aligning roller bearings have been used which allow installation errors and may lead to early failure due to wear on the raceway.

Noting that a larger load is applied to the rear row (farther row from the blade) of bearings than the front row (closer row to the blade), **NTN** unveiled the "asymmetric self-aligning roller bearing"[9] adopting **NTN**'s unique design of different roller lengths and contact angles on rows in 2017 **(Fig. 5)**.

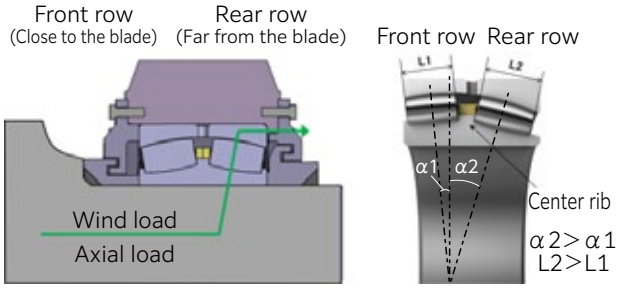


Fig. 5 Left: Loading condition, Right: Asymmetrical design

3.2 Bearings for machine tools and IoT

Bearings for main spindles of machine tools are required to offer ultra-high-speed operation with ultra-high accuracy. However, the new trends of integration and combination of machining processes require a single tool to handle deep cutting with medium to low speed rotation with high load resistance and fine cutting with high speed rotation. **NTN** developed the "Angular Contact Ball Bearing for High-Speed and Heavy-Cutting Machine Tools" in 2018 by optimizing the internal design of the conventional high-speed angular contact ball bearing "HSE type" achieving 30 % higher load carrying capacity and permissible axial load while maintaining high speed performance[10].

In addition, there is high demand for condition monitoring and IoT functions for reliability. **NTN** has newly added load detection and wireless functions to the unit "Sensor Integrated Bearing Unit"[11] which had been announced previously with integrated sensors in the outer ring spacer adjacent to bearing for realizing advanced condition monitoring **(Fig. 6)**.

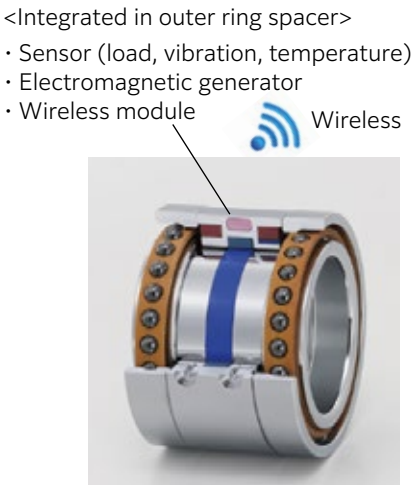


Fig. 6 Sensor Integrated Bearing Unit for Machine Tool Spindles

3.3 Rolling bearings for railway vehicles and insulation technology

Bearings are used in the journal, driving mechanism, and main electric motor locations of railway vehicles. Bearing performance and quality directly affect the safety of railway vehicles. Therefore, particularly high reliability is required among industrial machine bearings.

NTN is also working on technology development to respond to recent demand of high-speed operation and extension of maintenance intervals. Stray current corrosion can occur in the journal and main traction motor bearings. Usually, measures are taken on vehicles and its carriages, however, insulating bearings themselves can be a very effective measure. **NTN** has developed the "MEGAOHM™ Series"[12] with ceramic spray or resin coating on the bearing outer diameter. This development has been was received very well **(Fig. 7)**.

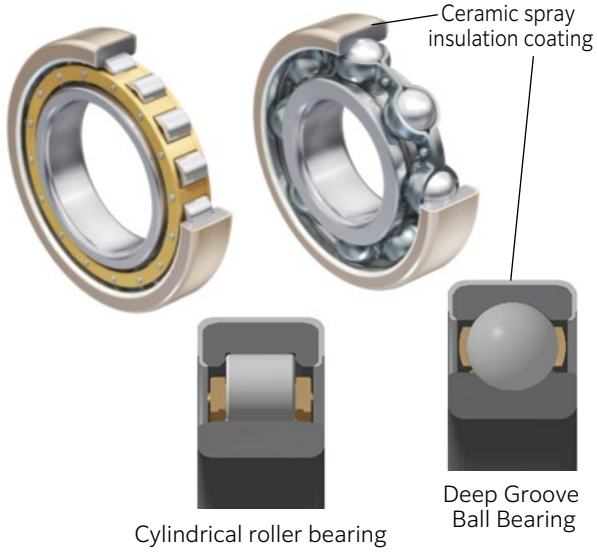


Fig. 7 Ceramic insulated MEGAOHM™ series

3.4 Condition monitoring service of bearings

NTN is currently developing a condition monitoring service (hereafter, "CMS"[*3]) for predictive maintenance by IoT and **NTN** sensing technologies in order to respond to the demand of energy saving, long and stable operation, and reduction of life cycle cost.

*3 Abbreviation of Condition Monitoring System

In the wind turbine area, **NTN** has already developed the condition monitoring system "Wind Doctor™." This development has been implemented in wind turbine systems with very favorable feedback **(Fig. 8)**.

For CMS to contribute to reduction of maintenance cost and improvement of equipment availability in the wind power generation business, highly accurate prediction and fault detection technology are required so that repair work can be scheduled at the right time with the remaining life of the components known.

For improved accuracy, data analysis technology and diagnosis algorithms must be developed, which integrate different kinds of information, such as operation and management of facilities, not only measurement data from sensors.

From these perspectives, **NTN** is promoting development of the CMS technology, effective for supporting maintenance activities, and intends to make specific proposals in the areas of railway vehicles, machine tools, and machinery equipment.

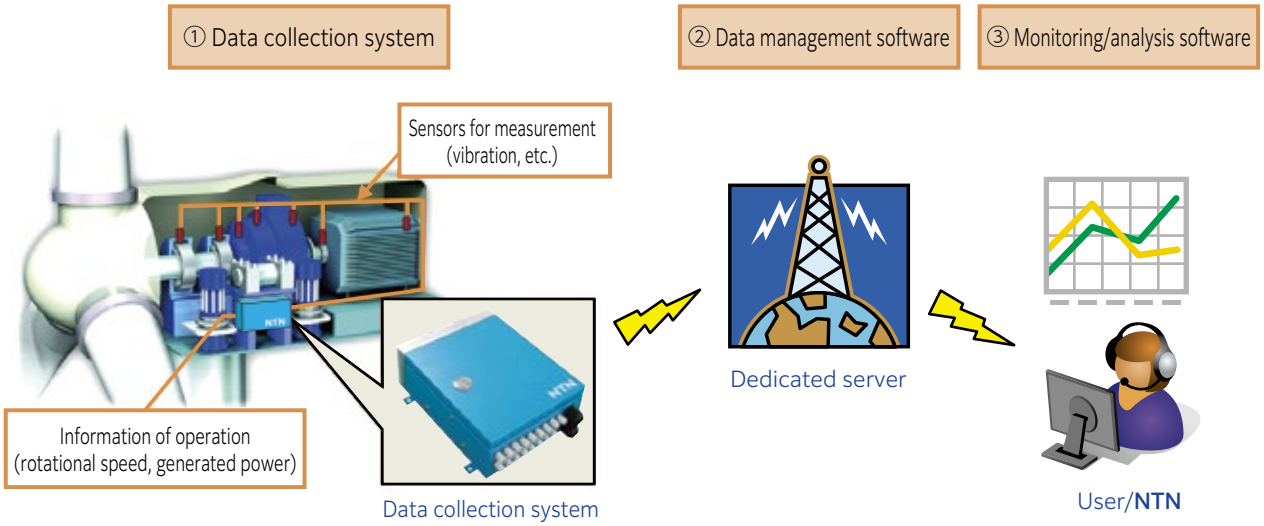


Fig. 8 System configuration of Wind Doctor™

4. Future Development

Changes in the market environment are about to occur.

・Carbon neutral
・DX(Digital transformation), IoT(Internet of Things)
・Reduction of productive population ratio

Challenges for rolling bearings are also changing in the midst of these changes. “Carbon neutral” raises expectations of renewable energy, especially wind turbines. The wind turbine facility will become increasingly larger and include offshore installations. Companies who can design and produce bearings that support rotors and blades of these turbines are few and far between, however, **NTN** can.

As mentioned previously, **NTN** is increasing the reliability of its bearings and contributing to the reduction of maintenance cost and increase of equipment availability in the wind turbine business through utilization of CMS.

NTN will also work on making bearings intelligent in the backdrop of “DX (digital transformation) and IoT (Internet of Things).” Moving forward, leveraging **NTN**’s sensing and analysis technologies, as well as AI (Artificial Intelligence), **NTN** will offer services to support efforts by users on fault prediction and predictive maintenance of bearings.

Adoption of automation and robots will accelerate due to the “reduction of productive population ratio.” In the area of industrial robots, high rigidity bearings are required for precise positioning. **NTN** is focused on development of bearings with higher rigidity within limited space. **NTN** is also marketing the “i-WRIST™” Wrist Joint Module, which leverages **NTN**’s base technology of bearings[13].

Bearings are also becoming a commodity due to the fierce competition of low-cost products. **NTN** is tackling the challenge of cost reduction as an important task by optimizing procurement of materials and components.

5. Summary

The rolling bearing will continue to be a critical machine element. **NTN** must strive to lead the world in technology development on the eternal objectives of “long operating life,” “ultra-high-speed,” “high rigidity” and “high reliability.” **NTN** is focusing on bearings that leverage IoT, condition monitoring and data collection of rotating machines, peripheral machines that utilize data, and development of applications, so that after 10 or 20 years, everyone will be amazed how rolling bearings have changed.

The **NTN** industrial machinery business remains indispensable, supporting development of world industry based on bearing technology and leveraging digital technology.

References

1) The history of NTN: 100 years (2019)
2) Masataka Nosaka, Satoshi Takada, Makoto Yoshida, Research and development of cryogenic tribology of turbopumps for rocket engines, Aeronautical and Space Sciences Japan, Vol. 58, Issue 681, (2010) 303-313.
3) NTN press release “Receives the Japanese Society of Tribologists, Technology Award” NTN website, https://www.ntn.co.jp/japan/news/press/news20030530_3.html
4) NTN Ball and roller bearings’ catalog, CAT. No.2203/J, A-19-21.
5) Kikuo Maeda, Hirokazu Nakashima, Hiroshi Kashimura, Development of Long Life TAB and ETA Bearings and Their Automotive Applications, NTN TECHNICAL REVIEW, No.65, (1996) 17-22.
6) Masahiro Yamada, Naota Yamamoto, Chikara Ohki, “ETFA” Bearings Strengthened by Fine Microstructure Design, NTN TECHNICAL REVIEW, No.88, (2020-2021) 99-104.
7) Keiichi Ueda, Technical Trend of the Precision Bearings for Machine Tools, Tool Engineer, Vol. 60 No. 16, (2019) 41-43.
8) Kazuki Sonoda, Tomohiko Obata, High Speed Machine Tool Main Spindle Bearings with Air Cooling Spacer for Grease Lubrication, Japanese Society of Tribologists, Proceedings for Tribology Conference 2020 Fall (2020) B-11 95-96.
9) Kazumasa Seko, Takashi Yamamoto, Asymmetrical Spherical Roller Bearings for Wind Turbine Main Shafts, NTN TECHNICAL REVIEW, No.86, (2018) 96-101.
10) Jin Takegahana, Mineo Koyama, Kouji Jinno, Yuya Tanaka, Angular Contact Ball Bearings for High-Speed and Heavy-Cutting Machine Tools, NTN TECHNICAL REVIEW, No.86, (2018) 56-61.
11) Shohei Hashizume, Yasuyuki Fukushima, Yusuke Shibuya, Yohei Yamamoto, Development of Sensor Integrated Bearing Unit for Machine Tool Spindles, NTN TECHNICAL REVIEW, No.86, (2018) 50-55.
12) Hideji Ito, Insulated bearing “MEGAOHM” series, NTN TECHNICAL REVIEW, No.71, (2003) 48-51.
13) Keisuke Kazuno, Hiroshi Isobe, Masaki Kagami, Jun Midomae, Yuki Shimura, Seigo Sakata, Yukihiro Nishio, Naoki Marui, Application Examples and Function Improvements of the Wrist Joint Module “i-WRIST™”, NTN TECHNICAL REVIEW, No.88, (2020-2021) 105-110.

Photo of authors

Etsu HARIMA

Operating Officer,
Corporate General Manager,
Industrial Business Headquarters