Activities Relating to Industry Bearing and Unit Products for Achieving a Carbon-neutral Society

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The automobile industry has entered a "once-in-a-century revolutionary era", and since the 2050 Carbon Neutral Declaration, the entire industry has been required to make major changes with no further delay.
This report introduces technologies and products contributing to a carbon-neutral society.

***Key Words**: industrial bearing. trend, carbon neutral, offshore wind turbine, hydrogen, superconductivity, magnetic bearing, precilence, high precision, FCEV, geothermal power generation, semiconductor, low temperature rise, ceramics, PFOA*

1. Introduction

Automobile industry is entering a “once-in-a-century revolutionary era”. It is affecting not only the automobile industry but also the industrial sector as a whole. The driving factors behind it are a declining workforce by Japan’s aging population and falling birthrates, along with developments for IoT and SDGs. Furthermore, in October 2020, the Japanese government officially announced its commitment to achieving carbon neutrality and a decarbonized economy by 2050. The announcement has now made decarbonization a matter of worldwide urgency. Under such circumstances, the usage environment and conditions of rolling bearings (bearings) are becoming harsher, and the needs for bearings are also diversifying. As a result, customers in a large number of fields that conventional bearings can no longer meet their needs is increasing. This report introduces some examples for contributing carbon neutrality such as long-life technology for industrial machinery equipment, semiconductor manufacturing equipment that is indispensable for IoT, AI and EV etc., robots that contribute to the efficiency of production lines due to the declining workforce, energy saving, renewable energy, hydrogen which is one of the promising candidates for next-generation energy for decarbonization.

2. Trends of Industrial Bearings and Units for Contributing Carbon Neutrality

The industry field has a wide base, and the usage environment and conditions are also diverse. Although it has become harsher and diversified, most areas in the industry field have fallen into price competition due to commoditization, and the shift of production bases to demand areas and the Asian region where production costs are low is accelerating. On the other hand, long-life technology including downsizing and lightening of industrial bearings, is a technology that can directly and indirectly contribute to carbon neutrality. Therefore, upgrading long-life material technology, heat treatment technology, various application compatible technology, experiment / analysis technology, etc. is a great opportunity to shift from the commodity fields to the value-added fields. Some technologies and products to meet these market needs are introduced in the following sections.

3. Technologies for Long-life

3. 1 Next-generation Long-life Bearings NK Bearings[1)]

In the industrial machinery fields that makes equipment such as agricultural and construction machinery, the usage environment and conditions of equipment are becoming harsher year by year, and the demand for extending the life of bearings contributed to the purpose of extending the life of the equipment is increasing. To meet these demands, we have mass-produced "NK bearings" that have achieved a long life level that was difficult to achieve with conventional technology.

Figure 1 shows the type of flaking, which is one of the bearing failures, and the countermeasures, and **Fig. 2** shows the development concept of materials for long-life bearings. Conventionally, it has been confirmed that "high hardness of the raceway surface" and "the appropriate volume of retained austenite (retained γ)" are effective for the flaking caused by foreign matter. In order to realize these studies, we have developed the

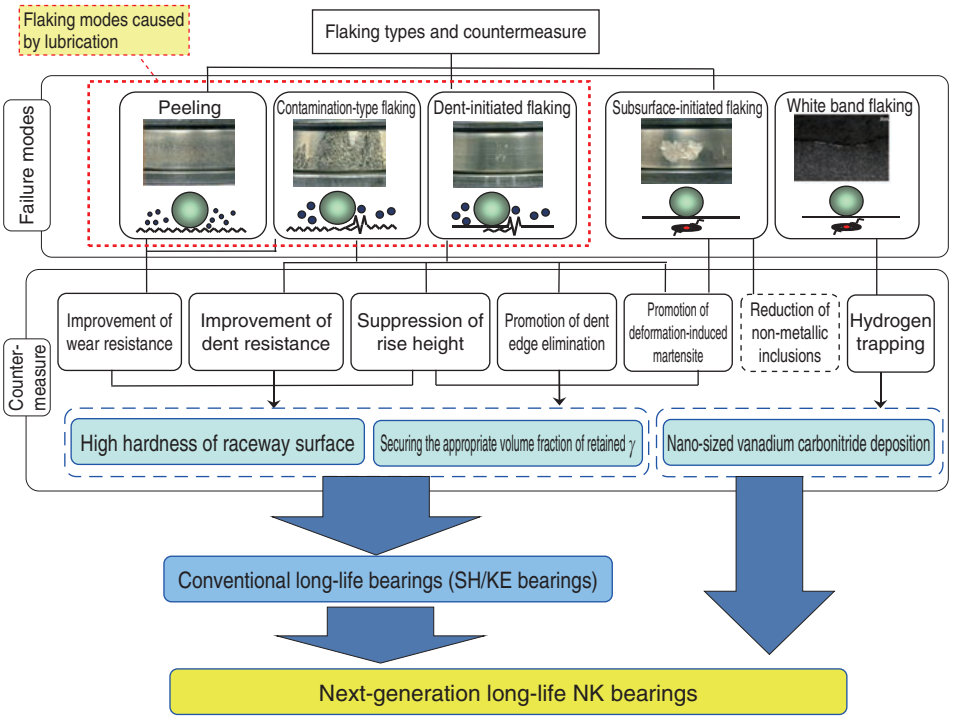


Fig. 1 Flaking types and countermeasures

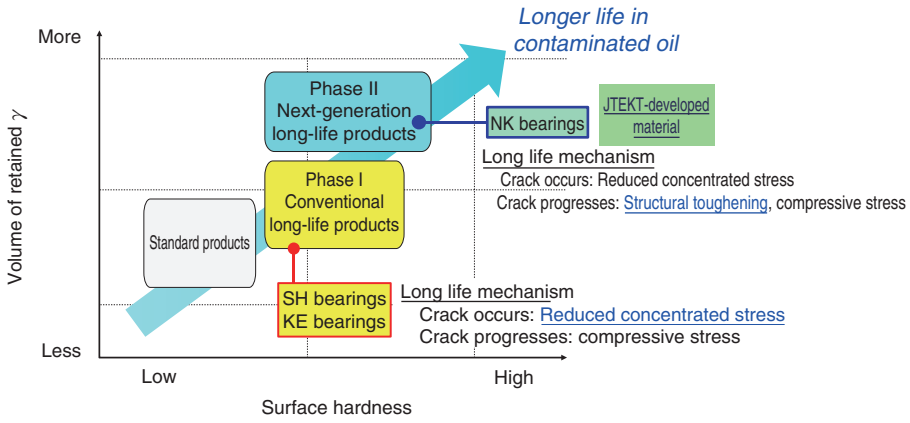


Fig. 2 Development concept of long-life bearing materials

Test equipment	Thrust load life test equipment
Test bearings	Tapered roller bearings $\phi30\times\phi72\times20.75$mm
Load	Fa = 25.89 kN
Rotation speed	2 000 min^{-1}
Lubrication	Gear oil 85W-90 (oil bath) In contaminated oil

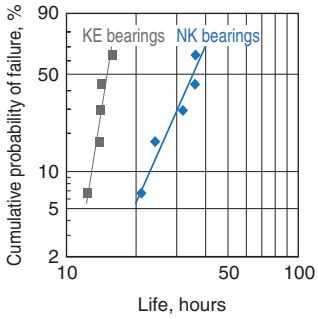


Fig. 3 Life test result of NK bearing in contaminated oil

optimum heat treatment technology and applied special heat treatment to SH bearings (special heat treatment is applied to bearing steel. Mainly applied to ball bearings) and KE bearings (special heat treatment is applied to case carburizing steel. Mainly applied to tapered roller bearings), is commercialized. The newly developed NK bearing is a product that has further extended bearing life by adding "Nano-sized vanadium carbonitride deposition" effect. NK bearings are next-generation long-life products "Phase II" with optimized material components and heat treatment conditions, as opposed to "Phase I", which was previously developed based on standard steel. NK bearings have achieved 1.5 times longer life than KE bearings which are conventional long-life bearings. **Figure 3** shows bearing life evaluation results of the NK and KE bearings in contaminated oil. In addition, recent research has shown that it is also effective for early flaking[2] with a willow-shaped white etching band in the cross section of the raceway surface for bearings for electrical accessories of automobiles, etc. Further expansion of NK bearings can be expected. We wish to contribute to the long-term stable operation of industrial machinery equipment with this bearings life extending technology.

4. Bearings for Semiconductor Manufacturing Equipment

4. 1 Bearings for Vacuum / Clean Environments for Complied with Environmental Regulations EXSEV®-EX

An amendment to the list of substances restricted under the European Union's REACH* regulation added PFOA (perfluorooctanoic acid) and related substances on July 4, 2020. We previously manufactured and sold DL bearings that use KDL grease with low-particle-emission in vacuum environments such as processes of oxidation and etching, etc.. But It was clarified that PFOA was emitted in the manufacturing process of this grease. Therefore, we have developed a vacuum / clean bearing "EXSEV®-EX" that uses grease manufactured without regulated substances in the manufacturing process. This product not only complies with environmental regulations, but also has the same or better performance in terms of low-particle-emission, outgassing, starting torque, running torque, sound, and life compared to competitor's products and conventional DL bearings. **Figure 4** shows a comparison of particle emission with competitor products and conventional grease, and **Fig. 5** shows a comparison of outgassing.

* REACH is an abbreviation for "Registration, Evaluation, Authorization and Restriction of Chemicals".

4. 2 Highly Corrosion-resistant Ceramics

Ceramics have lower toughness and poorer processability than metal materials, but on the other hand, they have excellent properties such as light weight, heat resistance, and corrosion resistance. **Table 1** shows the mechanical properties of various ceramics.[3] Compared to bearing steel, silicon nitride and silicon carbide have the characteristics of a density of 1/2 or less, coefficient of linear expansion of 1/4 to 1/3, light weight, and lower thermal deformation. On the other hand, there are ceramics such as zirconia that have similar characteristics to bearing steel.

Furthermore, we have developed a highly corrosion-resistant ceramic bearing, corrosion guard pro bearing-AZ (**Fig. 6**), which takes advantage of the characteristics of alumina-zirconia that does not contain Si in the material. Some semiconductor manufacturing equipment using this bearing can avoid the harmful effects of Si reaction products, and is expected to contribute to improving semiconductor productivity.

Figure 7 shows application of ceramics under various corrosive environments. Since various corrosive environments exist in CMP (Chemical Mechanical Polishing), cleaning process, etc., it is important to select suitable ceramics for each environment and apply them to bearings. We wish to contribute to the stable operation of semiconductor manufacturing equipment by providing suitable ceramic bearings for the usage environment and conditions of semiconductor manufacturing equipment.

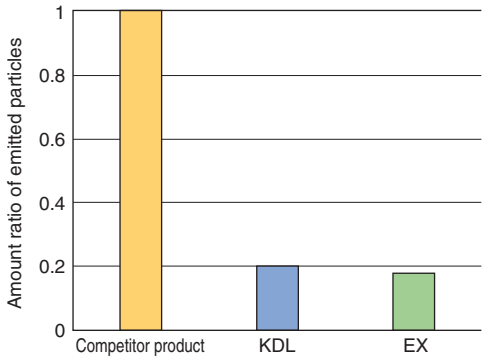


Fig. 4 Comparison of dust amount (Bearing)

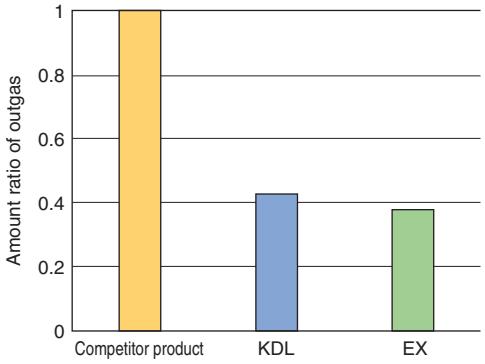


Fig. 5 Comparison of outgas (Grease)

Table 1 Mechanical properties of various ceramic materials

Property, units \ Ceramic material	Silicon nitride Si_3N_4	Silicon carbide SiC	Zirconia ZrO_2
Density, g/cm^3	3.2	3.1	6.0
Linear expansion coefficient, K^{-1}	3.2×10^{-6}	3.9×10^{-6}	10.5×10^{-6}
Vickers hardness, HV	1 500	2 200	1 200
Modulus of longitudinal elasticity, GPa	320	380	220
Poisson's ratio	0.29	0.16	0.31
Three-point bending strength, MPa	1 100	500	1 400
Fracture toughness, MPa·m$^{1/2}$	6	4	5
Heat resistance (in atmospheric air), ℃	800	1 000 or higher	200
Thermal shock resistance, ℃	750 or higher	350	350
Thermal conductivity coefficient, W/(m·K)	20	70	3
Specific heat, J/(kg·K)	680	670	460

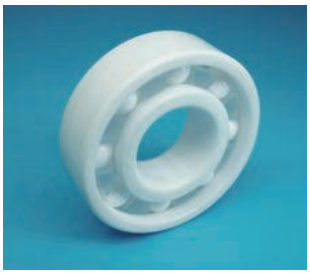


Fig. 6 Corrosion guard pro bearing-AZ (Alumina-zirconia)

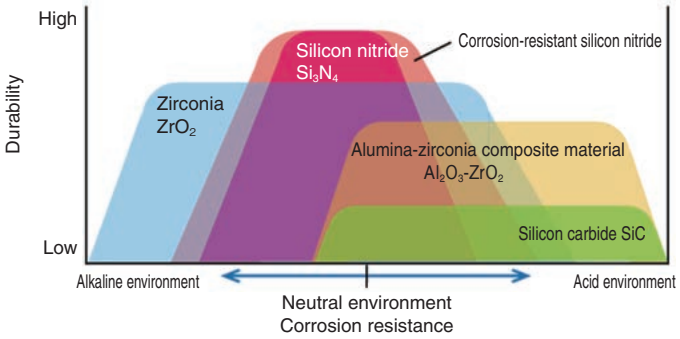


Fig. 7 Application of ceramics under various corrosion environments

5. Bearings for Robot Reduction Gears

One of the typical type of reduction gears for robots is a strain wave gearing. **Figure 8** shows their speed reduction mechanism. The bearing's inner ring is press-fitted into an oval camshaft (input shaft), and a wave generator (ultrathin ball bearing and oval camshaft) is deformed into an oval shape. One full rotation of the input shaft rotates the flex spline (output shaft) in the opposite direction by an amount equal to the difference in number of teeth. This amount of flex spline rotation is the output rotation speed. In addition, the bearing used for this reduction gear need to be easily deformed in order to follow the camshaft, therefore ultra-thin ball bearing (**Fig.9**) is used. Its thinness is even thinner than the 68 series of standard bearings (**Table 2**).

Figure 10 shows the performance requirements of strain wave gearing and the characteristics requirements of bearings. We wish to contribute to the stable operation of robots and robotic manufacturing lines using its robots by improving the performance and quality of bearings through optimized bearing materials, heat treatments, design, and production technology.

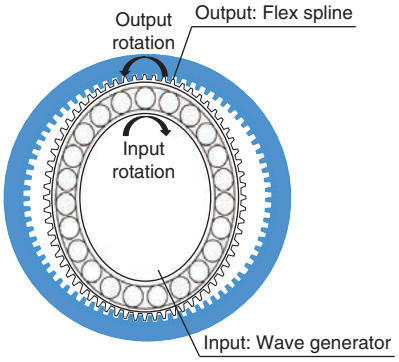
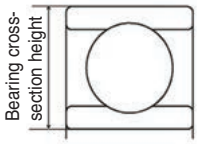
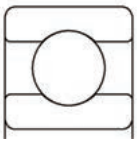


Fig. 8 Deceleration mechanism of strain wave gearing

Fig. 9 Ultra-thin ball bearings for strain wave gearing

Table 2 Design spec. for ultra-thin ball bearing

	Ultra-thin ball bearing (developed product)	68 series ball bearing (standard product)
Bearing cross-section		
Cross-sectional ratio (ball diameter/bearing height)	1.2	1
Bearing ring thickness ratio	0.6	1
Ratio of number of balls	1.3	1
Ratio of load capacity	1.5	1

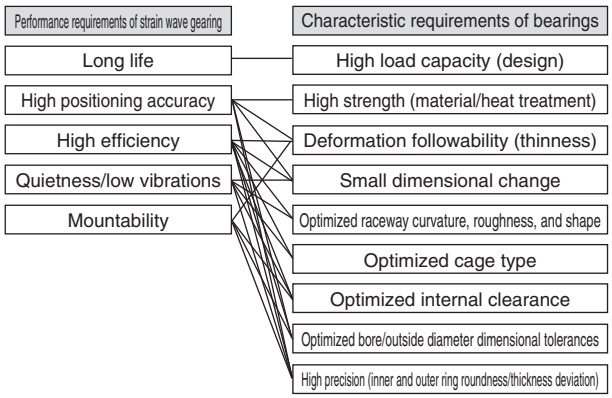


Fig. 10 Performance requirements of strain wave gearing and characteristic requirements of bearings

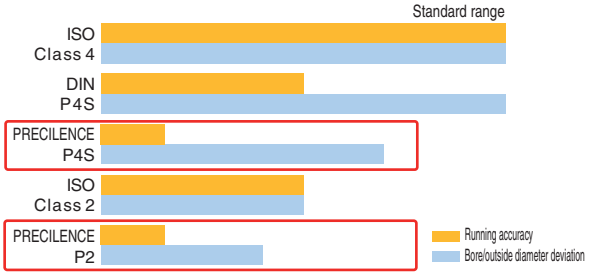


Fig. 11 Accuracy achieved by PRECILENCE

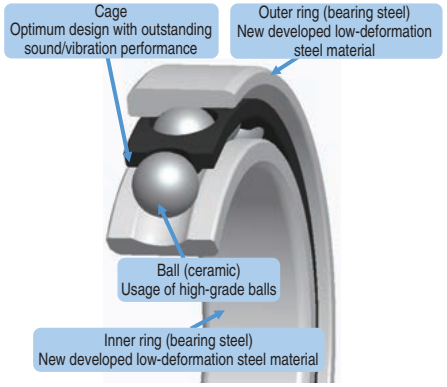


Fig. 12 Bearing structure of PRECILENCE

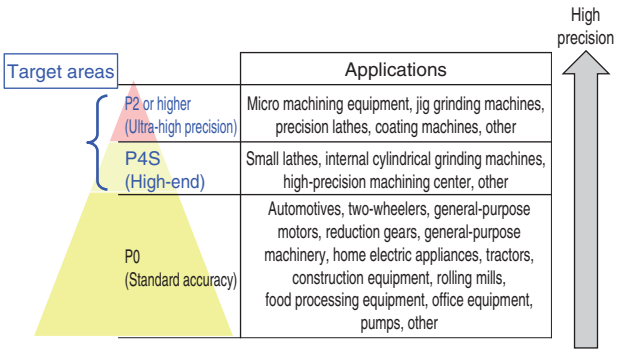


Fig. 13 Target area of PRECILENCE

6. Ultra-high Precision Bearings, PRECILENCE

The ultra-high precision bearing PRECILENCE was developed to meet the demands of higher machining accuracy and machining efficiency of industrial machinery equipment. **Figure 11** and **Fig. 12** show the achievement accuracy and bearing structure of PRECILENCE. Ultra-precision machining and micro machining are realized by the rotational accuracy that could not be achieved with conventional rolling bearings. At the same time, machining efficiency can be improved with high-speed performance, and the lubrication type can be changed (from oil lubrication to grease lubrication, etc.). Through these effects we wish to contribute to carbon neutrality by reducing the initial cost and life cycle cost. **Figure 13** shows the target area of PRECILENCE.

7. Energy-saving Technology

Reducing energy loss is one of the important efforts for achieving carbon neutrality. This section introduces a low-temperature rise technology, which is low friction torque technology, of oil bath lubricated tapered roller bearings for axles of Shinkansen. This is a technology that realizes a low-temperature rise thanks to the behavior control of lubricating oil by visualizing the behavior of lubricating oil and establishing an analysis method. In the oil bath lubricated tapered roller bearing (**Fig. 14**), analyzed to reduce the difference between actual lubricating oil behavior and CAE fluid analysis (**Fig. 15**) of it, and enabled the lubrication behavior analysis with CAE. As a result, we succeeded in reducing the temperature rise of the outer ring by about 6℃ (10%) compared to the current product by installing a labyrinth collar and a shield plate on the side face of the bearing (**Fig.16**) for controlling the behavior of lubricating oil. (Not adopted in the actual machine.) We wish to contribute to reducing the energy loss of rotating bodies using bearings by continuing to improve the fluid analysis and control technology.

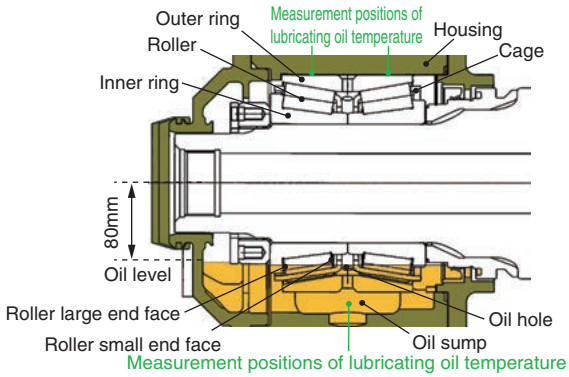
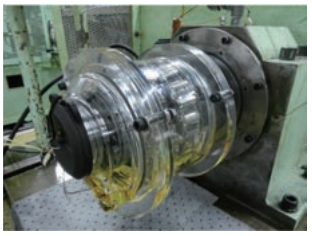


Fig. 14 Oil bath lubrication for tapered roller bearings



Visualization of lubricating oil behavior

CAE fluid analysis

Fig. 15 Visualization of lubricating oil behavior and CAE fluid analysis

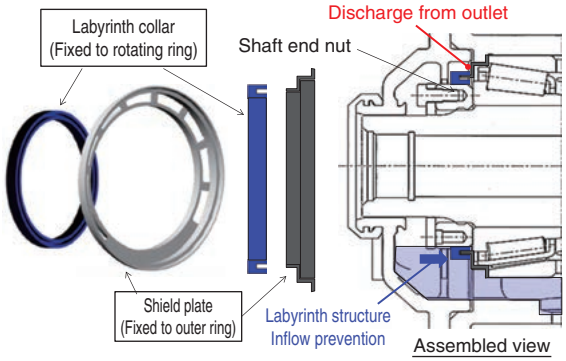


Fig. 16 Structure of developed product, assembled view

8. Contribution to Renewable Energy and New Energy

Table 3 shows the target values of reduction of CO_2 emissions and introduction of new energy for carbon neutrality. The target values of each new energy introduction will all be challenging. In order to achieve these figures, it is necessary for the public and private sectors to work together, and it is a major figures that cannot be achieved by conventional technology alone. Under these situation, we will introduce products, experimental technology, analysis technology, and sensing technology that have features not found in conventional bearings that can contribute to carbon neutrality.

Table 3 Target value of CO_2 emissions and introduction of new energy

	Current value	Medium-term target (2030)	Future target
Energy-related CO_2 emissions, tons	1.06 billion (2018)	Reduction from 930 million to 670 million (Announced by government in April 2021)	Virtually zero [Emission + Absorption] (2050)
Offshore wind power, kW	Nearly zero	10 million	30 to 40 million (2040)
Geothermal power generation, kW	593 000 (March 2020)	1.2 million (Announced by government in April 2021)	–
Hydrogen (installed capacity), tons	200 (2017)	Up to 3 million	20 million

8. 1 Main Shaft Bearings for Offshore Wind Power Generators

In 2050 carbon neutral, new capacity installations of offshore wind power generators (offshore wind turbines) will play an important role in achieving this. It is assumed that the wind turbine capacity per unit planned to be installed in Japan will be 10 to 15 MW, and the outside diameter of the bearing for main shaft is expected to be about ϕ3 to 5 m (**Table 4**, **Fig. 17**). In addition, in offshore wind turbines, a bearing design life with reliability coefficient 99%, and high reliability of 30 years or more are required because of the initial investment recovery and maintenance difficulty. We have developed a technology that measures the rolling element load distribution of actual bearings by accumulating the output data of the strain gauge attached to the roller in an ultra-small data logger and analyzing it (**Fig. 18**). Analyzed to reduce the difference between actual rolling element load distribution measurement results and FEM analysis (**Fig. 19**) of it, and enabled more accurate FEM analysis (**Fig. 20**). In addition, an actual size bearing evaluation testing machine (**Fig. 21**) have been already working. Through these efforts, we wish to contribute to improving the reliability of main shaft bearings for offshore wind turbines and to shorten the development period.[4)–6)]

Table 4 Summary of offshore wind turbines introduced in Japan

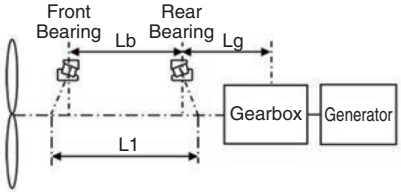
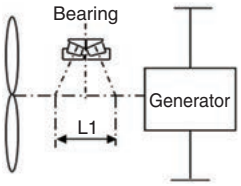
	Type 1	Type 2
Wind turbine capacity	10 to 15 MW	
Drivetrain structure		
Main shaft bearing type	 Single-row tapered roller bearing (× 2)	 Double-row tapered roller bearing
Bearing outside diameter	ϕ3m	ϕ5m

Fig. 17 Large size single-row tapered roller bearing

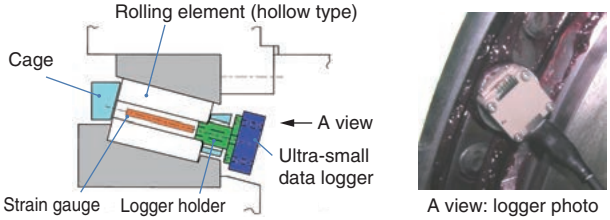


Fig. 18 Measurement method of rolling element load

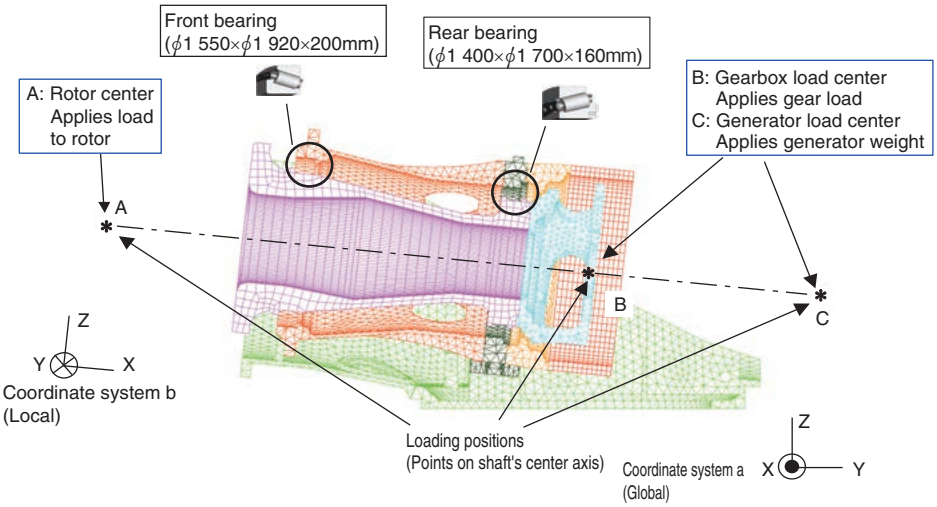


Fig. 19 FEM analysis model

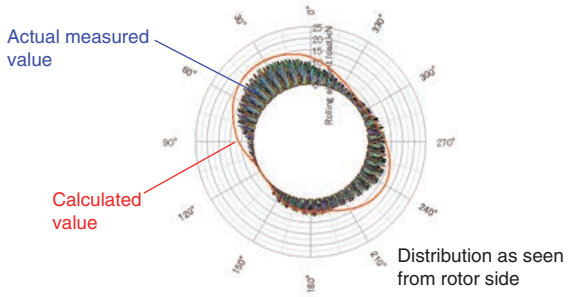


Fig. 20 Comparison of results obtained through actual measurement versus FEM analysis of rolling element load

Fig. 21 Actual size bearing evaluation testing machine

8. 2 Active Magnetic Bearings

Active magnetic bearings (magnetic bearings)(**Fig. 22**) are manufactured and sold by Koyo Magnetic Bearing Co., Ltd.* are attracting attention as products that can greatly contribute to the growth of new energy. Magnetic bearings have excellent features such as ultra-high speed rotation, energy saving, oil-free, maintenance-free, low vibration, and low noise because the rotating shaft is supported by electromagnetic force in a complete non-contact way. Taking advantage of these features, we wish to contribute to carbon neutrality with the aim of adopting it in the fields of hydrogen-related equipment, superconductivity, and renewable energy. **Figure 23** shows the target area of active magnetic bearings.

* It is a company jointly established by JTEKT Corporation and MUTECS Inc.

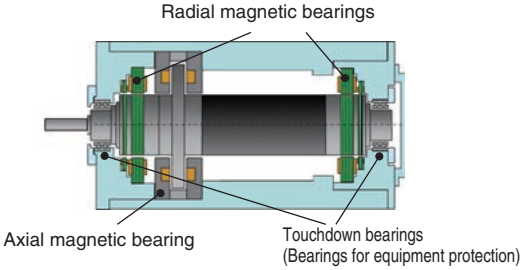


Fig. 22 Structure of active magnetic bearing

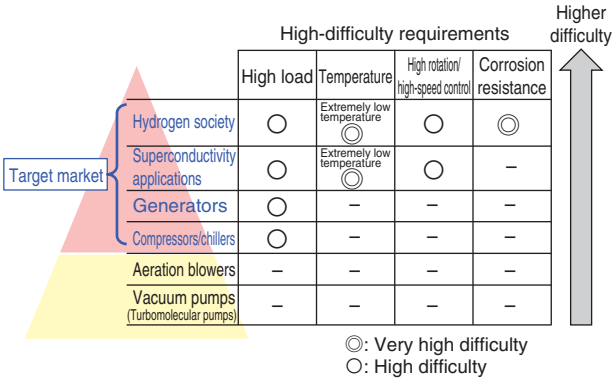


Fig. 23 Target area of active magnetic bearing

8. 3 Bearings for Hydrogen-resistant Environments EXSEV®-H2

Hydrogen fuel cell vehicles (FCEV), which generate power by generating electricity with hydrogen and oxygen, which is one of the carbon-neutral efforts in the automobile industry, are attracting attention as environment-friendly vehicles without CO_2 emission. In FCEV, in order to make effective use of hydrogen, a hydrogen circulation pump for reusing unreacted hydrogen in the fuel cell may be used. Since the bearings for the hydrogen circulation pump are used in hydrogen and steam, bearings that are resistant to hydrogen embrittlement*, and corrosion even in water vapor are required. Therefore, we have developed the bearings for hydrogen-resistant environments EXSEV®-H2 (**Fig. 25**), which has a durability that is more than 10 times that of the conventional product (**Fig. 24**) by adopting new materials and heat treatment. We wish to contribute to improving the safety and reliability of FCEV with this product.

* Phenomenon that the strength of metal is significantly reduced due to the intrusion of hydrogen.

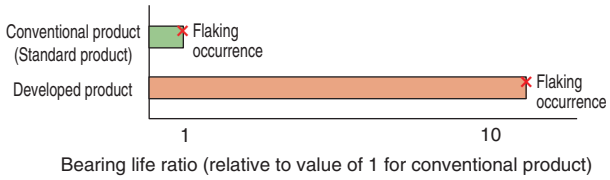


Fig. 24 Result of bearing life test under hydrogen atmosphere

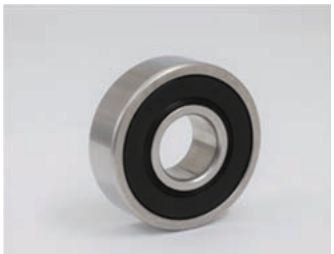


Fig. 25 Hydrogen-resistant bearing EXSEV®-H2

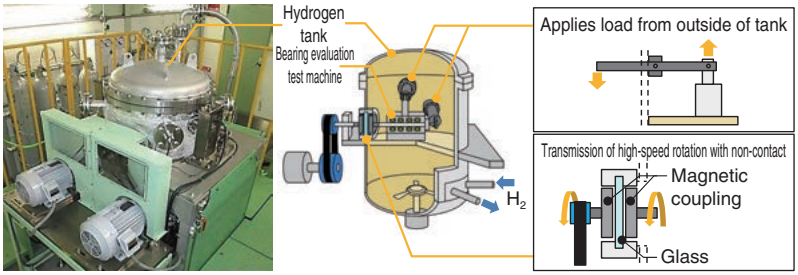


Fig. 26 Appearance and structure of testing machine

Table 5 Testing machine specifications

Items		Specification	Remarks
Hydrogen environment	Pressure	0.3 MPa	Less than high-pressure gas
	Purity	99.99% min.	Enclosed gas concentration
	Temperature	–30 to 120℃	Gas atmosphere temperature
Load	Radial	2.5 kN	Per bearing
	Axial	2.5 kN	
Rotational speed		10 000 min^{-1}	–

8. 4 Bearing Evaluation Testing Machine for Hydrogen Environments

Bearing evaluation testing machine for hydrogen environment was developed in 2019. This evaluation testing machine is first testing machine in this industry that can evaluate bearings under actual load and rotation conditions in a pure hydrogen gas environment. By adopting a special rotation transmission mechanism and loading mechanism, this testing machine can sustain the sealability of the hydrogen gas constant temperature tank* and can perform high-speed rotation test while applying radial load and axial load from the outside at the same time. In the future, we wish to contribute to the realization of a clean hydrogen society with zero emissions by using hydrogen environment evaluation technology. (This testing machine was also used to evaluate the bearings for hydrogen-resistant environments EXSEV®-H2 described in **Section 8. 3**.)

* A constant temperature tank is a container controlled to keep the internal temperature constant for a long time. In this case, the temperature of the hydrogen gas in the testing machine is sustained between –30℃ and 120℃.

9. Conclusion

In order to achieve carbon neutrality by 2050, major technological changes will be required. In recent years, a new work style called "remote work" has rapidly spread in the Covid-19 pandemic, and the CO_2 reduction effect* by remote work has also been calculated. In other words, changes are also required in the work style (development style). For this reason, by promoting digital transformation (DX), we wish to contribute to society by shortening the development period and constantly providing new technologies.

* If people who can work at home around the world work at home one day a week, their CO_2 emissions will be reduced by about 24 million tons / year (equivalent to London's annual CO_2 emissions).[7)]

*1 PRECILENCE is a registered trademark of JTEKT Corporation and DAIBEA Co., Ltd.

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