Prospects

NTN's Activities for the Electric Vehicle and Electrification of Automobiles

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With the Paris Agreement of 2015, countries around the world are stepping up efforts to become carbon neutral. Major countries such as Japan, the U.S., and the EU are aiming to achieve carbon neutrality before 2050 by expanding the introduction of clean energy and reforming their industrial structures. The automotive industries are accelerating the development and expansion of sales of electric vehicles that can reduce the generation of exhaust gas. This paper introduces NTN's products for energy-saving and electrification of automobile. The products contribute to carbon neutrality.

1. Introduction

Against the background of global warming, international efforts are accelerating toward achieving a decarbonized society, or, as it also known, carbon neutrality. The Paris Agreement adopted at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) in December 2015 set a long-term goal of limiting global average temperature increase to less than 2 ˚C above pre-industrial levels, with a further commitment toward a target of 1.5 ˚C below pre-industrial levels. To achieve this goal, the Paris Agreement targets early limits of greenhouse gas emissions and the achievement of carbon neutrality in the second half of the century. Furthermore, at COP26 in 2021, the 1.5 ˚C target was stated not as an aspirational target but as a shared global goal.

Based on the Paris Agreement, Japan's Ministry of Economy, Trade and Industry (METI) has led the formulation of a "Green Growth Strategy for Carbon Neutrality by 2050". The strategy calls for 100 % electric vehicles in new car sales by 2035 as one of the green growth strategies in the automotive industry, one of 14 sectors expected to grow in the future. The development and sales of electric vehicles, including EVs, are expected to accelerate in the future as part of efforts toward carbon neutrality. **Fig. 1** shows trends in automobile production and production forecasts for electric vehicles.

The trend of CASE **(Fig. 2)**, which collectively refers to Connected, Autonomous, Shared, and Electric (electrification), has come to the forefront as the prominent development trend in the automotive industry. For example, in the field of automated driving, the spread of various systems that support driving and drive control , turning, and stopping, which are the basic functions of automobiles, has been accompanied by a shift toward electrification, mainly through the use of by-wire systems. Against the backdrop of these trends, **NTN** is focusing on contributing to carbon neutrality and CASE by developing energy-saving and electrification-compatible products.

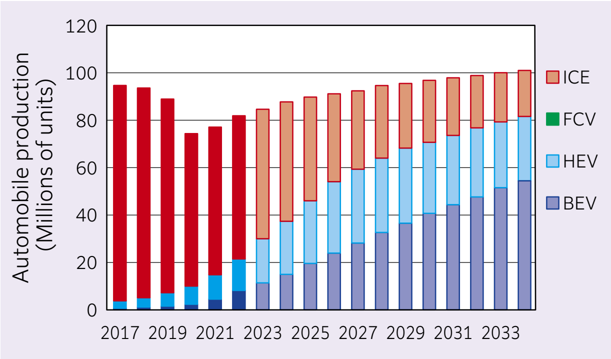

Fig. 1 Automobile production volume forecast[1)]

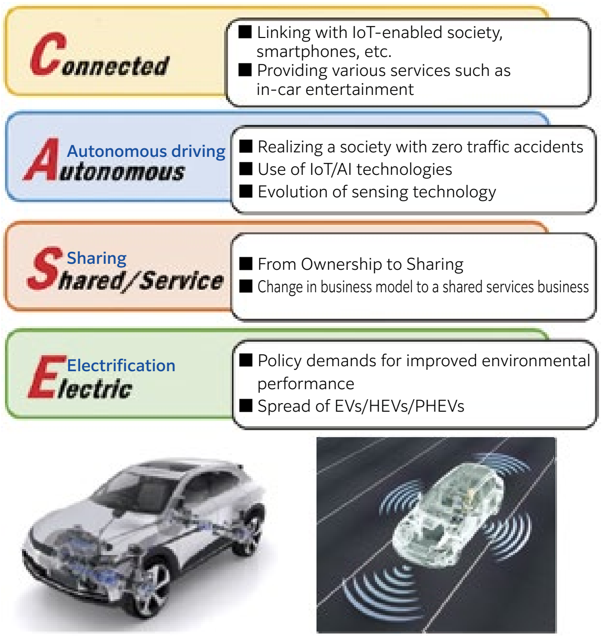

Fig. 2 Overview of CASE automotive trends

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2. Market Trends and Responding to These Needs with NTN's Research and Development

Table 1 shows market trends in the automotive industry, technological trends, and the products that **NTN** is developing to respond to market needs. A key challenge in electrification is to extend range while reducing power consumption. This is driving an increase in demand for compact, lightweight, low torque, and high efficiency components. There is also a growing demand for high-speed rotation drive motors to obtain higher motor output with the same size. Furthermore, as the overall weight of the drive unit is reduced and the housing becomes thinner, the rolling bearings are required to suppress creep phenomenon (whereby the mating surfaces of the housing and bearing gradually shift due to deformation of the outer ring caused by the load). In addition, to increase the efficiency of electric auxiliary equipment, there is a trend toward using lower viscosity lubricant and reducing the amount of lubricant supplied. The increasing use of rolling bearings under dilute lubrication conditions can increase the risk of premature bearing failure due to hydrogen embrittlement. **NTN** has developed long-life technology to prevent early bearing failure due to hydrogen embrittlement by applying new steel materials and special heat treatment technology.[2)]

On the other hand, many automakers expect that as the transition to higher levels of autonomous driving frees people from driving, it will increase demand for roomy, quiet vehicle interior space. This creates a need to improve flexibility in the layout of batteries and electric drive units, and to design components that contribute to the effective use of space. The increasing demand for SUVs in the global market and the trend toward longer wheelbases to increase battery capacity are increasing the minimum turning radius of vehicles. **NTN** is developing CVJs with higher angles and rear-wheel steering mechanisms to address this trend. In addition, to pursue safety and comfort, it is necessary to work on drive motors, brakes, suspension, steering, and system control that combines these components. **NTN** is also working to develop module type products for electrification by utilizing its core technologies in tribology, bearing design technology, mechatronics, and other areas. The following is a list of representative products developed by **NTN**.

3. Automotive products developed for EV and electrification

3.1 Deep groove ball bearing for high-speed rotation

The market for e-Axles is expanding due to the electrification of automobiles. Deep groove ball bearings, which support the motor shaft of e-Axles and the directly connected motor of reduction gears, are required to support high-speed rotation. As the rotational speed of deep groove ball bearings increases, centrifugal force causes contact between the cage pockets of the resin cage and the rolling elements (balls), which may result in seizure.

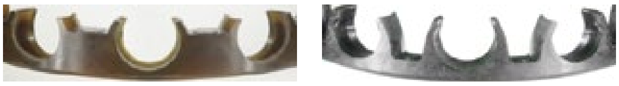
In response to this, we developed a high-speed deep groove ball bearing for EV/HEV with a new shaped resin cage that takes into account the deformation of the cage during high-speed rotation. We found conditions where $d_m n = 180 \times 10^4$ operation is possible with oil lubrication[3)]. Here, $d_m n$ is the product of the rolling bearing pitch diameter and rotational speed, and the unit is mm/min^{-1}.

Table 1 **NTN**-developed products that respond to market trends/technological trends/market needs for automotive electrification

Market trend	Technology trends	Developed products that meet market needs
Acceleration of electrification and energy saving	Downsizing and lightweighting	・Needle bearing unit for planetary gear reducers ・Creepless bearings
	Low torque	・Deep groove ball bearings with ultra-low friction seals ・Low Friction HUB Bearing Ⅳ
	Higher efficiency	・Higher efficiency fixed constant velocity joint CFJ
	Higher speeds	・High Speed Deep Groove Ball Bearing for EV/HEV
	Lower viscosity lubricating oil	・Hydrogen Embrittlement Resistant Bearings
Pursuing comfort	Drive stability	・Hub Bearing Modules with Rear Steering Function Ra-sHUB™
Pursuing safety	Improving electronic control technology	・Ball screw drive modules for electronic hydraulic brakes ・Electric oil pumps

The new shape resin cage has the following features. **Fig. 3** shows the appearance of the new shape resin cage.

(1) Adoption of high-strength materials
⇒ Improved rigidity and hot strength of cage
(2) Thickening of the pocket bottom to suppress deformation
⇒ Improved rigidity of the cage ring
(3) Thinned wall between cage pockets (weight reduction)
⇒ Reduction of centrifugal force deformation
(4) Installation of oil grooves on the inner surface of the cage pockets
⇒ Improved lubricity of cage and rolling elements



(a) Conventional product (b) New model product

Fig. 3 Exterior photo of resin cage

3.2 Deep groove ball bearing with ultra-low friction seal

We developed a deep groove ball bearing with ultra-low friction seal that reduces running torque by 80 % compared to the conventional contact sealed types by adopting a unique shaped low friction seal.

Rolling bearings used in electric drives such as e-Axles require not only long operating life but also lower torque. The conventional approach to preventing bearing operating life reduction caused by intrusion of hard foreign matter, such as gear wear particles generated in the reduction gears, has been to use contact sealed type bearings. But the problem with this was that the seal comes into contact with the bearing inner ring, which generates drag torque during rotation. In addition, the contact sealed type bearing is difficult to use in recent EV and HEV applications, which require high-speed rotation, due to the limitation of the circumferential speed limit of the seal.

Deep groove ball bearings with ultra-low friction seals employ a newly developed contact seal with arc-shaped (half-cylindrical shaped) micro convexes at equal intervals on the sliding contact zone of the seal lip to reduce running torque by 80 % compared to conventional products. This achieves a low-torque effect comparable to that of ball bearings with non-contact seals. During rotation, the wedge film effect of the micro convexes forms an oil film between the sliding surfaces of the seal and inner ring, significantly reducing seal drag torque despite the fact that it is a contact type seal. Furthermore, since the micro convexes on the seal lip are extremely small, they can prevent the intrusion of hard foreign matter harmful to the bearing, even through the lubricating oil, without the reduction of bearing operating life.

3.3 Needle bearing unit for planetary gear reducers

The needle bearing unit for coaxial e-Axle planetary gear reducers **(Fig. 4)** are compact in the axial direction. Planetary gear reducers with sun and ring gears in parallel on the same axis tend to use small-diameter, long-shaft planetary shafts. The bearings must be durable under high-speed rotation, dilute lubrication, and moment load conditions. Here we introduce needle bearings for planetary gear reducers that meet these needs.

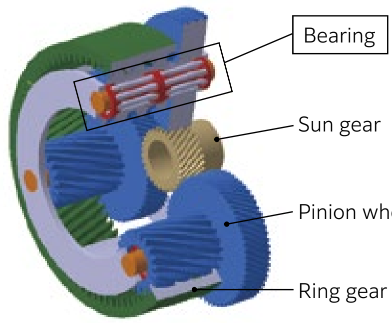


Fig. 4 Structure of co-axial type e-Axle planetary gear reducer

Needle bearing units for planetary gear reducers (bearing unit in **Fig. 4**) consist of rollers, cage, and shaft. The features of each component are as follows.

(1) Rollers (high carbon chromium steel, special heat treatment)
The crowning shape required for the function was optimized, reducing the maximum contact stress in a moment load environment.
(2) Cage (low carbon steel, carburized)
Improved cage fatigue strength by changing materials, optimizing weld geometry, and selecting the appropriateheat treatment (an improvement of 1.2 times compared to conventional products)
(3) Shaft (low carbon steel, special heat treatment)
Plastic deformation is reduced by selecting a material containing a lower amount of alloy components related to hardenability and by optimizing heat treatment (an improvement of 70 % compared to conventional products). The amount of retained austenite in the surface layer and surface hardness were optimized to improve durability.

3.4 Low Friction HUB Bearings

Over the years, **NTN** has conducted research and development in pursuit of lighter weight, longer operating life, and higher efficiency for hub bearings that support tire rotation. We have promoted the unitization of bearings and peripheral components, contributing to lower fuel consumption and improved ease of assembly through downsizing and lightweighting. We have developed products with longer operating life and lower torque through improvements in areas such as materials, heat treatment, grease, and seal structure. **Table 2** shows the Transition of improvements in low friction HUB bearings.[4)]

Recently, to respond to the global demand for improved fuel efficiency of automobiles and stricter CO_2 emission regulations, we have worked to further reduce torque by developing the Low Friction HUB Bearing Ⅳ" **(Fig. 5)**. The Low Friction HUB Bearing Ⅳ features a seal coating grease with a special thickening agent that reduces the running torque of the seal by 38 % compared to conventional grease while maintaining functions such as resistance against environmental contamination and low temperatures. Currently, the seal's performance is being evaluated, and the product will be introduced to the market as soon as possible. Furthermore, by optimizing the internal preload of the bearing and combining elemental technologies up to the Low Friction HUB Bearing Ⅲ[5)] **(Table 2)** developed in 2019, the bearing running torque was reduced by 67 % compared to Low Friction HUB Bearing Ⅰ.

Table 2 Transition of Improvements to Low Friction HUB Bearings

Low-torque technology application factor		Low Friction HUB Bearings			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ
Bearing	Bearing specifications, preload			○	◎
Bearing	Bearing interior grease		○	◎	←
Seal	Seal coating grease		○	←	◎
Seal	Lip design	○	←	←	←
Seal	Lip contact status		○	←	←
Seal	Number of lip contacts		○	←	←

○ : First return improvement, ◎ : Additional improvement

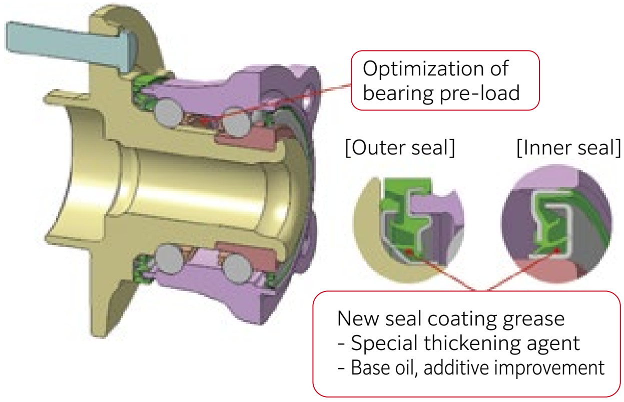


Fig. 5 Low Friction HUB Bearing Ⅳ

3.5 Higher efficiency fixed constant velocity joint CFJ[6)]

Power from engines and motors is transmitted to the tires via variable speed reducers and differentials through drive shafts. A key challenge for improving fuel efficiency and electricity costs in automobiles will be to reduce the torque loss of these power transmission paths.

The drive shaft consists of two constant velocity joints (CVJ), a fixed type and a sliding type, connected by a shaft, with a typical torque loss ratio of approximately 1 %. Here, we introduce the CFJ, which uses a proprietary spherical cross groove structure to reduce the torque loss ratio by more than 50 % compared to conventional products.

Fig. 6 shows the structure of the CFJ, which consists of an inner and outer ring with raceway grooves (tracks), eight balls that transmit rotational torque, and a cage that holds the balls. The torque loss of the CVJ is caused by energy loss due to friction between the parts. To reduce this internal friction, the CFJ has arc-shaped tracks on the inner and outer rings inclined in the axial direction and adjacent tracks arranged in mirror-image symmetry. In the conventional product, the load (**F1 and F2 in the figure**) of the ball pushing the cage is directed in one direction on all tracks. However, in the CFJ, the above-mentioned structure pushes the cage in different directions, so the internal forces cancel each other out on adjacent tracks, significantly reducing friction between internal parts compared to conventional products.

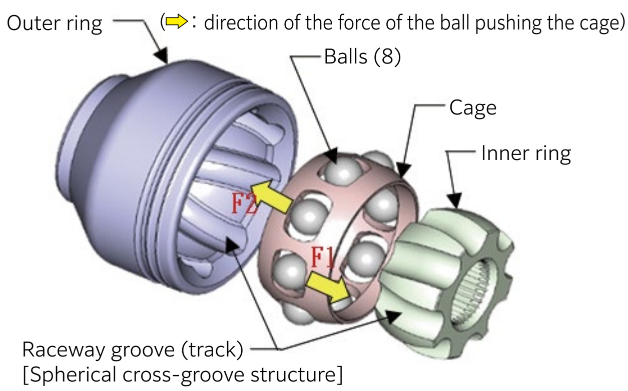


Fig. 6 CFJ structure and internal forces

CFJ achieved a torque loss ratio of less than 0.4 % (a reduction of 50 % or more compared to conventional products) at an operating angle of 9 degrees, enabling world-class transmission efficiency. The difference in efficiency from conventional products is known to yield corresponding improvements in fuel consumption and electricity costs. CFJ, which entered mass production in 2022, is expected to be a new product that can greatly contribute to decarbonization in the future.

3.6 Ball screw and ball screw drive module for electronic hydraulic brake

NTN has a strong track record in ball screws, one of our core technologies, for automotive applications starting in 2004, when mass production began. The features of **NTN** ball screws include (1) linear motion conversion efficiency of 90 % or higher, (2) high-load capacity **(Fig. 7)**, and (3) improved positioning and position retention due to the high reliability of circulating parts. **Table 3** shows examples of applications of **NTN** ball screws.

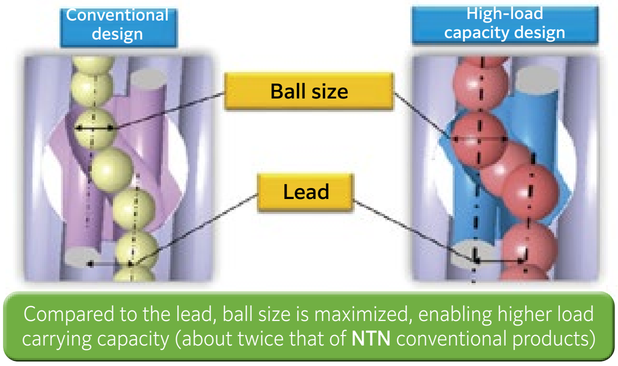


Fig. 7 Features of **NTN** ball screws

Table 3 Examples of applications of **NTN** ball screws

Location of application	Ball screw
AMT shift unit	
Variable valve lift mechanism	
Electronic hydraulic brake	**Fig. 8**

AMT : Automated Manual Transmission

As a modular product using ball screws, we introduce the ball screw drive module for electronic hydraulic brakes shown in **Fig. 8**. It is used in the brakes of vehicles such as EVs and HEVs as a regenerative mechanism that recovers kinetic energy during vehicle braking as electrical energy. To enable efficient recovery of kinetic energy as electricity, it is important to optimize the distribution of regenerative and hydraulic brakes so that they can instantly respond to changing braking effort. To address this issue, **NTN** has utilized its ball screw product technology to develop a ball screw drive module for electric hydraulic brakes that uses a motor drive to enable precise control of hydraulic brakes. We began mass production in 2012.

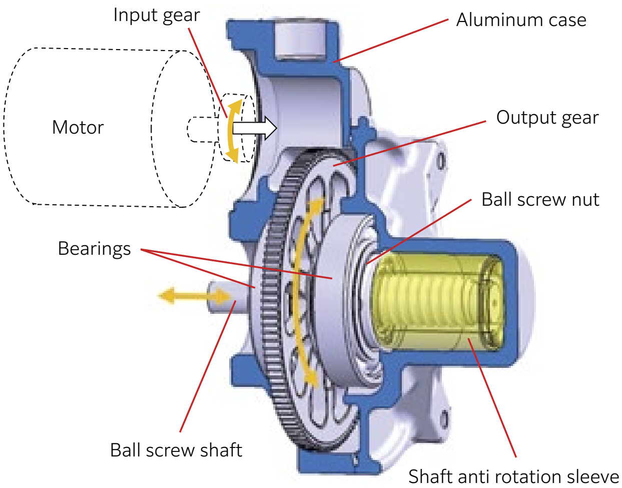


Fig. 8 Structure of the ball screw drive module for electronic hydraulic brake

As automatic braking becomes mandatory and more sophisticated, more responsive brakes will be required. Electric hydraulic brake systems are also being increasingly used to improve fuel efficiency and electricity costs. We believe that there will be a growing need for our ball screws and ball screw drive modules for electronic hydraulic brakes, which can contribute to a higher response of automatic brakes.

3.7 Electric oil pump

In ATs and CVTs, the clutch is operated hydraulically when starting and shifting gears. This hydraulic pressure is normally supplied by a mechanical oil pump driven by the engine. Electric oil pumps are increasingly being used to improve fuel efficiency by reducing oil pump drive loss and to secure hydraulic pressure and lubrication when the engine is stopped in vehicles equipped with a start-stop function. In recent years, the e-Axle, which integrates a motor, inverter, and reduction gearbox, has been used increasingly as a drive motor for EVs. The use of oil-cooled systems for cooling motors is expanding, as they offer a superior cooling effect to water-cooled systems and contribute to higher efficiency and smaller motors. It is expected that electric oil pumps will be increasingly used in electric vehicles. In response to this technological trend, **NTN** is developing an electric oil pump that can help enhance vehicle environmental performance **(Fig. 9**, **Table 4)**.

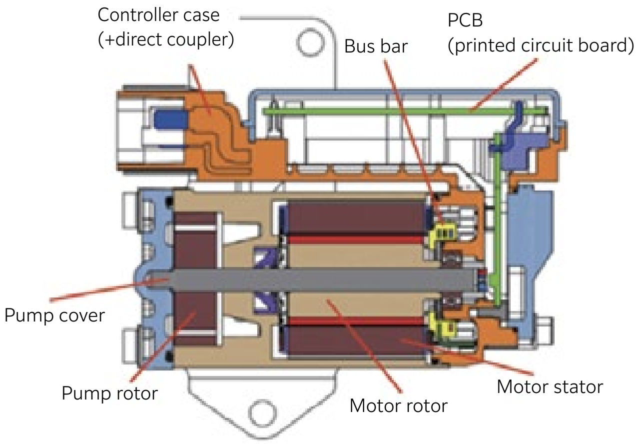


Fig. 9 Electric oil pump structure

Table 4 Electric oil pump specifications

Item	Details
Pump output	(1) 30 W or less (when used for idle stop) (2) 30-300 W (when used for e-Axle, etc.)
Voltage	12 V (to 48 V)
Hydraulic pump	Trochoid pumps (vane pumps)
Control	PWM (CAN compatible)
Features	- Lightweight and compact design achieved by the use of BLDC motors - Aluminum body for improved heat dissipation - Equipped with a rotation sensor to handle various operating conditions (low temperature, low RPM, etc.)

3.8 Hub Bearing Module with Rear Steering Adjust Function “Ra-sHUB™”

The hub bearing “Ra-sHUB™” with rear steering adjust function **(Fig. 10)** utilizes the strengths of our hub bearing base technology. We developed this as a steering system that adjusts to the driving condition of the vehicle, controlling the wheel steering angle and improving turning performance at low speeds and increasing vehicle stability at medium and high speeds.

Although first applied to mass-produced vehicles in the 1980s, rear-wheel steering systems were not widely used at that time because it was widely felt that the vehicle responded unnaturally to the driver’s operation of the steering wheel. In recent years, however, advanced control technology has made it possible to suppress the sense of an unnatural response. Adoption is increasing, particularly in luxury and sports cars. In addition, EVs tend to have a longer wheelbase and larger turning radius in order to secure battery installation space. There is a limit to reducing the vehicle radius of gyration by increasing the steering angle of the front wheels, and a rear-wheel steering system can assist in this reduction.

Conventional rear-wheel steering systems are limited to undercarriage structures such as multi-link systems. Structurally this made it difficult to achieve a large operating angle. The “Ra-sHUB™” integrates the steering shaft in the hub bearing with the steering mechanism, enabling installation in the same manner as conventional hub bearings, while maintaining a compact design. Regardless of the undercarriage structure that is chosen, it can be mounted on rigid axle structures such as torsion beams, and can be applied to rear-wheel steering systems with independent left and right wheels and large operating angles. Furthermore, the steering function can be housed in the wheelhouse, enabling effective use of space inside the vehicle.

Advantages of the rear-wheel steering system using “Ra-sHUB™” include the following.

(1) Reduction of vehicle turning radius
(2) Mounted on the left and right wheels, independent control of the steering angle
(3) Improved driving safety (vehicle attitude control)
(4) Improved fuel economy (reduced driving resistance)

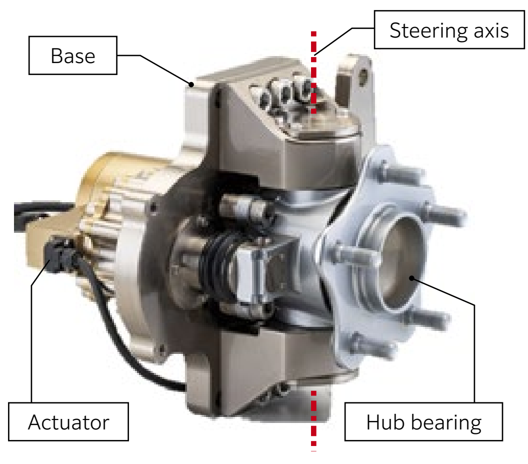


Fig. 10 Ra-sHUB™ (prototype)

4. Conclusion

In the automotive industry, technologies are being developed for carbon neutrality and CASE. This has driven changes in demand for the bearings, hub bearings, CVJs, and electric module products that we offer. **NTN** has been quick to identify these market trends, developing high value-added products with original technologies that lead to customer satisfaction. In this paper, we have introduced some of our recently developed products and technologies to respond to EVs and electrification in the automotive industry. In the future, we will continue to contribute to the promotion of carbon neutrality and the further development of the automotive industry through the development of new technologies and new products.

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