New Products

Introduction of Composite Material Products Used in Electrical Auxiliaries for Automobile

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The Composite Material Product Division at **NTN** has developed bearings, mechanical parts, and module products. These products make full use of tribology and are made of multi materials such as: resins, sintered metals, magnetic materials. In this article, we mainly introduce products for thermal management in automobiles.

1. Introduction

In recent years, the automotive industry has been in development of various technologies focused on the keyword of CASE. For example, motors and other power sources, inverters, and DC-DC converters are being developed for electrification. Meanwhile, cameras, sensors, and ECUs that integrate and control these accessories and their parts, are being developed for autonomous driving. As these accessories become smaller and lighter to improve the fuel efficiency and power consumption of automobiles, heat dissipation has become more difficult to manage due to the rise in heat generation of new automobile components. The addition of electrical and electronic devices that generate large amounts of heat due to high-speed, large-capacity communications (such as 5G) have made thermal management of the entire automobile an important theme for ensuring reliability. The shift to electric vehicles has also created new market demand for a quiet vehicle interior that offers a recreational environment free from the noise of a conventional engine.

This paper introduces examples of applications for composite material products and how they contribute to higher efficiency of accessories as they relate to thermal management of automobiles, and to improved cabin comfort.

2. Elastomer main shaft seal for electric compressors

The accessories related to thermal management are critical to the range and battery life of electric vehicles. This has led to the increased market demand for energy-saving and high-efficiency performance. These accessories contain various sliding parts made of high polymer materials (elastomers and resins) and their tribological properties are important.

While conventional internal combustion engine vehicles use belt-driven compressors powered by the engine, electric vehicles such as HEVs, PHEVs, and EVs use electric compressors. Electric compressors are used for cooling the cabin in HEVs and PHEVs, and for temperature control for batteries and other components – in addition to air conditioning in EVs. There are two types of compressors: scroll type and swash plate type.

Scroll type compressors are used because of their superior quietness. Scroll compressors use a main shaft seal that seals the refrigerant and refrigerating machine oil. **NTN** has developed a low-torque, low-leakage, BEAREE TP5300 main shaft seal that contributes to power savings and higher efficiency.

2.1 Structure of electric scroll compressors

A cross section of an electric scroll compressor is shown in **Fig. 1**. The refrigerant is compressed by the gyrating motion of the movable scroll, which is opposed to the fixed scroll. The movable scroll is driven by the rotation of the main shaft, and is supported by ball bearings. The main shaft seal has an inner diameter of about 20 mm with lips on both the inner and outer circumference to reduce leakage of refrigerant and refrigerating machine oil to the rotor side.

In EVs, electric compressors are used not only for heating and cooling, but also for the temperature management of batteries and other components. As a result, they operate for longer durations than in internal combustion engine vehicles. This has led to the need to improve the durability of electric compressors.

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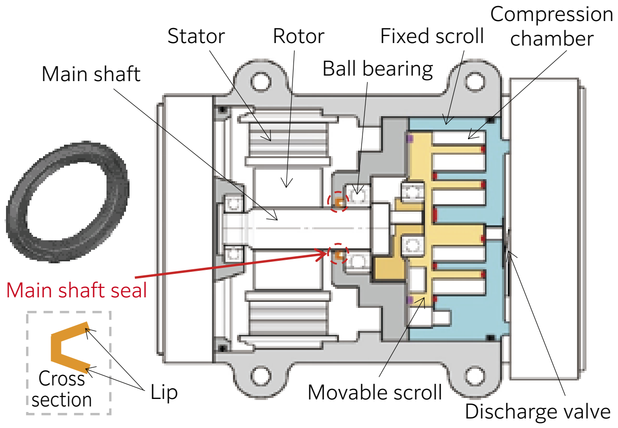


Fig. 1 Cross section of electric scroll compressors

2.2 Features of the BEAREE TP5300 main shaft seal

NTN's BEAREE TP5300 main shaft seal is made of a composite material that is formulated with a filling material in a thermoplastic elastomer – offering excellent friction and wear characteristics. Its flexibility (low elasticity) offers advantages such as low torque and low leakage. The lip reaction force caused by the interference with the shaft is small, and the lip tip (inner and outer sides) easily follow the shaft and housing. Further torque reduction is achieved by optimizing the lip design (thickness, angle, length, etc.).

Table 1 shows a performance comparison with a conventional polytetrafluoroethylene resin (PTFE) shaft seal. While conventional PTFE shaft seals are machined, the BEAREE TP5300 shaft seals can be injection molded, offering better design flexibility and reduction in manufacturing costs.

Table 1 BEAREE TP5300 and PTFE main shaft seal performance comparison

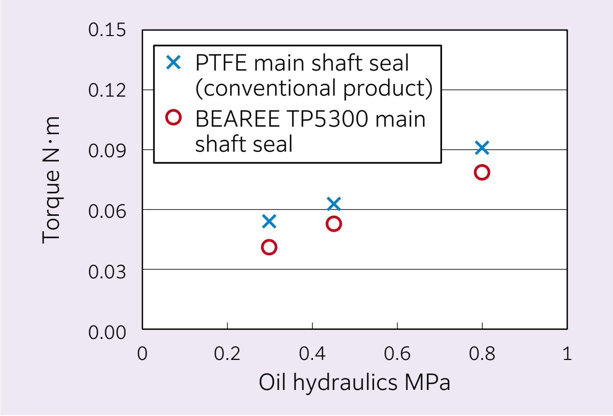
Item	BEAREE TP5300 main shaft seal	PTFE main shaft seal (Conventional product)
Base resin	Thermoplastic elastomer	PTFE
Processing method	Injection molding	Compression molding + machining
Flexibility of shape design	◎	△
Torque	◎	○
Leak	○	○
Durability	◎	△
Cost	◎	△

◎: Excellent ○: Good △: Acceptable

2.3 Friction and wear characteristics

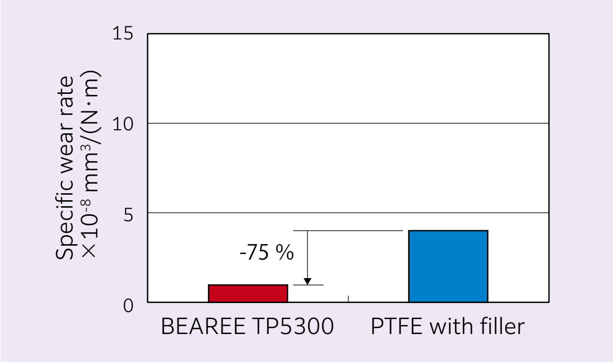
Fig. 2 shows the torque measurement results of the shaft seal in refrigerating machine oil. The torque of the BEAREE TP5300 shaft seal is 15 % to 25 % lower than that of the PTFE shaft seal, and the TP5300 seal has lower oil leakage. The oil leakage of the TP5300 seal is equivalent to the PTFE seal (less than 1 mL/min).

Fig. 3 shows the results of a wear test for BEAREE TP5300 and PTFE with filler, on a disc type testing machine. The BEAREE TP5300 has specific wear rate that is approximately one-fourth that of PTFE with filler.



<Test conditions>
PAG oil, Oil temperature 100 ˚C
Oil hydraulics 0.3 to 0.8 MPa
Rotation speed 7 500 min^{-1}, Steel main shaft

Fig. 2 Torque measurement results



<Test conditions>
Ring on disc type testing machine, PAG oil, Room temperature
Surface pressure 0.3 MPa, Speed 1 m/s
Opposing material SUJ2, 50 h

Fig. 3 Wear test results

3. Low torque plastic sliding bearings for electric water pump

Electric vehicles are equipped with an electric water pump that circulates cooling water, and an electric compressor for thermal management. Sliding bearings used in these pumps require even lower friction coefficients for lower fuel and power consumption.

NTN has developed a low torque plastic bearing with a significantly reduced friction coefficient in cooling water. This bearing features special lubrication grooves on the thrust surface of a PPS sliding bearing. This bearing is made of a proprietary composite material[1)2)] that combines materials such as polyphenylenesulfide (PPS), polytetrafluoroethylene resin (PTFE), and carbon fiber (CF).

3.1 Role and structure of electric water pump

Electric water pumps are classified by high-flow, medium-flow, and low-flow types, with each type having a different purpose in a vehicle. The high-flow type electric water pump is used for engine cooling, the medium-flow type is used for cooling the batteries, motors, and inverters, while the low-flow type is used for cooling and heating intercoolers and exhaust gas recirculation equipment.

Fig. 4 shows a cross section of a typical electric water pump. The rotor includes: the impeller, magnet, and sliding bearing, and is found in the pump housing. Meanwhile, the stator is arranged opposite the magnet and is freely supported by the shaft through the sliding bearing. The magnetic field generated by the energization of the stator causes the rotor to rotate about the shaft. Since the impeller is integrated with the rotor, the impeller rotates as the rotor rotates, and the cooling water is sucked into the pump housing.

The inner diameter of the sliding bearing is about 4 to 10 mm. During rotor rotation, radial and axial loads are generated. This causes the inner diameter surface and shaft of the sliding bearing, and the thrust surface and the thrust pad, to slide in the cooling water. The sliding bearing is pressed against the thrust pad on the impeller side, and the axial load is larger than the radial load. The frictional resistance of the thrust surface is thus greater than that of the inner diameter surface. To reduce the frictional resistance of the sliding bearing, it is therefore necessary to reduce the frictional resistance of the thrust surface.

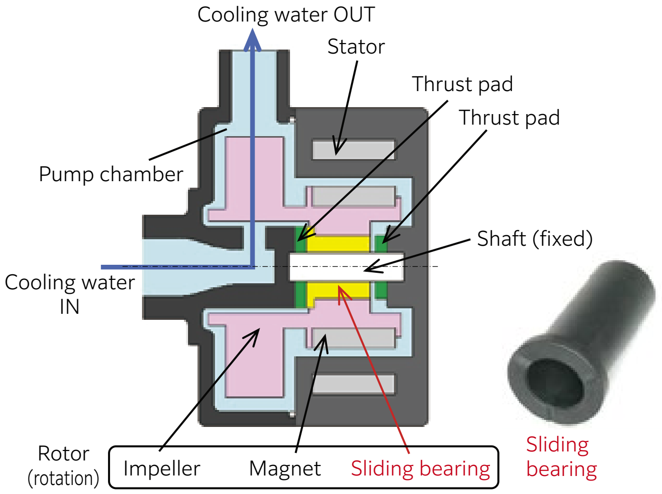


Fig. 4 Structure of electric water pump

3.2 Bearing thrust surface lubrication groove shape

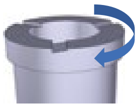
Sliding bearings in electric water pumps maintain low friction and low wear under good lubrication conditions (high speed and low load). However, during startup, shutdown, and when there is localized water film loss during operation, the friction coefficient increases due to contact between the sliding bearing and the thrust pad – increasing the likelihood of wear. As a countermeasure, lubrication grooves are included on the thrust surface of the sliding bearing.

In general, a rectangular lubrication groove shown in **Table 2(b)** is used as a lubrication groove on the thrust surface in sliding bearings for electric water pumps. This rectangular lubrication groove penetrates radially from the bearing bore to the outer diameter. The cross section has a simple rectangular shape, so it is conventionally applied to machined products such as the carbon sliding bearings used in water pumps.

NTN's low torque plastic bearings instead have special lubrication grooves on the thrust surface of the PPS sliding bearing, as shown in **Table 2(a)**. These special lubrication grooves have a shape that enables material transfer during injection molding. As shown in **Fig. 5**, the special lubrication grooves are designed so that the grooves gradually become shallower in the counter-rotational direction of the bearing. This causes cooling water to be forced into the shallower grooves during bearing rotation, and generate pressure by the hydrodynamic effect. As a result, the cooling water can easily penetrate the thrust sliding surfaces of the bearing.

Fig. 6 shows the dynamic friction coefficient in cooling water for three types of PPS sliding bearings with three shapes of thrust surface: one with special lubrication grooves, one without lubrication grooves, and one with rectangular lubrication grooves on the thrust surface. The dynamic friction coefficient of the PPS sliding bearing with special lubrication grooves is 65 % lower than that without lubrication grooves, and 30 % lower than that with rectangular lubrication grooves.

Table 2 Shape of lubrication grooves on thrust surface of each thrust bearing

Item	(a) Special lubrication groove	(b) Rectangular lubrication grooves	(c) No lubrication grooves
Thrust surface lubrication groove shape	Rotational direction of bearing 		
Sliding area ratio	0.88	0.95	1 (reference)
Pressure, MPa	1.06	1.00	0.93

Note: Surface pressure is the value in the test (load 128 N) described below.

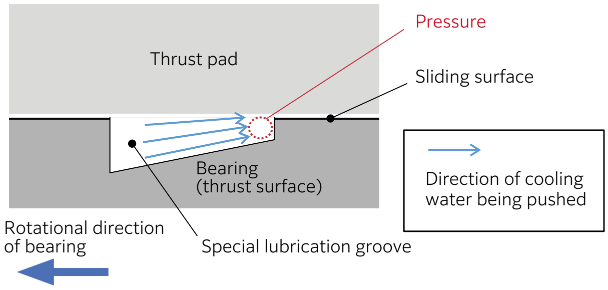
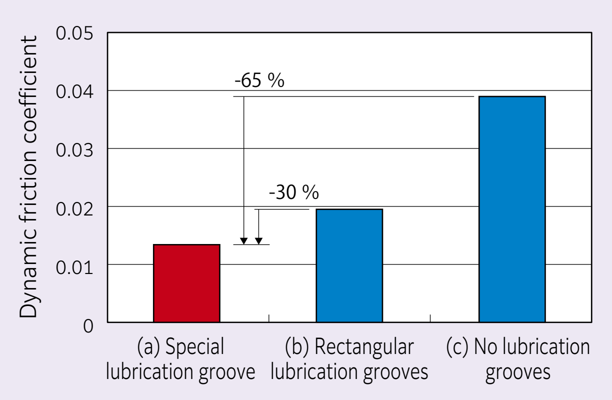


Fig. 5 Hydrodynamic effect from special lubrication grooves



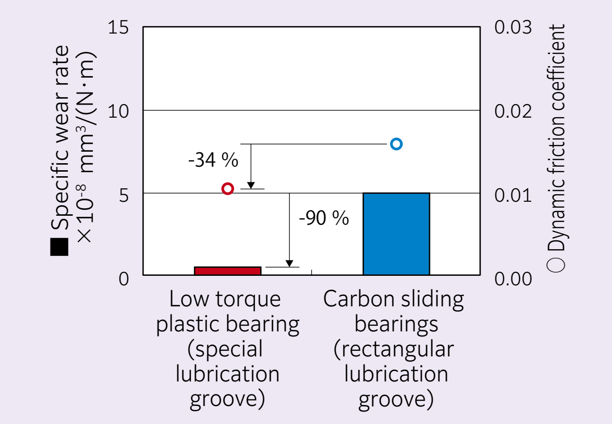
<Test conditions>
Ring on disc type testing machine cooling water (ethylene glycol 50 % concentration), Room temperature, 128 N load (surface pressure approx. 1 MPa), Speed 125 m/min, Opposing material SUS304

Fig. 6 Relationship between shape of lubrication grooves on thrust surface and dynamic friction coefficient

3.3 Friction and wear characteristics

Fig. 7 shows the results of friction and wear tests in cooling water for a low torque PPS sliding bearing, and a conventional carbon sliding bearing with three rectangular lubrication grooves as shown in **Table 2 (b)**. The low-torque plastic bearing (with special lubrication grooves) had a 34 % lower coefficient of dynamic friction and 1/10 th the specific wear rate as compared to the carbon sliding bearing (rectangular lubrication grooves). This difference in the dynamic friction coefficient is similar to the results for the rectangular lubrication groove and the special lubrication groove shown in **Fig. 6**.

Low torque plastic bearings are made of PPS composite material with fillers suitable for sliding in cooling water. These bearings have special lubrication grooves on the thrust surface, which provide lower friction and wear characteristics compared to carbon sliding bearings (rectangular lubrication grooves). Low-torque plastic bearings have various other excellent properties, as shown in **Table 3**.



<Test conditions>
Ring on disc type testing machine, Cooling water (ethylene glycol 50 % concentration), Room temperature, 128 N load (surface pressure approx. 1 MPa), Speed 125 m/min, Opposing material SUS304, 50 h

Fig. 7 Friction and wear characteristics of each type of sliding bearing

Table 3 Comparison of properties of each type of sliding bearing

Item	Low torque plastic bearing (special lubrication groove)	Carbon sliding bearings (rectangular lubrication groove)
Processing method	Injection molding	Machining
Chemical resistance	◎	◎
Impact resistance	○	△
Flexibility of shape design	◎	△
Friction properties (in cooling water)	◎	○
Wear resistance (in cooling water)	◎	○
Cost	◎	△

◎: Excellent ○: Good △: Acceptable

4. Sintered hydrodynamic BEARPHITE headlight cooling fan

In conventional internal combustion engine vehicles, the sound from interior accessories is typically less noticeable due to the noise of an internal combustion engine. With no more engine noise, the electrification of automobiles has led to a growing demand for quieter interior accessories reliable over a wide range of temperatures.

In recent years, energy-saving and long-life LED lights have entered the mainstream for headlights.

These require higher current to provide a visible light intensity, but subsequently result in a large amount of heat generated in the LED circuit board. The need for thermal management is therefore increasing, and the cooling fan motor used for heat dissipation **(Fig. 8)** must have stable performance over a wide temperature range, from low temperatures (- 40 ˚C) to high temperatures (100 ˚C).

NTN has developed a hydrodynamic bearing, Hydrodynamic BEARPHITE **(Fig. 9)**, that meets these requirements and is quiet over a wide temperature range.

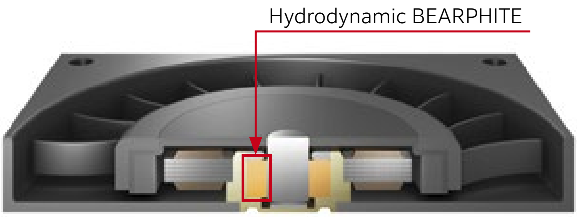


Fig. 8 Cooling fan motor

Fig. 9 Hydrodynamic BEARPHITE

4.1 Excellent quietness

Hydrodynamic BEARPHITE is a type of oil-impregnated sintered bearing manufactured by powder metallurgy and has herringbone-shaped hydrodynamic grooves on the bearing inner diameter **(Fig. 10)**. The hydrodynamic effect generated by shaft rotation forms an oil film in the bearing clearance and supports the shaft and bearing without contact.

Fig. 11 shows the results of determining the presence or absence of contact between the shaft and Hydrodynamic BEARPHITE by the electrical resistance method. This is done to confirm the difference in oil film formation depending on the presence or absence of hydrodynamic grooves. Based on the detected voltage, the oil film formation rate was set to 0 % for the contact state and to 100 % for the non-contact state. These results indicate that hydrodynamic grooves can support the shaft without contact.

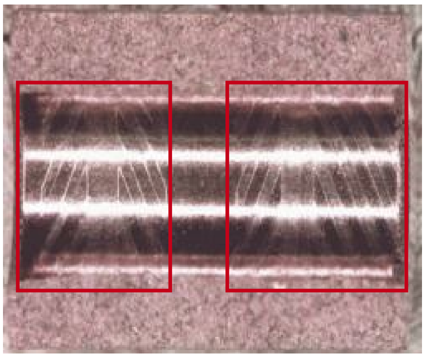


Fig. 10 Hydrodynamic BEARPHITE inner surface (red outlined areas: hydrodynamic grooves)

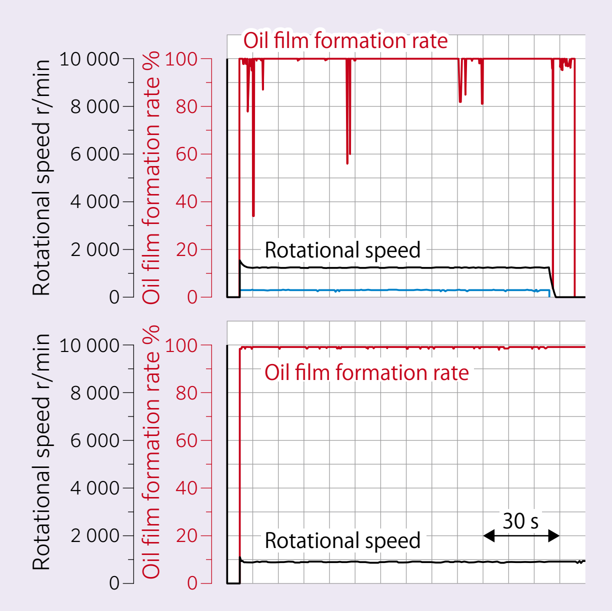


Fig. 11 Difference in oil film formation depending on presence or absence of hydrodynamic grooves (upper: no hydrodynamic grooves; lower: with hydrodynamic grooves)

Where a drop in oil film pressure is a concern[3], Hydrodynamic BEARPHITE generally remains quiet at low rotational speeds. This is why it is popularly used in cooling fan motors for information equipment, such as thin-type notebook PCs and mobile terminals. It is also being used in cooling fan motors for headlights because of its excellent quietness over a wide range of rotational speeds, from low to high speeds.

4.2 High reliability over a wide temperature range

In headlights, the bearing performance remains stable because of the minimum change in lubricant viscosity expected, over the wide temperature range required for headlights. A significant drop in lubricant viscosity at high temperatures reduces the hydrodynamic pressure effect generated by shaft rotation. However, the Hydrodynamic BEARPHITE, which applies a less viscous lubricating oil that decreases at high temperatures, offers excellent temperature characteristics when compared to conventional products. **(Fig. 12)**

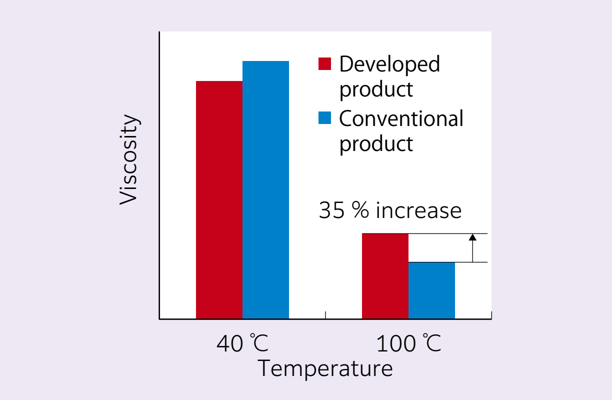


Fig. 12 Relationship between lubricating oil temperature and viscosity

Fig. 13 shows the eccentricity ratio calculation results of the shaft at high temperatures (100 ˚C). The eccentricity ratio is the ratio of shaft center displacement to radial clearance, and a lower eccentricity ratio means a larger minimum film thickness. The Hydrodynamic BEARPHITE can significantly reduce the eccentricity ratio as compared to conventional products, ensuring better bearing reliability over a wide range of temperatures.

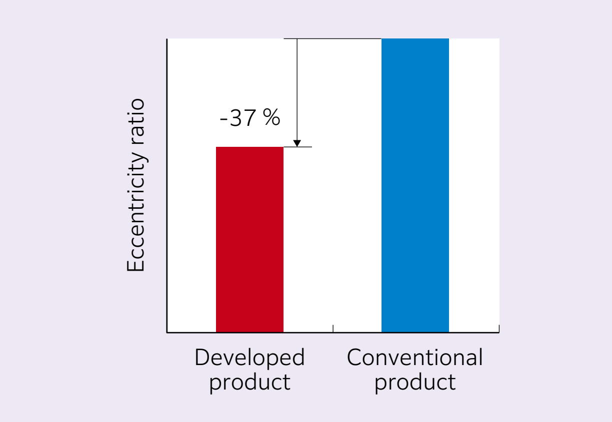


Fig. 13 Eccentricity ratio calculation results

Furthermore, as a feature of the powder metallurgy process, Hydrodynamic BEARPHITE can retain ample lubricant in the pores on the bearing surface layer and inside the pores **(Fig. 14)**. Therefore, even if the assumed operating temperature range is exceeded, there is an effect of suppressing seizure due to the contact between the shaft and the Hydrodynamic BEARPHITE.

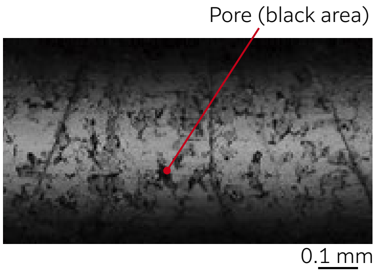


Fig. 14 Surface condition of Hydrodynamic BEARPHITE

5. Conclusion

This paper introduces a case in which **NTN**'s bearings and elemental parts made of resin, sintered metal, and other materials were adopted to save energy in automobiles and provide a comfortable cabin interior.

Thermal management has become vital to the development of vehicle electrification, autonomous driving, and connected automobiles. The UN-R51 international standard for four-wheeled vehicle noise has entered Phase 3 and is becoming stricter. In Phase 3, tire noise is taken into account, and the noise level during driving is required to be reduced from the level of a vacuum cleaner in Phase 2 to that of a washing machine. In addition, in a future where autonomous driving frees drivers from driving operations, it is expected that the demand for a quieter interior space will rise.

We will continue developing products and technologies that are key to improving thermal management and vehicle interior habitability, thereby contributing to the development of a mobile society with vehicles at its core.

References

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