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# Development of Direct-Cooling Technology for In-Wheel Drive System

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We are developing a small and lightweight direct-drive system towards realization in-wheel EVs. To achieve the world-class 2.5kW/kg power density of motor, we developed a direct-cooling motor that immersed core, coils and magnets in cooling oil and improved cooling efficiency. We conducted heat-run test on the test bench, it was demonstrated that direct cooling is effective and continuous operation is possible. Additionally, it was found that the coil temperature can be controlled by the flow rate of the cooling oil. In this paper, we report the concept of direct cooling and the results of the measurement.

## (1) Concept of direct cooling

As a method of liquid cooling for motor, there are two types of cooling method, water cooling and oil cooling. Oil cooling is easy to improve the cooling efficiency compared with water cooling in order to heat transfer directly from the heating site to the cooling oil. In conventional oil cooling, cooling oil is flown by the high speed rotating rotor, or is splayed into the coils.

We are developing direct cooling to increase the output density more than conventional oil cooling. Fig. s1 shows the concept. In the direct cooling, all the inside of the motor is filled with cooling oil and the heating part is completely immersed with oil. The heat transfer rate from the heating site to the cooling oil is increased by pumping cooling oil, and the contact area between the heating site and the cooling oil is also increased. Therefore, the cooling efficiency is further enhanced, compared with conventional oil cooling.

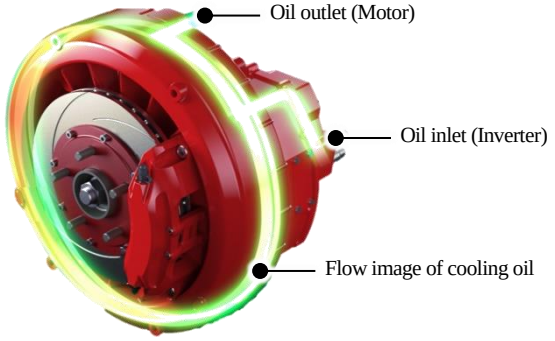


Fig. s1. Concept of direct cooling.

## (2) Heat run test

The heat run test of the actual in-wheel motor was carried out on the test bench. It circulates while cooling oil is cooled by the oil circulation system, and it is energized until the outlet temperature of the coil end temperature and cooling oil is saturated. When the temperature of each part is saturated, it increases the copper loss by increasing the current, and continues the energization until the temperature is saturated again.

The results are shown in Fig. s2 and Fig. s3. Loss and coil end temperature rise are proportional, and even under operating conditions of equivalent to 50% of the maximum output, the temperature rise of the coils were 50K or less. Therefore, the cooling effect of direct cooling has been demonstrated. In the motors like direct drive that have a large percentage of copper loss in total loss, we confirmed that the flow rate and the coil temperature of the cooling oil were inversely related.

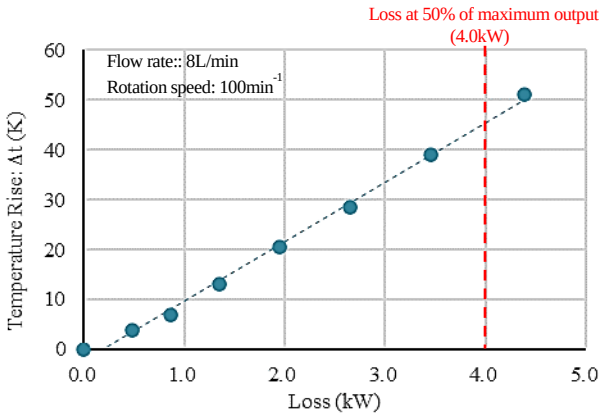


Fig. s2. Relationship between loss and temperature rise.

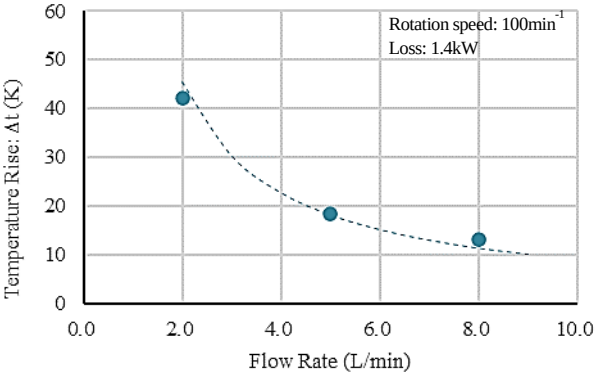


Fig. s3. Relationship between flow rate and temperature rise.