Development of Compact High-Performance Motor with Hermetically Sealed Cooling Structure

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KEY WORDS: **EV and HV systems, motor, cooling /heat and temperature,** downsizing [A3]

The electrification of vehicles has been expanding rapidly in recent years with the movement to achieve carbon neutrality. The e-axle motors installed in electric vehicles use large amounts of mineral resources such as rare metals, copper, etc., for which there are concerns about material supply risks, and thus there are calls to reduce the amounts of materials used in the interest of expanded electrification in the future. Much research has been done up to now on reducing the amount of rare minerals used in magnets to address these requirements. Going forward, however, it appears likely that the even more important demand will be for downsizing, which will also contribute to a reduction in the quantity of materials used in motors as a whole, including copper, electrical steel sheet, and so on. Downsizing the motor is considered to require a high level of cooling performance. In the development here, a cooling method with higher performance than conventional methods was developed. The target for the motor being developed was to maintain basic performance while achieving downsizing of 40% (torque density and power density enhanced by a factor of 1.7) relative to conventional motors.
The basic specifications of the developed motor were set as a stator outer diameter of 160 mm with a core axial length of 99 mm, allowing 40% downsizing from conventional motors. In addition, multi-layer arc magnets (Fig. 1) that can use magnet torque and reluctance torque together were adopted with the interior permanent magnet synchronous motor (IPMSM) as a base. In order to achieve a balance between the target torque of 280 Nm and power output of 150 kW, a five-turn configuration that has double the current density of a conventional configuration was adopted. Regarding efficiency characteristics, downsizing the motor makes it possible to increase efficiency in the low-load range, and thus efficiency characteristics during normal driving can be considered equivalent to those of conventional motors. As opposed to the conventional cooling method, which cools the coil by dripping the coolant automatic transmission fluid (ATF) onto the coil end portion from directly above, the new cooling method developed here has a structure for oil cooling not only the coil end portion but also the coil inside the slot, so that it cools the whole coil (Fig. 2). The method was also made capable of direct cooling of the coil inside the slot with ATF by feeding the ATF into one end of the coil under pressure so that it passes through the slot interior and is discharged from the coil end portion at the other end (Fig. 3).
A prototype motor was fabricated and its torque, power, efficiency, and cooling characteristics were measured. As a result, conventional efficiency characteristics were maintained while achieving downsizing by 40% (torque density and power density increased by a factor of 1.7) (Fig. 4). Regarding the cooling performance, this approach was also confirmed to provide double the amount of cooling of the conventional approach.

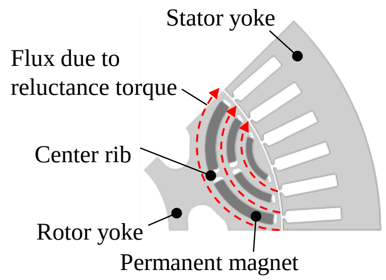

Fig. 1 Magnetic circuit model

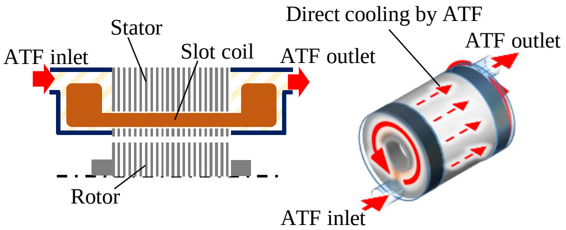

Fig. 2 Proposal cooling method

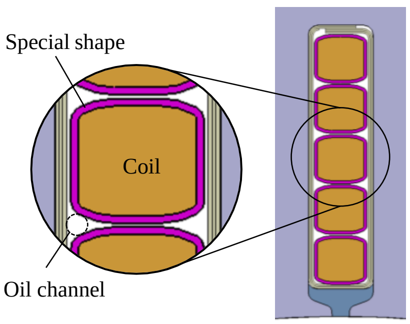

Fig. 3 Section of slot

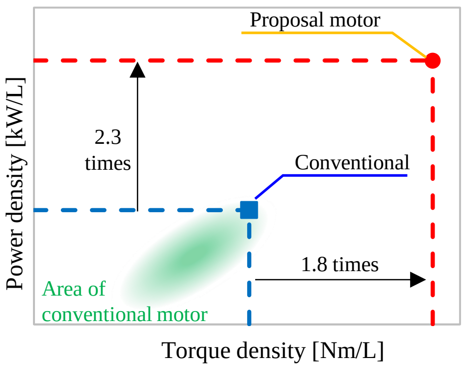

Fig. 4 Torque density and power density