Development of a high power density in-wheel motor using Halbach array magnets

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We are developing compact and lightweight in-wheel motors that can increase the cruising range for EVs that are becoming more prevalent in the de-carbon society. This paper proposes the technology to increase the motor torque by Halbach array magnets as a technology to achieve the world- class motor power density of 2.5 kW/kg. FEM analysis shows that a Halbach-array type magnet layout can obtain a large gap magnet density with a small amount of the magnets compared with conventional SPM type.

(1) Halbach array magnets for high power density

Conventionally, a Halbach array has been known as a magnet layout capable of improving the gap magnetic flux density. Generally, it is realized by giving a magnetization distribution such that the magnetic flux is concentrated in the gap in the surface permanent magnet (SPM) type magnet layout. However, in the case of such an SPM type, there is a concern that the gap magnetic flux density cannot be sufficiently increased due to the lengthening of the magnetic path inside the magnet. Therefore, in this research, a rotor with a Halbach array type magnet layout consisting of flat plate-shaped main pole magnets, spoke magnets, and core parts placed in the center of the poles was developed.

As a result of FEM analysis, when the spatial distribution fundamental wave effective value of the gap magnetic flux density of the SPM type was 1.00 pu, it was 1.06 pu in the Halbach array type. The amount of magnets used was 0.61 pu for the Halbach array type when the SPM type was 1.00 pu. Therefore, it was clarified that the developed Halbach array type can realize a high gap magnetic flux density with a small amount of the magnets as compared with the conventional Halbach magnetization. The results shows the superiority of the developted Halbach array type magnet layout.

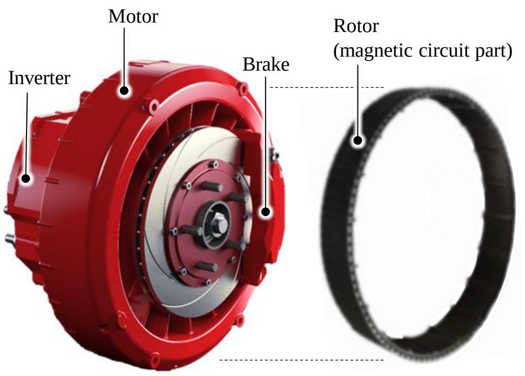

Fig. 1s. Prototype (left: external appearance, right: rotor).

(2) Prototype and measurement

We prototyped an in-wheel system using the developed Halbach array magnet rotor. Fig. 1s shows the appearance of the in-wheel system including the inverter and the rotor. The rotor is fixed to the shaft via a housing located on the inner circumference side, and power is transmitted to the wheel.

The prototype in-wheel system was installed in a test bench and a load test was conducted. The wheel side of the in-wheel system was fastened to the test bench, and DC power and cooling oil were input and output from the inverter side. The DC voltage was 380 V. Fig. 2s shows the measured waveforms of voltage and current at a maximum output of 60 kW (600 min^{-1}, 960 Nm). Although the current waveform contains high-order pulsating components corresponding to the carrier frequency of the inverter, it was a substantially sine wave, and it was confirmed on the actual machine that it can be stably driven as an in-wheel system including the inverter.

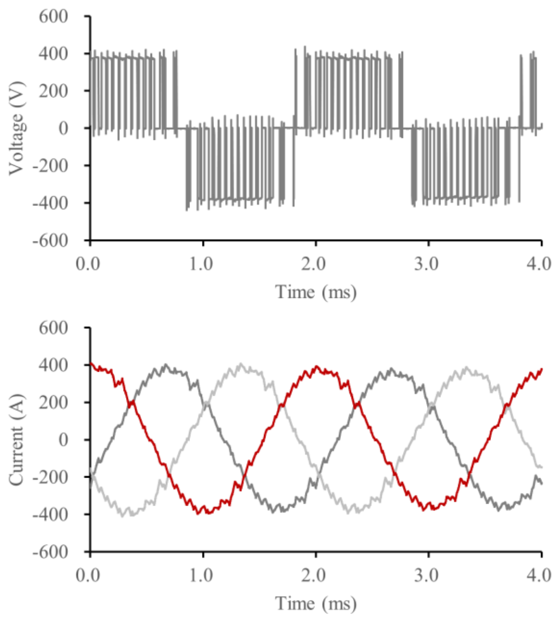

Fig. 2s. Measured waveform under the maximum output at 960 Nm and 600 min^{-1} (upper: voltage, lower: current).