Analysis of Novel Brushless DC Motors Made of Soft Magnetic Composite Core

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Abstract — The soft magnetic composite material has the merits of the low eddy current loss and the flexible machine design and assembly. This paper develops new brushless DC motors made of this material. The shape of the developed motor is similar to a hybrid type stepping motor, and the motor has hollows of the stator main teeth in order to reduce the copper loss. This paper clarifies the steady state characteristics of the motors using the three-dimensional finite element analysis.

I. Introduction

As well known, the soft magnetic composite (SMC) material has several merits including low eddy current loss, three-dimensional isotropic ferromagnetic behavior, flexible machine design and assembly, a prospect for reduced production costs, and relatively good recyclability. However it has a little poor magnetic property. The saturation flux density is low and the unsaturated relative permeability is not high. Therefore, the exchange of the laminated core into the SMC core in conventional motors cannot give a good performance. Several motors utilizing the SMC material have been developed and analyzed, for example, claw pole motors [1], [2], permanent magnet motors [3]-[9], an induction motor [10] and a linear motor [11]. We have also manufactured a cylindrical type of linear actuator made of the SMC core and have clarified its steady state characteristics [12], [13].

This paper develops new brushless DC motors made of the SMC core. They look like a hybrid type stepping motor. In order to reduce the copper loss, we have made the hollow in the stator teeth. First, this paper introduces a newly developed brushless DC motor made of the SMC core and analyzes the steady state characteristics using the 3-D finite element method.

II. New Brushless DC Motor with SMC Core

Fig. 1 shows the developed brushless DC motor made of the SMC core. The shape of this motor is similar to a hybrid type stepping motor. The stator has six main teeth, whose tooth tip has two sub-teeth. It is noted that there are hollows in the stator main teeth for the reduction of the length of stator coil, which results in the reduction of copper loss and the reduction of motor volume. The rotor is made of four cores, and a magnet is put between two cores. The magnetic flux produced by permanent magnets flows through three-dimensional direction except for the stator core as shown by the arrow in Fig. 1. Therefore, the SMC material is suitable to this type of motor. We have manufactured two kinds of motor. Motor A has 10 rotor teeth and 12 stator sub-teeth, and motor B has 16 rotor teeth and 18 stator sub-teeth.

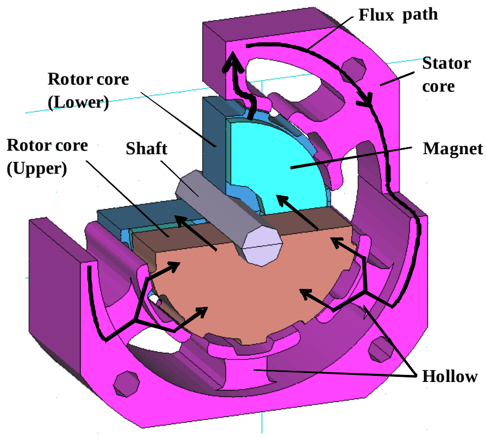


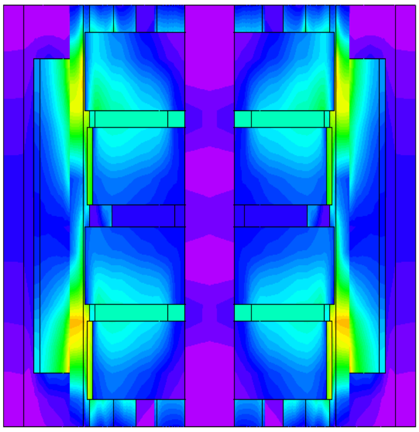
Fig. 1. The developed brushless DC motor made of SMC core.

III. Analysis of Steady State Characteristics

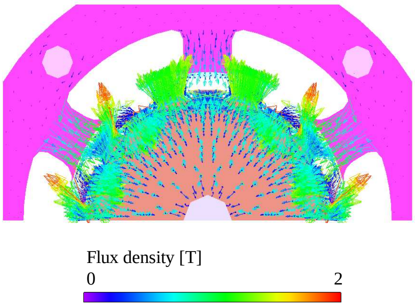
The 3-D finite element analysis was carried out for a half model, because of the symmetry in $r-\theta$ plane. Fig. 2 shows the flux density distribution at no-load. It is shown that the magnetic flux concentrates at the stator sub-teeth and the rotor teeth, and that the maximum flux density becomes about 2[T].

Fig. 3 shows the electromotive force at no-load when the motor is rotating at 1000min^{-1}. Although the calculated electromotive force of the motor A with 10 rotor teeth and 12 stator sub-teeth is slice different from the measured one, the calculated result of motor B has very good agreement with the measured one.

When the developed motor is used as a brushless DC motor, the d- and q-axis inductances are important because of the reluctance torque. The calculated d-axis inductance is approximately the same as the q-axis one. Therefore, the current phase angle is set to be 0. Fig. 4 shows the steady state characteristics when the motor is driven as the brushless DC motor with a sinusoidal stator current. It is shown that the electromotive force goes ahead of the stator current even when the current phase angle is 0, and that its shape becomes like a triangle. The average torque of motor A is approximately the same as the motor B, but the shape includes torque ripple. It is also shown that the input power of the motor B includes larger ripple than that of the motor A.

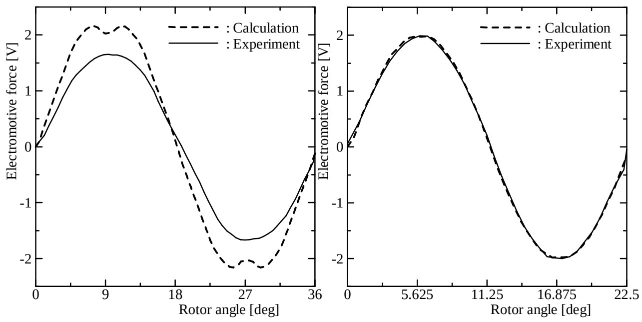


(a) $r-z$ plane



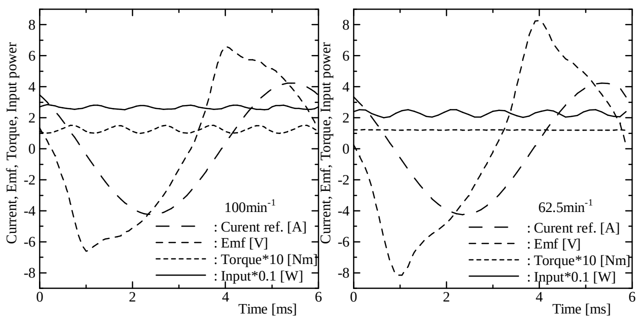
(b) $r-\theta$ plane

Fig. 2. Flux density distribution at no-load.



(a) Motor A (b) Motor B

Fig. 3. Comparison of the calculated electromotive force and the measured one at no-load.



(a) Motor A (b) Motor B

Fig. 4. The calculated steady state characteristics of the developed brushless DC motors made of SMC core.

IV. Conclusion

This paper has developed the novel brushless DC motors, whose stator and rotor are made of the SMC core, and have analyzed their steady state characteristics. The difference between the characteristic of the motor made of the SMC core and that of the conventional laminated core will be calculated and clarified in the full paper.

V. References

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