Characteristics Analysis of a Novel Motor with Two Controllable Rotors Employing 3-D FEM

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A number of automobiles have been fitted with electric motors and their inverters recently. In order to decrease the number of motors and inverters, we have proposed a motor with two controllable rotors, which consist of 2 rotors and 1 stator. However, the previous motor was difficult to be practically used due to its complicated structure. In this paper, we propose a novel motor with two controllable rotors, and its characteristics are verified using finite element analysis.

***Index Terms*—AC motors, brushless motors, finite element analysis**

I. Introduction

THE ELECTRIFICATION OF AUTOMOBILES has been gaining momentum recently, and more and more automobiles are being fitted with electric motors and their inverters. In order to decrease the number of motors and inverters, a motor with two controllable rotors shown in Fig. 1 was proposed [1-2]. This motor has two rotors and one stator. The two rotors can be independently controlled using superimposed currents created by a 6-phase inverter. One rotor is driven by a 3-phase current and another is driven by a 6-phase current. However, this motor has problems such as low heat dissipation and complicated support structure of the stator because the stator is sandwiched by the two rotors. In order to solve these problems, a motor with the stator on the outside of the rotors shown in Fig. 2 was proposed [3]. This motor has two rotors and one stator, and its two rotors can be independently controlled using superimposed currents. However, this motor has problems such as complicated support structure of the middle rotor. In this paper, we propose a novel motor with two controllable rotors to solve these problems. In order to evaluate the magnetic interference between rotors, the cogging torque of the two rotors are computed using 3-D FEM analysis. The component of the cogging torque is analyzed using FFT analysis, and the magnetic interference between rotors is discussed.

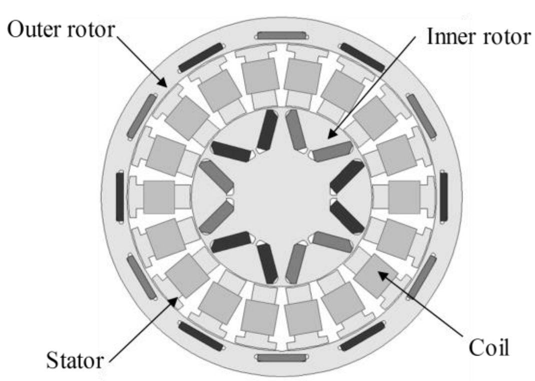

Fig. 1. Conventional motor with two controllable rotors.

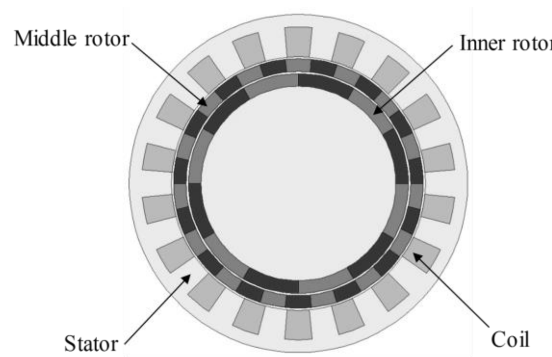

Fig. 2. Our previously proposed conventional motor with two controllable output shaft.

II. Structure

Major specifications of the proposed motor are shown in Fig. 3 and Table I. The proposed motor has one stator and two rotors as shown in Fig. 3. The 3- and 6-phase rotors are driven using 3- and 6-phase currents, respectively. This motor has high heat dissipation because the stator is located outside. The two rotors can be easily supported because the two rotors are axially located with each other. The 3-phase and 6-phase rotors have 16 and 8 poles, respectively, and the stator has 24 slots with concentrated windings. The 3-phase and 6-phase rotors are driven as 3- and 6-phase PM synchronous motors, respectively, by using superimposed currents generated by a 6-phase inverter, where the 3- and 6-phase currents do not interfere with each other.

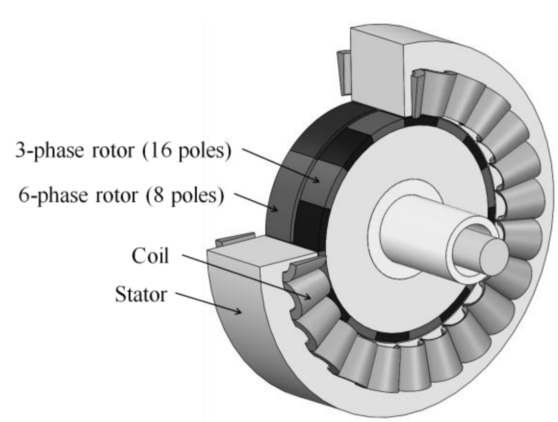

Fig. 3. Novel motor with two controllable rotors.

TABLE I
ANALYTICAL MODEL SIZE

Size	ϕ300×65 mm
Rotor diameter	ϕ180 mm/each
Rotor thickness	30 mm/each
Distance between rotors	5 mm
Air gap length	1 mm
Number of coil turns	120
Permanent magnet	*Br*=1.3T Thickness=7 mm

III. ANALYSIS METHOD AND RESULT

The cogging torque of the proposed motor is computed in 4 conditions shown in Table II, where one rotor is fixed or excluded in order to investigate the magnetic interference between the two rotors.

The computed cogging torque waveforms when the rotor is rotated by 45 deg are shown in Figs. 4 and 5. In order to investigate the components of these cogging torque waveforms, FFT analyses are applied. The components of the cogging torque waveforms are shown in Figs. 6 and 7. The fundamental orders of the cogging torque of the 3- and 6-phase rotors when being rotated by 45 deg is 6, and 3, respectively. From Figs. 6 and 7, the fundamental order cogging torques of the condition 1 and 2, and condition 3 and 4 are almost the same. In addition, the harmonic components of the cogging torque of the condition 1 and 2, and condition 3 and 4 are also almost the same. From these, the magnetic interference between rotors when the axial air gap length between rotors is 5 mm can be ignored. In the final paper, the influence of the axial air gap length on the cogging torque is described.

TABLE II
ANALYSIS CONDITION

	3-phase rotor	6-phase rotor
Condition 1	rotate	fixed
Condition 2	rotate	excluded
Condition 3	fixed	rotate
Condition 4	excluded	rotate

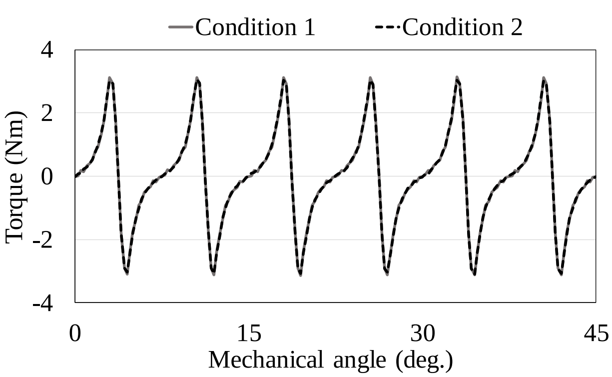

Fig. 4. Cogging torque waveform in condition 1 and condition 2.

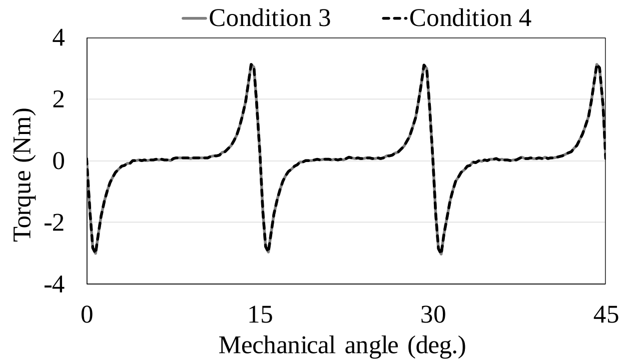

Fig. 5. Cogging torque waveform in condition 3 and condition 4.

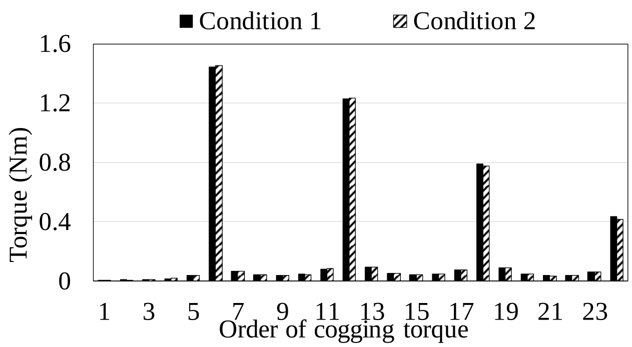

Fig. 6. Order of cogging torque waveform in condition 1 and condition 2.

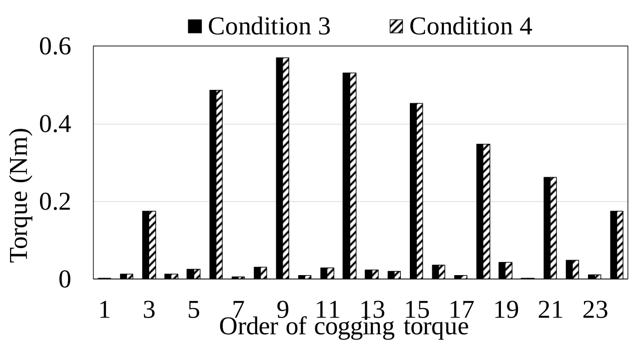

Fig. 7. Order of cogging torque waveform in condition 3 and condition 4.

IV. CONCLUSION

In this paper, a novel motor with two controllable rotors was proposed. The magnetic interference between rotors was investigated using the computed cogging torque waveforms. The magnetic interference between rotors could be ignored when the axial air gap length is 5 mm. In the final paper, the axial air gap length is changed. In addition, the current torques will be discussed.

REFERENCES

[1] Minoru Arimitsu, Yuji Naruse, Yuusuke Minagawa, Masaki Nakano and Takashi Inoue, "Characteristics of a Coaxial Motor Driven", SAE TECHNICAL PAPER SERIES, 2005-01-3755 (2005) 1-9

[2] Naruhiko Tan, Minoru Arimitsu, Yuji Naruse, June Watanabe, "Cooling Performance Design for Super Motor and Its Experimental Validation",The International Power Electronics Conference,(2005) 1482-1488

[3] Noboru Niguchi , Katsuhiro Hirata, Atsushi Miyagawa, Yo Sakaidani, "A Novel Motor with Two Controllable Output Shafts Using Superimposed Current", Proceedings of IEEE International Magnetics Conference, Dresden, FQ-5, pp.2328-2329, 2014.05