Electromagnetic Field Characteristic Analysis of Interior Permanent Magnet Motor considering Operating Conditions

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This paper deals with the characteristic analysis of interior permanent magnet synchronous motor (IPMSM) with 6 poles and 9 slots according to the operating modes. By employing rare-earth magnet, the analysis model also applies concentration coil winding type in its stator structure. The IPMSM type is widely applied as a traction motor of electric vehicles with various advantages, and the motor is operated in both motor mode and generator mode. With small scale analysis model, this paper investigates the electromagnetic characteristics by considering the operation mode.

***Index Terms*—IPMSM, load condition.**

I. Introduction

Interior permanent magnet synchronous motor (IPMSM) has various benefits such as higher energy density and comparatively wider operating range in comparison with surface-mounted permanent magnet synchronous motor (SPMSM) [1]-[2], so it is widely applied in the traction motor of electrical vehicle systems. In this case, the electrical machine is operated in both motoring mode and generating mode, those characteristics are required to be specifically analyzed. Therefore, this paper deals with the characteristic analysis of IPMSM with 6 poles and 9 slots, and investigation according to operating mode condition, which are AC load, DC load and motoring mode, is performed.

II. Electromagnetic Field Analysis of IPMSM according to Operating Condition

A. Analysis Model

In Fig. 1, the analysis model is presented, and it has 6 poles in the rotor while 3-phase concentration winding is located in 9 slots of the stator. More design specifications are presented in Table I.

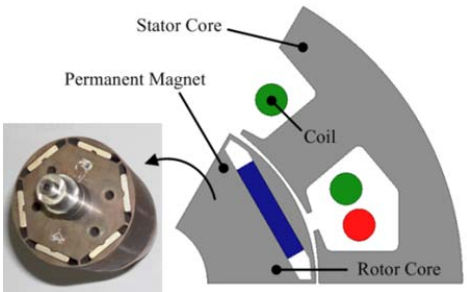

Fig.1. Analysis model (1/4 partial model) and manufactured rotor with PM.

TABLE I Design Specification of Analysis Models

Specification	Value
Outer Diameter of Stator Core	100(mm)
Inner Diameter of Rotor Core	20(mm)
Stack Length	55(mm)
Number of Coil Turns	84(Turn)
Remanence of Permanent Magnet	1.24(T)
Line to Line Resistance	2.5(ohm)

B. Comparative Investigation according to PM Design

In this paper, various rotor types by considering PM design are comparatively investigated to effectively determine the best machine type, such as the reduction of cogging torque and torque ripple. Among the various design specifications, the PM shape has high influence on motor performance, and this study focused on the relationship with the PM shape and torque characteristics. For instance, Fig.2 presents the induced voltage characteristics in no-load condition while Fig.3 is the comparative results of cogging torque according to the machine types. In this case, identical stator is employed for those three machines with different rotors. In this case, since Type B satisfies aimed value of the induced voltage with reasonable cogging torque, it is determined as the final model.

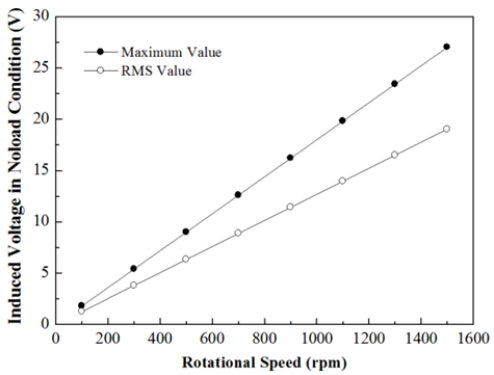

Fig.2.No-load induced voltage characteristics according to rotor types.

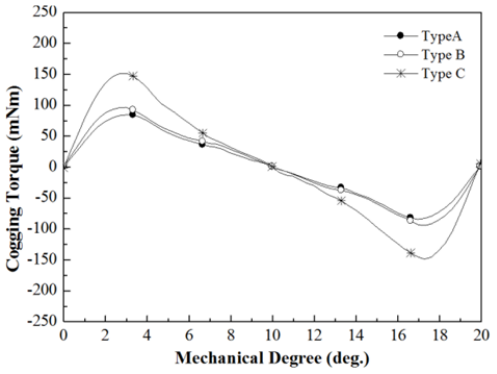

Fig.3.Comparison of cogging torque characteristics according to rotor types.

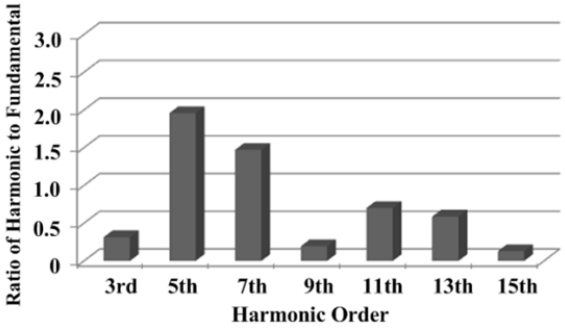

Fig.4.FFT results of no-load induced voltage of finally designed model.

Furthermore, Fig.4 shows the Fast-Fourier Transform results of no-load induced voltage, and it is confirmed that the fifth harmonic component is relatively higher than the others. The fifth harmonic component is the main source of torque ripple when it is operated by sinusoidal currents. Compared to the other motor types, it will be presented that the finally designed model has lowest value to contribute the reduction of noise and vibration.

C. Generating characteristics in AC and DC load conditions.

When the machine is in generating mode, it is directly connected with a power converter with energy conversion from the AC power to DC power. In general, for the electrical machine performance evaluation, AC load is dealt with while DC load attracts low attention. However, the phase current characteristics due to DC load condition can have high DC load attracts low attention. However, the phase current due to

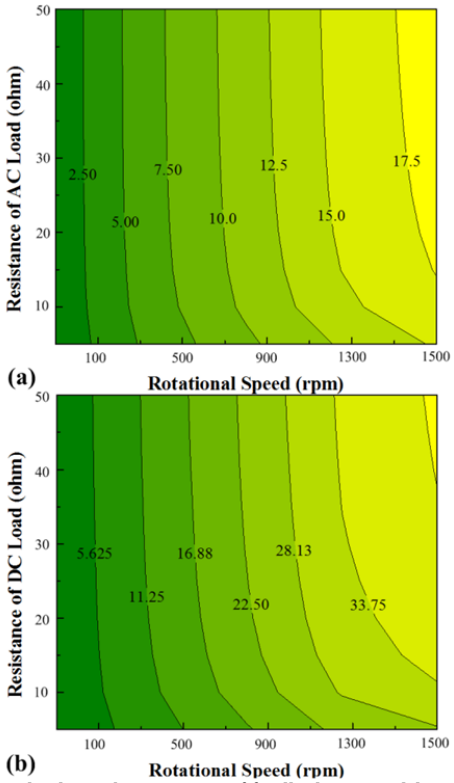

Fig.5.Generated voltage characteristics of finally design model according to load conditions : (a) AC load condition, (b) DC load condition.

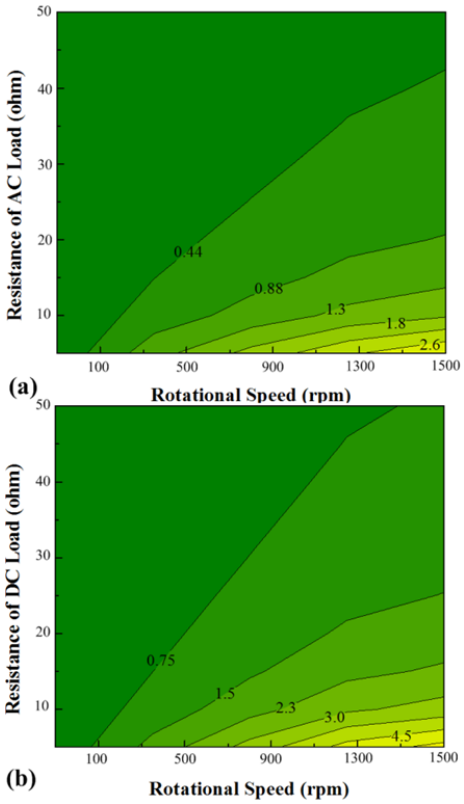

Fig.6.Phase current characteristics of finally design model according to load conditions : (a) AC load condition, (b) DC load condition.

DC load condition can have high influence on the machine performance. Therefore, the comparison of generating characteristics according to load condition is very importance. In Fig.5 and Fig.6, the generated voltage and resulting current characteristics are presented according to load resistance and rotating speed conditions.

III. Conclusion

This paper will present the comparative characteristics of interior permanent magnet synchronous machine according to various load conditions based on finite element method. By considering the rotor types according to the shape of PMs and the others, the efforts to minimize the torque ripple and cogging torque will be specifically illustrated. Besides, for the experimental verification, the finally designed model is manufactured, and the performance evaluation with the machine will be presented for the contribution to potential industrial and academic readers.

References

[1] T. M Hahns, G. B. Kilman, and T. W. Neumann, “Interior permanent magnet synchronous motors for adjustable-speed drives”, *IEEE* Trans. Ind. Appl., vol. IA-22, no. 4, pp.738 – 747, Jul./Aug. 1986.

[2] Rukmi Dutta and M. F. Rahman, “Design and Analysis of an Interior Permanent Magnet (IPM) Machine With Very Wide Constant Power Operation Rnage”, *IEEE* Trans. Energy Convers., vol. 23, no. 1, pp.25-33 Mar. 2005.

[3] Rukmi Dutta and M. F. Rahman, “A Comparative Analysis of Two Test Methods of Measuring d- and q-Axes Inductances of Interior Permanent-Magnet Machine”, *IEEE Trans. Magn.*, vol. 42, no. 11, pp. 3712–3718, Jov. 2006.