계자권선형 12슬롯-10극 자속 역전식 동기 전동기의 최적 설계

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Optimal Design of Field-Excitation Flux-Switching Synchronous Machine for ISG Application

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ABSTRACT

In recent years, ISG (Integrated Starter and Generator) system receives a great attention for electric electrification of normal gasoline vehicle. As a cost effect machine design, an ISG without a permanent magnet is considered. A 12slot 10pole field excitation flux switching synchronous machine (FEFSSM) is designed and analyzed via JMAG. The active parts such as the field excitation coil and armature coil are located on the stator. The rotor part consisting of single piece iron makes it more robust and suitable to apply for high speed motor drive system application coupled with reduction belt. The design target is the motor with a maximum torque of 40Nm, a maximum power of 10kW and a maximum speed of 14000 rpm. In this paper, design optimization method is proposed for high torque capability.

Ⅰ. Introduction

Conventional permanent magnet synchronous motors (PMSMs) exhibit high torque density and high efficiency, so it has been developed for various industrial applications such as electric vehicles(EVs). However, they have some problem because of the permanent magnets located in the rotor. When the motor operate in high speed range, rotor temperature rising causes poor thermal dissipation and irreversible demagnetization of magnets. Then, the machine is ultimately limited the power density.[1] Also, the rotor geometry and construction of PMSM is complicated. This leads to high manufacturing cost.

Many novel and new flux switching permanent magnet (FSPM) machine topologies have been developed. FSPM is simple and robust and suitable for high speed operation. Since both the magnets and armature coils are housed in the stator.[1] However, permanent magnets are not always preferable for the machine design. Although PM machines exhibit high torque density and high efficiency, the rare earth magnet material, e.g. NdFeB, is expensive and the working environmental temperature may limit its application In addition, the fixed PM excitation causes low field weakening capability when the machine operate at high speed. In order to overcome these problem, one of the possible solution is to replace the magnet excitation by the DC winding excitation.[2]

This paper propose 3 phase 12slot 10pole field excitation flux switching synchronous machine (FEFSSM) for ISG application. the design target is he motor with a maximum torque of 40Nm, a maximum power of 10kW and a maximum speed of 14000 rpm. In this paper, design optimization method is proposed for high torque capability and analyze via JMAG.

Ⅱ. Topology and Design Optimization of FEFSSM

1. Basic Concepts

Field excitation flux switching synchronous machine (FEFSSM) is based on the flux switching permanent magnet machine. The active parts such as the field excitation coil and armature coil are located on the stator. The rotor part consisting of single piece iron makes it more robust and suitable to apply for high speed motor drive system.

A. Topology

12slot 10pole FEFSSM topology is showed in the Fig. 1. 12slot 10pole and 12slot 14pole design variants represent very good slot pole combination for the electric vehicle applications. Also, 12slot 10pole combination obtains balanced symmetrical back emf waveforms.

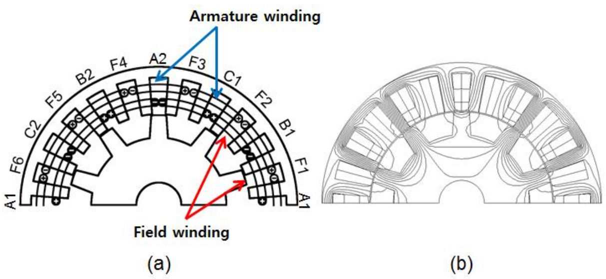

Fig. 1 12slot-10pole FEFSSM (half model via JMAG). (a) FEFSSM topology and winding configuration. (b) Flux line distribution.

B. Operation principle

the polarity of the DC field flux linkage in the coil reverses when the rotor pole aligns the alternative stator tooth that belongs to the same phase, i.e., realizing the "flux switching" action.[3]

2. Design Optimization

At first, we choose design parameter by conventional design method. And then, we vary each parameter and analyze 2 D finite element method (FEM) via JMAG.

From the Fig. 2, flux linkage is saturated in the high field current density. When the field current density is 25A/mm^2, phase flux linkage become maximum value. The optimized field current density should be equal to the armature current density(rms). For the optimal design, we choose same field current density and armature current density as 25A/mm^2.

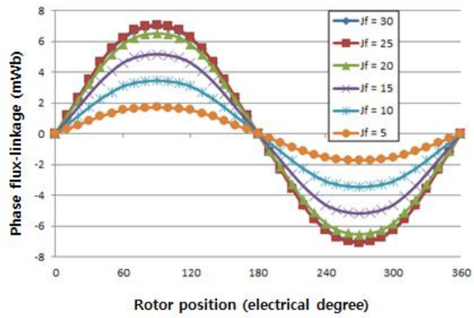

Fig. 2 Flux-linkage waveforms of FEFSSM with different field current density.

A. Split ratio

Firstly, the variation of electromagnetic performance with split ratio, the rotor radius over the stator radius, is investigated since the split ratio is a key parameter in machine design. Fig. 3 shows that the torque varies significantly with split ratio. The optimized split ratio is 0.65 when the current density is 25A/mm^2.

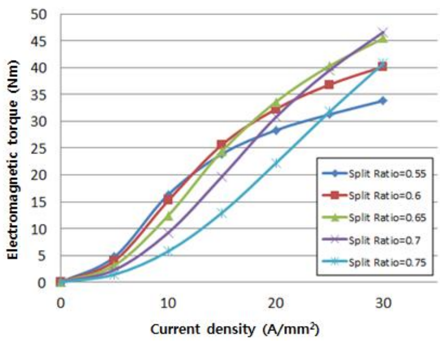

Fig. 3 Torque-current density characteristic of FEFSSM with different split ratio, $I_d = 0$.

B. Slot area ratio

Slot area ratio means the field slot area over the armature slot area ratio. The minimum copper loss can be obtained when the slot area ratio is 1.[2]

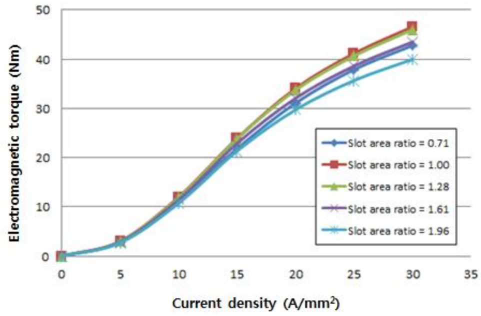

Fig. 4 Torque-current density characteristic of FEFSSM with different slot area ratio, $I_d = 0$.

C. Rotor pole width

Conventionally, the rotor pole width have the preference same width of the stator tooth. So, we split the rotor pole width and simulate the machine's torque by FEM. The optimized rotor pole width is 7.4mm.

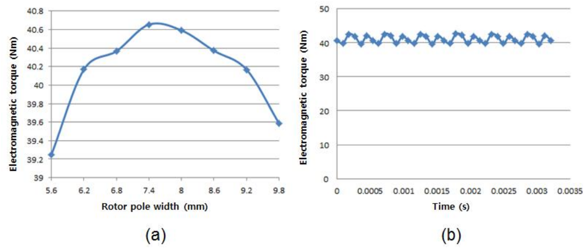

Fig. 5 (a) Torque versus rotor pole width at $J = 25A/mm^2$. (b) Optimized Torque at $I_d = 0$, $J = 25A/mm^2$.

III. Conclusions

In this paper, 12slot 10pole field excitation flux switching synchronous machine (FEFSSM) is proposed and analyzed. First, we studied basic concept of FEFSSM with emphasis on the topology and the operation principles. Second, we also studied design optimization for high torque density with split ratio, pole width, slot area ratio. Finally, we choose optimal design for ISG application, and design target is satisfied.

References

[1] Z.Q. Zhu, "Advanced Flux Switching Permanent Magnet Brushless Machines", Proceedings of the IEEE, Vol. 46, No. 6, pp. 1447 1453, 2010, June.

[2] C.T. Chen, Z.Q. Zhu, S. Iwasaki, and R. Deodhar, "Low Cost Flux Switching Brushless AC Machines", VPPC, 2010, September.

[3] M. Cheng, W. Hua, J. Zhang, and W. Zhao, "Overview of Stator Permanent Magnet Brushless Machines", Proceedings of the IEEE, Vol. 58, No. 11, pp. 5087 5101, 2011, November.

[4] E. Sulaiman, T. Kosaka, N. Matsui, "A New Structure of 12Slot 10Pole Field Excitation Flux Switcing Synchronous Machine for Hybrid Electric Vehicles", EPE, 2011, September.