비대칭 U - 코어 고정자 구조를 가진 새로운 2상 영구자석 동기전동기의 특성해석

조 비*, Thomas Anthony Lipo**, 권병일*
*한양대학교, **위스콘신-매디슨 대학교

Characteristic Analysis of A Novel Two-Phase Permanent Magnet Synchronous Motor with Asymmetric U-core Stator Structure

Fei ZHAO*, Thomas Anthony Lipo**, Byung-Il Kwon*
*Hanyang University, **University of Wisconsin-Madison

Abstract - This paper presents a novel two-phase two-pole permanent magnet synchronous motor (PMSM) with asymmetric U-core stator structure. The construction and parameters of the novel two-phase U-core PMSM are compared with a conventional U-core single-phase PMSM (SPMSM). Then transient characteristics such as torque, back-emf, and power loss of the both PMSMs are analyzed by using 3-D Finite Element Method (FEM). Under the same condition of rated input current, synchronous speed, similar dimensions and volume, FE results show that the two-phase PMSM with U-core stator has significantly less torque ripple than single-phase U-core PMSM, with similar power loss and efficiency.

1. INTRODUCTION

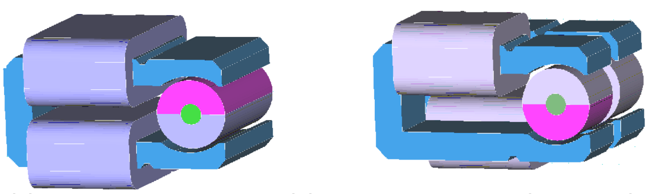
Owing to cost effective ferrite magnets and power electronics, permanent magnet brushless motors can successfully replace introduction motors in some low-power applications due to their high efficiency, high power factor, and simple control. Low power single-phase and two-phase electric PM motors are widely used in various devices and especially in many household appliances. Hence, the small single-phase U-core PMSM has found growing applications with the simple design and low cost production [1] - [3].

Based on the structure of single-phase U-core pm motor, this paper proposes a novel U-core structure of a two-phase PMSM, wherein the front magnets shift 90 electrical degrees with respect to the behind pair and the length of normal single-phase motor is divided into same two parts. Compared with conventional single-phase U-core PMSM by FEM results, the proposed motor has similar average torque and power loss, but much less torque ripple. Since there is no previous work for the structure design or any characteristic analysis of proposed two-phase U-core PMSM, its basic model has to be built based on the ready-made structure of single-phase U-core PMSM. The characteristics and performance of both motors i.e. back-emf, linkage flux, electromagnetic and average torque are analyzed by using 3-D finite element method.

2. STRUCTURE DESCRIPTION OF PMSMS

2.1 Structure of U-core PMSMs

In Fig. 1 (a), the model of reference motor - single-phase U-core PMSM is introduced. Two stator windings of the motor wound around the laminations are connected in series [2]. However, as a consequence of its simple construction, the U-core SPMSM has poor performance, such as torque pulsations, high stator leakage inductance, poor utilization of PMs and no preferred direction of rotation with uniform airgap [4].



(a) Single-phase PMSM (b) Two-phase PMSM (proposed)
<Fig. 1> Modesl of PMSMs with U-core stator

In two-phase U-core PMSM, shown in Fig. 1 (b), the stator and rotor are divided one half through axial and the front permanent magnet pair shifts 90 electrical degrees with respect to the behind pair. And two phase windings distribute on different stator arms.

2.2 Main Materials and Parameters

For effective cost, the permanent magnets attached in rotor are made of ferrite with parallel magnetization, whose parameters are remanence Br = 0.354 T and coercivity Hc = -240 kA/m. The magnets should be safely held together by non-magnetic sleeve against centrifugal force. Stator stacks are made of silicon steel, and windings of each phase in proposed motor are connected in series. where is current injected.

When compare series of motors, the average torque is almost designed for similar value for similar applications.

$$T = \frac{P_{out}}{\Omega} = \frac{P_{out}}{2\pi f/60} \tag{1}$$

Since two motors have same synchronous speed, their output power should be similar.

$$P_{out} = ei \tag{2}$$

Here assume same current is injected in the windings, so EMF should be similar.

$$e = 4.44 fkN\phi \tag{3}$$

$$\Phi = BS = \mu HS = \mu iNS \tag{4}$$

One part stator's cross-sectional area of SPMSM is twice of that of proposed motor,

$$S_{SPMSM} = 2S_{proposed} \tag{5}$$

where, Ω - angular velocity of the rotor, e- EMF produced by half coils, i - input current in winding, Φ - magnetic flux filled in half of the airgap.

From equations (2) - (4), to keep output power similar, coil turn number winded around one stator arm of SPMSM should not be same with proposed motor. Tab. 1 shows the main rated parameters and equivalent FE model dimensions.

<Tab. 1> Motor Parameters

Motor Parameters	Units	SPMSM	Proposed Motor
Rotor poles	-	2	
Frequency	Hz	60	
Synchronous speed	rpm	3600	
Rotor outer diameter	mm	20	
Airgap length	mm	1.2	
Coil turns per phase	-	1800	
Equivalent length	mm	40	46
FE model volume	cm^3	146.4	163.3
Rotor length	mm	40	20*2

3. ANALYSIS APPROACH

3.1 Principle of Operation

If the desired current waveform is available, the PM power is constant when the pole is active, then at any moment the useful PM torque is produced by all 4 poles.

Here, the current power supply has a 90 phase degree shifted. Consider, if two single phase PMSMs are joined by installing two rotors on the same shaft and two stators in one machine frame. In this case, when one part is at its fully aligned position, the other is exactly at its none aligned position. Electrically the two sets of windings are 90 degree out of phase. From equations (6) and (7), since the frequency of reluctance torque pulsating is double that of current, the reluctance torques produced by the two sets are 180 degree out of phase, so that they essentially cancel each other completely. That means there will produce much more smooth torque, where the cost of a 6 mm larger size and the additional copper can be justified.

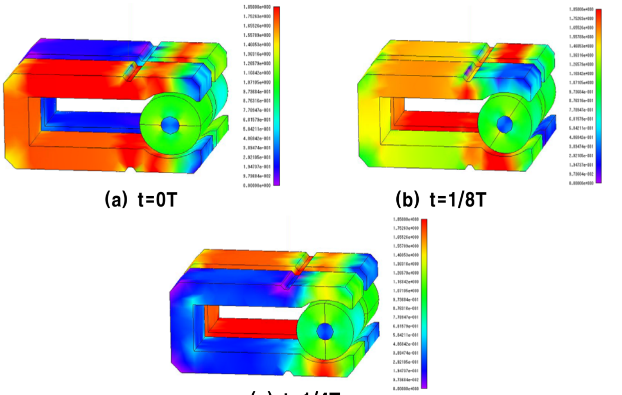
$$\Lambda_p = \Lambda_{pm} + L_p i \tag{6}$$

$$T_p = \frac{1}{2} i^2 \frac{dL_p}{d\theta} + i \frac{d\Lambda_{pm}}{d\theta} = T_{prm} + T_{ppm} \tag{7}$$

where, Λ is flux, $L_p i$ is current induced flux, T_{prm} is reluctance torque and T_{ppm} is the PM torque. There is no electromagnetic coupling between these two sets. Therefore, a space must be provided for an end winding region between the two sets of stators.

3.2 Characteristics Comparison

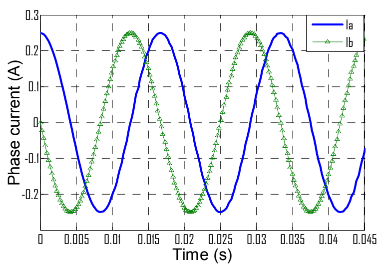
To compare the two U-core PMSMs, same rated values should be chosen and similar equivalent dimensions should be built. That means the structure of proposed motor analyzed in this section maybe not so necessarily optimal. Flux density distributions of proposed two-phase PMSM in different moments are shown below in Fig. 2. When rotor is rotating, two phases currents alternately produce MMF.



(a) t=0T (b) t=1/8T (c) t=1/4T

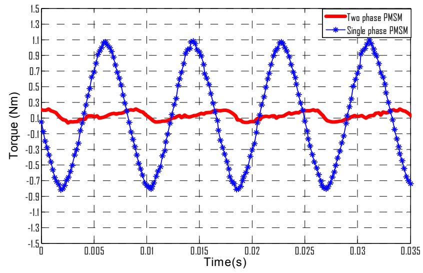
<Fig. 2> Flux density distribution's variety of two-phase PMSM

In Fig. 3, two-phase AC current sources are injected into windings respectively, which is 0.25 A, 60 Hz, shifted by 90 degree. And FEM analysis has been performed in constant speed condition, 3600 rpm. The iron loss of stator core, copper loss of coils, Joule loss and Hysteresis loss have been considered. Although the total turns of each motor are different, the copper material expenses are similar because of the similar total coil lengths.



<Fig. 3> Phase current of two-phase PMSM (proposed)

From Fig. 4, the average torques of the SPMSM and proposed two-phase motor have been set as the similar value, 0.123 Nm and 0.126 Nm. However, the torque ripple of SPMSM is more than 1, which is far larger than that of the proposed two-phase PMSM (71.5%). Because of the similar volume, the torques per volume of both motors are also similar. The main comparison parameters of two PMSMs are list in Tab. 2.



<Fig. 4> Torques of two-phase and single-phase U-core PMSMs

<Tab. 2> Comparison results between two PMSMs

Items	Units	SPMSM	Proposed Motor
Input current (rms)	A	0.25	
Synchronous speed	rpm	3600	
Average torque	Nm	0.123	0.126
Torque ripple	-	>100%	71.5%
Back EMF	V	311	200
Copper loss	W	4.25	5
Iron loss	W	2.9	2.82
Joule loss	W	0.96	0.92
Hysteresis loss	W	1.98	1.9
Total loss	W	10.09	10.64
Efficiency	-	82.1%	81.7%

4. CONCLUSION

The structure and performance of the proposed 2-phase 2-pole PMSM with U-core asymmetrical stator were illustrated in this paper, and main characteristics were compared with conventional single-phase U-core PMSM by 3-D FEM analysis.

The characteristic analysis results showed that the two-phase PMSM with U-core asymmetrical stator had a significant advantage - less torque ripple than conventional single-phase U-core PMSM, with similar average torque, power loss, equivalent FE model volume and material expense. And the FEM data also confirmed the analysis results. In future report, operation method of the proposed two-phase U-core PMSM will be concerned.

This research was supported by WCU (World Class University) program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (R33-2008-000-10104-0)

REFERENCE

[1] L. Petkovska, G. Cvetkovski, “FEM based simulation of permanent magnet synchronous motor performance characteristics”, in Proceedings of CES/IEEE 5th Intern. Power Electronics and Motion Control Conference - IPEMC'06, Vol 1/3, pp.254-258, Shanghai, China, 2006.

[2] L. Petkovska, G. Cvetkovski, “FEM analysis of single phase Permanent Magnet Synchronous Motor”, EUROCON '09. IEEE, pp. 709, 2009.

[3] D. Ishak, O. Sidek and S. Taib, “FE Modeling of 2-Phase Permanent Magnet Motor for High-Speed Applications”, IEEE Trans. Ind. Appl., Vol. 41, No. 2, pp. 599-608, 2005.

[4] V. Ostovic, "Performance Comparison of U-Core and Round-Stator Single-Phase Permanent-Magnet Motors for Pump Applications", IEEE Trans. Ind. Appl., Vol. 38, No.2 pp. 476-482, 2002.