

Dual Rotor Flux-Switching Permanent Magnet Machine with Drum Winding

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This paper presents investigation of dual rotor topology of flux switching permanent magnet machines (FSPMMs). First, conventional single rotor 12 slots 10 poles (12S10P) FSPMM was analyzed as comparison criteria of this work. From the main dimensions of the conventional machine, dual rotor 12S14P FSPMMs were designed. Designed dual rotor topologies adopted the drum winding configuration, and was compared with conventional concentrated winding. To validate the work, finite element method (FEM) analysis results of the designed machines were compared with the conventional machine.

Index Terms— AC motors, Brushless motors, Permanent magnet motors, Finite element analysis

I. INTRODUCTION

FROM 1950s, Flux-switching permanent magnet machine (FSPMM) has been studied for decades [1]-[2]. These studies were encouraged by its unique operating principle, and advantages that emerge from its structures which are robust rotor and stator positioned permanent magnets. Such advantages are high torque density, simplicity of magnet heat dissipation, low demagnetization, and low cost magnets. However, FSPMM has drawbacks of high cogging torque and torque ripple. These drawbacks causes control difficulty, noise and vibration. So it is important to reduce cogging torque and torque ripple for the machine performance improvement. In order to reduce cogging torque and torque ripple, various methods were applied. Methods suggested for FSPMM in various papers were skewing, manipulation of rotor or stator configuration, additional bridge to stator, harmonic current injection [3]-[5]. Additionally, two stator one rotor or one stator two rotor topologies were designed for FSPMM to improve the performance [6]-[7].

In this paper, dual rotor topology was suggested to resolve the cogging torque and torque ripple issue, and to improve the machine performance. First, conventional 12 slots 10 poles (12S10P) FSPMM was analyzed as comparison criteria of this work. Keeping the main constraints such as the motor volume and electrical loading, dual rotor FSPMM was designed. Slot and pole combination was changed to 12S14P in dual rotor topology, to have practical machine structure with same frequency on inner and outer winding. Dual rotor 12S14P FSPMM was divided in two cases by the existence of non-magnetic ring barrier which separates inner and outer flux path as can be seen on Fig. 1 (b), (c). Each dual rotor topology was compared with difference of their winding configuration. Drum winding, also known as toroidal winding, was adopted to be compared with the conventional concentrated winding.

II. DUAL ROTOR TOPOLOGY DESIGN

To show contribution of the work, conventional FSPMM was designed with specifications on Table I as shown in Fig. 1. (a), in order to compare the performance with dual rotor topology machines. Using same specifications of the designed

conventional machine, dual rotor topologies were designed as shown in Fig. 1. (b), (c).

TABLE I
SPECIFICATIONS OF CONVENTIONAL MACHINE

Item	Unit	Conventional 12S10P FSPMM
Outer diameter	mm	130
Axial length	mm	85
Air-gap length	mm	0.5
Slot fill factor	-	32.6
Magnet grade	-	Ferrite / 0.43 T
Steel sheet	-	50H1300

Dual rotor topology of FSPMM usually requires two different input current frequency due to rotor pole number difference [8], or trapezoidal magnet shape in order to make inner and outer rotor pole numbers same [9]. But in this work, dual rotor topology which solves these two issues were designed. In consideration of manufacturing complexity, square shaped magnets were used. Conventional FSPMMs use ratio of 1:1:1 = stator iron teeth: magnet thickness: slot opening to produce back emf of balanced sinusoidal waveform. Following this method, inner part of the machine was designed by the certain ratio, with 12S14P combination. Outer part of the machine was designed with ratio of 1:1:3 = stator iron teeth: magnet thickness: slot opening, to have practical slot area with 12S14P combination also. Consequently, inner and outer part of the machine had same frequency due to same slot and pole combination. With these conditions, the machine will have square shaped magnets, and will require only one inverter.

Dual rotor topology was designed in two cases, with barrier, and without barrier as shown in Fig. 1. (b), (c). This non-magnetic barrier separates the machine into two different machines, which does not share the stator flux together. These two cases were also compared for its each performance in next section.

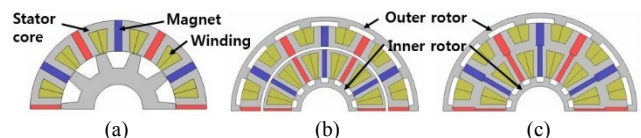


Fig. 1. Designed machines (a) Conventional 12S10P FSPMM (b) Dual rotor 12S14P FSPMM with barrier (c) Dual rotor 12S14P FSPMM without barrier

Drum winding was adopted to take advantage of dual rotor topology. Drum winding is usually used to solve the complex winding fixation in open slots [10], which includes FSPMM topology. It also reduces number of winding work while manufacturing since drum winding requires only one time winding compared to conventional concentrated winding requires two times of winding, as shown in Fig. 2. Additionally, in dual rotor FSPMM topology, drum winding tends to produce more back emf due to higher phase coil flux-linkage as shown on Fig. 3. (a).

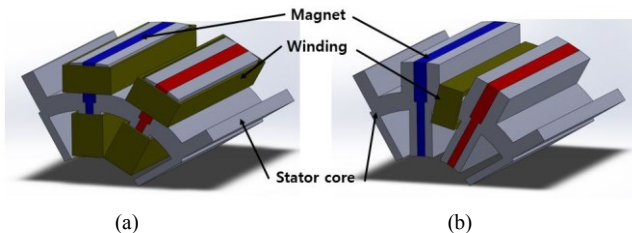
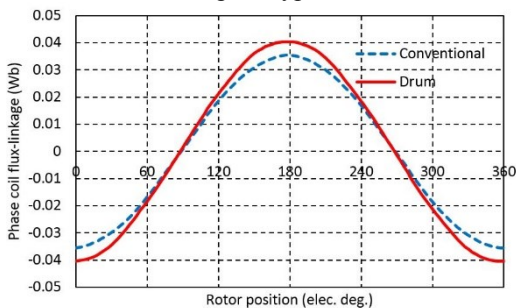


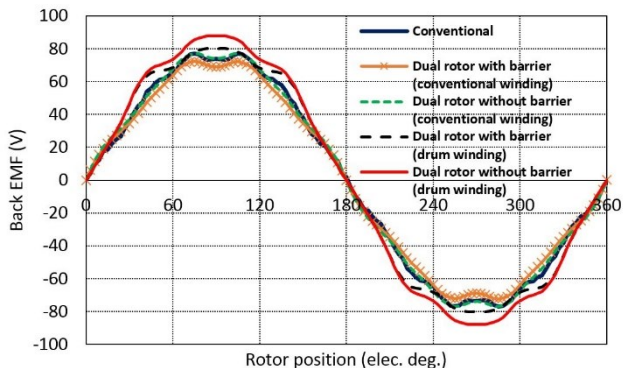
Fig. 2. Winding configurations (a) Conventional concentrated winding (b) Drum winding

III. FEM ANALYSIS RESULTS

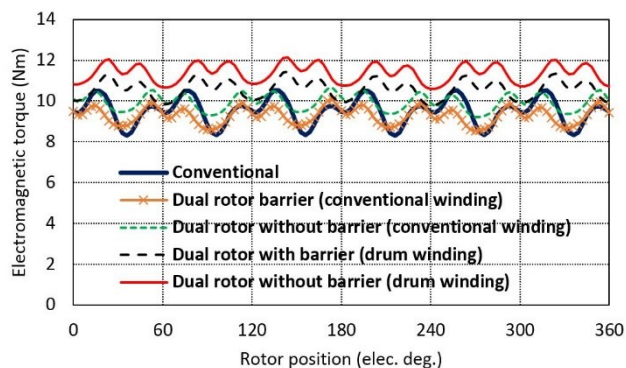
FEM analysis was done for each topology to verify the work. Analysis results of each topologies were compared at Fig. 3. (b), (c), and Table I. Results showed that dual rotor topology without barrier using drum winding had best performance with highest torque density and lowest torque ripple. It also showed less saturation on the rotor pole, which causes frequently in FSPMM machines due to its saw-toothed wheel-like rotor. Further study of the dual rotor model to increase the torque with low torque pulsations by study of relative rotor angle position and optimization will be shown in the full paper. Experiment results of the manufactured prototype will be included also.



(a)



(b)



(c)

Fig. 3. FEM analysis results of each machine (a) Coil flux-linkage of phase A for conventional concentrated winding and drum winding (b) Comparison of Back EMF with each machine (c) Comparison of electromagnetic torque with each machine.

TABLE II
COMPARISON OF PROPOSED FSPMMs WITH CONVENTIONAL

Item	Unit	Conventional 12S10P	Dual rotor with barrier 12S14P	Dual rotor without barrier 12S14P	Dual rotor with barrier 12S14P	Dual rotor without barrier 12S14P
Winding	-	Concentrated winding			Drum winding	
Back emf	Vrms	54.47	51.39	54.84	58.78	62.81
Average torque	Nm	9.51	9.28	9.94	10.58	11.37
Cogging torque	Nm	2.27	0.69	0.70	0.69	0.70
Torque ripple	%	23.3	16.4	14.4	15.8	13.7

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