Comparison of Two Different Rotor Topologies for 44Pole-48Slot Fractional Slot Concentrated Winding Permanent Magnet Synchronous Machine

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***Abstract*— This paper deals with a 44pole-48slot fractional slot concentrated winding permanent magnet synchronous machine (FSCW PMSM) for low speed direct drive. Two different rotor topologies, surface permanent magnet (SPM) rotor and consequent pole (CP) rotor, are optimized and compared in depth both analytically and experimentally. The experimental results confirmed FSCW PMSM with CP rotor can achieve almost equivalent performance at rated state when compared to FSCW PMSM with SPM rotor with 33% less PM material.**

***Index Terms*—Consequent pole, fractional slot, direct drive, permanent magnet synchronous machine, response surface methodology**

I. Introduction

It has been reported that a lot of research works on fractional slot concentrated winding permanent magnet synchronous machines (FSCW PMSM) have been performed in line with increasing demand for low speed direct drive applications such as traction, automation, and renewable energy generator due to high torque density, high efficiency and low torque ripple characteristics [1]. However, cost issues related to PM material rise to the surface due to the recent rare earth crisis. Recent research on consequent pole rotor topology for low speed direct drive has been theoretically investigated to show feasibility and practicality with less permanent magnet material [2].

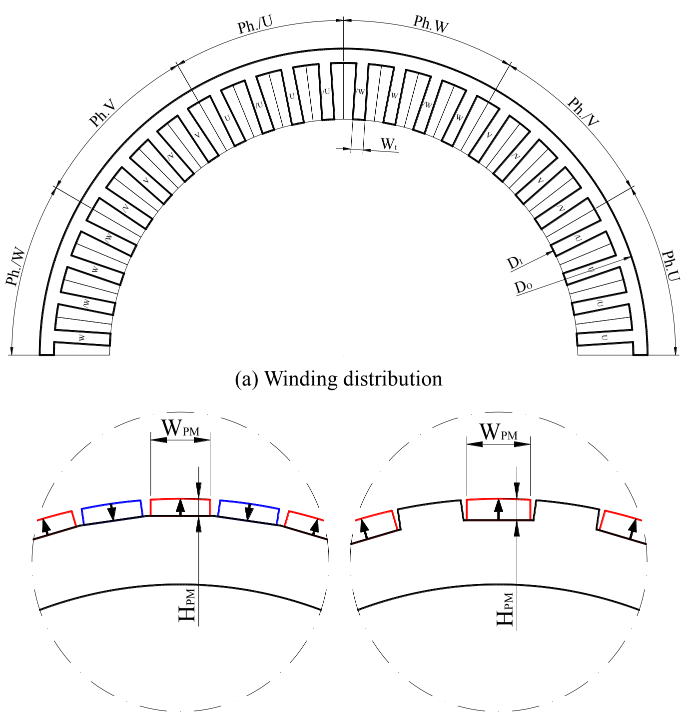
This paper introduces and characterizes a 44pole-48slot FSCW PMSM by 2D finite element analysis (FEA). Two different rotor topologies are considered and optimized by response surface methodology (RSM) coupled with 2D FEA for the maximum rated torque and the minimum PM volume. The validity of the analysis is examined and confirmed by prototype test.

II. RSM Optimization Combined with 2D FEA

Fig. 1 shows stator winding distribution and design variables for RSPM optimization. More detailed analysis and optimization will be discussed in the full paper. Specifications and geometries after optimization are summarized in Table I.

Fig. 2 compares no load induced voltage and average torque characteristics obtained by 2D FEA. It should be noticed that almost the same no load induced voltage can be achieved by CP rotor, which uses 33% less PM than SPM rotor. This implies that they can generate almost equivalent output torque if magnetic saturation is not excessive. In the average torque comparison, it can be stated that torque vs. current characteristics of the two models are practically the same up to rated state. However, it is observed that the torque vs. current curve of FSCW PMSM with CP rotor becomes non-linear as the current rises beyond the rated state while FSCW PMSM with SPM rotor still shows a good linearity. It seems that this non-linearity is caused mainly by the magnetic saturation since CP rotor structure eventually reduces magnetic air-gap by replacing N or S polarity PM with lamination steel core.

Fig. 3 shows prototype used for the experimental validation. Torque vs. current curves of the two models were measured at 300RPM and compared in Fig. 4(a) which shows that the two models generate practically the same torque up to rated state as predicted in FEA. Efficiency curves of the two models at different load conditions were also measured and compared in Fig. 4(b) which shows the efficiency of FSCW PMSM with CP rotor is equivalent to the other. In the full paper, analysis considering loss all loss components and experimental comparison will be discussed more in detailed.



(a) Winding distribution

(b) SPM rotor (c) CP rotor

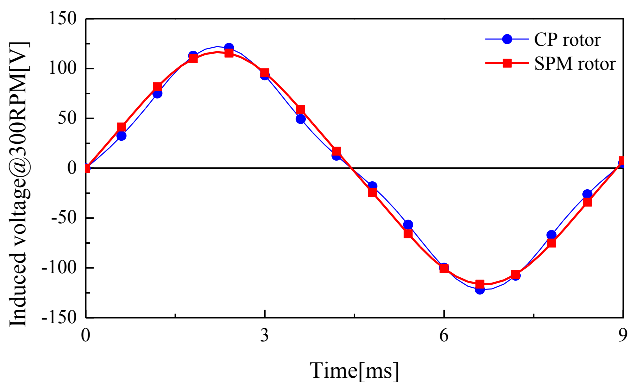
Fig. 1. Analysis FSCW PMSM geometry

III. Conclusion

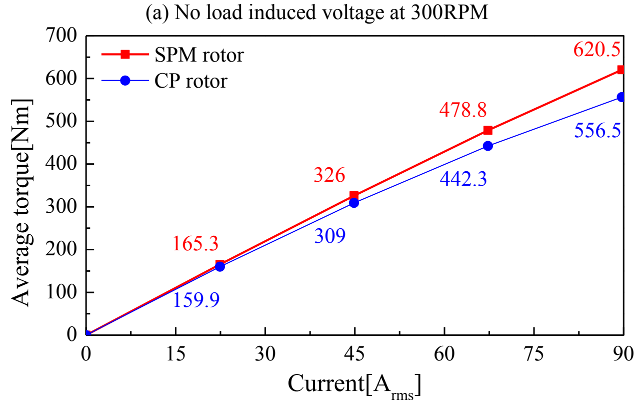
This paper dealt with extensive FEA in comparison with prototype experiments to compare two different rotor topologies. It was confirmed that the analysis results agree well with the experimental results, revealing that CP rotor topology can be a cost effective solution because it uses less PM material than the conventional SPM rotor topology.

TABLE I
ANALYSIS FSCW PMSM SPECIFICATIONS AND DIMENSIONS

Item	Value		Unit
	SPM rotor	CP rotor	
Number of poles	44		-
Number of slots	48		-
Airgap length(g)	0.5		mm
Tooth width(W_t)	6.0		mm
PM width(W_{PM})	14.0	15.0	mm
PM thickness(H_p)	4.0	5.0	mm
Stator outer diameter(D_O)	300.0		mm
Stator inner diameter(D_I)	231.0		mm
Stack length	150.0		mm
Number of turns/coil	14		-
Resistance/Ph.	0.074@20℃		Ohm
Rated current/Ph.	44.9		A_{rms}
Rated torque	290		Nm
Rated RPM	300		RPM
PM material	B_r=1.295T, μ_r=1.05@20℃		-
Core material	S18		-



(a) No load induced voltage at 300RPM



(b) Average torque vs. current

Fig. 2. FEA comparison

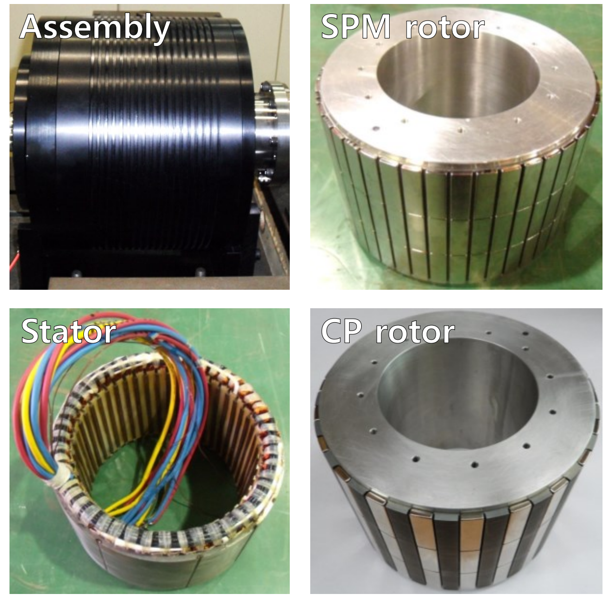
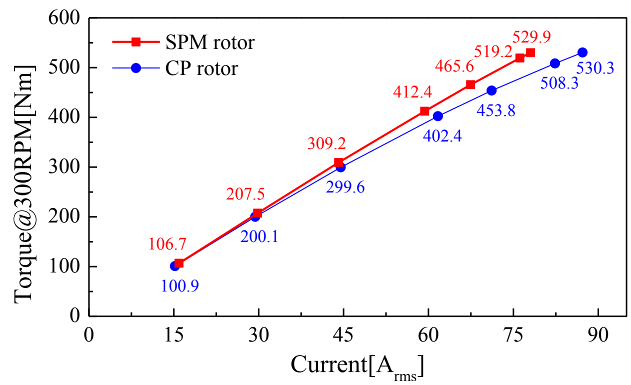
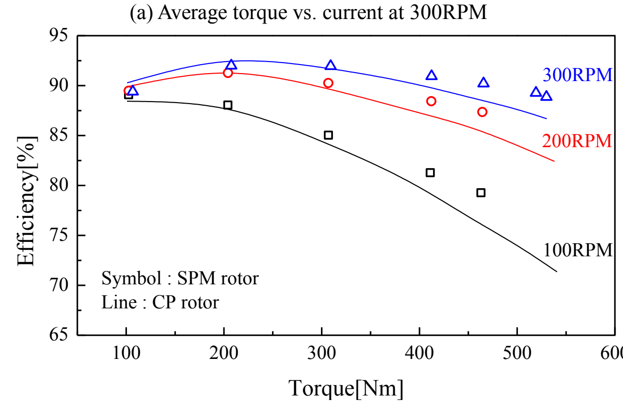


Fig. 3. Prototype



(a) Average torque vs. current at 300RPM



(b) Efficiency

Fig. 4. Experimental comparison

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