Simple Modeling and Prototype Experiments for a New High Thrust, Low Speed Permanent Magnet Disk Motor

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Abstract — Fully integrated electric propulsion systems are gaining popularity in both commercial and military sectors. Propulsion motor manufacturers are investigating new direct drive solutions for use in electric ships. These applications require motors with high torque output at low speeds. Such requirements were the motivation for the design of a new PMSM with a novel topology. This paper describes the efficient mathematical model used to optimize this design. Initial results from a prototype are also included and discussed.

I. Introduction

Permanent magnet motors have long been recognized as a promising option for high-torque applications. Due to the short pole pitch characteristic of certain types of PMSM designs, these machines can have high output at low speeds, but TFMs are plagued by low power factor [1]. In order to improve on previous designs, the authors developed a theoretical model of a transverse flux PMSM and subsequently built and tested the prototype of a new design.

II. Mathematical Model

The theoretical model for the authors' machine was created by breaking down a transverse flux PMSM into its fundamental components. The basic unit of the model was one pole of the machine. A diagram of this basic unit is shown in Fig. 1a.

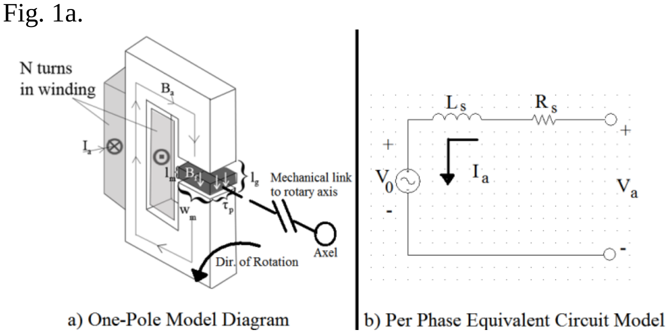

Fig. 1. Theoretical Model Components

Fig. 1b shows the equivalent circuit for one phase composed of *n* connected C-cores. The equations showing how the field flux, armature flux, air gap reluctance, per-phase inductance, self-induced EMF, power factor and thrust are calculated will be shown in the full paper. This simplified mathematical model enabled the authors to perform quick calculations for early comparison of the important performance factors of differing designs.

III. Results from Prototype No-Load Testing

Using the theoretical model detailed in Section II, the authors designed and built the prototype in Fig. 2.

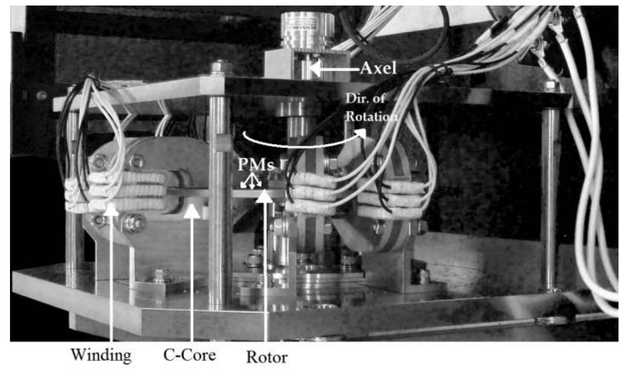

Fig. 2 Prototype PMSM

Performance data for initial no-load testing is given in the column titled "Emperical Value" in Table I. The values predicted by the authors' model is also given in Table I.

TABLE I
COMPARISON OF THEORETICAL AND EMPIRICAL DATA

Variable	Theoretical Value	Empirical Value	Increased Winding	Increased Input Freq.
Freq. f	33 Hz	33 Hz	33Hz	60 Hz
N	84	84	420	84
L_s	8.86e-4 H	2.06 mH	51.5 mH	2.06 mH
R_s	0.74 Ω	0.74 Ω	1.8 Ω	0.74 Ω
I_a	4 A	4 A	4 A	4 A
V_0	6.44 V RMS	4.94 VRMS	24.7 VRMS	9 VRMS
Φ_0	5.24e-4 Wb	4.01e-4 Wb	2.84e-4 Wb	2.84e-4 Wb
B_0	0.87 T	0.67 T	0.47 T	0.47 T
B_a	5.0e-4 T	5.0e-4 T	25.0e-4 T	5.0e-4 T
PF	0.98	0.98	0.60	0.98
η	0.68	0.63	0.77	0.75
$P_{mechanical}$	77.3 W	59.3 W	296.4 W	108.0 W
Torque	6.72 Nm	5.15 Nm	25.8 Nm	5.16 Nm
Force Density	50kN/m^2 = 0.49 atm	38kN/m^2 = 0.4 atm	145kN/m^2 = 1.5 atm	38.2kN/m^2 = 0.4 atm

IV. Conclusion and Future Work

In the full paper the authors introduce a new mathematical model for transverse flux type PMSMs. A prototype machine and test data for that machine are also shown. The authors conclude that careful design of the volumetric distribution of the field magnets and other machine variables can optimize the trade-off between PF and thrust. Future work will involve further characterization of the prototype through dynamic testing. The data from these tests will give insight into improving the authors' theoretical model.

V. References

[1] Yu, Zhao and Chai Jianyun, "Power Factor analysis of transverse flux permanent magnet machines," Proceedings of ICEMS 2005, Vol.1, pp.450-459, Sept. 2005.