Design and Analysis of Electric Controlled Permanent Magnet Excited Synchronous Machine

Ryszard Palka, Piotr Paplicki and Marcin Wardach
West Pomeranian University of Technology, Department of Power Systems and Electrical Drives
Sikorskiego 37, 70-313, Szczecin, Poland, E-mail: marwar@zut.edu.pl

***Abstract*—In this paper, a new type of machine – namely, the Electric Controlled Permanent Magnet Excited Synchronous Machine (ECPSM) possessing field weakening capability - is proposed and tested. The key is to incorporate a simple fixed DC-coil into a stator of the machine. Thus, the resulting new type of motor can offer effective flux control. The design method of the ECPSM machine is presented in detail. By combining the use of GOT-It-software and Flux3D application for the optimization of a finite element model, the static and transient electromagnetic performance are investigated. Experimental results of the ECPSM are given to verify the validity of the proposed machine.**

***Index Terms*—Permanent magnet machines, electric vehicles, magnetic fields, finite element methods, optimization, testing, inductance measurement, voltage measurement.**

I. INTRODUCTION

Permanent magnet brushless (PMBL) machines have become more widely used for a variety of industrial applications due to their high efficiency, high power density, high drive performance and maintenance-free qualities. However, they are used in modern drives for electro-mobiles and often suffer from uncontrollable flux, thus limiting their constant-power operation for EVs in high speed regions. There are many ways for solving this problem described in literature [1]-[5] e.g.

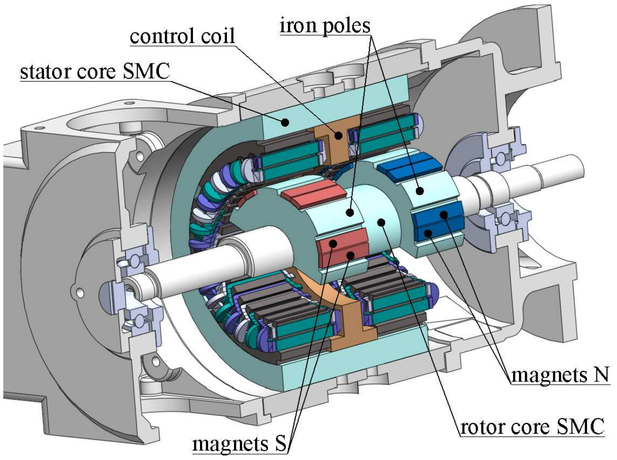
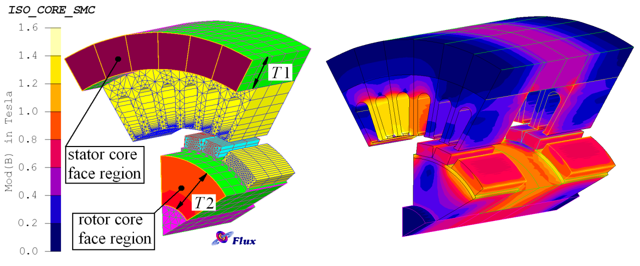


Fig. 1. Cross section of ECPSM with the double surface-mounted PM rotor and three phase windings stator structure with fixed excitation control coil.

The purpose of this paper is to present an advanced computation and optimization method for the 3D finite element model (FEM) of the ECPS machine as shown in Fig.1 that contains both PMs and the DC field control coil to increase (full) or decrease (weak) the magnetization level of the machine [6]-[7]. To demonstrate the operating principle of the ECPS machine and its features, a finite element analysis (FEA) has been applied and fully carried out. The main task of the analysis was to obtain the necessary parameters for designing, optimizing and controlling the machine.

II. MACHINE DESIGN

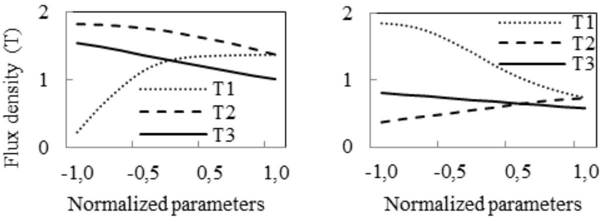
In order to find the best design solution for the ECPSM machine, its wide field weakening capability, high power density and high efficiency were taken into account during the analysis. Therefore, one of the purposes of this study was to find the optimal thickness of the rotor and stator core made from soft magnetic composite (SMC) materials without exceeding a magnetic field into full magnetization level. Therefore, during the analysis, some of the geometric parameters, such as the thicknesses of: the core SMC stator region - *T*1, the core SMC rotor region - *T*2 (according Fig. 2) and the thickness of magnets - *T*3, have been varied and explored. A 3D FEA of the machine has been performed according to the given criteria and fine numerical evaluation by using the new powerful and reliable optimization tool GOT-It and Flux3D ver.10.4 released by CEDRAT [8]. The simulation tools have allowed to effectively optimize the ECPSM machine with several objectives and constraints.



a) b)

Fig. 2. Magnetic field distributions. (a) Cross section FEModel. (b) Full FEModel.

Figs. 3-4 show, as result of simulation studies, the impact of the core SMC thickness on the magnetic saturation magnetization level. The figures indicate the variations of magnetic flux density (maximal value) on the stator and the rotor core face region (Fig. 3), as well as rated electromagnetic torque (Fig. 4) around a reference point. Each curve corresponds to a variation of one free parameter inside its entire domain of variation, the other parameters remaining fixed at their reference values. This gives a short overview of the robustness analysis. In order to plot the free parameters on the same horizontal axis, they are all normalized between [-1;+1].



a) b)

Fig. 3. Magnetic flux density - maximal value on the SMC core face region. (a) Rotor face region. (b) Stator face region.

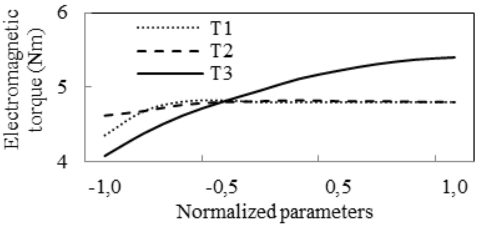
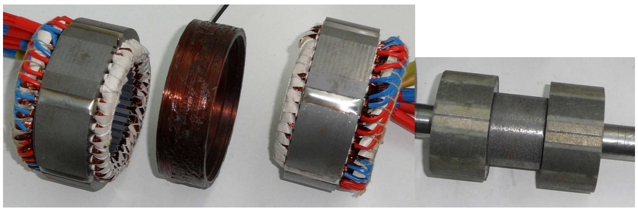


Fig. 4. Electromagnetic torque versus normalized $T1$-$T3$ parameters.

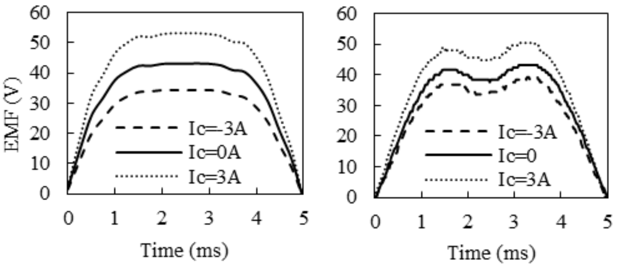
To verify the FEA results, the performance of the ECPSM machine prototype, which is partially shown in Fig. 5, was tested.



a) b)

Fig. 5. Parts of the ECPSM machine. (a) Stator. (b) Rotor.

Figure 6 shows no-load back-emf waveform at 1000 rpm speed and different magnetization level (excitation current control coil I_c). In addition, table I lists the peak values and the root mean square (RMS) of back EMF.



a) b)

Fig. 6. Back EMF waveforms under different magnetization level. (a) Simulated. (b) Measured.

TABLE I

BACK EMF AT DIFFERENT CURRENT CONTROL COIL (AT 1000 rpm)

	Simulated			Measured		
	I_c=-3A	I_c=0A	I_c=3A	I_c=-3A	I_c=0A	I_c=3A
V_{Peak} (V)	34.3	43.1	53.1	39.2	43.2	50.4
V_{RMS} (V)	28.4	35.8	44.2	27.2	30.4	36.0

III. CONCLUSION

In this paper, the design and analysis of the new ECPSM machine have been presented and discussed. Thanks to the new optimization tool GOT-It, it was possible to set-up an optimization problem easily and quickly and to find the best configurations of the machine in accordance to the design objectives and the associated constraints. The relationships between the main design parameters and performance requirements have been established. By employing a simulation model in the time-stepping FEA, the online magnetization characteristic of the motor is successfully obtained. The comparison between the experimental results and the results achieved from 3D FEM of the machine using an advanced coupling technology computation method has revealed a satisfying level of accord. Moreover, the results show that the proposed machine can offer effective online flux control and a wide constant-power speed range. By optimizing the shape and position of the PMs and iron poles in the rotor, the performance of the proposed machine has been further improved, making it more suitable for its application in EVs.

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