ELECTRIC CONTROLLED PERMANENT MAGNET SYNCHRONOUS MACHINE – SELECTED EXPERIMENTAL RESULTS

MASZYNA ECPMSM – WYBRANE WYNAKI BADAŃ EKSPERYMENTALNYCH

Abstract: The paper presents selected experimental results of an ECPMSM machine (Electric Controlled Permanent Magnet Synchronous Machine) excited by permanent magnets with extended magnetic field control capability, dedicated to electric vehicle (EV) drives. Rotor, stator and additional direct current fixed coil for field control of the machine are shown in detail. Influence of the additional excitation DC control coil current on the performance of the machine as: motor torque, efficiency and back-EMF has been also discussed.

Streszczenie: W artykule przedstawiono wybrane wyniki badań eksperymentalnych maszyny ECPMSM (Electric Controlled Permanent Magnet Synchronous Machine) wzbudzanej magnesami trwałymi z możliwością regulacji pola wzbudzenia, dedykowanej do napędu pojazdów elektrycznych. Pokazano w szczegółach budowę wirnika, stojana i dodatkowej cewki prądu stałego do regulacji pola magnetycznego maszyny. Wykazano wpływ prądu cewki DC na przebiegi i zmiany momentów, sprawność oraz napięcie indukowane maszyny.

Keywords: electrical machines, experimental results, permanent magnet, field control, efficiency maps

Słowa kluczowe: maszyny elektryczne, badania eksperymentalne, magnesy trwałe, regulacja strumienia wzbudzenia, mapy sprawności

1. Introduction

Nowadays, there is a great interest to develop hybrid electric machines for EV drives. It is mainly caused by requirements of wide-range speed control at constant power of the drive. There are many ways of solving this problem that have been described in literature, e.g. in papers [1-14]. The article presents the experimental investigations on the prototype of ECPMSM machine developed by the authors. Accordingly to previously simulation and experimental studies [15-19] the prototype has been successfully built.

2. Structure of ECPMSM machine

The cross-section of the prototype machine is presented in Fig. 1. The rotor construction, shown in Fig. 2, consists of two identical parts. One of them includes permanent magnets with outside magnetization direction (north pole polarization), and the second one magnetized in the opposite direction.

The specific feature of the machine is the existence of an additional DC control coil located between two laminated stators. This coil can be supplied by the DC-chopper in order to control the excitation field of the machine. Stators are located inside the bushing core made from magnetic powder material (Somaloy 500 + Kenolube 0,5%) with epoxy resin. Three parts of the stator i.e.: DC control coil and two laminated stators are presented in Fig. 3.
3. Test results of ECPMSM machine

The prototype of the ECPMSM machine has been tested on experimental stand presented in Fig. 4. It consists of the ECPMSM machine, load/drive PMSM 8LSA75 (B&R) machine, torque meter and power supply system.

In order to supply and control of the machine specific three-phase voltage inverter and DC/DC converter (for auxiliary coil power supply) have been used. Classical Field Oriented Control (FOC) algorithm has been applied with linear PI controllers, working independently on the d and q axis current components. Power Analyzer Norma 5000 (Fluke), digital oscilloscope, torque and position meters have been used to determine both no-load and load characteristics i.e.: torque curves, efficiency maps and voltage waveforms etc. Whole drive system and measurement devices were controlled by central computer.

First, the characteristic of the cogging torque peak-to-peak values $T_{cogg}$ depending on the DC control coil current value in range from $I_{DC} = -5$ A to $I_{DC} = 5$ A have been measured and shown in Fig. 5.

Obtained results show that the values of the cogging torque depend on the DC control coil current value and they are strongly increased during strengthening of the magnetic field.

In the next stage of the research back-EMF waveforms, values and harmonics have been measured. Fig. 6 presents the characteristics of the back-EMF rms value of the phase stator windings versus the DC control coil current $I_{DC}$ at 1000 rpm of the rotor speed.

Fig. 5. Peak-to-peak of the cogging torque $T_{cogg}$ depending on the coil current $I_{DC}$

Fig. 6. Rms value of the back-EMF vs. DC control coil current

Fig. 7. Amplitudes of 1st (a); 5th, 7th and 11th harmonics of back-EMF vs. DC control coil current (b)
During the Fourier analysis the amplitude values of 1\textsuperscript{st}, 5\textsuperscript{th}, 7\textsuperscript{th} and 11\textsuperscript{th} harmonics of back-EMF were also determined and shown in Fig. 7b. This figure shows that the quality of the back-EMF (i.e., harmonic content) increases mostly for 5\textsuperscript{th} harmonics by field weakening. Moreover, Fig. 6 and 7 show that the excellent field control range of the machine is achieved when the DC control coil current $I_{DC}$ is in range from -2 A to +2 A. Therefore, in further investigations and analysis, only three values of DC control coil current $I_{DC}$ = -2, 0, +2 A have been taken into account.

Next the back-EMF waveforms for the above mentioned values of the DC control coil current have been performed and shown in Fig. 8. It can be clearly observed that the DC control coil current affects the back-EMF waveforms and its values.

Moreover, initial comparative studies with $d$-axis demagnetization current to realize the flux-weakening control strategy allow to conclude that the proposed method of excitation adjustment is very attractive.

![Fig. 8. Back-EMF waveforms for different DC control coil currents](image)

In addition, the efficiency map of the machine for the three values of the DC control coil current have been determined and shown in Fig. 9. Based on the experimental results of the prototype machine, it can be concluded that across the tested range of speeds and torques the field control technique (both weakening and strengthening) operates but causes a slightly decrease in efficiency values.

It should be noted that the presented studies are only preliminary results of the prototype ECCMMSM machine. The authors are confident that the planned tests of the prototype performed at full loading conditions (rated torque 40 Nm, maximum speed 5000 rpm.) will show improved efficiency of the machine in extended measured range.

![Fig. 9. Efficiency maps for $I_{DC} = -2$ A (a); $I_{DC} = 0$ A (b); $I_{DC} = 2$ A (c)](image)
4. Summary
The paper presents selected results of experimental investigations of the prototype ECPMSM machine with permanent magnets and extended excitation control features. Obtained test results show noticeable effect of the DC control coil current on the field control range of the prototype ECPMSM machine. In further studies authors plan to execute experimental tests in broader range in generator and motor regime.

5. References
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Authors
mgr inż. Michał Bonisławski, michal.bonislawski@zut.edu.pl;
prof. dr hab. inż. Ryszard Palka, rpalka@zut.edu.pl;
dr inż. Piotr Paplicki, paplicki@zut.edu.pl;
dr inż. Marcin Wardach, marwar@zut.edu.pl;
West Pomeranian University of Technology, Szczecin,
Department of Power Systems and Electrical Drives,
ul. Sikorskiego 37, 70-313 Szczecin, tel.: +4891 449 48 73

Additional information
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