Study of a High Speed Motorization with Improved Performances dedicated for an Electric Vehicle

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***Abstract*— the paper presents the study of an entirely electromagnetic traction system to be used for electric vehicle (EV) application. The traction system is composed by a permanent magnet motor which is linked to a magnetic gear, to transfer the mechanical power to the wheels of the EV. In order to have a reduced mass and compact electromagnetic traction system, the traction motor will work at very high speed: 40500 rpm. The paper will present the study of such a system, and its energetic and mechanical performances. The results are validated numerically through finite element analysis.**

***Index Terms*— high speed motor, magnetic gear, electric vehicle, finite element analysis.**

I. Introduction

The high speed electrical machine, used in different applications, presents several advantages like reduced volume/mass, decreased costs for the active/passive parts used in the construction of the machine, and robustness [1]-[3]. The disadvantage is related to the mechanical losses and vibrations, and the electronics limitation to supply adequately the machine in transient regime at high frequencies. These influence of these disadvantages can be reduced or eliminated when using magnetic gear, magnetic bearings and the proper control unit. The advantage of a magnetic gear (MG) is clear: reduced maintenance, improved reliability, reduced acoustic noise an inherent over-load protection [4]-[6].

Up to now, the high speed machines were used in applications like compressor, air-conditioning systems, which do not have important dynamics. For electric vehicle applications we cannot speak about “working in permanent regime”. The transients are the common operation of the electric traction. The fast and repetitive acceleration or breaking will exploit the electrical drive’s capability to assure the demanded speed and torque. To respond to this issue, this paper presents the study of an entirely electromagnetic traction system for the propulsion of an electric vehicle (EV). The high speed traction system is very compact and reduced in volume and mass, and will permit us to increase the autonomy of the EV, which is a very important feature for todays’ automobiles. This is the novelty that this paper claims to address.

To be more specific, the application discussed in this paper concerns an EV which will be motorized by a 40 kW electric motor and a magnetic gear associated to it, to assure the needed power flow to the traction wheel. The electric motor is of synchronous type, excited through permanent magnets and running at 40500 rpm, thus being called a high speed permanent magnet synchronous motor (HS-PMSM). Also, the magnetic gear is of brushless type. The study is oriented to the electromagnetic traction system capable to assure the desired torque with maximized energetic and mechanical performances (meaning reduced losses and consequently improved efficiency, and reduced torque ripples). These performances will be evaluated by using the finite element analysis (FEA).

II. The Electromagnetic Traction System

A. The study of the HS-PMSM used for the motorization of the EV

In order to have a reduced volume and mass of the electrical machine, and with very good electromagnetic and energetic performances, several considerations should be taken into account:

- Very good quality materials should be used;
- The number of magnetic poles should be the lowest possible, in order to avoid the increase of supplying frequency, and consequently of the iron loss which affects the efficiency of the machine;
- Appropriate geometrical/winding topology should be adopted.

A steel material appropriated for the construction of a HS-PMSM is the VACODUR50, which has a reduced ‘H’ value (20kA/m) and high saturation level (2.35 T), for sheets of 0.2 mm. This will allow reduced iron loss, which is depending on frequency. For the magnets, we have chosen SmCo rear earth PM, capable to work at 150°C without losing the magnetic properties (and with 1.05 T remanent flux density).

The HS-PMSM under study runs at 40500 rpm and weights around 6 kg, which is great for such amount of power (40kW). Even if we take into consideration the mass of the MG, the overall weight of electromagnetic traction system is much lower than in the case of classical mechanical gear. This will be another advantage of the proposed HS-PMSM. *(More details on the machines geometry and comments related to the power density will be presented in the final paper).*

For the specified speed, and for the lowest number of poles (2), the supplying frequency is 675 Hz. At 40 kW, the rated torque is 9.45 Nm. For such conditions, the power electronic devices and the controller need to work (for a good dynamics), beyond the 16 kHz switching frequency, which is common for industrial inverters. Thus, a special control unit should be considered. Anyway, it is clear that, in order to have an adequate control we need to have very smooth mechanical performances, meaning reduced torque ripples. To achive this goal, three windings configurations were employed (w1, w2, w3) in order to obtain a torque wave with ripples below 1%. Some results of the FEA are presented in Fig. 1 and Fig. 2.

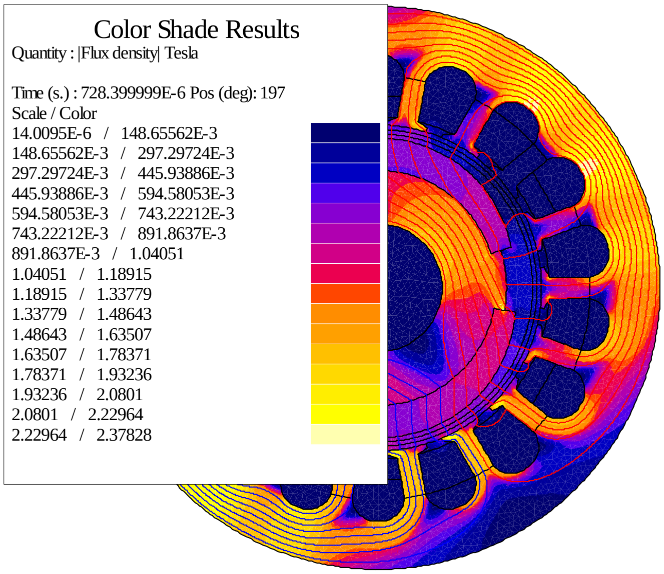

Fig. 1. Flux density & field lines in the active parts of the HS-PMSM.

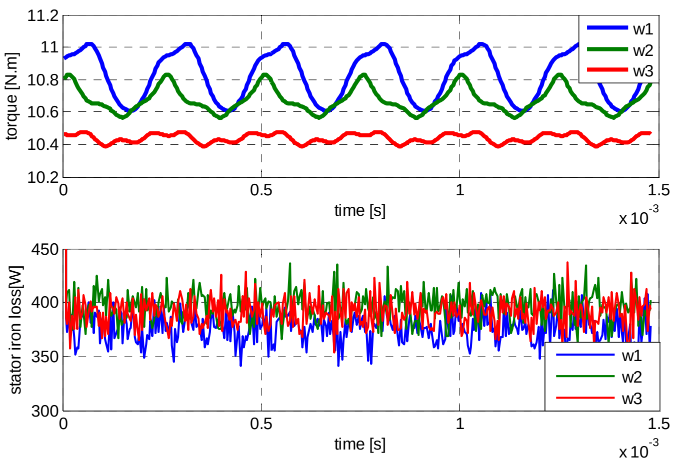

Fig. 2. Torque and iron loss curves for the studied HS-PMSM at rated operating conditions.

Here, based on the above two figures we should conclude that the designer accepts a certain saturation of the core of the machine, in order to reach the goal of having very smooth torque, which will be capable to be controlled at 40500 rpm. We only specify here that for the winding configuration noted with 'w3' has obtained the lowest torque ripple, but also a reduced torque of 5%. Knowing that the rated torque is of 9.45 Nm, the decrease of average torque is acceptable in the perspective of a control strategy, knowing that the inverter itself will affect the supplying voltage (for the simulation results presented in Fig. 2, a pure sinusoidal supply was considered). Regarding the iron loss, the 'w3' configuration presents the highest level of iron loss, due to the iron saturation, but the increase is not significant (20 W, representing 0.05% against 40kW output power).

The conclusion of this study on the proposed HS-PMSM is that our machine produces very good mechanical and energetic performances, at a very good power density level.

B. The study of the MG used for the motorization of the EV

For the magnetic gear a special attention should be paid to the ratio between the poles of the high speed (interior) and low speed rotor [4]. In our case, the number of poles of the low speed rotor will be 26, while the number of iron pieces which interfere in the production of the output torque, is 27. This has produced the lowest variation on the output torque.

In order to have a clue on the MG structure and the flux density repartition within its active parts, see Fig. 3.

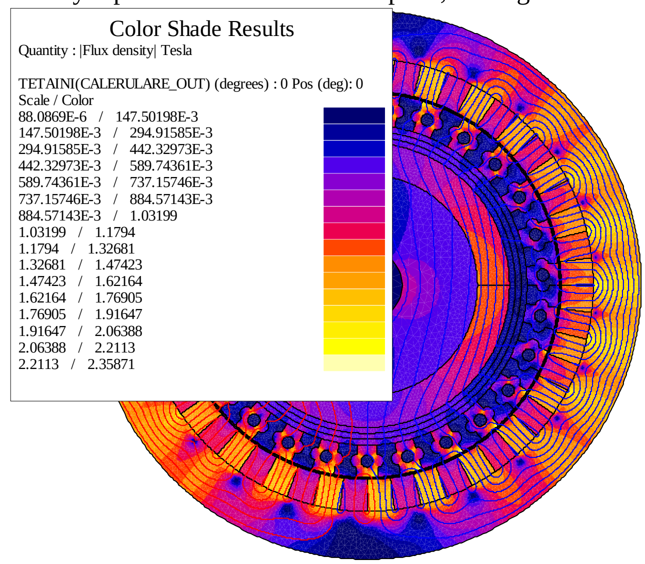

Fig. 1. Flux density & field lines in the active parts of the studied MG.

(More results on the electromagnetic gear, and the conclusions of the study, are given in the final manuscript)

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