Analysis of a High Speed Induction Machine used for the Propulsion of an Electric Vehicle

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Abstract— **The paper deals with a high speed induction motor used for an electric vehicle. A 40 kW machine, operating at a rated speed of 40500 rpm is designed and analyzed in the paper. After exposing the reasons that determined the choice of an induction motor for such an application, a particular topology of a machine is analyzed here. The aspects that arise during the design procedure and operation of such a motor are discussed in detail in the paper. Various choices that influence the performances of the machine are analyzed both by analytical and numerical methods. Given the novelty of such an application, the numerical analysis has a very important role, to validate the choices made in the design process.**

***Index Terms*— high speed induction machines, electric vehicles, finite element methods.**

I. INTRODUCTION

The high speed rotary motors are used mainly in compressors, pumps and machine tools [1, 2, 3]. For such applications, the needed torque is practically constant, while the machine works most of the time in permanent regime. Thus, the use of high speed electrical machines is justified, since involves a reduce volume and, consequently, of cost for the drive system. The high speed machines involve important problem related to the control dynamics and the limits of the power converter (switching frequency) and control unit (real-time computation) will be exploited.

Various studies analyzing the most suitable structures for such applications were carried out. Since the rotor of a high speed motor must withstand high centrifugal forces [4], the following motor designs can be used for high speed operation:

- cage induction motor (IM) with closed rotor slots;
- solid rotor IM;
- variable synchronous reluctance motor (VRSM);
- interior rotor type permanent magnet (PM) brushless motor and non-ferromagnetic sleeve ;
- brushless motors with surface PM rotor;
- switched reluctance motor (SRMs).

In terms of cost (no permanent magnet needed) and mechanical and control robustness (the VRSM and SRM are difficult to be controlled), the induction machine seems a good candidate. Thus, we propose here to use it for the propulsion of an electric vehicle. The main advantage for high speed motorization is a reduced motor volume, for the same stator line current density and air-gap magnetic flux-density. Hence a small dimensions motor can be used for driving the wheels of an electric vehicle. In order to meet the torque requirements of such a vehicle, a gear box coupled to the shaft of the electrical machine must be used.

The paper will investigate the limitations and performances for a proposed high speed IM of 40kW, capable to run an electric vehicle with improved energetic performances and reduced torque ripples. The study is sustained by numerical computation based of finite element method (FEM). In perspective, a high speed IM prototype will be constructed.

II. DESIGN CONSIDERATIONS

A 40 kW induction motor operating at a rated speed of 40500 rpm was designed. The machine has two pole pairs and is driven using a converter at a frequency of 681 Hz. The reason of using just one pair o poles is to limit the supplying frequency and consequently the iron loss of the IM. Also, in order to obtain a small dimension machine, with good performances, a special cooling systems and very good materials for the construction of the iron core must be used. VACODUR allows flux densities of up to 2.35 T. For the windings ordinary copper was considered. Comparing to the conventional induction machines where a maximum value of 8 A/ mm^2 is accepted for current density of the stator windings, here the water cooling system used allows a value of up to 12 A/ mm^2. In the aluminum rotor bars the allowed current density can be increased as well.

The application requires some dimensioning limitations. Thus, the outer diameter was imposed to be 105 mm. In addition, an 18 slots steel sheet of 0.2 mm thickness was used for the construction of the stator. The stator inner diameter of the designed induction machine is 60.8 mm. One of the most important issues is the choice of the air-gap. A good cooling requires that the radial clearance gap between the motor stator and rotor must be relatively large. However, this would decrease significantly the performances of the machine. A tradeoff between these two major issues was found here by choosing the air-gap to be 0.5 mm.

The motor will be supplied at 380 Vdc, from a battery. The stator winding is in star connection. As we shall prove in the paper, the torque ripples are very small, so a simple one layer winding type offers good performances for the proposed induction machine. The influence of the length of the machine on its performances was also analyzed in the design stage.

A critical point, regarding especially the small dimensions of the machine, is the shaft diameter. Since an induction machine developing a torque of about 9.45 Nm has a shaft diameter of minimum 19 mm (mechanically imposed), it is clear that the ratio between the rotor bar and the rotor yoke length must be very exactly computed in order to meet all the conditions for an optimum performance of the motor.

One of the most difficult tasks concerning the induction machine design is to choose the number of aluminum rotor bars. A greater number of the rotor bars (than the stator slots) means a very thick rotor tooth which is inadmissible at a motor operating at such a high speed. On the other hand, a smaller number of bars lead to a greater current in each bar, and hence a significant current density in the rotor bars. Another difficult aspect is the shape itself of the rotor bar, which was also studied by the authors. Round, trapezoidal and inclined rotor bars were evaluated. (More results from such analyze will be given in the final paper.)

III. NUMERICAL ANALYSIS

The analysis was performed using Flux2D. The numerical computations are particularly important and they validate the choices made in the design process [5].

The results obtained on the proposed cage induction machine with 13 rotor bars and 18 slots are presented here. One of the major goals of the numerical analysis was to obtain the flux density map in the stator and in the rotor of the machine, Fig. 1, and the air-gap flux density modulus in Fig. 2. One can notice the flux density values in the stator armature: the core is not saturated however. In the rotor core both the yoke and the teeth are partially saturated. We agree to accept a partial saturation of the stator and rotor core, in order to reduce the ripples on the torque wave. In order to limit the current density in the rotor bars, their surface must be as large as possible. The height of the yoke influences greatly the performances of the motor. If it is very small is has the advantage of allowing a bigger current density in the bars and reducing the torque ripples due to the high saturation of the yoke, Fig. 3.

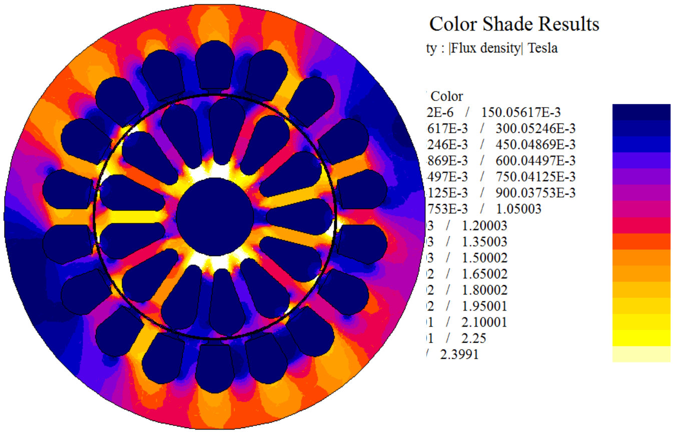

Fig. 1. Flux density map in the stator and rotor.

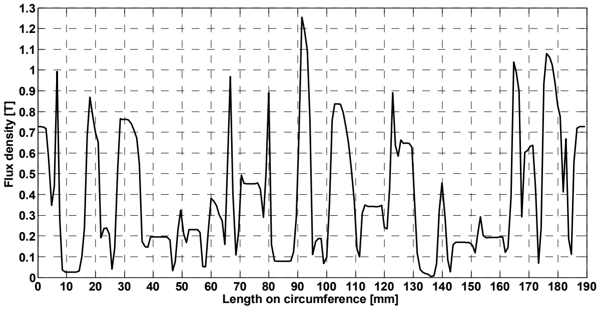

Fig. 2. Variation of flux density modulus in the air-gap

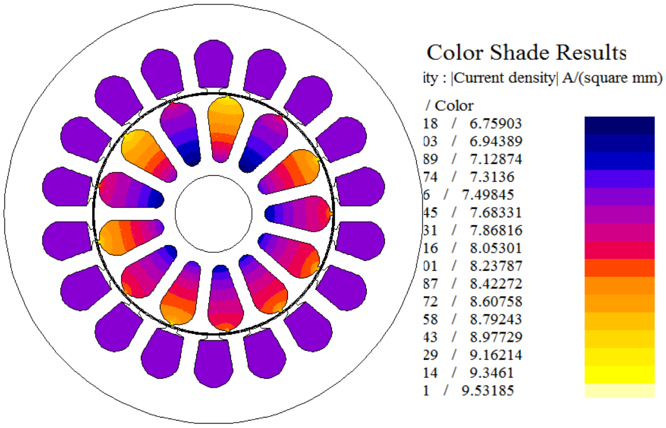

Fig. 3. Current density map in the stator windings and rotor bars.

The torque value decreases however if the yoke is too saturated. The torque obtained for the considered topology is given in Fig. 4. The ripples are relatively small, as expected, and its value is higher than the computed one from mechanical power.

(More results and conclusion will be given in the final paper in order to depict the advantages and shortcomings of the IM which make it a strong candidate to be used for driving an electric vehicle).

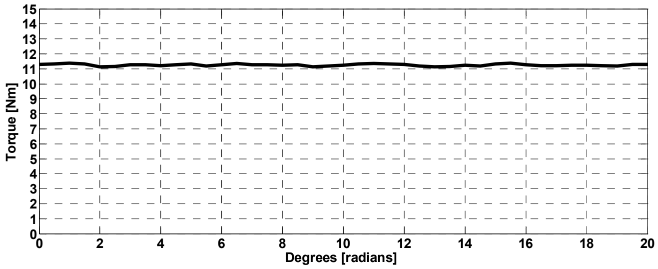

Fig. 4. Torque versus position.

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