

2D NUMERICAL MODEL OF THE SYNCHRONOUS MACHINE WITH PERMANENT MAGNET USED FOR THE PROPULSION HOVERBOARD

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Abstract: The aim of this paper is to determine a 2D numeric model for the study of the magnetic field of a three phase permanent magnet synchronous motor (PMSM). The motor is embedded in the driving wheel, used in the propulsion of a two-wheels electric hoverboard. It is determined through a series of experiments and the variation in time of the curves of the induced voltage in the stator's three phase winding and is calculated from the 2D numerical model, while functioning as a generator for a given number of rpm (nominal rpm), at no-load running. The calculation of the magnetic field through the method of finite 2D elements allows the determination of magnetic loads and the characteristics at no-load and load functioning of permanent magnet synchronous machines (PMSM) used at electric motion.

1. INTRODUCTION

The fabrication of electric machines in their actual form is defined from the beginning of the last century and specialists involved in this domain have worked more on the performance improvement of the machines already existent and to a more appropriate adaptation of different control strategies.

During the design stage of the electric machines, for each small improvement brought to the functional or energetic characteristics it must be put a significant effort. This situation is disrupted by the automotive industry (a very significant industry, with a production of over 20 million units per year) where radical changes are registered which will also have an effect on the electric machines installed into the car's dashboard. The conditions imposed by the environment regarding emission standards are determining a transition from the traditional automobile with a high degree of pollution towards the hybrid automobile and, in the future, towards the electric automobile which has no emissions.

An important criteria in the choice of an electric vehicle is represented by its autonomy. This represents the distance travelled in km by

the vehicle before the full discharging of the battery.

The battery represents the vehicle's source of energy, characterized by a capacity measured in ampere hour (Ah) and by the maximum number of charging-discharging cycles.[1],

These characteristics are dependent upon the type of the electric motor, of its rated power, of the mechanical characteristic and the possibility regenerative braking. In the research regarding the fabrication of electric automobiles it is proposed the solution of an electric motor embedded in the wheel, which utilizes an electric differential to control the direction of travel.

Permanent magnet synchronous motors (PMSM) do not have brushes and are called "brushless motors" by the specialized literature.

Hoverboard is a self-balancing scooter used for personal transportation. Its weight is 10 kg and it can resist at a maximum load of 100 kg. It has two wheels with a diameter of 6.5 inches and a brushless motor with a maximum power of $P_{max}=350W$ embedded in each wheel. The total output which provides motion of the two wheels is $P=700W$ (Fig.1). Each motor has a driver which also serves the role of an electric differential that allows driving in curves. Brushless motors are powered by a Lithium-Ion

battery with a capacity of 4400 mAh that provides autonomy from 15 to 20 km and a top speed of 12 km/h. The time required to charge the battery is 2 hours. [1]



Fig. 1 The fabrication of a hoverboard

2. THE DESCRIPTION OF PERMANENT MAGNETS SYNCHRONOUS MOTOR

The component parts of the permanent magnets synchronous motor (PMSM) embedded in the wheel, for the electric vehicle propulsion are shown in Fig. 2.



Fig. 2 The fabrication of the motor embedded in the wheel

Nominal data of the brushless motor is:

- maximum power $P_m=350W$
- nominal electric voltage $U= 36V$ (star wiring on stator)
- nominal speed $N_n=250$ rpm
- frequency of stator current $f_1=200Hz$
- pairs of rotor poles $p=15$
- stator slots $Z_s=27$
- numbers of permanent magnet rotors $N_p=30$
- outer diameter of wheel $D = 170$ mm

The characteristics of the permanent magnet of the NdFeB type:

- relative magnetic permeability $\mu_r = 1.05$
- remanent magnetic induction (to 20°C) $B_r=1.1$ T
- permanent magnets in the rotor are radially magnetized

- maximum temperature supported $T = 120$ °C
- length of ferromagnetic fittings: 24 mm (rotor) and 23.5 mm (stator)
- the machine's air gap is 1 mm wide
- the dimensions of the permanent magnet are: length $l_m=20$ mm, width $b_m=10$ mm and height $h_m = 2.5$ mm. The permanent magnets used are of the NdFeB type, and their demagnetization feature is represented in Fig.3, It's equation being:

$$B = \mu \cdot H + \mu_0 \cdot M_p = \mu \cdot H + B_r \quad (1)$$

where B_r represents the remaining induction of the magnet, and μ it's incremental permeability.

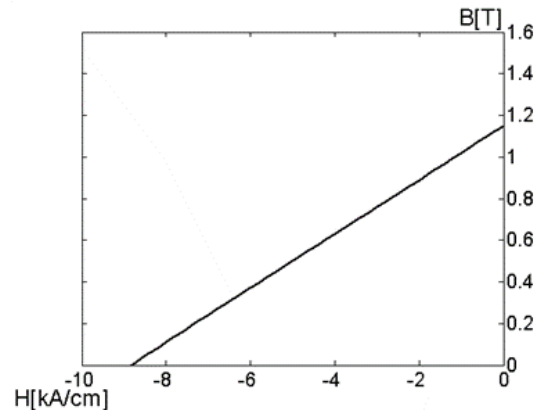


Fig. 3 Demagnetization curve of the NdFeB magnets

The 2D geometric model for calculating the magnetic field of the MSMP is represented by a cross-section of the motor in Fig. 4 in the 2D FLUX software program.

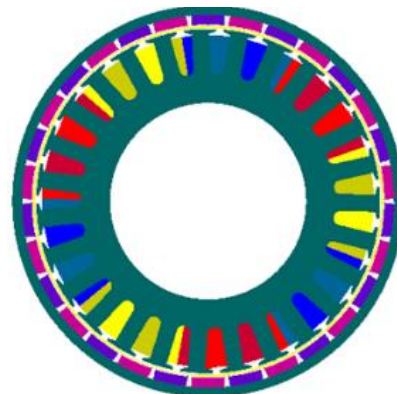


Fig.4 The field of calculation of the magnetic field in 2D Flux

The magnetization curve of the magnetic core of the stator is shown in Fig. 5

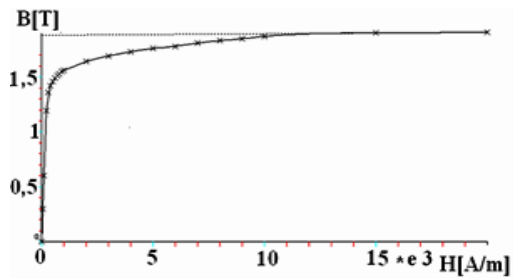


Fig.5 Magnetization curve of the magnetic core

The discretization network in 2D finite elements in the airgap containing the rotor magnetic circuit, permanent magnets and stator slots are shown in Fig. 6.[4],[5]

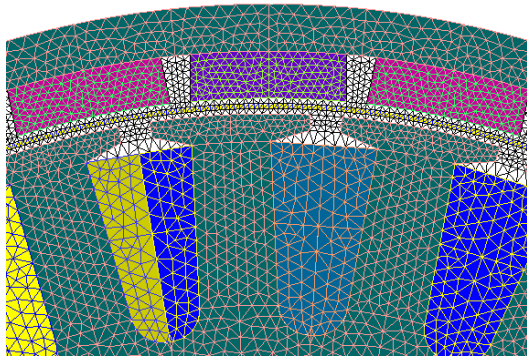


Fig. 6. 2D mesh airgap.

3. 2D NUMERIC MODELING AND EXPERIMENTAL VERIFICATION OF THE MACHINE IN GENERATOR MODE

The study of PMSM in generator mode is necessary, because as a control system (two-way controller) is required to allow the recoverable electric braking with generator mode operation (which switches the operating mode of the machine from motor to electric generator). In this case, when it goes down a slope, the machine switches to electric generator mode and it can charge the battery pack, if the system is equipped with thyristor rectifier so that a rectified voltage of value corresponding to the battery voltage (36 V) is permanently achieved.[5] The electronic system related to the machine's systems in generator mode is independent of the related operation during motor mode. Switching the system to another can be done automatically (changing the torque of the machine). Analyzing the periodicity and symmetry conditions of the

physical model, the field magnetic problem presented in Fig.4 is a parallel plane and the numerical model for the magnetic field study is 2D. Modeling and numerical simulation of the no-load generator regime, using the 2D finite element methods [2], [3] was realized with the specialized program "2D Flux" - product of CEDRAT company [4].

In order to reduce the computing effort, one third of the machine consists of 9 stator slots and 10 rotor poles, setting the periodicity conditions at the borders is presented in Fig. 7

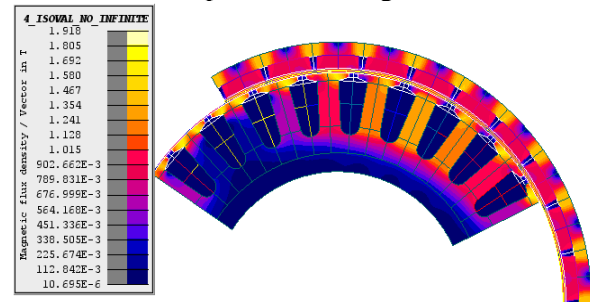


Fig.7 Magnetic flux density map in magnetic cores and rotor rotated by 26 degrees

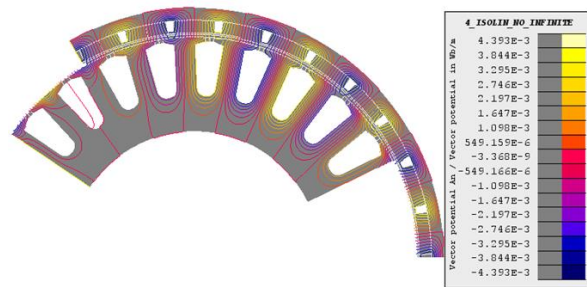


Fig. 8 Distribution of magnetic field lines in magnetic cores

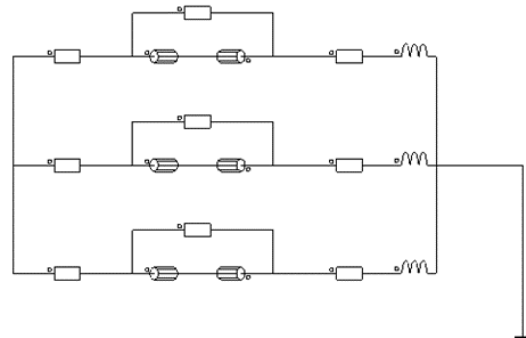


Fig 9 The electrical circuit associated with the three-phase winding

In the magnetic transient regime, a magnetic field problem coupled with magnetic circuit for speed $n = 160$ rpm is solved. Calculate

the voltage induced on the phase no load for a period corresponding to 26 degrees and the step 0.5 degrees and the graph is shown in Fig. 10

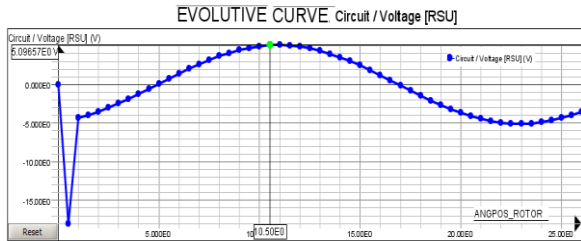


Fig.10 Voltage induced on the calculated phase $n=160\text{rpm}$

In generator mode driven with speed $n = 160\text{rpm}$, measure the three-phase voltages induced on phases with the oscilloscope with a step $dt = 8 * e^{-5} \text{ s}$ and is represented in Fig.11

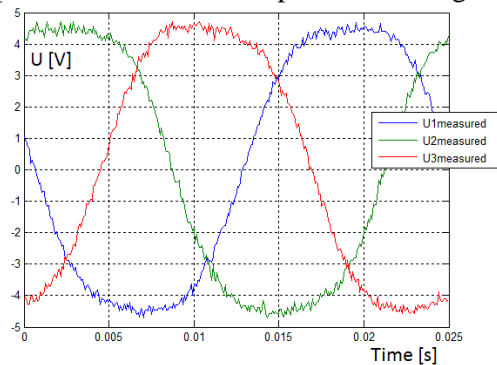


Fig.11 Three-phase voltage measured

In order to validate the 2D numerical model, the voltage on the measured phase is compared with that calculated for one the period as in Fig.12

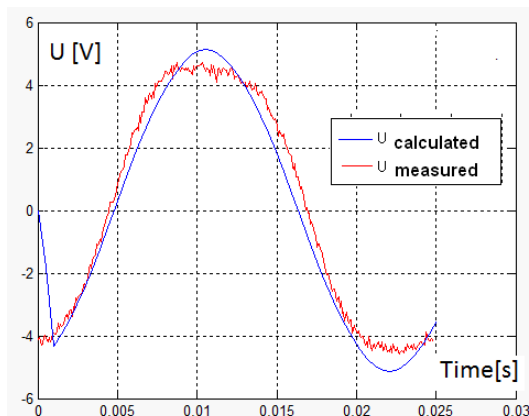


Fig.12 The voltage on the measured and calculated phase

4. CONCLUSIONS

The theme presented is topical in the context of the large-scale use of urban electric vehicles with energy efficiency and high reliability.

In Fig.12 was able to validate the study of the operating characteristics of the synchronous machine operating in generator mode by comparing the results obtained by numerical methods with the results measured in the laboratory. The validated 2D numerical model is a prospective solution in finding an optimal configuration of the studied MSMP

5. REFERENCES

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