ANALYSIS OF AN OUTER-ROTOR RELUCTANCE MOTOR USING THE TRANSIENT MAGNETIC MODEL

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REZUMAT. Lucrarea este destinată să ofere contribuţii analizei unui Motor Reluctant cu Rotor Exterior (MRRE). Este un motor cu reluctanţă variabilă cu un stator intern cu 16 poli dinţaţi si un rotor extern dinţat, special proiectat pentru a fi un motor „în-roată". Analiza sa este bazată pe modelul Magneto-Tranzitoriu, realizat cu software-ul FLUX2D. Aplicaţia Magneto-Tranzitorie perminte studiul fenomenelor create de un câmp magnetic variabil în timp. În scopul îmbunătăţirii modelului existent, a fost implementat circuitul electric pentru una din fazele MRRE-ului. Deasemenea, în vederea îmbunătăţirii rezultatelor, studiul a fost realizat pentru număr diferit de spire.

Cuvinte cheie: Motoare reluctante, Metode element finit, Inductie electromagnetică.

ABSTRACT. The paper is intended to bring contributions to the analysis of an Outer-Rotor Reluctance Motor (ORRM). It is a variable-reluctance motor with an internal 16-pole toothed stator and an external toothed rotor, special design to be an "in-wheel" motor. Its analysis is based on a Transient Magnetic model, realized with FLUX 2D software. The Transient Magnetic application allows the study of the phenomena created by a time variable magnetic field. In order to improve the existing model, a electrical circuit was implemented for one of the ORRM's phases. Also, in order to improve the results, the study was made for different numbers of turns of the coil conductor.

Keywords: Reluctance motors, Finite element methods, Electromagnetic induction.

1. INTRODUCTION

A special construction motor was designed for light electric vehicles (LEVs). For this new motor, a finite element analysis was initiated. By building finite element models for the motor, one can analyze the motor's geometry and physical phenomena. This method offers the possibility of modifying the model in order to obtain an optimization of it. The implementation of the finite element method was realized with the FLUX 2D software, which it is suitable for designing, analyzing and optimizing a rotating machine and other electromagnetic devices.

2. MOTOR DESCRIPTION

The ORRM is a variable-reluctance stepping motor with an internal 16-poles stator, a disc-shaped external rotor and an air-gap with toothed structure. The motor is of a flat construction, so it can fit inside the front wheel of a LEV. For this case one must consider an inverse construction of the motor, as it was depicted in Fig. 1. The stator is fixed on the front wheel shaft and is surrounded by the rotor. The rotor is linked to the wheel rim through spokes [1].

The ORRM is powered through four phases, each phase is made out of 4 series mounted windings and has alternating magnetic orientation. On each stator pole it is coiled only one winding [2].

This construction suits the purpose of providing a direct drive with high torque at low speed.

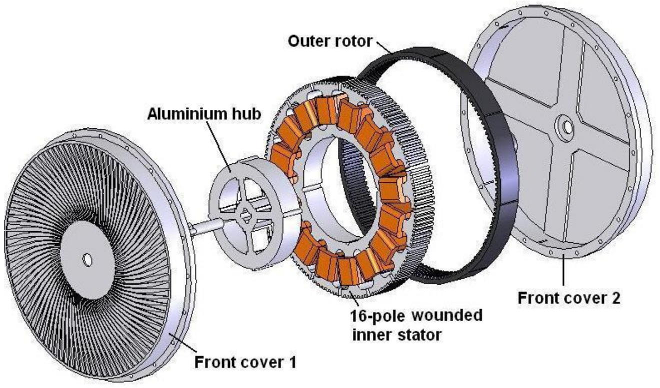


Fig. 1. Main ORRM parts [3]

Table 1, provide de general data that were used to start the designing of this motor.

General data of the motor

Magnitude	Symbol	Units	Value
Output torque	T_o	Nm	33
Output power	P_o	W	500
Supply power	P_{in}	W	625
Battery voltage	V_b	V	36
Battery current	I_b	A	17.36
Phase current	I	A	8.7

Table 1

3. THE ORRM MODEL IN FINITE ELEMENT

Geometry and mesh

The geometry was built to represent the entire 2D plan of the motor (Fig. 2). The dimensions were obtained from the classical design of variable reluctance motors [4]. In order to limit the infinite domain, an Infinite box Disc was defined around the motor to close the study domain and to had a null filed to infinity [5].

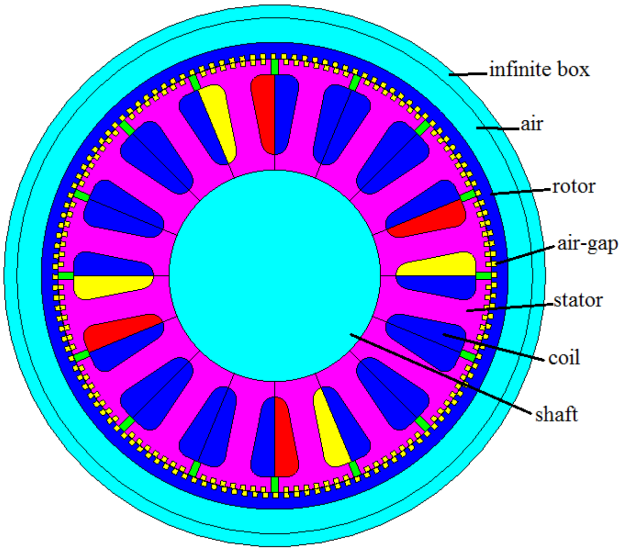


Fig. 2. Motor geometry including the Infinite Box Disc

After the geometry was built and verified an important step follows, the implementation of Mesh based on finite element method. The image of the mesh domain was depicted in Fig. 3.

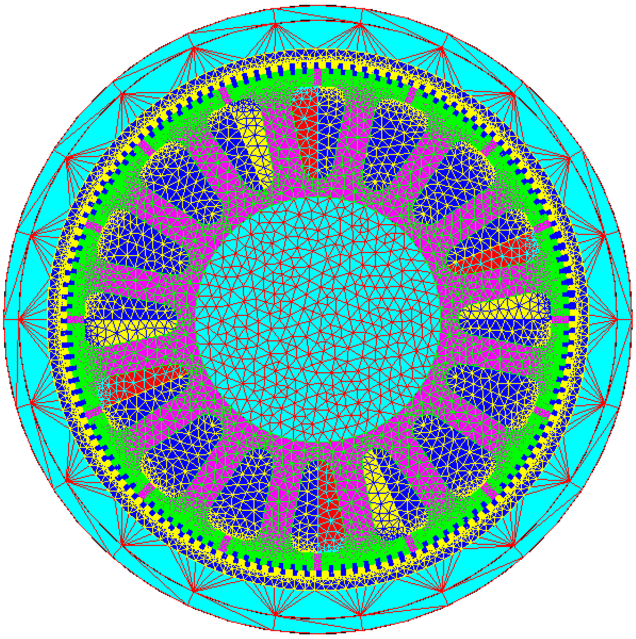


Fig. 3. Mesh of the domain

The Mesh point and Mesh line were manually set. The Mesh generator for faces was set automatic and it was based on Delaunay algorithm. Mesh construction represent the most time consuming step in defining the model. For this reason one may need to compromise between the quality of meshing and time/computer memory consumption [5].

Transient magnetic application assumes a rotating air-gap. Throughout the solving process, the software rebuilt the mesh everytime a change in the moving part position apears. A perfect mesh for rotating air-gap should contain only a single layer of triangular elements with shape as close as possible to an equilateral triangle [5]. Because the air-gap thickness was 0.25mm, building a mesh for air-gap with elements close to an equilateral triangle was possible only with a large number of nodes and this situation may caused a memory out error.

In the present case, the shape of triangle mesh elements of air-gap was close to the rectangular triangle (Fig. 4).

The mesh step was finished with a mesh check and the result was presented below:

"Surface elements:

Number of elements not evaluated : 0 %
Number of excellent quality elements: 92.24 %
Number of good quality elements : 1.12 %
Number of average quality elements : 2.34 %

Number of poor quality elements : 4.31 %
Number of abnormal elements : 0 %
Number of nodes: 70599
Number of line elements: 6625
Number of surface elements: 35288
Mesh order: 2nd order”

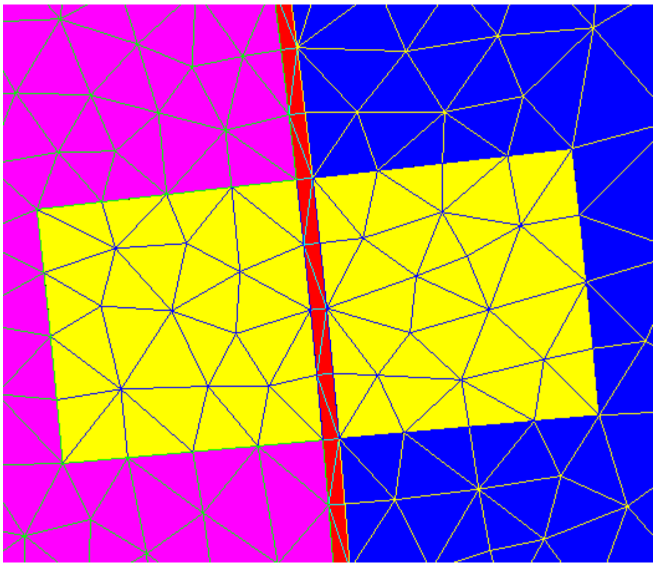


Fig. 4. Mesh in the air-gap zone

Physical sets and solving

The model of motor was set to Transient Magnetic application which allows the study of the phenomena created by time variable currents [5].

All faces were grouped in regions of faces according to the region they are representing, than the material was set for each region. For stator and rotor laminations the material used is M700–50A. After its definition, with Material Database of Flux, a curve of magnetization was obtained, as shown in Fig. 5.

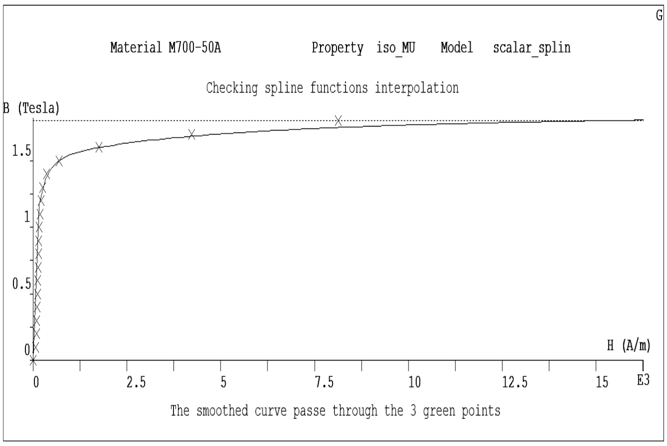


Fig. 5. Magnetization curve of M700-50A material

For the electrical part of the motor, only the coils of one phase were represented, the others coils were set as faces with air or vacuum. In the 2D model, a coil was represented by two faces placed on both sides of a stator pole.

From this point on, two models were presented for this motor. The difference between them was the way the electrical parts were described into the software. In the first model of the motor, the coils were described without an electrical circuit.

For the first model, one of this two faces had a negative orientation of the current and the other one had a positive orientation of the current, but both were powered by the same conductor. The IN face must being set with negative orientation of the current and the OUT face seted with positive orientation of the current. In Figure 6, the coils of the phase were represented, the yellow faces representing the IN regions and the red faces representing the OUT regions. The rest of the coil regions were not powered.

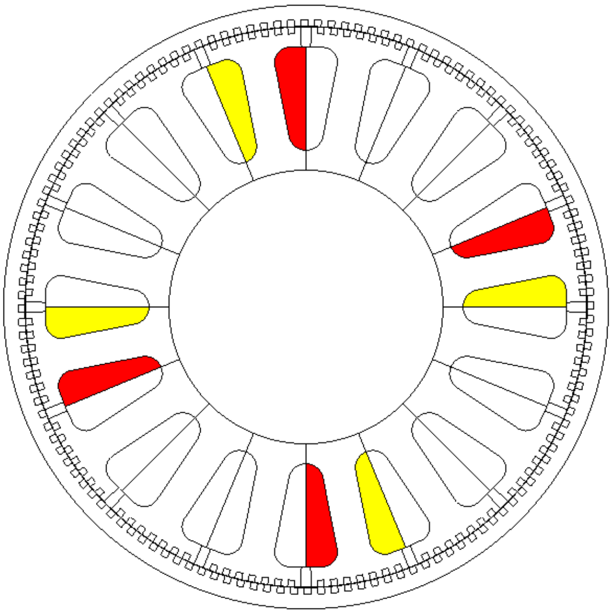


Fig. 6. Display of coils

The second model was built with an electrical circuit which describes the first phase of the motor. For each face representing half of a coil, a conductor was defined.

The electrical circuit for the second model was depicted in the Fig. 7.

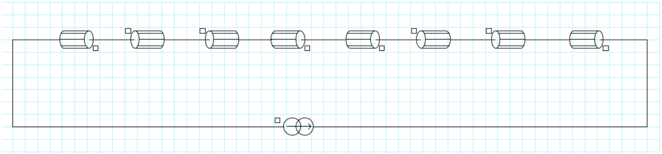


Fig. 7. Electrical circuit

In both cases, the number of turns on the coil was set to 180.

The solving process was time dependent and with an imposed angular velocity. The problem was solved for the following parameters: angular velocity 143 rpm, a time step equal to 7.5e-4 s and the study time limit set to 3e-2 s.

4. POST-PROCESSING RESULTS

After solving these two models of the ORRM with a Transient Magnetic problem, a parallel between results was created.

In Fig. 8, a map of magnetic flux density was shown and represents the magnetic flux produced when one phase was powered without the electrical circuit.

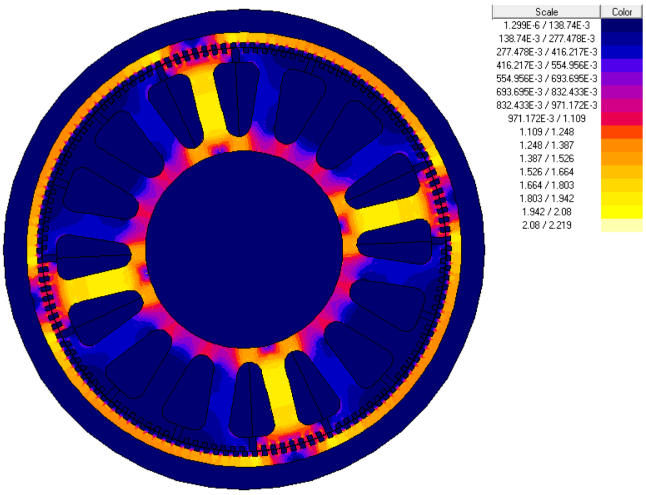


Fig. 8. Magnetic flux density, represented in color shade

For the same position of the rotor, with aligned teeth, a map of the magnetic flux density was represented, this time for the model of the motor with electrical circuit (Fig. 9).

These two representations of the magnetic flux density, displayed in color shade, bring the same values. The second model was built to verify the results obtained in the first model without an electrical circuit.

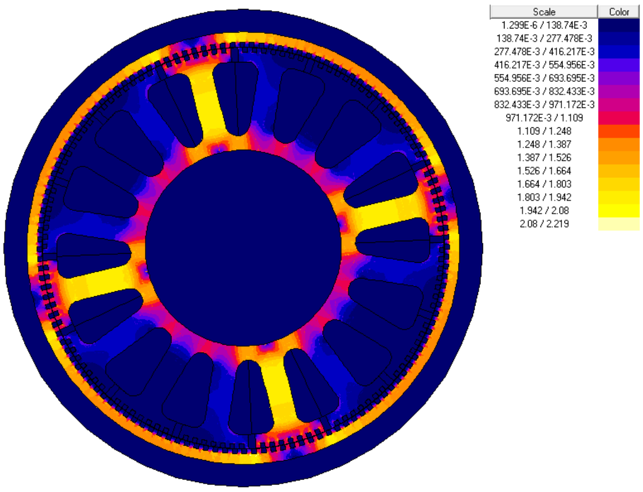


Fig. 9. Magnetic flux density for the problem with electrical circuit

In both cases, the maximum values of the magnetic induction were over the saturation limit.

The magnetic flux too, can be studied through an isovalues equiflux representation (Fig. 10).

Between two equipotential lines (or equiflux lines) flows the same quantity of flux. The flux density, which is a spacial derivative of the Potential vector, will therefore be as large as the space between the lines. Moreover, the equiflux lines indicate the magnetic field direction which is tangent to the lines in all points [5].

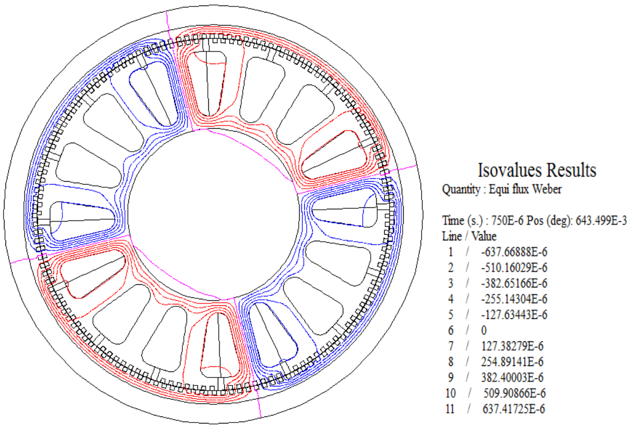


Fig. 10. Isovalues results

A difference between results for these two models appeared at the 2D curves for mechanical power and for magnetic torque variation in time.

In Fig. 11, the mechanical power curves for both models are represented (the left is for the model without electric circuit). In the same way was the magnetic torque depicted in Fig. 12.

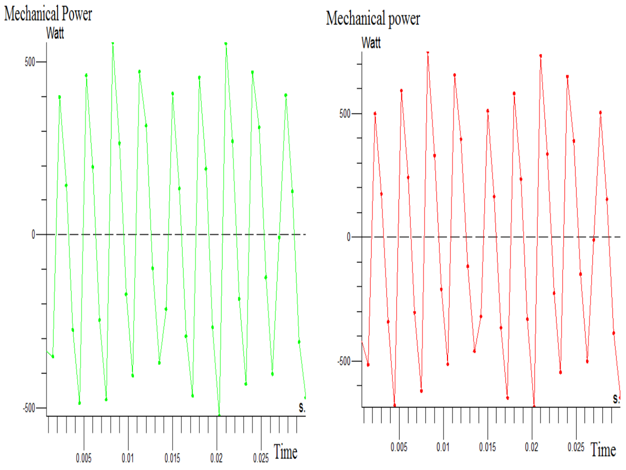


Fig. 11. Mechanical power variation in time

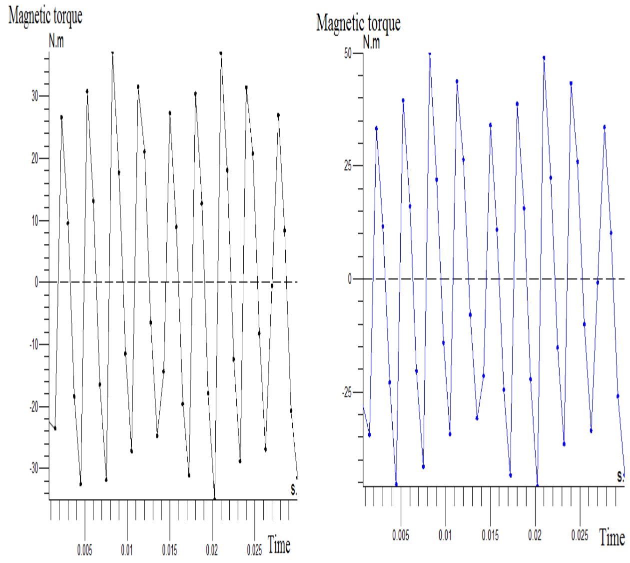


Fig. 12. Magnetic torque variation in time

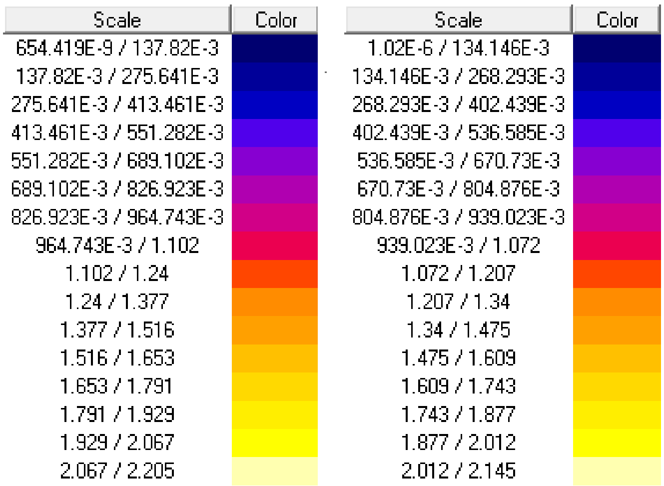
The peak values of the curves were higher for the model with electrical circuit.

In an attempt to reduce the magnetic induction in the motor, some modifications were performed on the number of turns of the coil's conductor.

The actual number of turns is 180 and two other cases were created: one with 135 turns and another with 120 turns, both for the model with electrical circuit. For these two other cases, only the magnetic flux density was studied.

Fig. 13 represents only the scales of values for magnetic induction. The map of magnetic flux density remains the same. On the left of the figure is the scale for the model with 135 turns per coil and on the right the scale for the model with 120 turns per coil.

In a quick view at the values scale, it is visible that the peak value remains over the material's saturation limit.



Scale	Color	Scale	Color
654.419E-9 / 137.82E-3	🟦	1.02E-6 / 134.146E-3	🟦
137.82E-3 / 275.641E-3	🟦	134.146E-3 / 268.293E-3	🟦
275.641E-3 / 413.461E-3	🟦	268.293E-3 / 402.439E-3	🟦
413.461E-3 / 551.282E-3	🟪	402.439E-3 / 536.585E-3	🟪
551.282E-3 / 689.102E-3	🟪	536.585E-3 / 670.73E-3	🟪
689.102E-3 / 826.923E-3	🟪	670.73E-3 / 804.876E-3	🟪
826.923E-3 / 964.743E-3	🟥	804.876E-3 / 939.023E-3	🟥
964.743E-3 / 1.102	🟥	939.023E-3 / 1.072	🟥
1.102 / 1.24	🟧	1.072 / 1.207	🟧
1.24 / 1.377	🟧	1.207 / 1.34	🟧
1.377 / 1.516	🟧	1.34 / 1.475	🟧
1.516 / 1.653	🟧	1.475 / 1.609	🟧
1.653 / 1.791	🟨	1.609 / 1.743	🟨
1.791 / 1.929	🟨	1.743 / 1.877	🟨
1.929 / 2.067	🟨	1.877 / 2.012	🟨
2.067 / 2.205	⬜	2.012 / 2.145	⬜

Fig. 13. The scales of values for magnetic induction

5. CONCLUSIONS

The paper presented four ORRM models in finite element. The model with electric circuit had been built in order to improve the first model. As the results show, there are a few differences between them. The last two models are attempts at finding solutions at the magnetic induction values. The modification of the number of turns was not enough. A further study with different number of turns and a different section for the coil conductor is recommended. Possible modifications of the motor geometry, the stator in particular, should also be taken into account.

ACKNOWLEDGMENTS

This paper was supported by the "Improvement of the doctoral studies quality in engineering science for development of the knowledge based society-QDOC" project; contract no. POSDRU/107/1.5/S/78534, project co-funded by the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013.

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