Annals of the University of Craiova, Electrical Engineering series, No. 33, 2009; ISSN 1842-4805

7TH INTERNATIONAL CONFERENCE ON ELECTROMECHANICAL AND POWER SYSTEMS

October 8-9, 2009 - Iaşi, Romania

MAGNETIC FIELD ANALYSIS OF AN INVERSE RELUCTANCE MOTOR FOR LIGHT TRACTION PURPOSES

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Abstract – The paper is a 3D approach of a special reluctance motor for the implementation of individual urban transportation. First, the motor was designed using classical approach and then its model is systematically built for 3D analysis. Geometry and mesh in 2D and 3D representation are introduced as preliminary study for complete FEM analysis. Significant results concerning the distribution of magnetic flux are presented following 3D analysis.

Keywords:*inverse reluctance motor, base geometry module, 3D analysis, flux density.*

1. INTRODUCTION

The solutions of direct (in-wheel) driving of light electric vehicles (LEV), such as bicycles, tricycles and scooters may replace conventional motors [1], provided the motor is of special construction, adapted for low-speed/high-torque characteristics. The paper describes a new type of reluctance motor, with a toothed air gap, that allows the reduction of rotor movement, to fulfill the requirement of a direct gearless driving vehicle.

The strategy of designing this new motor involves two main parts: classical design, respectively FEM analysis [2]. Classical design represents a pre-dimensioning stage designated to provide main geometric magnitudes for FEM analysis. This second stage is able to optimize motor as electromagnetic and electromechanic device and offers an excellent premise for a successful motor prototype.

The paper is intended to present gradually the new approach of a special reluctance motor using high performance software environment as Flux 3D [3].

2. MOTOR DESCRIPTION

The reluctance motor is of inverse construction, with an inner 16 pole toothed stator and a toothed outer rotor, that allows a direct low speed – high torque driving of LEV. Figure 1 depicts principled motor structure inside the front wheel of a bike.

As mentioned above, the motor is first classically designed using conventional methods for variable-reluctance motor [4], based on specific application of LEVs. As result, the main motor characteristics are determined, these being the start conditions for the 3D study of magnetic field, using Flux software. The main part of these data is shown in table1.

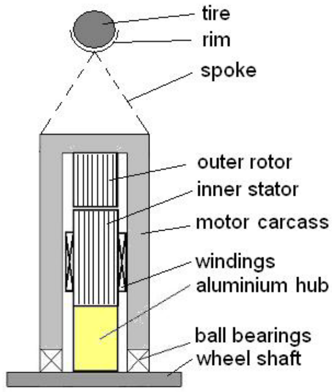

Figure. 1: Inverse reluctance motor.

3. FEM ANALYSIS

3D analysis is accomplished by passing the following main steps: Geometric construction or import/Mesh generation/Assignation of physical properties/Solving process/Result post-processing.

First, field element (FE) - model of the motor must be introduced. By taking into account the machine symmetry along its axial length and by using the periodicities, FE-model can be reduced to one-sixteenth of its original size, as shown in figure 2. In this way, the base geometry module is created.

Item	Symbol	Unit	Value
Number of rotor teeth	z_r		132
Number of teeth/stator pole	z_s		8

Number of steps/rot	N_p		528
Tooth base dimension	a	mm	4
Air gap diameter	D_δ	mm	336
Air gap magnitude	δ	mm	0.25
Active length of the motor	L_a	mm	40
Number of wires/pole	w		180
Pole width/height	L_p/ h_p	mm	21/43
Width/height of pole piece	L_{tp}/ h_{tp}	mm	60/12

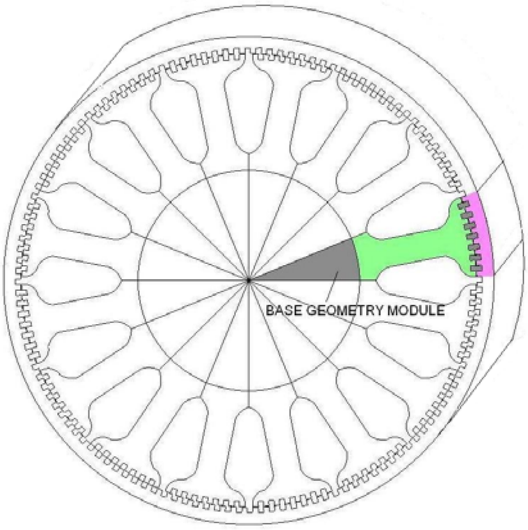

Figure. 2: Definition of base geometry module.

3.1. 2D Model

For a better development of analysis, 2D model of the motor must be built first and then 3D model will be deduced by extrusion. The 2D model is shown in

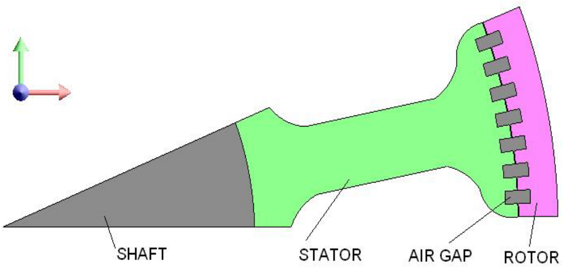

figure 3.

Figure 3: 2D model.

Particularly, geometry and mesh generation of 2D FE-model is developed by the following steps:
- preparing the model
  - establishing periodicity
  - defining coordinate system
  - establishing transformations
- generation of geometric entities
  - points
  - lines
  - faces
- propagate faces (in case of multiple modules)
- mesh generation
  - mesh points
  - assignment of mesh points to points
  - mesh lines
  - assignment of mesh lines to lines
  - meshing lines
  - meshing faces.

2D model is represented on Z plane in cylindrical system of coordinates and comprises the following faces: stator, rotor, air gap, and shaft. Transformations are used in case of building multiple models, e.g. 2-pole, 4-pole, 8-pole or 16-pole modules. These multi-pole representation are obtained by propagation of the four faces of 2D model.

Mesh generation is made with a dedicated control menu and is fulfilled by “mesh faces”. Figure 4 shows surface mesh of 2D module, as result.

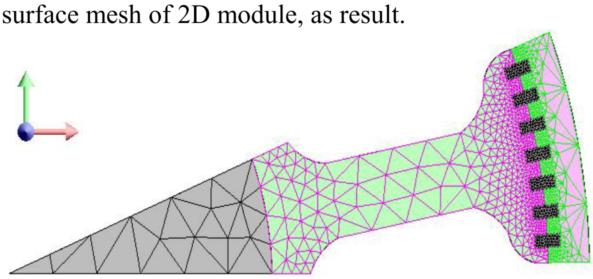

Figure 4: Mesh for 2D model.

Normally, meshing the 2D model is an automatic generation process for this type of the motor. The only care for designer is to choose adequate mesh points and lines.

3.2. 3D Model

3D model is obtained by using dedicated commands, as extrusions. The 2D geometry of the base model is extruded in the direction of Z-axis of coordinate system. Extrusion of the 2D model is performed via an extrusion line of a length equal to axial length of the machine, L_a. For clarity, the 3D geometry and mesh are developed along the following steps:
- defining infinite box (cylinder)
- including geometric transformation for extrusion
- closing the infinite cylinder
- extrusion command
- build faces and volumes
- mesh generation.

The **infinite box** of cylinder shape is used for surrounding extruded model by a determinated air region, in order to delimitate volumes when Flux 3D performs field computation.
Extruded model, as depicted in figure 5, emphasizes important new lines, as follows:

AB - extrusion line

BC, DE, FG – closing lines for contouring the infinity cylinder.

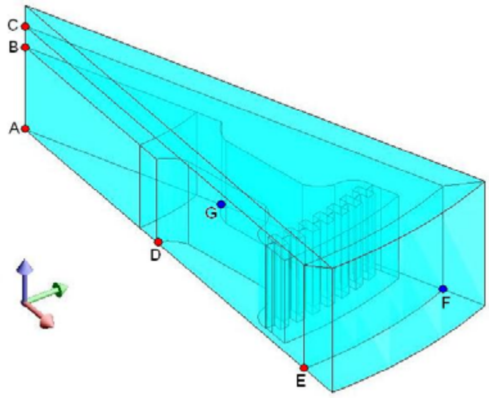

Figure. 5: Extruded model.

These lines allow defining the six volumes, as: stator, rotor, air gap, shaft, air and infinity cylinder. Figure 6 depicts these volumes, as parts of base geometry module, introduced at the beginning of the study (fig. 2).

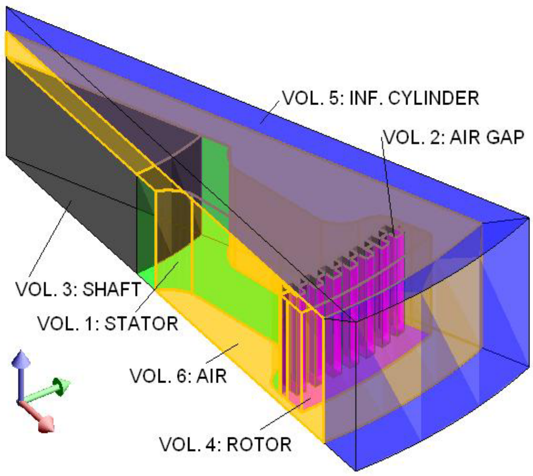

Figure 6: Volumes of base geometry module.

Now **3D mesh** can be created. In this purpose, an extrusive mesh generator is defined into the volumes, in order to ensure the mesh density in the direction of Z-axis. In addition, a linked mesh generator is used for linking the side faces of the model. The model is meshed using adequate commands, including faces and volumes. The surface mesh obtained is represented in figure 7.

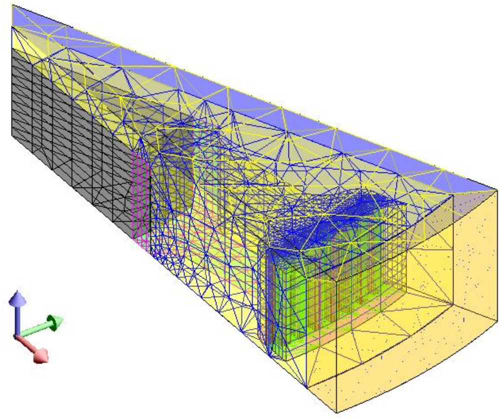

Figure 7: 3D mesh view.

Following the design way, another important step consists in **coil management**. In this purpose, the entire winding per one stator pole must be first designed. A new cylindrical coordinate system is defined for COIL, with the origin in the geometrical centre of stator pole. The main specifications of the whole coil are (figure 8):

- Type: RECTANGULAR COIL
- Coordinate system for definition: COIL
- Dimensions along Ox: 32 mm
- Dimensions along Oy: 49 mm
- Filet radius: 6.5 mm
- Coil section: RECTANGLE, height = 43 mm, width = 9 mm
- Number of turns per coil: 180
- Fill factor: 1/1.2.

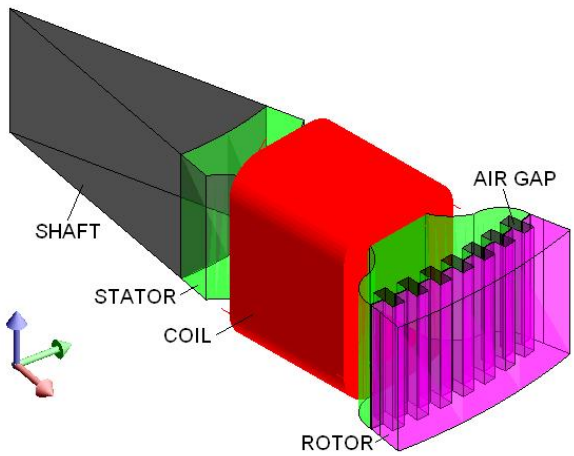

Figure 8: Coil placement.

A better image of geometric results is obtained by propagation of volumes. This multiplying process enables multi-pole representation of the motor. Figure

9 is a 3D representation of the magnetic circuit of the whole motor, as designed in Flux 3D.

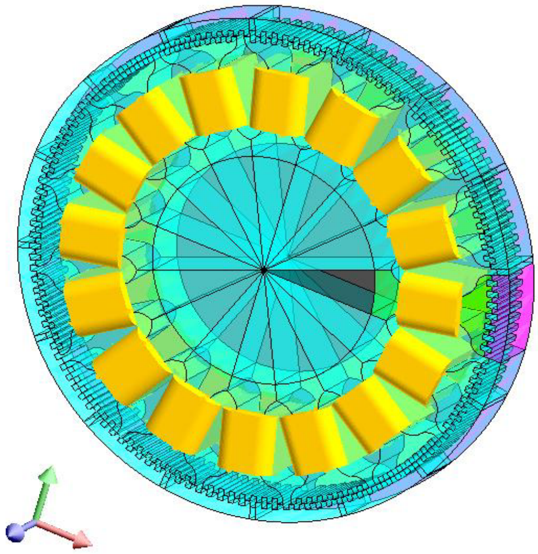

Figure 9: 3D view of 16-pole motor.

4. RESULTS AND COMMENTS

At this point all preliminaries for FEM approach of the motor are completed. The 3D FE model may be extended to 4-pole or 16-pole analysis in order to acquire magnetic and mechanic characteristics of the motor.
Following all steps, one can obtain a large palette of graphic representation of the magnetic circuit. Fig. 10 shows the Flux 3D screen after post processing the results.

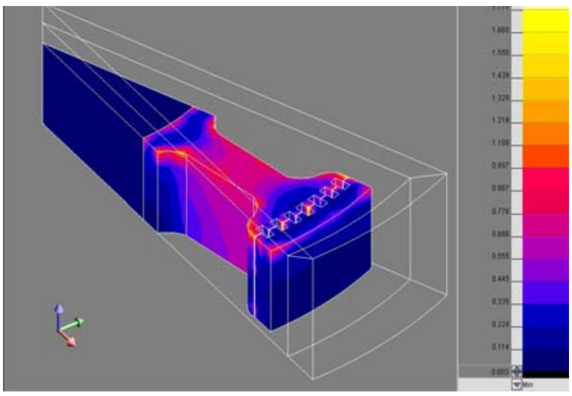

Fig. 10. Flux 3D screen.

As observed, the magnetic field density reveals an unsaturated magnetic circuit of the motor, that being a premise for trying to reduce as possible the iron volume.
Other computations related to flux magnitude through coils are made with the purpose to verify corresponding result from classic design. Figure 11 depicts the result window returned by Flux 3D.

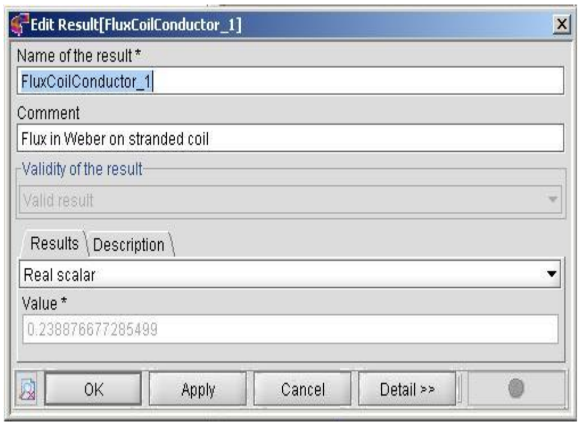

Fig 11. Computed flux magnitude.

5. CONCLUSIONS

The best way to optimal design of the new motor for direct driving the LEV is to combine classical design with 3D-FEM analysis. Classical design offers geometrical and material data for starting the 3D study, using the Flux 3D environment. Geometry and mesh represent the first steps in this study and offer all preliminaries to complete 3D analysis. Isovalues of flux density reveal no saturation effects and the calculation of flux through a coil confirms its classically deduced magnitude.

Acknowledgment

The authors bring special thanks to Cedrat - France, which provided conveniently for us the software license of Flux 3D in the Laboratory of Reluctance motors and applications, Technical University of Cluj-Napoca, Romania.

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