Software tool based on reluctance network automatic generation for electromagnetic devices modeling

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***Abstract* — This paper deals with *MRNSoftware;* a new tool for automatic generation of Mesh based Generated Reluctance Network (MGRN) for electromagnetic devices modeling. The used modeling approach is detailed in the case of a Permanent Magnet Linear Machine (PMLM). Thanks to *MRNSoftware*, it is shown that it is possible to quickly obtain a semi-numerical model of studied structures. The open circuit magnetic field components obtained from the MGRN model are compared to those obtained from a Finite Element Analysis (FEA) showing a very good agreement.**

I. INTRODUCTION

For electromagnetic modeling of electrical machines, analytical models are fast but do not take into account local magnetic saturation or complex geometries [1]. Numerical methods and mostly Finite Element Analysis (FEA) are popular for design/optimization, but have long computation durations especially for 3-D models. The semi-numerical Magnetic Equivalent Circuits (MEC) approach combines fast computation time and good accuracy. MEC approach takes saturation effects into consideration. In this paper, existing Computer-Aided Design (CAD) tools based on Reluctance Network (RN) modeling are overviewed. Then, a new modeling tool (*MRNSoftware*) founded on Mesh based Generated Reluctance Network (MGRN) technique is presented through a 2-D model of a Permanent Magnet Linear Machine (PMLM). The modeling approach, on which the developed tool is based, is validated by comparing its results to those obtained from FEA. Finally, possibilities of the tool for future developments with a focus on parameterisable models are discussed.

II. RELUCTANCE NETWORK CAD TOOLS

MEC have started to regain popularity among machine designers and two types of MEC approaches are employed: Expert Reluctance Network (specifically developed for a fixed topology); and MGRN as a more generic approach [2]. Even with a more generic technique, most works have been dedicated to specific topologies as induction machines in [3] or PM flux-switching machine in [4]. Regardless, a little number of CAD software exploiting RN modeling has appeared. On the academic side and in literature, we can mention Turbo-TCM [5] dedicated to small-power turbo-alternator modeling. On the commercial software side, RMxprt in the ANSYS Electromagnetic package [6] includes pre-defined designs of stator and rotor topologies that can be combined into one whole machine model for performance assessment. SPEED [7] uses various analytical formulations as complementary to FEA but again with pre-defined geometries. In another approach, Reluctool [8] is based on lumped-parameter MEC (Expert Reluctance Networks) for the modeling of electromagnetic devices and includes an optimization module for pre-design purposes. Reluctool models are intimately linked to a given topology, and reluctance network needs to be built based on the expertise of the designer. All the previously mentioned software come with a graphical interface that allows interactions with the user/designer but none of them allow the automated processing of an arbitrary geometry. On this aspect, for a given structure, a dedicated MEC model needs to be developed. This makes model development duration longer for MEC methods as compared for FEA. Furthermore, if geometry parameters vary in large scale, the model will no longer be valid and will have to be readjusted. MGRN approach with an automatic mesh based generation of reluctance network frees the designer from developing a specific model for a given topology and allows the automated processing of arbitrary geometries. The aim is to address parameterisable models for parametric studies and optimization.

III. MODELIZATION WITH *MRNSOFTWARE*

MRNSoftware is developed within MATLAB environment and its interface is similar to other CAD software for electromagnetic device modeling. The aim of the *MRNSoftware* tool is to include: 1) Modeler (for geometry processing); 2) Meshing tool (for geometry discretization, material and boundary condition definition along with sources distribution leading to reluctance network building); 3) Solver (for the Solving of the algebraic equations system); 4) Post-processing (for displaying/exploitation of results). In this case, as an alternative to the modeler as an integrated module, geometry is developed on an external modeler then the file is exported in Autocad DXF file format to be processed in *MRNSoftware*.

A. Geometric model and boundary conditions

The PMLM geometric parameters and material proprieties are given in [9]. The geometry displayed on the main layout (Fig 1) is loaded as a DXF format file then unit and active length are specified.

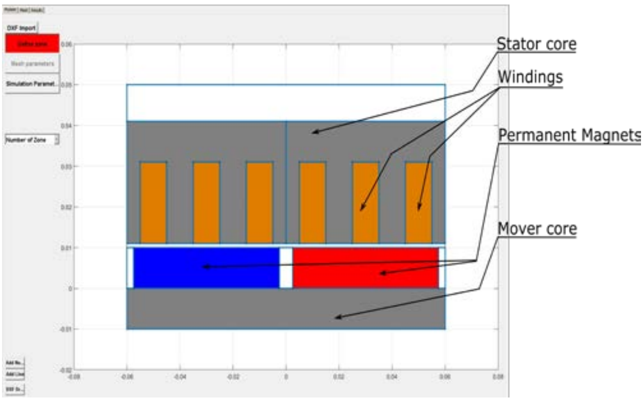

Fig 1. Main layout ***(MRNSoftware)***

Boundary conditions need to be defined as a first step of the process so they can be taken into account when building the permeance matrix describing the network. A Periodic boundary condition is applied on the right and left border of the considered space meaning that the set of elements on those borders need to be connected i.e. node number n_x (number of elements in the x direction) is connected to node number 1 and so on through all the layers as illustrated on Fig 2. Tangential flux condition is applied on the lower and upper border meaning that the elements on those layers lose one of their branches (Fig 2).

B. Mesh and sources assignment

In order to generalize the method to different structures and geometries, an automatic mesh generator is required. This meshing tool performs a discretization of the geometry into a number of elementary reluctance blocks. First, the model is divided into zones and regions according to geometry or material change. The size of element is specified according to the minimal spacing in each region of the model. A conformal meshing is then applied as illustrated on Fig 3. At the end, the number of element is the same as the number of nodes for which the equation system is solved. Magneto-motive sources need to be distributed equally on the branches of the magnetization direction (y direction) in the elements through all layers of the PM zones (Fig 3). The nodal-based matrix equation system to be solved in (1) is derived from the space discretization and the distribution of sources.

$$[P]^{-1}_{nn\times nn}\,[\Phi_s]_{nn\times 1} = [U]_{nn\times 1} \tag{1}$$

Where: [P] is permeance matrix; [U] is scalar magnetic potential in each node; [Φs] is the sum of flux sources for each node and nn the total number of nodes.

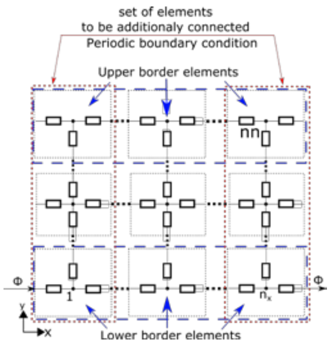

Fig 2. Element layers and boundary conditions

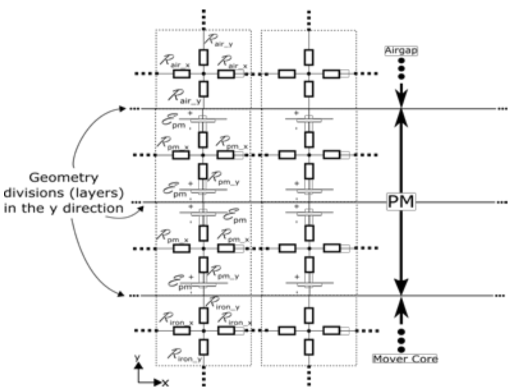

Fig 3. Mesh and sources distribution

C. Results and comparison

Fig 4 shows the Flux density chart at displacement xd = 0 mm and on Fig 5 are illustrated Airgap normal flux density and tangential field at displacement xd = 35 mm for the FEA model and MRN model and show that results are in good agreement.

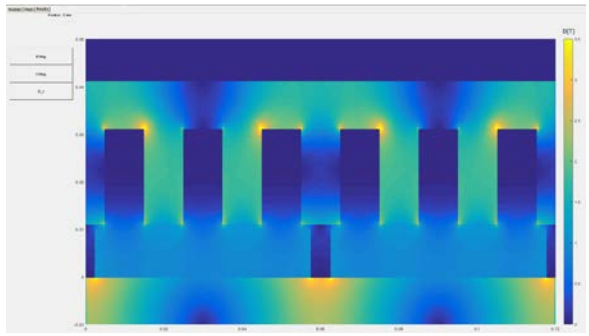

Fig 4. Flux density chart (***MRNSoftware***) at displacement xd = 0 mm

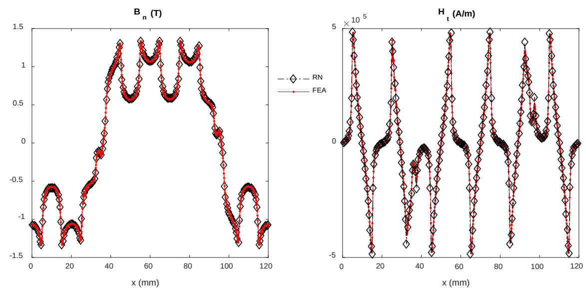

Fig 5. Airgap Normal Flux Density and Tangential Field at displacement xd = 35 mm

Comparisons with FEA and computational methods of the ***MRNSoftware*** tool will be presented in a more extensive manner in the final version of the paper. Possibilities of the ***MRNSoftware*** on parameterisable models will also be explored.

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