A New Methodology for Early Stage Magnetic Modeling and Simulation of Complex Electronic Systems

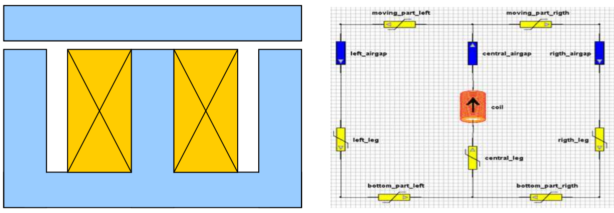
O. Martins, S. Guédon and Y. Maréchal
Grenoble Electrical Engineering Laboratory (G2Elab)
ENSE3 - Bat. D, 961, rue Houille Blanche, BP. 46, 38402 Saint Martin d'Hères Cedex, FRANCE
Olivier.Martins@g2elab.grenoble-inp.fr

Abstract — This paper presents a new methodology called Flex-CM for Flexible Compact Modeling to build and interface compact models. A complex electrical system is split into independent parts. Each part is numerically modeled using a discrete approach then reduced to save memory and time at the simulation stage. The resulting pluggable and reduced model is called a micro-model. Then, a fast-to-simulate macro-model of a full system can be obtained by assembling the micro-models.

The Flex-CM model is presented as an alternative of reluctance network models, to perform a magnetic analysis at an early stage of the system design. The Flex-CM models are found to have number of advantages over reluctance networks, resulting however on larger models.

I. INTRODUCTION

The first step of an electromagnetic system design consists in sizing the system, i.e. set the system parameters which enable to satisfy the design specifications. The sizing process is divided into two steps. First, a pre-sizing step consists in building a simplified analytical model of the system to find a first solution of the optimization problem. Then, a second model, more realistic based on numerical methods, is built to refine the first solution. Over the past few years, several studies on reluctance networks models have shown the efficiency of these simple and fast-to-simulate models for the pre-sizing step. Recent works on the topic have even led to the development of modeling software like Reluctool which enables to build a reluctance network model of an electronic system [1].



Electromagnetic actuator   Reluctance network model

Fig. 1. Reluctance network model of an electromagnetic actuator

The main difficulty in magnetic modeling of systems by reluctance network models is that it requires the definition a priori of the leakage fluxes. So, this method needs a certain expertise and a good knowledge of the magnetic behavior of the system. Moreover, considering systems with moving parts, the reluctance modeling have different topologies during time.

II. THE FLEX-CM METHODOLOGY

The Flex-CM methodology can be presented like a trade off scale between reluctance network models and numerical models. The resulting models can be used at the pre-sizing steps and use numerical methods which prevents the definition a priori of leakage fluxes. More precisely, the Flex-CM methodology is made up of 6 steps (Figure 2).

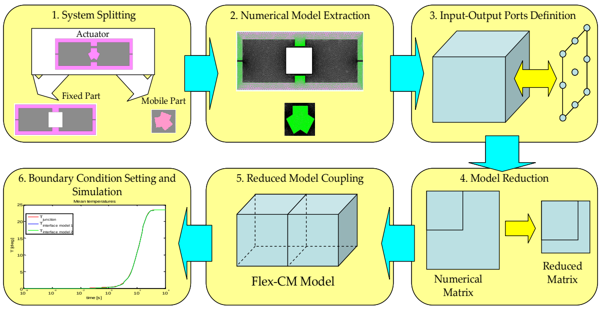


Fig. 2. Flex-CM Methodology

Firstly, given the geometry and the magnetic properties of a global system, a new description is created **splitting the system into elements**. The full system can be split according to fixed and moving parts of the system. This first step consists also in defining the interfaces of the system which are classified into different groups: source interfaces, measure interfaces and coupling interfaces. The next 3 stages are then applied on each part of the system.

Secondly, given the description of a component part, a **numerical model is built and extracted**. The numerical model is finely meshed and built without boundary condition. The results of the extraction are the conductance matrix G, the geometrical properties of all meshing nodes, and the nodes identifiers belonging to the interfaces of the model.

Thirdly, the extracted model is huge then slow to simulate. A reduction method can decrease the number of unknowns of a system, building an equivalent model between input-output ports of the model. So, sub-sampled interfaces are defined to substitute for the initial interfaces to reduce the number of initial interface nodes. The nodes belonging to the sub-sampled interfaces **define the input-output ports of the model**. A trade-off scale between very compact to very accurate model is available and must be set by the user. Then, the sub-sampled interface nodes are said as a linear interpolation of the initial interface nodes. The resulting model is given by the numerical model in which sub-sampled interfaces replace initial ones.

Fourthly, **the matrix G is reduced** to decrease the dimension of the system, preserving the stability and the eigenvalues of the system. The process is called a Moment Order Reduction (MOR). In this application, the Guyan static condensation [2] is chosen to reduce the model because it enables to keep the geometrical sense of the ports of the model, in order to couple the models after reduction. The reduced model is called a micro-model and is about 1000 times smaller than the initial model.

Fifthly, **the micro-models are coupled** to model the magnetic behavior of the full system. These micro-models are coupled together through their respective interface nodes. The interfaces of the models to connect are not supposed to have the same geometrical configuration. Therefore, the coupling process in ensured by the Lagrange multipliers method [3]. The resulting model is called Flex-CM for Flexible Compact Model.

The final step is the **setting of the simulation conditions** in order to simulate the magnetic behavior of the full system. It consists in applying fixed magnetic potential in source interfaces and to simulate the model to compute the magnetic field in measure interfaces.

III. Evaluation of the Performances of the Methodology

The methodology is applied to an electromagnetic actuator to evaluate the performances of the method, in terms of accuracy, flexibility and simulation time. The actuator is made up of two stators separated by air gaps and a rotor. A finite element model is built and simulated to define a reference. Fixed magnetic potentials are applied on each air gap surface, to symbolize a permanent magnet, and the magnetic field in the sensor region is computed as a function of the rotor rotation angle α (Figure 3).

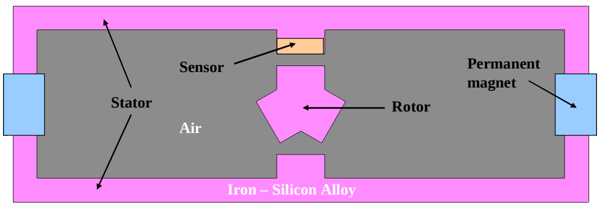
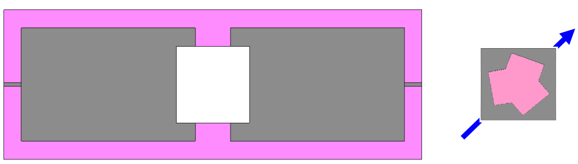


Fig. 3. Electromagnetic actuator

Then, the Flex-CM methodology is applied to the actuator. The goal of the method there is to build a "parametric" model as a function of the angle α. According to the first step of the method, the system is split into two elements: a fixed element and a mobile element (Figure 4).



Fixed model Mobile model

Fig. 4. Actuator splitting

Then, according to the following steps, micro-models of fixed and mobile elements are built and coupled together to reconstruct the magnetic behavior of the full system. The Flex-CM generation needs about 8 minutes for one position of the rotor (2 minutes for each step extraction, node selection, reduction and coupling).

The characteristics of both finite element and Flex-CM models are summarized in the following table.

TABLE I
FINITE ELEMENT AND FLEX-CM MODELS CHARACTERISTICS

Model	Finite Element Model	Flex-CM Model
Node number	155000	139
Simulation time for one rotor position	1 minute	<1 second
Time for modifying the rotor position	10 minutes	4 minutes

The finite element and Flex-CM models of the actuator are simulated for rotor rotation angles from 0° to 360° with a 10° step. The magnetic field in the sensor computed with both models is illustrated on the figure 5.

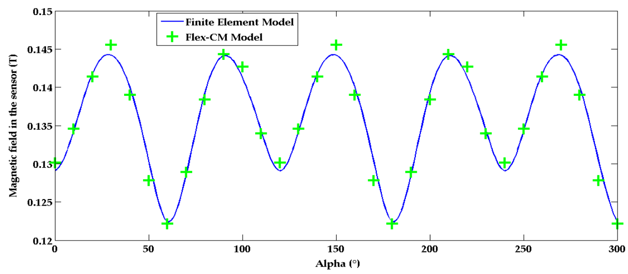


Fig. 5. Magnetic field in the sensor versus rotation angle α computed with finite element and Flex-CM models

This figure shows a good accuracy of the Flex-CM model comparing with the reference simulation of the finite element model, whatever the rotor rotation angle.

IV. Conclusion

The Flex-CM model is presented as an alternative of reluctance networks to perform a magnetic analysis at an early stage of the system design. In addition, the use of numerical methods enables to build models of complex systems, avoiding the definition a priori of leakage fluxes. Moreover, the models are flexible, so they can be independently modified without generating another full Flex-CM model. Nevertheless, the methodology needs competences in numerical modeling and results in larger models than reluctance networks.

V. References

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