Efficient Reluctance Network Model for Modelling, Design and Optimization of Linear Switched Reluctance Motor

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In this paper, we propose an efficient reluctance network for modeling a linear switched reluctance motor. The proposed reluctance network model takes into account the magnetic characteristic and the flux leakage. Consequently, the proposed model, compared with finite element method, gives precise results of the electromagnetic characteristic. The proposed variable reluctance network developed is able to be coupled with other tools in order to optimize the linear machine.

***Index Terms* — Electromagnetic analysis, Finite element analysis, Magnetic flux, Magnetic forces.**

I. INTRODUCTION

THE Linear Switched Reluctance Motors (LSRMs) consist in an efficient solution for precise linear displacements applications [1]. Many research papers work on the design and the optimization of these machines. The Finite Element Method (FEM) is generally used when precise results are indispensable [2]. However, this method takes an important time for problem analysis. Moreover, the FEM cannot be coupled with rapid optimization algorithms [3]. The second method used in the design of linear machines is based on the reluctance network model [2],[3],[4]. In this paper, we are concerned with the development of a new reluctance network model for modeling and optimization of linear machines. A 3-D view of the studied machine is presented in Fig1.

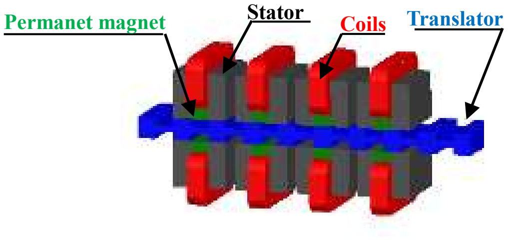

Fig.1. Double Sided Linear Switched Reluctance Motor

The double sided LSRM mechanical dimensions are summarized in table I.

TABLE I
LSRM DESIGN SPECIFICATION

Name	Symbol	Values (mm)
Tooth width	b	50
Air gap width	e	1
Translator thickness	L	200
Translator pole length	hdm	20
Translator cylinder head	hcm	20

In the second section, the proposed reluctance network model is presented and discussed. The results comparisons with the finite element method are presented in section III. The conclusions and perspectives are given in section IV.

II. RELUCTANCE NETWORK MODEL

The concept is based on the subdivision of the magnetic circuit of the machine, into a sufficient number of elements, known as flux tubes. Each flux tube is associated with a magnetic reluctance which depends on circuit dimension and the magnetic behavior. The originality of this model consists in its ability to calculate the electromagnetic characteristics for various positions from unaligned to aligned positions using a simple run and an unique topology of model. An elementary structure of the LSRM with the respective reluctances is represented in Fig.2.

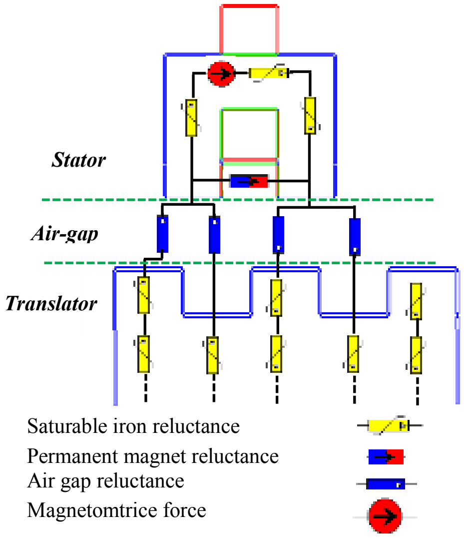

Fig.2. Construction of the reluctance network.

A. Reluctance of the air gap

The air gap flux tubes are basically composed of straight lines with a constant length. However, the section of the air gap increases with the displacement x. Hence, the air gap reluctance is parameterized with the displacement and it is given by the following expression:

$$\Re_e = \frac{e}{\mu_0.x.L} \tag{1}$$

The salient in the mobile canalizes a non-neglected part of the magnetic flux. Hence, the salient is modeled by reluctances expressed as follows:

$$\Re_s = \frac{hdm+e}{\mu_0.(b-x).L} \tag{2}$$

B. *Reluctances of the stator*

Generally, the magnetic reluctance of a ferromagnetic material, with a length l and a section S, can be written as:

$$\Re_{fer} = \frac{l}{\mu_0 . \mu_r . S} \tag{3}$$

μ_r is the relative permeability of the ferromagnetic material. The ferromagnetic circuit of stator is divided into three different magnetic reluctances connected in series. These reluctances depend on both the stator geometrical parameters and the magnetic permeability.

C. *Reluctances of the permanent magnet*

Each permanent magnet inserted in the stator is modeled by a magnetomotive force and a reluctance parametrized with the geometrical and magnetic parameters of the permanent magnet. This magnetomotive force and the reluctance of the permanent magnet can be written respectively as:

$$E_a = \frac{B_r}{\mu_0 . \mu_a} L_a \tag{4}$$

$$\Re_a = \frac{1}{\mu_0 . \mu_a} \frac{L_a}{S_a} \tag{5}$$

μ_a is the relative magnetic permeability of the permanent magnet.

D. *Reluctances of the translator part*

For the purpose of considering the majority of the flux lines in the network reluctances, the translator part is modeled by different reluctances. The flux in the translator teeth, which must be aligned with those of the stator in the aligned position, increases with the displacement. Hence the reluctance of the teeth is inversely proportional to the displacement and it can be written as:

$$\Re_{dm} = \frac{hdm}{\mu_0 . \mu_r . x . L} \tag{6}$$

E. *Reluctances of the leakage flux*

Both flux leakages between the stator and the translator on one part and on the stator on the other are represented by the circumferences arcs. This leakage flux strongly influences the flux with considerable effect on the magnetic field in this actuator. As a matter of fact, RN simulation results obtained by neglecting the leakage flux lead to important errors compared to FEM. The leakage flux is modeled by a magnetic reluctance given by the following expression:

$$\Re_f = \frac{\theta}{\mu_0 . L} \frac{1}{\ln\left(\frac{\mathrm{R}_{ex}}{\mathrm{R}_{in}}\right)} \tag{7}$$

Where θ is the angle of the circumferences arc. R_{ex} and R_{in} are respectively the exterior radius and interior radius of the circumferences arc. Hence, each part of the flux leakage is modeled by an adapted magnetic reluctance. The parameters of the magnetic reluctances are parameterized with the displacement of the mobile part. Indeed, the flux path of each part increases or decreases with the displacement of the mobile part. More details will be given in the full papers. The reluctance network is modeled in the software Reluctool and the Finite Element Model of 1/4 LSRM are represented in Fig.3.

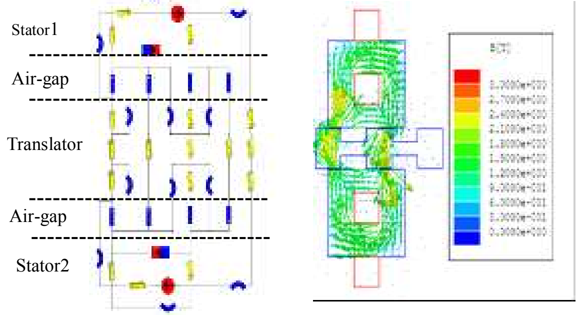

Fig.3. Reluctance network model and Finite Element Model of 1/4 LSRM

III. STATIC FORCES COMPARISON

The propulsive forces calculated with RN model implemented on " Reluctool" software and FEM, for three different current excitations are given in Fig. 4. As shown above, force curves are almost identical. Hence, the RN model of the LSM is in accordance with the FEM.

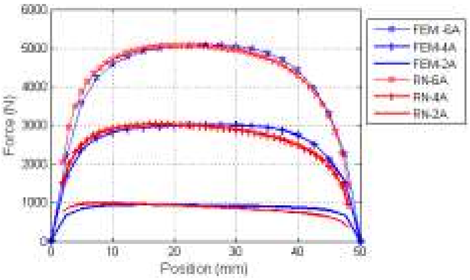

Fig.4. Propulsive forces calculated with FEM and RN model

IV. CONCLUSION

A precise reluctance network model is developed to model, design and optimize a linear actuator. This model is developed using "Réluctool" software and is validated using FEM. The efficiency of this model is its ability to generate automatically the electromagnetic characteristics for any mobile part positions. This model has a good numerical stability and leads to precise force computation. The model is currently applied for sizing by optimization.

V. REFERENCES

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