Journal of Engineering and Applied Sciences 2 (7): 1199-1202, 2007

Axial Magnetic Forces Comparison in Linear and Nonlinear Model of Ferromagnetic Core of Magnetic Actuators

[1]H. Allag, [1]M.E.H Latreche, [2]M.R. Mekideche and [2]N. Ikhlef
[1]Laboratory of L.E.C, Department of Electrotechnic,
University of Constantine, 25000 Constantine, Algeria
[2]Laboratory of L.A.M.E.L, Department of Electrical Engineering,
Jijel University BP 98, Ouled Aissa-Jijem, Algeria

Abstract: Several works were developed for local and global magnetic force calculation, this works are based on different theories such as a simplified magnetisation model and energy approach, generally this models are applicable for a ferromagnetic materials considering their linear comportment, or in reality the magnetisation phenomena (saturation phenomena) of these materials make possible to take into account a non-linear model known as the Hysteresis model. In this study, we present the method of Maxwell stress tensor and its application in ferromagnetic material calculation using the model of Preisach Hysteresis which will be integrated to 2D FEM calculation code. For a simulation result we use two axisymetrical actuators from which the essential curves are presented such as the force time variation, the mechanical behaviour (displacement) and the magnetic quantities (magnetic field, magnetic induction).

Key words: Magnetic force, electromagnetic actuator, magnetic hysteresis, preisach model

INTRODUCTION

The magnetic forces are the essential quantities in electromagnetic systems functioning, such as electrical machines, electromagnetic actuators….etc.

The force and the torque of electric machine are usually evaluated by FEM (Mizia *et al*., 1988), applying lorentz formula (Kabashima *et al*., 1988) the Maxwell stress tensor (Marinescu and Marinescu, 1988) and the principle of virtual work displacement (Coulomb, 1983).

In this research, we use the Maxwell stress tensor method which is applicable for a ferromagnetic material.

FORCE USING MAXWELL STRESS TENSOR

The force using Maxwell stress tensor is:

$$F_m = \oint_S T_m.dS = \oint_S (T_m.n)\, dS \qquad (1)$$

Where T_m is the Maxwell stress tensor the global force is expressed:

$$F = \frac{1}{\mu_0}\oint_S \left((B.n)B - \frac{1}{2}(B^2)n \right) dS \qquad (2)$$

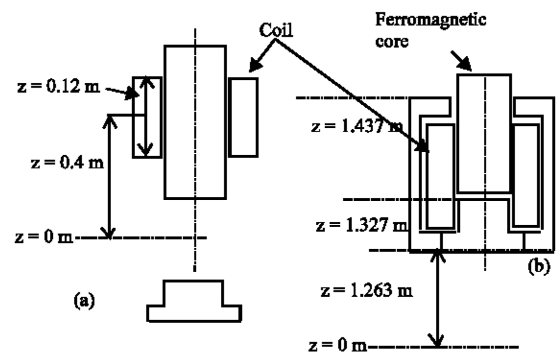

Fig. 1: Axisymetrical actuators

We note that the global magnetic force that ensues of surface calculation remand unchanged if instead of Laplace force we must consider forces exercising on ferromagnetic materials (Srairi, 1996).

LINEAR AND NONLINEAR MODEL IN MAGNETOSTATIC

For our simulation we have chosen two axisymetrical actuator types as shown in Fig. 1. The global magnetic force exerted on there ferromagnetic core is calculated using Maxwell stress tensor using 2Df inite elements

Corresponding Author: H. Allag, Laboratory of L.E.C, Department of Electrotechnic, University of Constantine, 25000 Constantine, Algeria

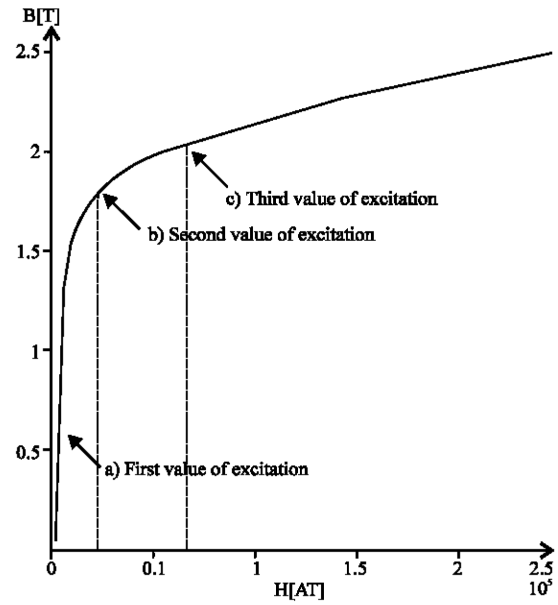

Fig. 2: First magenetization curve B(H)

method, with constant permeability μ, but for taking into account saturation phenomena we choose the variable reluctivity function model (Marroco, 1977; Feliachi, 1981) its first magnetization curve is shown in Fig. 2.

Figure 3 represent the variation of global axial magnetic force as a function of vertical position for a ferromagnetic core of the first actuator with and without take into account the saturation phenomena for three respective values of excitation field, whose the first is situated in the linear zone where the variations of magnetic forces for the two models are identical Fig. 3a, contrary when we comes closer toward the saturated zone we notes that the gap between the values of forces (linear and non-linear model) is more important Fig. 3b-c.

For the second actuator the simulation result is shown for the interval of displacement z = [1.4-1.52 m] the maximum force in absolute value are observed in position z≈1.4 (continues line) for linear case (μr = 192) and for a nonlinear corresponding at the third value of excitation (Fig. 2.) the force are shown in dashed line.

As a result of this simulation part, we note that actually the force is less important than in the linear case and it because of material saturation and the calculation while taking in account this phenomenon we leads to the more precise results that is observed in Fig. 3 and 4.

HYSTERESIS MODEL IMPLEMENTATION

One of the more used models to represent the Hysteresis of magnetic material are incontestably the

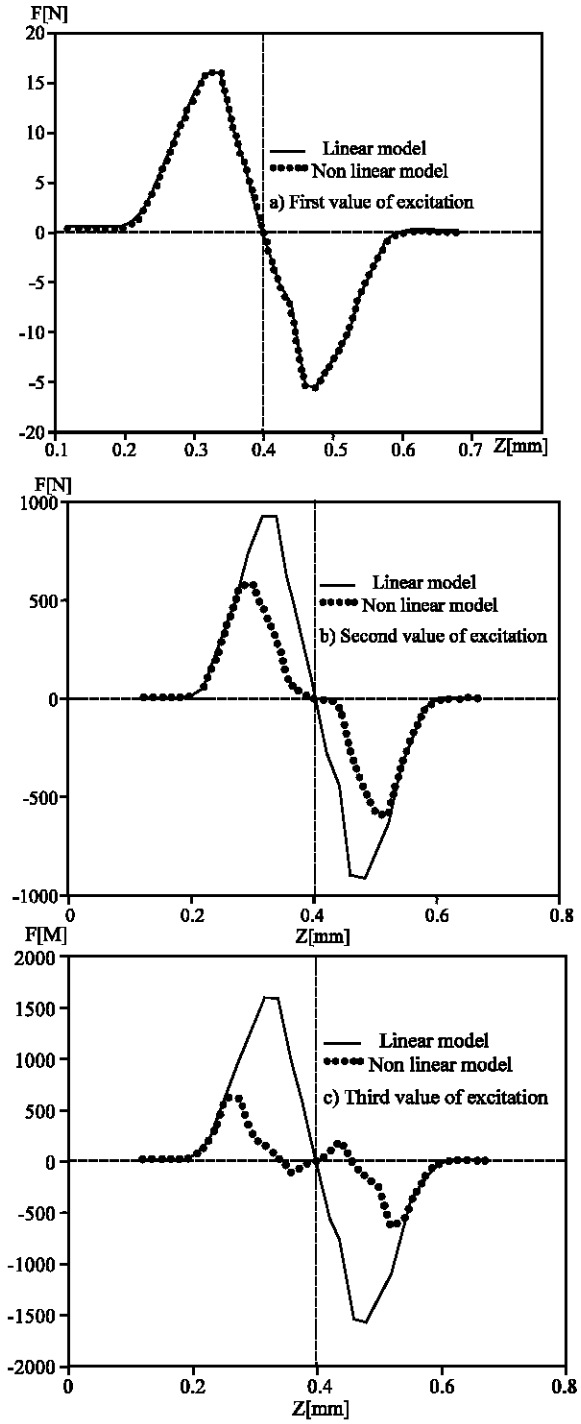

Fig. 3: Variation of global force for different positions of ferromagnetic core (from the lower position until the high one)

model proposed by the physicist German Preisach (Bernard, 2000; Amir, 2002). Its merely intuitive approach is based on the observation of the magnetization

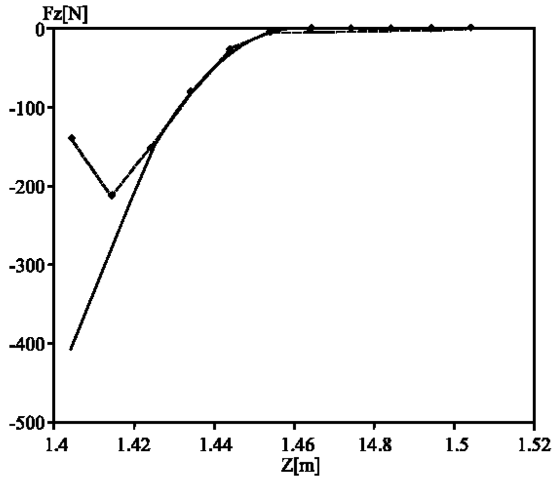

Fig. 4: Variation of global force for different positions of ferromagnetic core (second acuator)

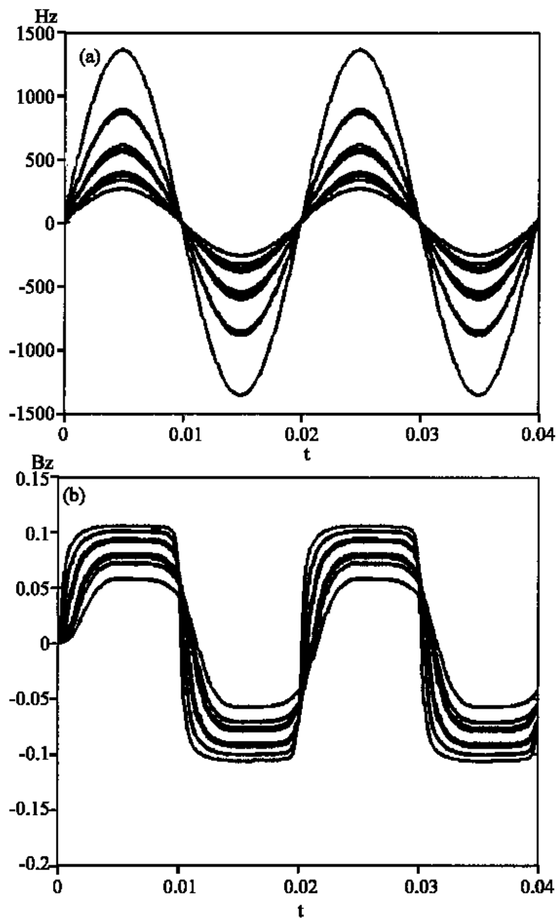

Fig. 5: Axial components of magnetic field and induction as function of time for all elements of mesh of ferromagnetic region

mechanism. Thus, the evolution of the magnetic configuration of a material submitted to different fields

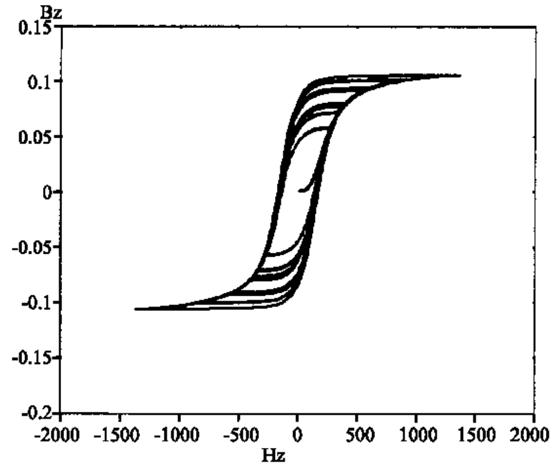

Fig. 6: Bz as function of Hz for all elements of mesh of ferromagnetic region z = 0.38 m

can be as well studied by M(H) cycles -magnetization as function of fields- or from the plan of Preisach (α, β) (Bernard, 2000; Amir, 2002).

Formulation in magnetic potential vector of non linear magnetodynamic problem: This type of formulation applies to systems containing time varying sources that generates eddy currents with variation of fields.

The model obtaining from Maxwell's and laws of surrounding behavior equations with considering:

Displacement currents are negligible facing conduction currents, the speed of displacement and electric charges are equal to zero.

We obtain the formulation in magnetic potential vector A as follow

$$\sigma\frac{\partial A}{\partial t} + \mathrm{Rot}\left(\frac{1}{\mu_0}\mathrm{Rot}\,A\right) = J_S + \mathrm{Rot}\,M \tag{3}$$

Where Js is source current density, σ is electric conductivity and μo is magnetic permeability

The non-linear magnetic behavior is introduced by the M = f(H) Hysteresis model.

The result concerning the magnetic field H and magnetic induction B (Hz, Bz components) for all elements of mesh concentrated in ferromagnetic core of the first actuator as shown as function of time [s] in Fig. 5.

From this variation of magnetic field correspond the magnetic induction variation Fig. 5b. which present several periodic curves in saturated states (the number of curves equal to the number of elements of the mesh in ferromagnetic region) (Fig. 6).

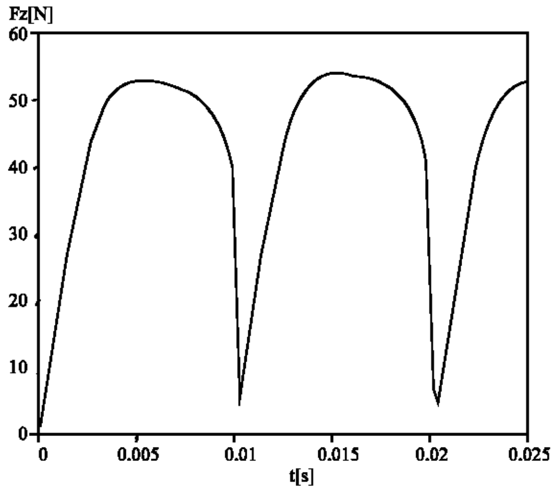

Fig. 7: Force variation as function of time for z = 0.38 m

For axial force result we calculate it for one position of ferromagnetic core of the first actuator (0.38 m) and for $Js = 10^5 \sin(2\pi 50.t)$ (Fig. 7).

CONCLUSION

The importance to introduce non linearity in our calculation is to observe the more real and precise results of electromagnetic quantities and therefore, their repercussion on magnetic forces.

We saw that the forces are less important in nonlinear case that those in linear one, therefore their values are limited by the saturation of the material. what is observed well in magnetodynamic case while considering the states of saturation by Hysteresis cycles predicted by the model of Preisach.

REFERENCES

Amir, N., 2002. Modélisation de l'Hystérésis dans les matériaux magnétiques et introduction de modèle dans le logiciel de simulation aux éléments finis flux 3D, Thèse de doctorat Institut National Polytechnique de Grenoble.

Bernard, Y., 2000. Contribution à la modélisation du système électromagnétique en tenant compte du phénomène d'Hystérésis, Thèse de doctorat, Univ. Paris X I Orsay.

Coulomb, J.L., 1983. A methodologies for determination of global electromechanical quantities from a finite element analysis and its application to the evaluation of magnetic forces, torques and stiffness. IEEE. Trans. Magn., MAG., 19: 2514-2519.

Feliachi, M., 1981. Contribution au calcul du champ électromagnétique par la méthode des éléments finis, Conservatoire national des arts et des métiers.

Kabashima. T., K. Kawahara and T. Goto, 1988. Force calculation using magnetizing currents. IEEE. Trans. Magn., 24: 451-454.

Marinescu, M. and N. Marinescu 1988. Numerical computation of torque in permanent magnet motors by Maxwell stresses method. IEEE. Trans. Magn., 24: 463-466.

Marroco, A., 1977. Analyse numérique de problèmes d'électrotechniques. Ann. Math. Quebec, 1: 271-296.

Mizia, J., K. Adamiaka. A.R. Eastham. and G.E. Dawson, 1988. Finite element force calculation: Comparison of methods for electric machines. IEEE. Trans. Magn., 24: 447-450.

Srairi, K., 1996. Modélisation d'actionneurs électromagnétiques alimentés en régime transitoire, Thèse de doctorat en électronique, Ecole doctorale science pour l'ingénieur de Nantes.