

# Study Dynamic Regime of a Electromagnet Using Finite Element Method

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**ABSTRACT:**Dynamic regime of an electromagnet can be studied using the finite element method. In this work were studied using several variants of electromagnets that generate vibrations using ferromagnetic materials of superior quality. Highlighting the main indices qualitative dynamic regime can be achieved most conveniently about graphics using calculation methods based on the theory of finite elements.

**KEYWORDS:**dynamic regime, electromagnet, attraction force, FEM analysis.

## I. INTRODUCTION

In the electromagnets design is required to know the force of attraction developed by the main types of electromagnets. For two polar parts delimited by two parallel surfaces each with area  $A$ , located at the  $\delta$  distance of one another, in the presence of a constant magnetic field  $H$  in the direction of the  $\delta$  air gap, the magnetic energy formula is:

$$w_M = \frac{B \cdot H}{2} A \cdot \delta, \quad (1)$$

by using, the theorem of general forces, Maxwell's equations for attraction force  $F$  produce by an electromagnet is:

$$F = -\frac{d}{dS} \left( \frac{B \cdot H}{2} A \cdot \delta \right) = -\frac{B^2 A}{2\mu_0} = -\frac{\Phi^2}{2\mu_0 A}, \quad (2)$$

considering:

$$\begin{aligned} B \cdot H &= \Phi \\ H \cdot \delta &= U_m = \Phi \cdot R_m = \frac{\Phi}{\Lambda}, \end{aligned} \quad (3)$$

we can write the next formula:

$$F = -\frac{1}{2} \Phi \frac{dU_m}{d\delta} = \frac{1}{2} U_m^2 \frac{d\Lambda}{d\delta}, \quad (4)$$

Where:  $U_m$  is magnetic voltage between the polar surfaces,

$R_m$  – magnetic reluctance of air gap,

$\Lambda$  – permeance of the same area, defined as inverse of reluctance.

For the electromagnets with a single excitation circuit, the formula of magnetic energy using inductivity is:

$$W_m = \frac{i\psi}{2} = \frac{1}{2} Li^2, \quad (5)$$

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

according to the theorem of general forces, we obtain the formula for the attraction force:

$$F = \frac{1}{2} i^2 \frac{dL}{d\delta} \tag{6}$$

Thus, for the calculation of the attraction force produced by an electromagnet is necessary to determine the magnetic flux, the magnetic induction inside the air gap, the inductivity, the magnetic reluctance and permeance.

## II. THE CALCULATION OF THE ATTRACTION FORCE DEVELOPED BY THE MAIN TYPES OF ELECTROMAGNETS

Knowing the value of the flux, inductivity or permeance of an electromagnet we can determine the attraction force produced by the electromagnet by using one of the formulae (2), (4) or (6).

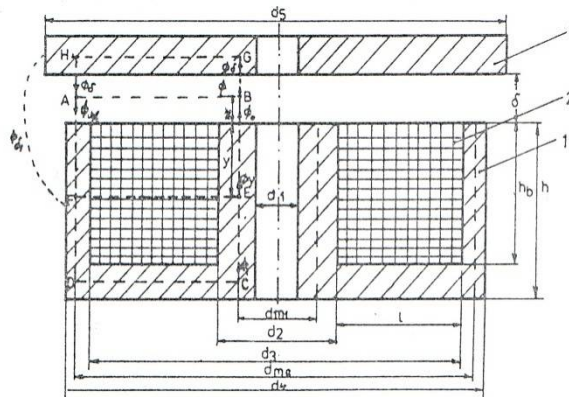


Fig. 1 Electromagnet model

For example, the mantel electromagnet from fig. 1, considering formulae (6), and other general equations, the attraction force can be written:

$$F = -\frac{1}{2} \cdot \frac{\lambda}{sh^2(p\delta)} \cdot (N \cdot i)^2 = -\frac{1}{2} \cdot \frac{1}{\alpha\delta^2} \left( \frac{p\delta}{sh(p\delta)} \right)^2 \cdot (N \cdot i)^2 \tag{7}$$

if we ignore the dispersion ( $\lambda \rightarrow 0$  and  $p \rightarrow 0$ ), we obtain:

$$F = -\frac{1}{2\alpha} \left( \frac{Ni}{\delta} \right)^2 \tag{8}$$

For the mantel electromagnet from fig. 1, which has the height  $h_b$  of the window much smaller than its width  $l$ , according to (6) and (7) the force has the formula:

$$F = -\frac{1}{2} (Ni)^2 \left[ \frac{\lambda}{sh^2(p\delta)} + \frac{\lambda_h \cdot \pi \cdot d_2}{12(h_b + \delta)} \right] \tag{9}$$

We notice that if  $h_b$  is bigger, then equation (9) becomes equation (7), thus being a general form for it.

## III. THE CALCULATION OF MAGNETIC FIELD USING NUMERICAL METHODES

Numerical methods, in comparison with analytical methods, present a bigger application area, having fewer restrictions. This methods lead to acceptable results if certain quality and convergence criteria are maintained. Usually, we use the next simplified calculation hypotheses:

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

- linear and homogeneous medium ;
- stationary regime;
- solenation is uniform distributed on the entire section of the coil( $J=const.$ )

In our study, we use **MagNet** software for the numerical field analyses of electromagnetic vibrator. This allows calculating the magnetic field and also other electromechanical parameters (fluxes, forces, moments, etc.) using finite element method.

FEM has two aspects that have to be treated with great attention, because they can cause important errors:

- Boundary conditions: any type of analysis implies an infinite domain, impossible to study with FEM, so is required a restriction through closed surfaces and to enforce some boundaries conditions which gives as results close to the real ones.
- Discreteness: The implementation of the nodes and finite elements net, from geometric point of view and of rank of interpolating polynomial, to describe correctly the behavior of the magnetic field in the analyzed domain is the most complex part of an FEM analysis. For an element the magnetic induction is described as a polynomial function of rank smaller with one unit then the rank of the interpolating polynomial, thus is necessary to have more nodes and/or to increase their rank. The software creates automatically the net depending on the parameters we want to calculate.

### IV. RESULTS OBTAIN WITH FEM ANALYSIS

The base configuration of the electromagnet from (fig. 2) is formed from active materials electro technical steel plate cold laminated CR 1010, for columns, fixed and mobile parts of the electromagnet, and electro technical copper with the conductivity  $\sigma = 5,77 * 10^7$  S/m for coils.

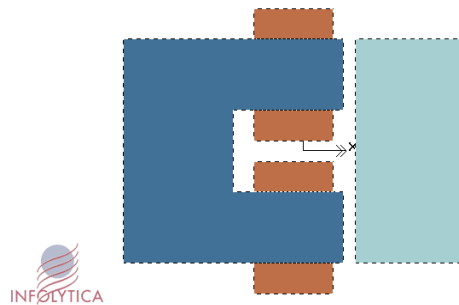


Fig. 2 Base configuration of an electromagnetic

The configuration of other models is identical with the base configuration only that the material for the magnetic circuit was changed with other types of ferromagnetic materials.

To study and to calculate the force produced by an electromagnet there are five configurations, in each of them the magnetic circuit is composed by the following materials: CR 1010 for the base configuration, M19 for model number two , A1 9 for model number three , L800 another ferromagnetic material for the fourth model and for the last model the TR 52 material was used .The characteristics of the magnetization curve for all these materials are given in MagNet software.

Each of the configurations described above were analyzed with FEM method through the package of software for the analysis of electromagnetic field, named InfolyticaMagNet version 6.11.

The analysis are completed ignoring the hysteresis effect of the magnetic material , its behavior corresponding to the magnetization curve and with the next values for the current through the windings : 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5 A , which gives us the electrical charges of our electromagnet.

Prior to the simulations themselves to the test by testing "of almost almost" necessary degree refining the mesh (size of finite elements) to avoid time high or system crashes, even if it is equipped with powerful processor and RAM extended without dropping the significant results of the analysis and in particular regarding the calculation of forces.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

Such analysis was reached polynomial interpolation of the second order and a refinement of the mesh on the geometry of the electromagnet as shown in Figures 3 and 4. In Fig. 3 it is playing a mesh for column yoke and armature, and in Fig.4 the air-gap network is shown with a refining (thickening network) as good soles polar opposite.

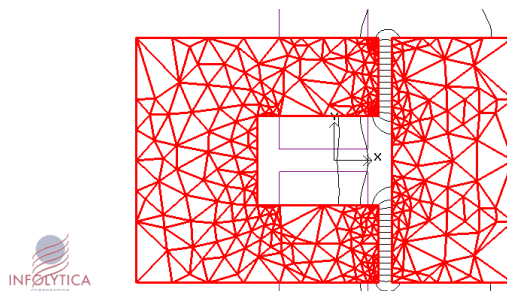


Fig. 3 Network and reinforcement mesh for column

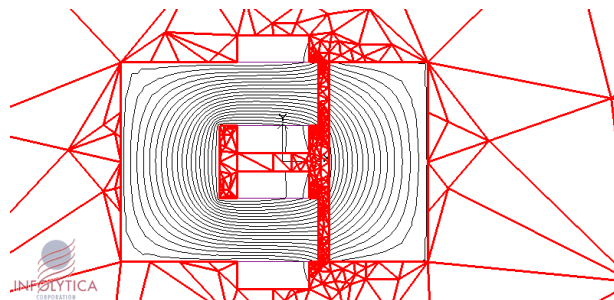


Fig.4 Mesh network of gap

For each model of study were conceived twelve problems to calculate the magnetic field , having as a parameter the dimension of the air gap , with values which grow by 0.5 mm from 0.5 mm to 6 mm.

In the followings are presented the results of an FEM analysis given by InfolyticaMagNet software, version 6.11.

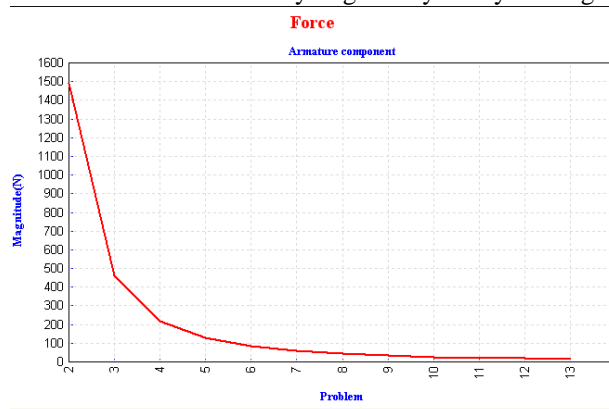


Fig. 4 The force characteristic for CR 10 and for a 1 A current

In the figure above appears the force chart,  $F=F(x)$ , having as function variable the variation of air gap for the base configuration of an electromagnet with a 1 A current.

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

After analyzing all the models and obtaining the numerical results for each model, were able to draw a family of curves with force characteristic for all configurations. Thus a comparative analysis was made for all the force characteristics depending on the size of air gap.

The charts below will be played characteristic strength for the five types of materials and windings current values of 0.1, 0.5, 1, 2, 3, 4, 5 A, carrying electrical charges of the electromagnet.

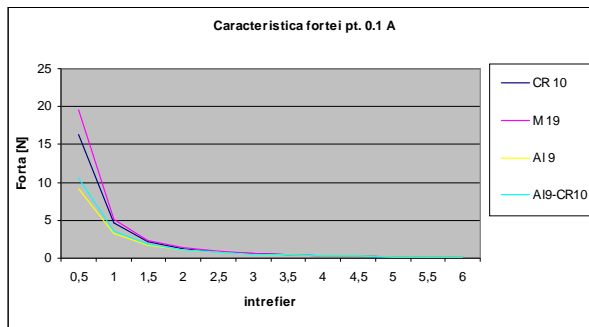


Fig. 5 The force characteristic for a 0.1 A current

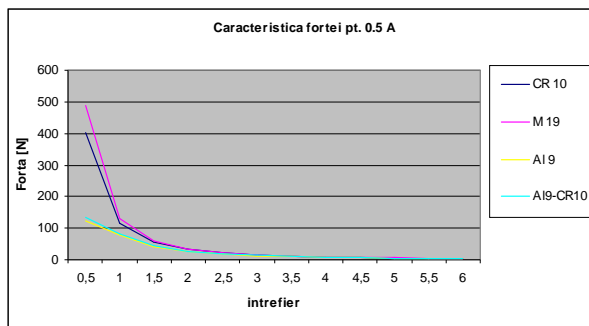


Fig. 6 The force characteristic for a 0.5 A current

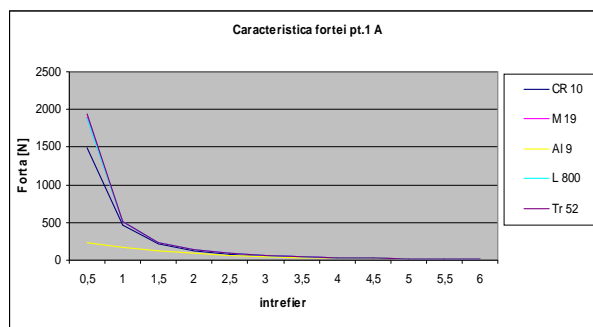


Fig. 7 The force characteristic for a 1 A current

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

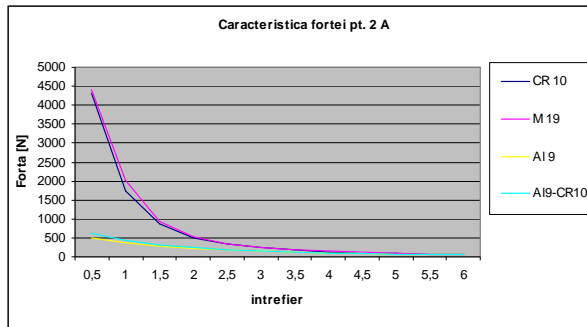


Fig. 8 The force characteristic for a 2 A current

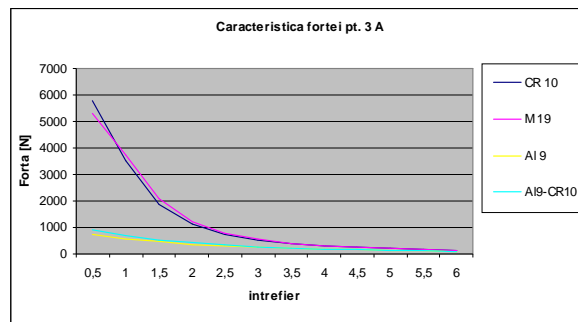


Fig. 9 The force characteristic for a 3 A current

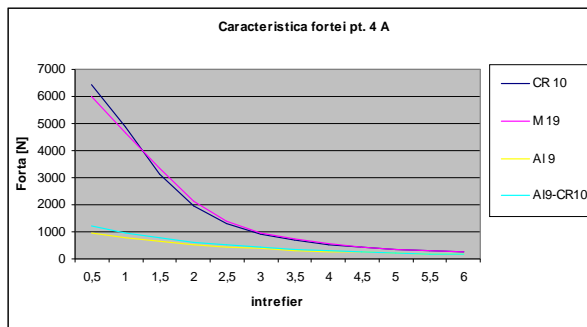


Fig. 10 The force characteristic for a 4 A current

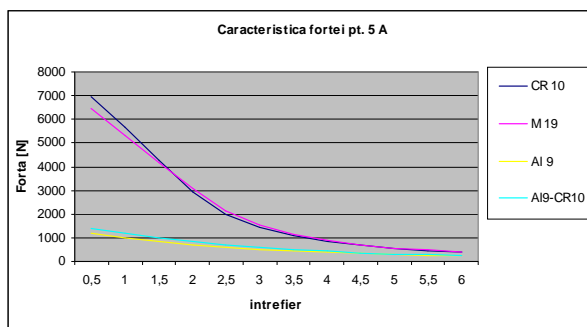


Fig. 11 The force characteristic for a 5 A current

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

Also, we presented the variations charts of the force depending of the air gap for each type of material having as parameter the current passing through the coils. In the below charts are given for each type of material the force characteristic with the value of the current between 0.1-0.5 A.

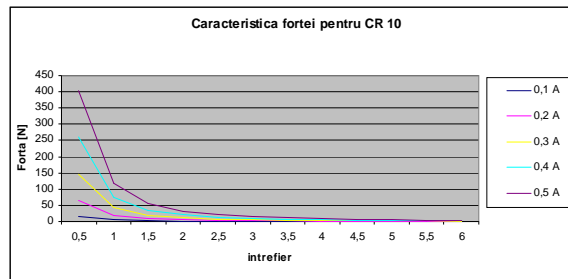


Fig. 12 Force characteristic for CR 10

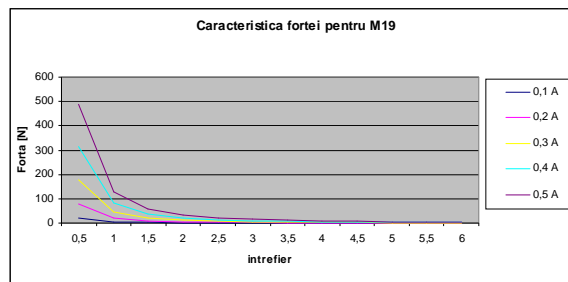


Fig. 13 Force characteristic for M19

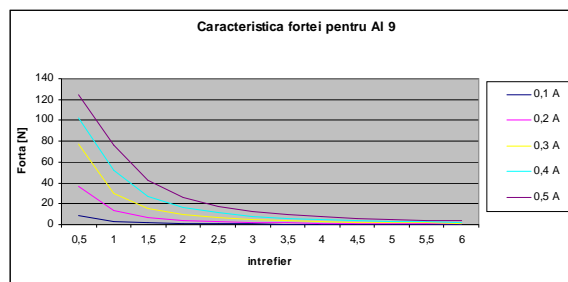


Fig. 14 Force characteristic for Al 9

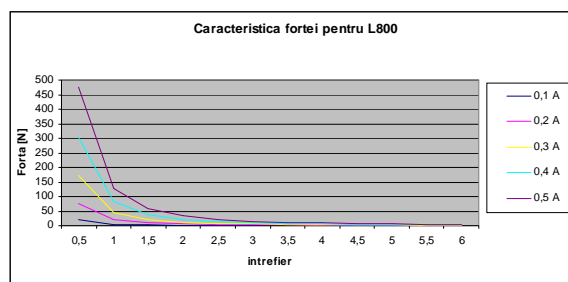


Fig. 15 Force characteristic for L 800

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 12, May 2016

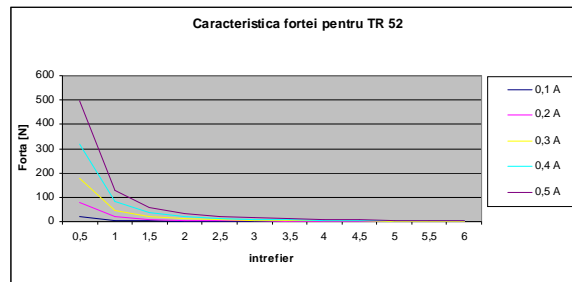


Fig. 16 Force characteristic for TR 52

Possibilities "linearization magnetic materials" exposed to heavy electric medium and large, is relatively low, due to saturation, correction model by coefficients having a degree of generality rather narrow and accuracies less controllable, it is necessary as a way of solving problems field nonlinear numerical analysis.

The major disadvantage of numerical analysis of several independent parameters, to the emergence of solutions to discrete representations, namely values that should be attached unequivocally parameter values that led to these values. With the increasing number of parameters expressing the solution appears increasingly difficult fields with continuous appearance (small intervals of change in parameters).

A case is the study, which analyzes several models in which order to avoid a solution impossible appreciated as behavior of the variation of parameters considered, it was conducted on areas of variation thereof selected, namely such that to cover the ranges of optimal in accordance with current technology and materials.

## V. CONCLUSIONS

After making a comparative analysis between the force characteristics we observe the following:

- by using ferromagnetic materials with superior quality we can obtain better values of the force developed by an electromagnet ;
- the value of the force produced by electromagnetic vibration generators will depend mostly of the electrical charges from the vibrator
- by using a combination of magnetic and ferromagnetic materials for the construction of the magnetic circuit we can obtain smaller vibrations of the force within the air gap , but the value of force produced will also be smaller than the case when we used high quality electro technical materials
- the parameters of the dynamic regime of an electromagnet , variable in time , independent or associated , are : current , flux , attraction force , movement of air gap , ( air gap ) , speed and acceleration of this movement ;
- the quality evidence of these parameters is made the most comfortable using graphic presentations from the methods based on FEM

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