7th INTERNATIONAL MULTIDISCIPLINARY CONFERENCE
Baia Mare, Romania, May 17-18, 2007
ISSN-1224-3264

CONTRIBUTIONS TO THE CALCULATION OF THE FORCE DEVELOPED BY THE ELECTROMAGNETS USING FEM

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Abstract: *This paper presents results obtained for the calculation of the force developed by electromagnets for a given configuration using the finite elements method. The calculation was performed for five types of ferromagnetic materials and for different electrical charges of the electromagnet.*
Key words: *sorting process, electromagnetic sieves, finit elemenet*

1. THE FORCE DEVELOPED BY THE MAIN TYPES OF ELECTROMAGNETS

In the electromagnets design is required to know the force of attraction developed by the main types of electromagnets.

For two polar parts delimitated by two parallel surfaces each with aria *A*, located at the δ distance of one another, in the presence of a constant magnetic field *H* in the direction of the δ air gap, the magnetic energy formula is:

$$w_M = \frac{B \cdot H}{2} A \cdot \delta, \tag{1}$$

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

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

considering:

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

we can write the next formula:

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

Where: U_m is magnetic voltage between the polar surfaces,

R_m – magnetic reluctance of air gap,

Λ – 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:

$$W_m = \frac{i\psi}{2} = \frac{1}{2}Li^2, \tag{5}$$

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.

2. 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).

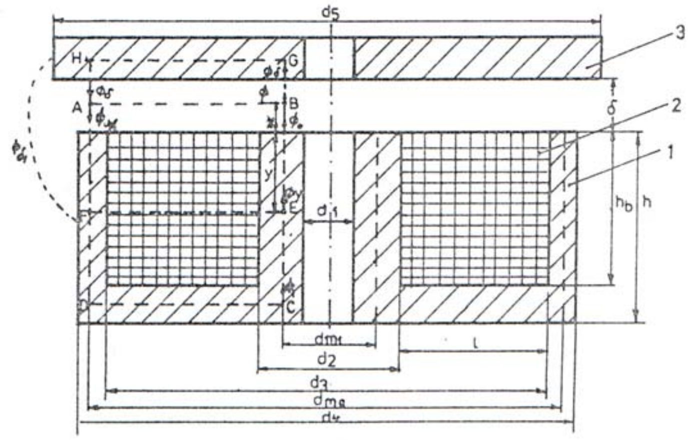


Fig. 1 Electromagnet model

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 then 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.

3. 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:

- 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 VEM. This allows to calculate the magnetic field and also other electromechanical parameters (fluxes, forces, moments, etc.) [4] 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 a 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 nods and/or to increase their rank. The software creates automatically the net depending on the parameters we want to calculate.

4. 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 σ = 5,77 * 10^7 S/m for coils.

The geometrical characteristics of electromagnet are:

- length of armature L_a = 11 cm;
- width of armature l_a = 7,5 cm;
- height of armature h_a = 6 cm;
- width pole end plate l_{tp} = 3,5 cm;
- width of window L_f = 4 cm;
- length column L_c = 11 cm;
- width column l_c = 7,5 cm;
- height column h_c = 11 cm;

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.

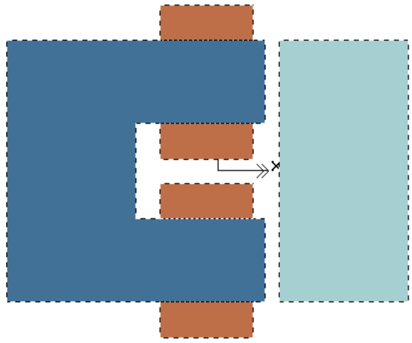


Fig. 2 Base configuration of an electromagnetic

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 Infolytica MagNet version 6.11.

The analysis are completed ignoring the hysterezis 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 .

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 Infolytica MagNet software , version 6.11 .

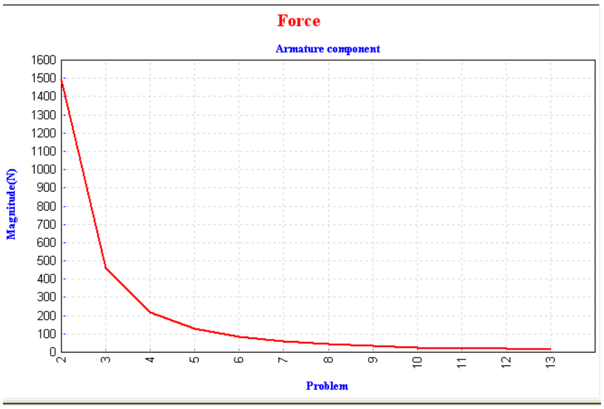


Fig. 3 The force characteristic for CR 10 and for an 1 A current

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 .

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 .

In the chart below is represented the force characteristic for all five types of materials .

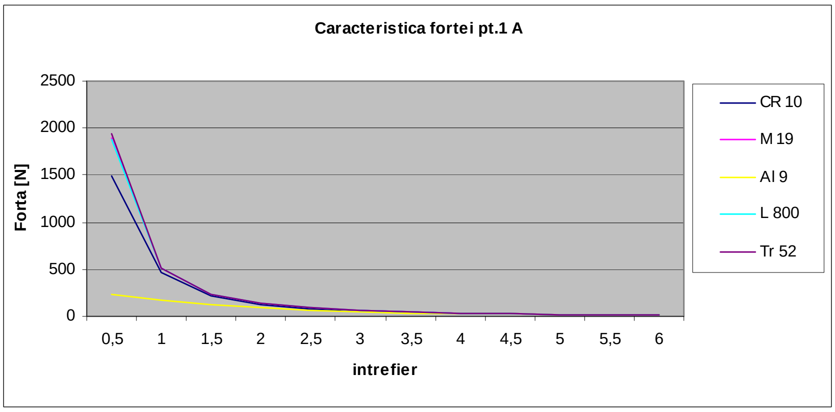
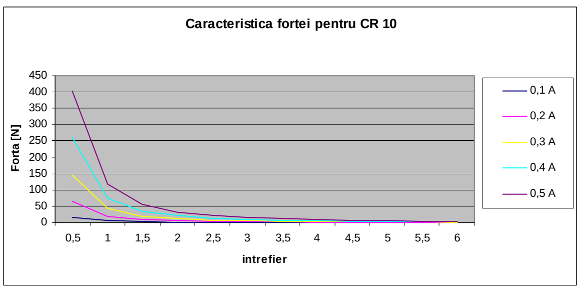


Fig. 4 The force characteristic for a 1 A current

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 .



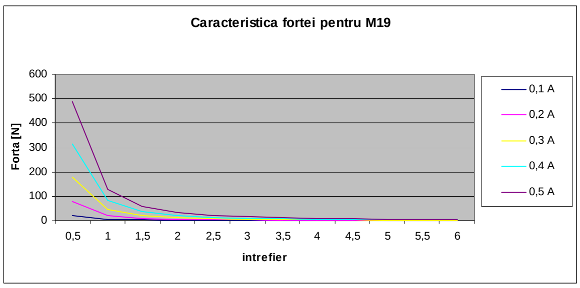


Fig. 5 Force characteristic for CR 10

Fig. 6 Force characteristic for M19

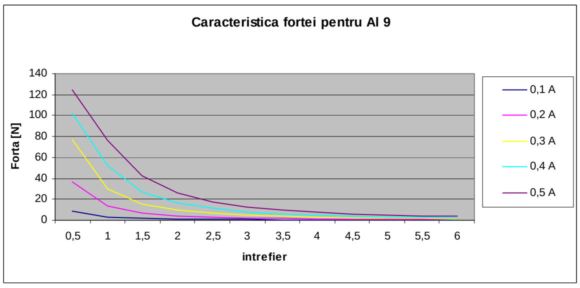


Fig. 7 Force characteristic for Al 9

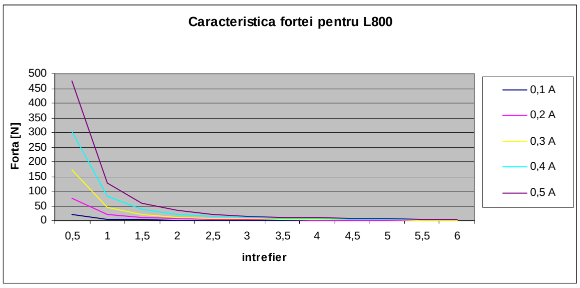


Fig. 8 Force characteristic for L 800

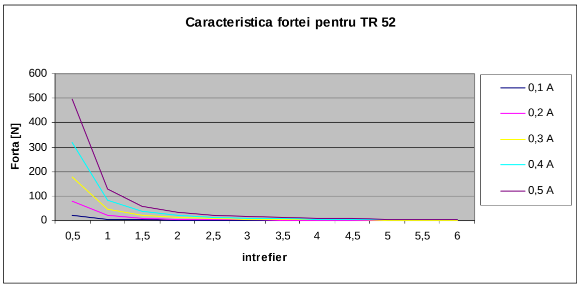


Fig. 9 Force characteristic for TR 52

5. CONCLUSION

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 then 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

6. REFERENCES

[1] ANDEA, P., *Electromagneții,* Editura Helicon, Timişoara, 1993, p.261
[2] DARIE, S., *Vibratoare electrice*, Editura Tehnică, Bucureşti, 1987, p. 214.
[3] HORGOS, M., *Contribuții privind optimizarea parametrilor caracteristici ai procesului de sortare pe ciururi cu rezonanță,* Teza de doctorat, Universitatea de Nord Baia Mare, 2006.
[4] [***] *An introduction for Infolyitica Magnet 6.11*