Computation of Electromagnetic Forces and Torques on Overline Magnetic Separator

Mirka I. Popnikolova Radevska[1] and Blagoja S. Arapinoski[2]

***Abstract*: In this paper will be presented an approach to improved nonlinear magnetic field analyses of the Overline Magnetic Separator (OMS), on the basis of FEM as a represent of the numerical methods. By using the iterative procedure, Finite Element Method, it will be calculated the nonlinear distribution of magnetic field, under rated excitation on the (OMS). The electromagnetic field on the basis of the fluxes and flux densities in the particular domain of the (OMS), will be defined. The electromagnetic forces and torques will be calculated.**

***Keywords* – Overline Magnetic Separator, Finite Element Method, Electromagnetic force, Electromagnetic torque.**

I. INTRODUCTION

The rated data of the(OMS) that will be analyzed in this paper are rated data: $I_n = 31.4\,\text{A}$, $U_n = 220\,\text{V}$ .The three dimensional cartezian system is used for the analyses.(bide analiziran vo pravoagolen koordinaten system.) Maximum clearance distance is $d = 0.42\,\text{m}$. A nonlinear interactive procedure is applied, calculations are carried out quasistatically, at given transportation line position. Real Overline Magnetic Separator OMS, product of Steinert is presented in Fig. 1, and OMS Model is presented in Fig. 2.

Fig. 1. Overline Magnetic Separator OMS

[1]Mirka I. Popnikolova Radevska is with the Faculty of Technical Sciences, I.L.Ribar bb, 7000 Bitola, Macedonia, E-mail: mirka.radevska@uklo.edu.mk

[2]Blagoja S. Arapinoski is with the Faculty of Technical Sciences, I.L.Ribar bb, 7000 Bitola, Macedonia, E-mail: blagojarp@mt.net.mk

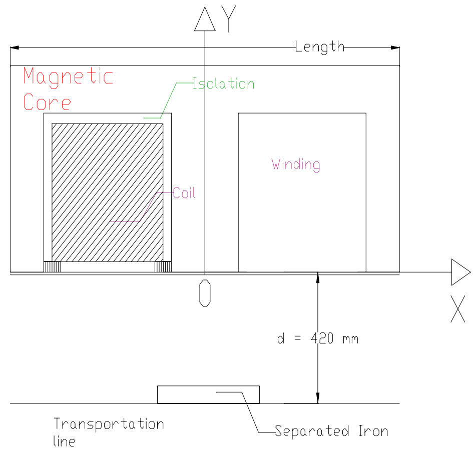

Fig. 2. Model of Overline Magnetic Separator OMS.

II. OMS MODEL IN FEM 4.0

FEM has possibility to solve magnetic vector potential and consequently magnetic flux density by solving relevant set of Maxwell equations for magnetostatic case as well as for time harmonic case. In magnetostatic case field intensity $\mathbf{H}$ and flux density $\mathbf{B}$ must obey:

$$\nabla\,\mathbf{H} = \mathbf{J} \tag{1}$$

$$\nabla\,\mathbf{B} = 0 \tag{2}$$

subject to a constitute relation between $\mathbf{B}$ and $\mathbf{H}$ for each material:

$$\mathbf{B} = \mu\,\mathbf{H} = \frac{1}{v}\cdot\mathbf{H} \tag{3}$$

and for nonlinear material permeability μ is actually function of $\mathbf{B}$.

FEM goes about finding a field that satisfies Eq. 1-Eq. 3 via a magnetic vector potential. Flux density is written in terms of the vector potential $\mathbf{A}$, as:

$$\mathbf{B} = \nabla x \mathbf{A} \tag{4}$$

This definition of $\mathbf{B}$ always satisfies Eq. 2. Then Eq.1 can be redefined as:

$$\nabla\,x\left(\frac{1}{\mu(\mathbf{B})}\nabla\,\mathbf{A}\right) = \mathbf{J} \tag{5}$$

As first step in program pre-processing part, input is the OMS geometry and material properties for all separators domains are defined. This includes current density and conductivity in both OMS windings as well as magnetic properties, including magnetization curve for non-linear calculations.

In order to be able to solve the problem with FEM, boundary conditions on the outer electromagnets geometry must be defined. For analyzed separator Dirichlet boundary conditions are used.

On Fig. 3 mesh of finite elements is presented which is derived fully automatically and it is consisted of 24975 nodes and 49851 finite elements.

On Fig. 3, mesh of finite elements is presented which is derived fully automatically.

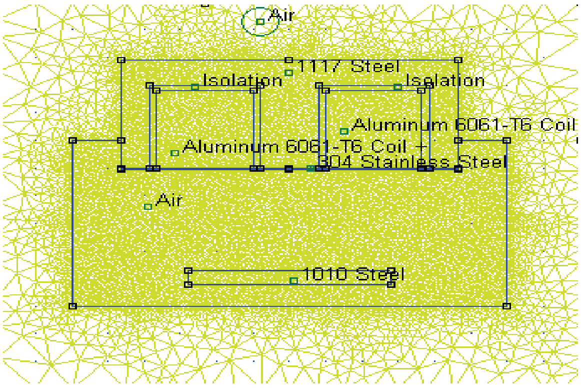

Fig. 3. Finite element mesh in cross section of OMS1.

When a more accurate calculation of the magnetic vector potential is needed, then mesh density should be increased especially on interface between two different materials. In that case contour of integration passes at least two elements away from any interface or boundaries. Greater mesh density increases the computation time. So, the good way to find mesh which is “dense enough” in order necessary accuracy to be achieved and still computation time to be reasonably small is comparation of results from different mesh densities can be picked smallest mesh which gives convergence to the desired digit of accuracy.

In OMS post processing part, we make comparison of electromagnetic characteristics in three cases: OMS1 with super malloy main core, which separates pure iron, OMS2 with 1117 steel main core, which separates 1010 steel and OMS3 with M_45 steel main core, which separates 1006 steel. OMS1, OMS2, are separating materials with one form and OMS3 another. Especialy the differences on magnetic field density can be seen on Fig. 4, Fig. 5 and Fig. 6 respectively.

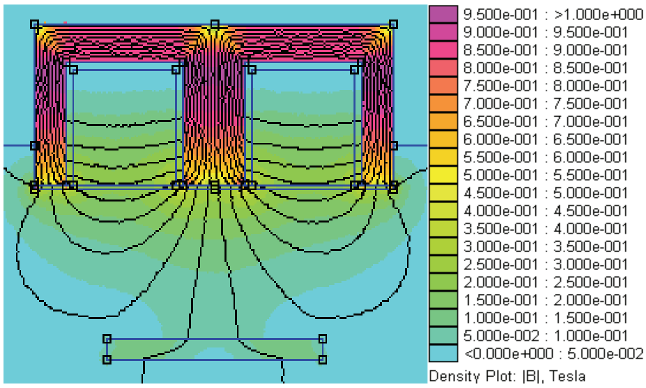

Fig. 4. Magnetic field density on OMS1.

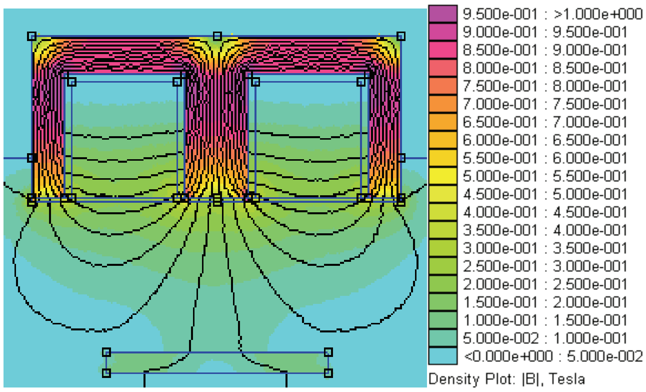

Fig. 5. Magnetic field density on OMS2.

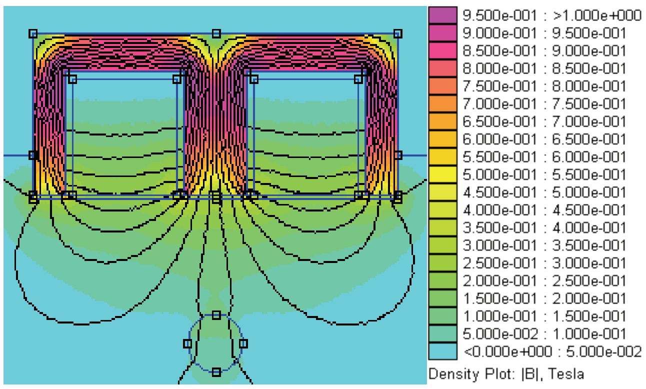

Fig. 6. Magnetic field density on OMS3.

III. ELECTROMECHANICAL CHARACTERISTICS

The knowledge of electromagnetic forces and torque characteristics is very important matter for analysis of OMS. In this paper numerical calculation of electromechanical forces and torques that are calculated on the base of Maxwell’s Stress Tensor and Weighted Stress Tensor are applied on the OMS.

Maxwell’s Stress Tensor prescribes a force per unit area by magnetic field on a surface.The net force on an object is obtained by creating surface totally enclosing the object of interest and integrating the magnetic stress over that surface.

The differential force produced is:

$$dF = \frac{1}{2}\left(H\left(B \cdot n\right) + B\left(H \cdot n\right) - \left(H \cdot B\right)n\right) \qquad (6)$$

where n denotes the direction normal to the surface at the point of interest.

Weighted Stress Tensor Integral greatly simplifies the computation of forces and torques, as compared to evaluating forces via the stress tensor line integral of differentiation of co-energy. Merely select the blocks upon which force or torque are to be computed and evaluate the integral. No particular “art” is required in getting good force or torque results (as opposed to the Stress tensor line integral), although results tend to be more accurate with finer meshing around the region upon which the force or torque is to be computed. One limitation of the Weighted Stress Tensor integral is that the regions upon which the force is being computed must be entirely surrounded by air/or abutting a boundary. In cases in which the desired region abuts a non-air region, force results may be deduced from differentiation of co-energy.

The forces characteristics on directions x and y axis, versus different clearance distances and rated current for OMS1, OMS 2 and OMS 3 are presented in Fig.7 and Fig. 8.

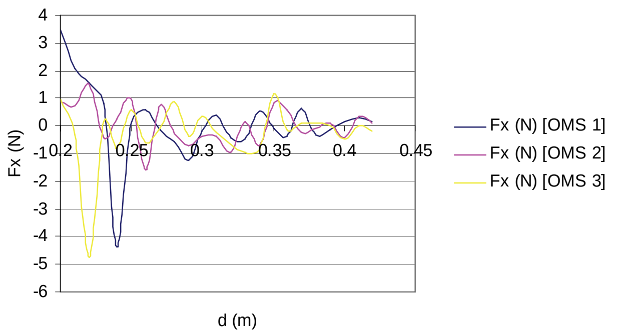

Fig. 7. Forces on direction x-axis, versus different clearance distances for OMS1, OMS2 and OMS3.

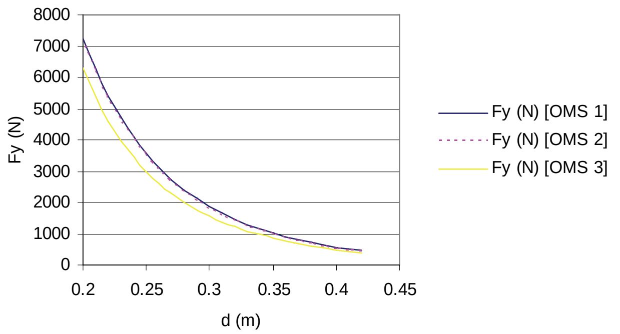

Fig. 8. Forces on direction y-axis, versus different clearance distances for OMS1, OMS2 and OMS3.

The torque characteristics versus different clearance distances and rated current, for OMS1, OMS2 and OMS3 are presented in Fig. 9.

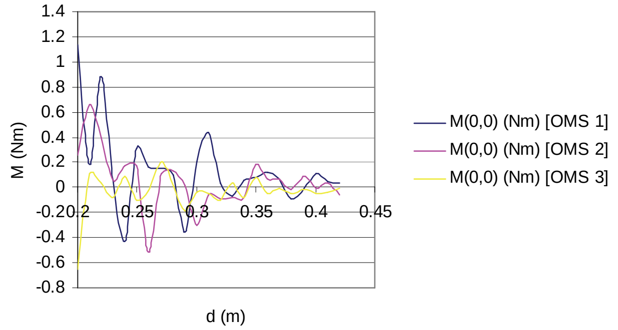

Fig.9. The torque characteristics versus different clearance distances for OMS1, OMS2 and OMS3 .

The forces on directions x and y axis characteristics versus different currents and constant clearance distance $d = 0.37\,mm$ for OMS1, OMS 2 and OMS 3 are presented in Fig.10 and Fig. 11.

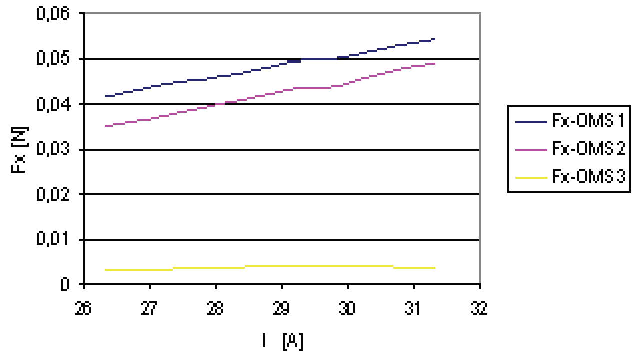

Fig.10 Forces on direction x-axis, versus different currents for OMS1, OMS2 and OMS3.

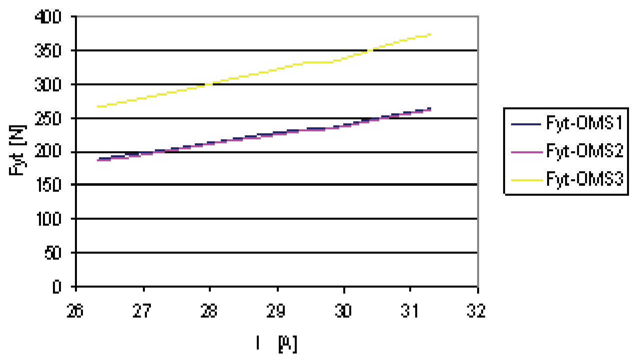

Fig. 11. Forces on direction y-axis, versus different currents for OMS1, OMS2 and OMS3.

The torque characteristics $M_t = f\left(I\right); d = const.$, were computed with weighted stress tensor integral for OMS1, OMS2 and OMS3 are presented in Fig. 12.

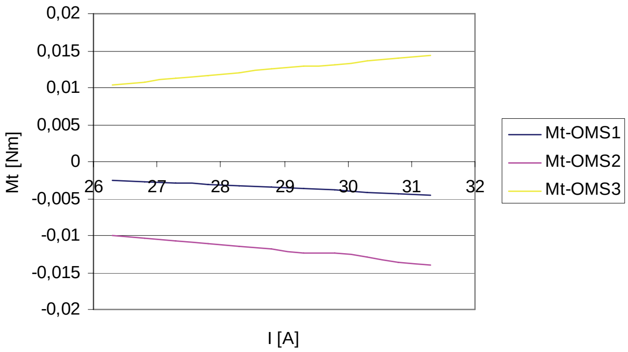

Fig 12. The torque characteristics versus different currents and constant distance clearance for OMS1, OMS2 and OMS3 .

Magnetic field co-energy is defined:

$$W_C = \int \left(\int_0^H B\left(H^{'}\right) dH^{'} \right) dV \qquad (7)$$

On base of the Eq. 7, the magnetic co-energies are computed and their characteristics versus different currents and constant clearance distances for OMS1, OMS2 and OMS3 are presented in Fig. 13:

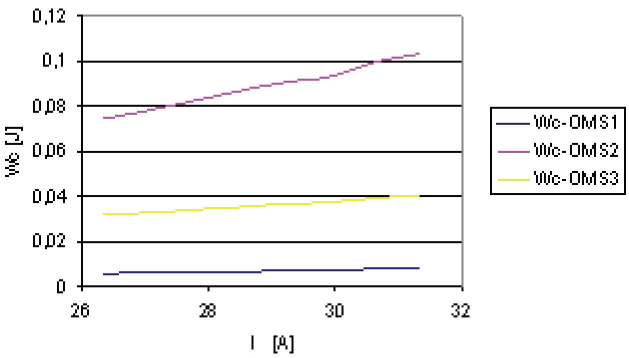

Fig 13. The magnetic co-energy characteristics versus different currents and constant clearance distance for OMS1, OMS2 and OMS3 .

IV. Conclusion

In this paper the non-linear magnetic field analyses and computation of electromagnetic and electromechanical characteristics are presented. For this purpose as the most suitable, Finite Element Method is applied. Additionally electromagnetic forces and torque are calculated for rated load current and different clearance distance and for constant clearance distance and different currents. Also in this paper forces and torques are computed via Maxwell's Stress Tensor and Weighted Stress Tensor. Magnetic field co-energy is also computed an presented in this paper.

References

[1] M. Popnikolova Radevska: "Calculation of Electromechanical Characteristics on Overband Magnetic Separator with Finite Elements", ICEST 2006, p.p. 367-370, Sofia, Bulgaria 2006.

[2] D. Meeker, "Finite Element Method Magnetics Version 4.2", User's Manual, 2006 .

[3] STEINERT Betriesanweisungen fur Uberbandmagnetscheider und Aushebemagnete, Technische Daten TD UME P, 2002.

[4] John Wiley & Sons, "ELECTROMAGNETIC DEVICES" New York-London-Sydney.