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THREE DIMENSIONAL NUMERICAL SIMULATION OF A MAGNETIZER BASED ON BITTER COIL

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Abstract: *This paper presents the 3-D numerical analysis of a magnetisation device using FLUX 3D, a software based on the finite elements method. A simplified model of the Bitter coil was built taking into account the software constraints. The simulations were conducted in stationary, steady state AC and transient regimes. The obtained results are analysed using both graphical data and numerical values of the electromagnetic field quantities. The simulations include the presence of a magnetic sample inside the Bitter coil.*
Key words: *Magnetic materials, 3-D numerical analysis, electromagnetic potentials.*

1. INTRODUCTION

Magnetic materials have a large utilization daily. They are not found already magnetized in their natural form, so it was necessary to create devices which would magnetize them. Most magnetizing equipments contain coils. The material performance is a assured by its magnetization and therefore a more powerful magnetic field is needed [1]. In general, in order to obtain such high magnetic fields (over 1,6T) superconductor coils could be used. However, the magnetic field is limited under certain conditions and these superconductor coils cannot be used at higher temperatures; in this case other solutions had to be found [2].

At the beginning of the 1930s the Bitter resistive coils were developed – they consisted of a succession of very thin circular conducting plates which are placed in helical layers, each plate having cooling holes for water to flow through. The devices created with these types of coils can generate magnetic fields of very high values (over 30T) [3].

This paper considers a simplified model of the Bitter coil, which was built taking into account the FLUX3D© [4] software constraints; the 3-D numerical analysis of a magnetisation device uses the finite elements method. The simulations were conducted in stationary, steady state AC and transient regimes.

2. NUMERICAL MODELING USING FLUX3D

To solve the electromagnetic field problem, a 3-D software was used. FLUX3D is based on the finite elements method – a numerical technique for finding approximate solutions for partial differential equations which describe the electromagnetic field behavior [5][6].

The behavior of the magnetizer was studied in two cases: the device alone and afterwards with a sample placed in the middle of it. The analysis was made for stationary magnetic regime, steady state AC permanent regime (at 50 Hz) and transient regime.

In order to obtain a better solution, the mesh was adapted to the geometry using control points and lines – the mesh density has been defined around certain points and the lines have been arithmetically divided by imposing the number of mesh segments. FLUX 3D combines different forms of finite elements during creating the mesh – triangular or rectangular mesh elements for the sides and brick or tetrahedral mesh elements for the volumes [4].

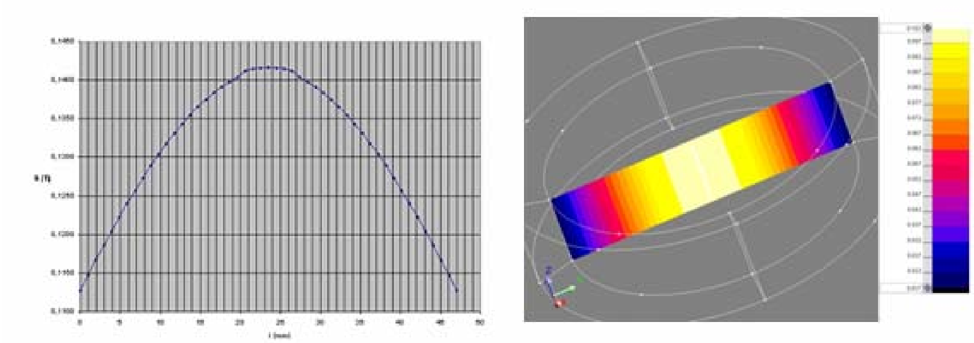
The formulation in electromagnetic potentials was automatically established by the program for the different regions: for thin regions and air is used the reduced scalar magnetic potential Φ_{red} and for the coil the formulation uses the vector electric potential **T** and the scalar magnetic potential Φ [4][7].

Because the material regions cannot be simultaneously assigned with supply currents and eddy currents, an approximating method employing a filiform coil was used in the device simulation.

The numerical simulation produces accurate results if the mesh is fine and adapted around the corners and edges. In our case, good results were obtained with a mesh having around hundreds of thousands tetrahedral elements.

3. 3-D NUMERICAL ANALYSIS

The first analysis of the device was made in the stationary magnetic regime. The simulation used a massive coil with the same volume of material as the original coil of the magnetizer device.



a. b.

Fig.1. a) Magnetic flux density vs. position on the coil axis; b) Magnetic flux density color map

In order to obtain the magnetic flux density variation chart in the middle of the coil, a support line was defined straight through its center. The obtained numerical values showed that in the middle of the coil there are the highest values of magnetic flux density (fig. 1.a), also confirmed by the flux density color map for the entire coil (fig. 1.b).

The magnetizer was also analyzed in the stationary magnetic regime, taking into account the presence of the high permeability sample (μ_r=10000) in the middle of the coil. It was observed that by inserting the sample the lines of the magnetic field are attracted to it (fig. 2). Detailed numerical values of the magnetic flux density in the middle of the coil can be analysed in figure 3.

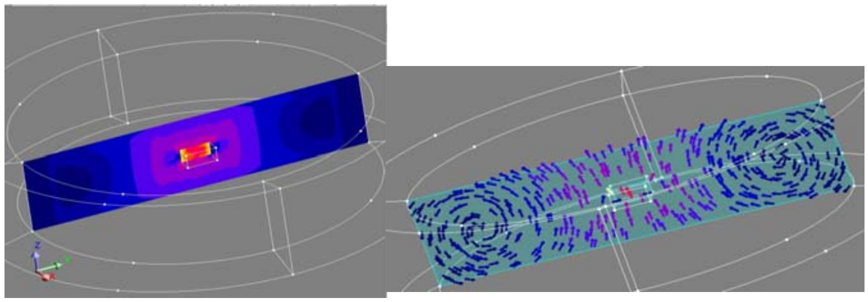


Figure 2. Magnetic field map and vectors for stationary magnetic regime

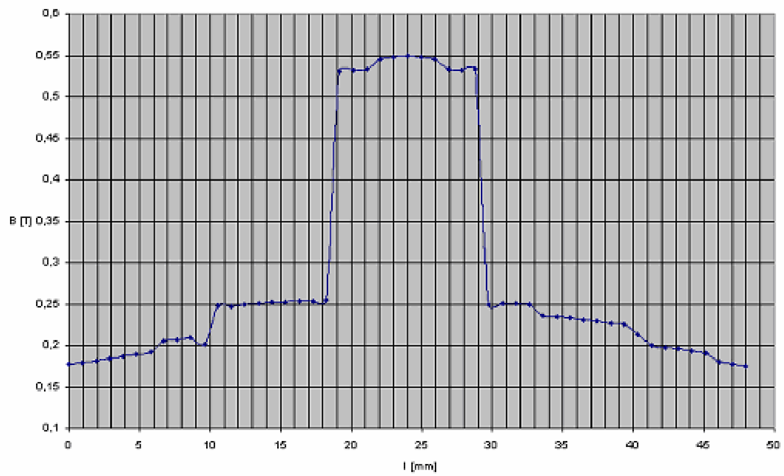


Fig. 3. Magnetic flux density vs. position on the coil axis

For the steady state permanent regime at a frequency of 50 Hz, the results were similar to the stationary regime. The frequency changing did not modify so much the flux density values, showing only a slight increasing.

The third analysis of the device was made for the transient regime. For the simulation, a copper coil with 7 turns was used. The coil was defined in FLUX3D software as „solid conductor”. In order to model the supply currents, a filiform coil was inserted in the middle of the coil volume, a sine current flowing through it (fig 4).

a. b.

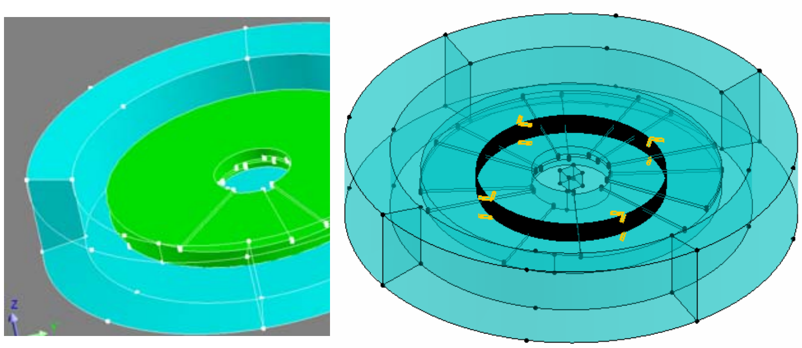


Fig.4. Geometry of the magnetizer modeled by a filiform coil: a) without sample; b) with sample

The postprocessor of FLUX3D can be used to obtain color maps or vector maps (see fig. 5). The values of the magnetic fields in different points could be also usefull.

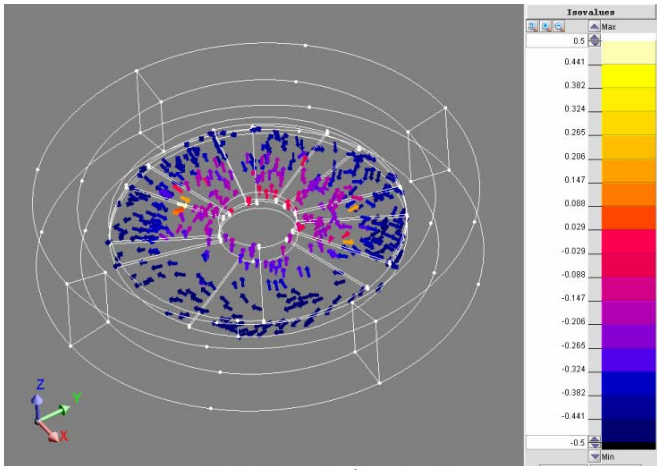


Fig.5. Magnetic flux density

The magnetic field problem being linear, the magnetic flux density variation is sinusoidal because the supply current is sinusoidal. The magnetic flux density color map is modified in time according to this time variation law. For example, at t = 5 s this map looks like in figure 6.

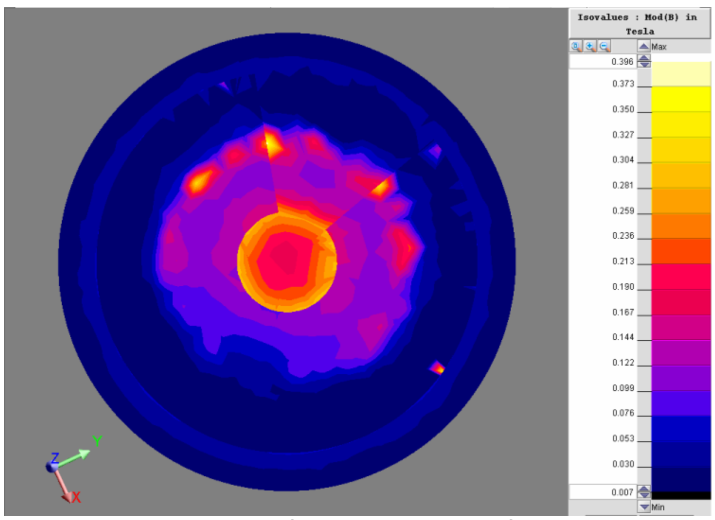


Fig.6. Magnetic flux density color map for t=5s

Another simulation of the same model for transient regime was made, but this time a linear magnetic sample inside the coil was considered. The sample has a high magnetic permeability, μ_r=10000. The shape of the magnetic field map shows the same phenomenon of the attraction of the *B* lines thought the sample body (fig. 7).

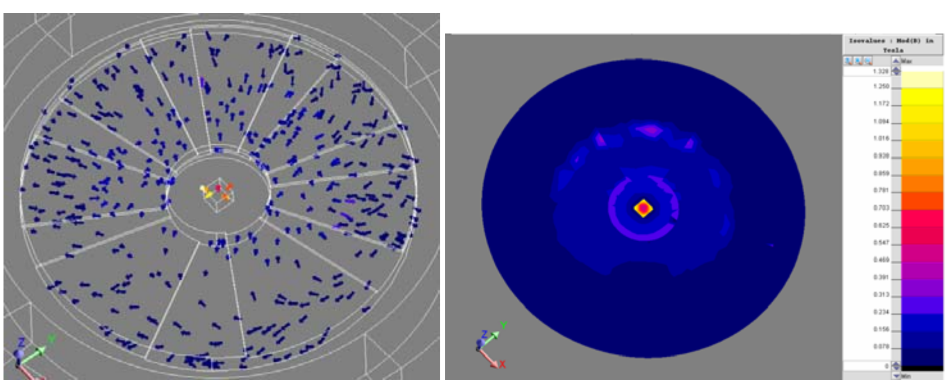


Fig.7. Magnetic vectors and magnetic field map for transient problem at t=5s

The vector map of the current density shows that eddy currents are opposed to the supply currents in the Bitter coil (fig. 8).

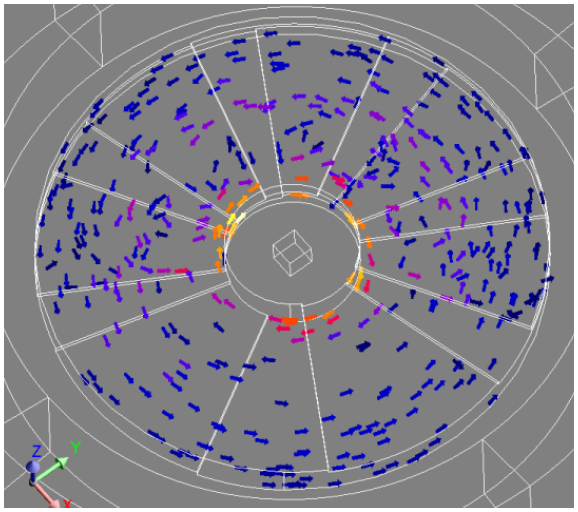


Fig.8. Eddy currents density map

In the final simulation, the magnetic linear sample is replaced with a non-linear one having the initial relative permeability equal to 3500, the magnetic saturation polarization of 0.5 T and a value of 0.5 for the adjustment coefficient of the *B*(*H*) curve knee. In this case, the numerical results are more accurate and in figure 9 is represented the color map of the magnetic flux density.

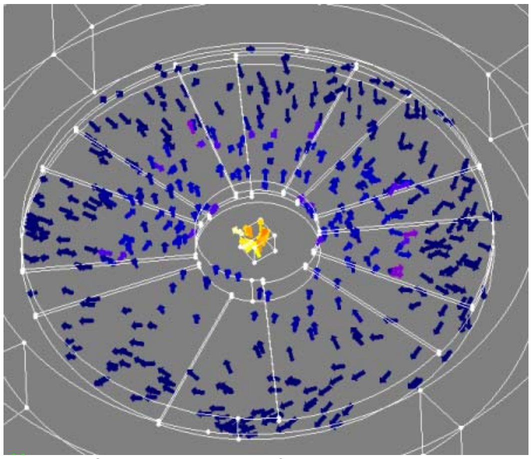
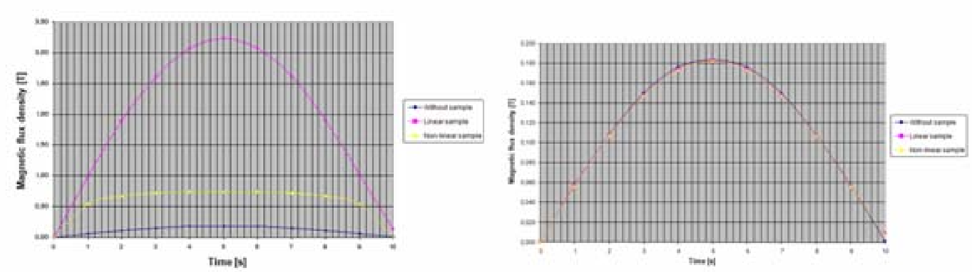


Fig.9. Magnetic flux density vector for a non-linear magnetic sample

The comparison of the results obtained for the three problems in transient regime (with a linear sample, with a non-linear sample and without the sample) showed that the highest values of magnetic flux density are obtained in the case of the linear sample and the lowest values are recorded when there is no sample inserted. By choosing two points - one on the sample and the other on the coil - observations could be made on how the magnetic flux density evolves in time for the 3 cases – see figure 10.



a. b.

Fig.10. Magnetic flux density vs. time a) inside the sample; b) outside the sample

4. CONCLUSIONS

A numerical approach was used for the analysis of the magnetization device – finite elements method implemented in FLUX3D software. The simulations were done for three cases: magnetic stationary regime (0Hz), steady state permanent regime (50Hz) and transient regime. In the last two cases the Bitter coil was studied with and without a feromagnetic sample inserted in its center.

The results obtained for the stationary and steady state problems are similar. When a sample with high magnetic permeability is inserted in the middle of the device, the magnetic flux density for the area it occupies was of 3 to 4 times higher than when the sample is not used. These results are due to the concentration of magnetic field lines in the sample and around it.

For the transient regime, the magnetizer was analysed in three cases: without any sample, with a linear sample (μ_r=10000) and with a nonlinear sample (a magnetising curve specific to soft magnetic materials having the initial relative permeability μ_r=3500). An approximate solution has been computed using a filiform coil to simulate the supply sinusoidal currents. The values of the magnetic flux density varied differently inside and outside the sample.

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