MODELLING OF THE MAGNETOVISION IMAGE WITH THE FINITE ELEMENT METHOD

***Michał Nowicki*[1], *Roman Szewczyk*[1]**

[1] *Institute of Metrology and Biomedical Engineering, Warsaw University of Technology,*

ul. Św. Andrzeja Boboli 8 , 02-525 Warszawa, Poland
E-mail: m.nowicki@mchtr.pw.edu.pl

Received 24 May 2014; accepted 28 May 2014

1. Introduction

This paper presents an application of finite element method for magnetostatic modelling of the magnetovision images of small, ferromagnetic objects. Calculations are based on the free open-source Elmer software. Existing passive gradiometer systems have very low resolution. They are designed for deep-level search of relatively big targets, such as unexploded aircraft bombs, and rarely are used for magnetic imaging, using data logging and GPS systems [1,2]. Therefore a high-resolution scanning system is designed for search of small targets from small distance, such as potentially dangerous baggage.

Ferromagnetic materials can be magnetized by Earth magnetic field. Because their magnetic permeability is much higher than that of air, their presence distorts the lines of geomagnetic flux. Moreover, most ferromagnetic elements have their own residual magnetism, which in effect causes them to act like a magnetic dipole. The overall effect would be extremely hard to calculate using analytical methods, therefore finite element method was implemented. Furthermore, comparison between modelling results and actual measurements is important. To investigate this subject, special test stand was constructed, consisting of magnetovision scanner and high precision tri-axial Helmholtz coils. The magnetovision scanner is capable of planar magnetic field vector values distribution measurement, utilizing tri-axial high sensitivity magnetoresistive sensor. The Helmholtz coils were used to set the reference magnetic field for the measurement..

2. Test Stand

In order to measure and discriminate the permeability and remanence related distortion effects, special test stand was constructed, consisting of tri-axial magnetovision scanner and high precision Helmholtz coils (fig. 1). The magnetovision scanner is capable of planar magnetic field vector values distribution measurement, utilizing tri-axial high sensitivity magnetoresistive sensor. Thin-film magnetoresistive sensors are the most suitable for magnetic imaging. They exhibit high sensitivity and have small size - typically 1x1 mm, or less [3]. Principle of operation and the target application and abilities of the magnetovision scanner has been previously described in [4].

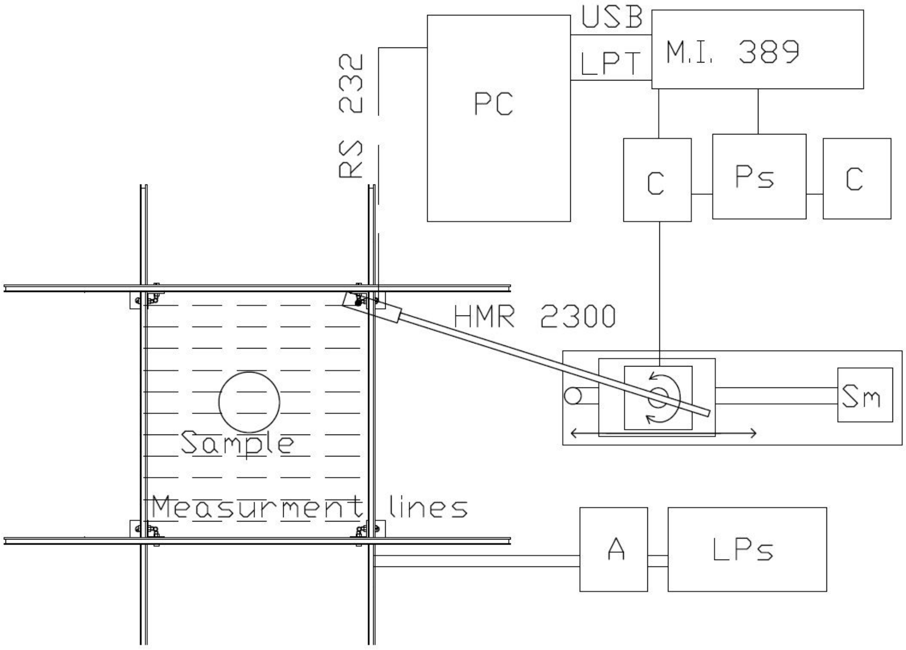

Figure 1: *Developed magnetovision test stand, consisting of high resolution tri-axial magnetovision scanner and high precision Helmholtz coils.*

3. Modelling methodology

For the modelling of the magnetovision images, finite element method was used in the open-source software Elmer. First, the shape of the sample was written in the .geo format, together with 'imaging' planes of a cube around the sample and a cylinder with a volume of constant magnetic flux distribution, serving as the background. Next, the basic geometrical shapes were loaded into open source Netgen 5.1 software, and meshed with very fine meshing granularity. Typical number of interconnected objects was 150 000, which allowed for relatively high modelling resolution. The mesh was then exported and saved in .gmsh2 format. In order to prepare the meshes for further processing, and remove unnecessary nodes, additional cleaning of them was made using the Elmergrid –autoclean function.

Finished meshes were loaded into the Elmer software, together with .sif files defining the bodies, materials, physical values (for example relative magnetic permeability of the sample) and active solvers and equations. WhitneyAV solver included in the MagnetoStatic module of the software was utilized, which allowed for calculation of the magnetic flux density and magnetic field strength in every node of the modelling area. The ElmerGUI VTK postprocessor allows for many different kinds of visualization of the results, including colorbar surfaces, vectors, isosurfaces and isolines.

4. Results

Modeled results of various magnetovision images were obtained, for different samples geometries, sizes and magnetic permeabilities. On the figure 3 the typical result is shown, for a steel cylinder sample of 70 mm diameter, on a 200x200 mm measurement plane. The external constant field was set in the axis of the sample, perpendicular to the measurement plane, to simulate natural geomagnetic field. Positive and negative disturbances of constant external magnetic field are clearly seen. Arbitrary units of magnetic flux density of the postprocessor are used. For this simulation, only the magnetic permeability related effect is considered, the sample was treated as a perfectly demagnetized one.

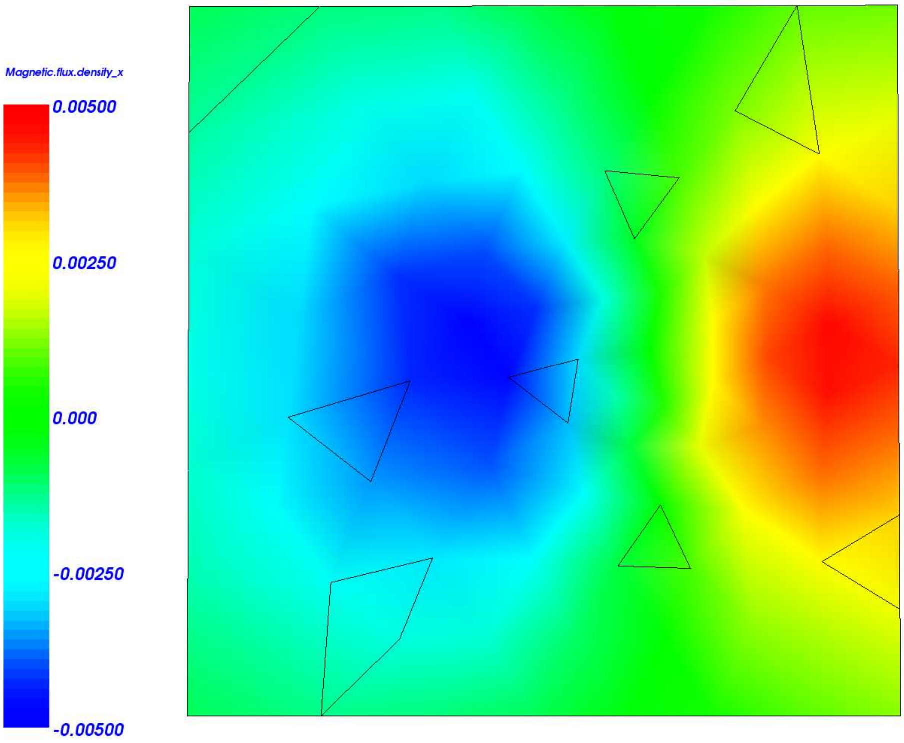

Figure 3: *Modeling results of the magnetic flux density distribution in the plane above the high-permeability cylindrical sample, in constant external perpendicular magnetic field.*

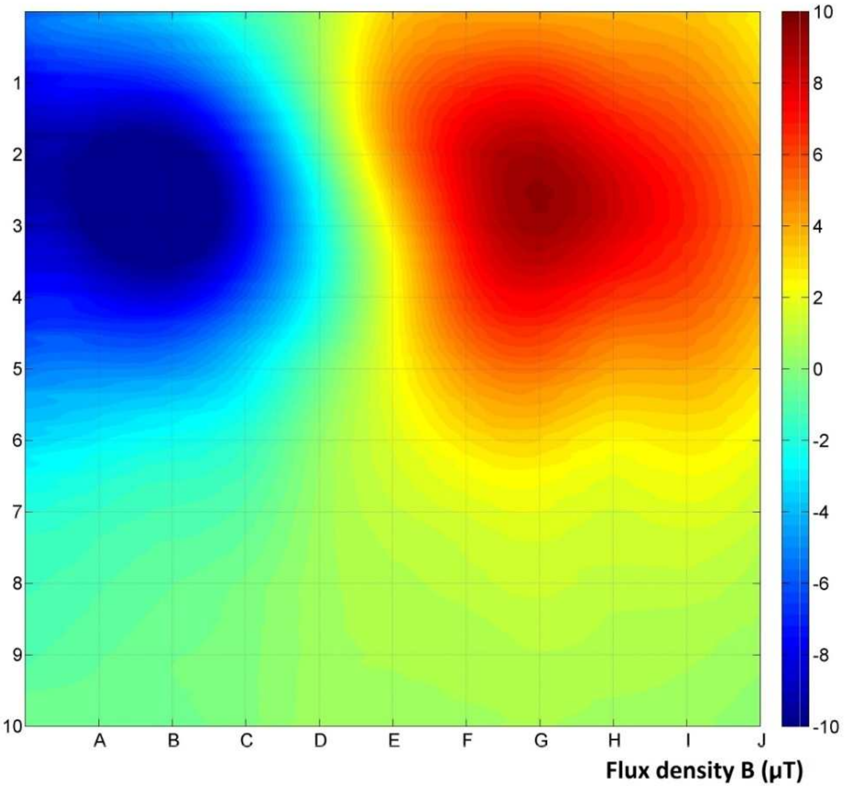

Figure 3: *Real-world magnetovision measurement results for the same geometrical, material and external field conditions*

In the real world measurements, samples have always some level of remanent magnetization, which typically causes magnetic field disturbances on the similar level of magnitude, but adds complexity to the obtained images. Nonetheless, on figure 4 actual magnetovision measurement of real world equivalent of the sample considered above is shown, with same constant field direction set by the Helmholtz coils. As can be seen, the overall shape of the results, and even the distribution and relative gradient of the positive and negative disturbances is strikingly similar. The planar disturbances distribution can be ‘rotated’ with the sample, and complex or strong magnetic remanence in the sample would confuse it further.

5. Conclusions

Experimental setup for planar measurements of vector distribution of weak magnetic fields distortions and to differentiate its sources was developed. Moreover, new methodology of modelling of the results was presented. The developed methods allow a visualization of the distribution of the magnetic induction vector absolute values, its gradient as well as the value and direction of the magnetic flux density vector in different measurement points. Experimental investigation allowed for direct measurement of permeability and remanence-related distortion effect. For simple sample geometries the modelling results bear striking resemblance to the magnetovision images obtained IRL, which validates usage of this method of calculations based on the open-source software for finite elements magnetostatic modelling. Based on the results, the location and size of the object can be determined, which is very useful from practical point of view [4].

Acknowledgement

This work was partially supported by The National Center for Research and Development, grant no. O ROB 0015 01/ID15/1.

References:

[1] Guelle D., Smith A., Lewis A., Bloodworth T., Metal detector handbook for humanitarian demining. Office for Official Publications of the European Communities, Luxembourg, (2003).
[2] Billings S. D. Discrimination and classification of buried unexploded ordnance using magnetometry. *IEEE Transactions on Geoscience and Remote Sensing*, **6**, 1241. (2004)
[3] Tumański S. , Thin film magnetoresistive sensors ; Taylor & Francis, England, (2001).
[4] Nowicki, M., Szewczyk, R. Ferromagnetic Objects Magnetovision Detection System. *Materials,* **6**, 5593 (2013).