EXPERIMENTS WITH THE EFFECT OF NON-HOMOGENOUS PARTS INTO MATERIALS

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Summary The article describes possibility of the deformity magnetic field numerical modeling into surroundings of the measured dia – paramagnetic specimens. This deformation study is given for the purposes MR measuring, where MR images are deformed from the point of view of susceptibility heterogeneous materials. For the numerical simulation was chosen elementary configuration. The results was verified by MR experimental measurement. As the MR measurement method was used techniques of the gradient echo

1. INTRODUCTION

Measurement method for measuring susceptibility of the homogenous materials by magnetic resonance (MR) techniques were detailed described in texts [4] – [7] and the results were verified by finite element methods (FEM) numerical simulations. For measuring susceptibility of the heterogeneous materials with the complicated shapes MR techniques (it was described in [8] - [9]) hadn't always unique outgoing values. It is necessary find the method, how it is possible reliable measured results verify. One of the possibility of verification is the use of FEM numerical analysis with ANSYS system. The main advantages of the FEM ANSYS system is the ability to solve the multi-physical models, anisotropic materials and possibility to use of APDL programming language. This all advantages haven't the other programs together.

The aim of our work is to find simply model for numerical modeling and NMR experiment- verification. There can be changed heterogeneous material properties and next experimentally measured. The idea of increase of MRI is in the hybrid experimental and numerical inverse method. The numerical results are used in the MRI experimentally obtained data. The application of numerical results to the NMR post-processing can much more increase the final images.

2. GEOMETRICAL MODEL

The Fig. 1 describes the sample geometry for the numerical modeling. On both sides, the sample is surrounded by the referential medium (clay). As shown in fig. 1, in the model there are defined five volumes with different susceptibilities. The materials are defined by their permeabilites : material No. 4 – the medium outside the cube (air, χ=0), material No. 3 – referential medium (clay, χ = -9,92.10^{-6}), material No. 2 – the cube and the in-homogeneity covering (sodium glass, χ = -11,7.10^{-6}), material No. 1 - the material inside the in-homogeneity (water, χ = -12,44.10^{-6}). The permeability rate was set with the help of the relation μ=1+χ.

For the sample geometry according to fig. 1, the geometrical model was built in the system Ansys by FEM. In the model there was applied the mesh of elements, type Solid96 (ANSYS). The boundary conditions (4) were selected for the induction value of the static primary magnetic flux density to be B_0 = 4,7000 T in the direction of the z coordinate (the cube axis) – corresponds with the real experiment carried out using the MR tomograph at the Institute of Scientific Instruments, ASCR Brno.

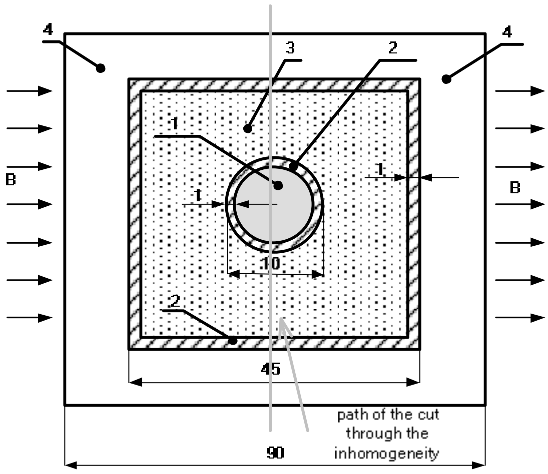

Fig. 1 The sample geometry for numerical modeling, path of magnetic flux density evaluation

3. NUMERICAL ANALYSIS

The numerical modeling was realized using the FEM with the ANSYS system and it was detailed described into reference [4]. The numerical modeling results are represented in fig. 2, fig.3. The numerical modeling results were then used for the representation of the module of magnetic flux density $\boldsymbol{B}$ along the defined path. For the model meshing, the element sizes selected as optimum were $0{,}25.10^{-3}$m and $0{,}125.10^{-3}$ m. The boundary conditions $\pm\varphi_m/2$ were set to the model edges, to the external left and right boundaries of the air medium, as represented in fig.1. The excitation value $\pm\varphi_m/2$ was set by using again the relation (4).This is derived for the assumption that, in the entire area, there are no exciting currents, therefore there holds for the **rot** $\boldsymbol{H}$ = **0** and the field is irrotational. Consequently, for the scalar magnetic potential φ_m holds

$$\boldsymbol{H} = -grad\varphi_m \tag{1}$$

The potential of the exciting static field with intensity H_0 is by applying (2)

$$\varphi_m = \int \boldsymbol{H}_0 \cdot \boldsymbol{u}_z dz = H_0 \cdot z \tag{2}$$

where $\boldsymbol{u}_z$ is the normal vector on z direction. Then

$$H_0 = \frac{B}{\mu_0 \cdot \mu_r} \tag{3}$$

Then

$$\pm\frac{\varphi_m}{2} = \frac{B \cdot z}{2\mu_0} = \frac{4{,}7000 \cdot 90 \cdot 10^{-3}}{2\mu_0} \tag{4}$$

where z is the total length of the model edge.

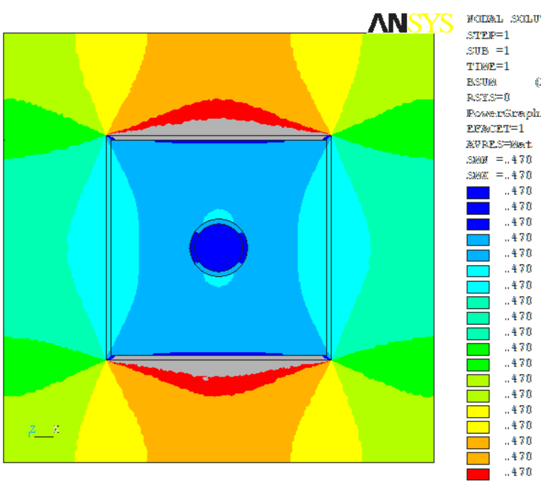

Fig. 2 The numerical solution of the FEM model in the ANSYS system, distribution of module magnetic flux density B

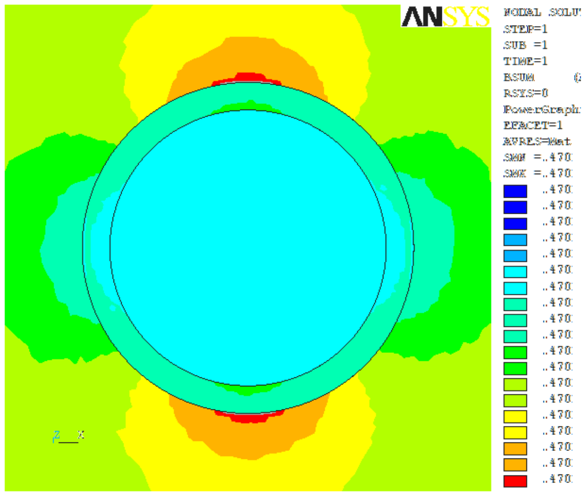

Fig. 3 The numerical solution of the FEM model in the ANSYS system, distribution of module magnetic flux density B

4. EXPERIMENTAL MEASUREMENT

The experimental measuring was realized using the MR tomograph at the Institute of Scientific Instruments, ASCR Brno. The tomograph elementary field B_0 = 4,7000 T is generated by the superconductive solenoidal horizontal magnet produced by the Magnex Scientific company. The corresponding resonance frequency for the 1H cores is 200 MHz. The numerical modeling and analysis of the task have verified the experimental results and, owing to the modifiability of the numerical model, we have managed to advance further in the experimental qualitative NMR image processing realized at the ISI ASCR. As the MR measurement method was used technics of the gradient echo. The results spectral characteristic into water in-homogeneity are given into fig. 4. The relation for computation frequency to the magnetic flux density distribution change ΔB is

$$\Delta B = \frac{2\pi\, \Delta f}{2{,}67\, e^8} \tag{5}$$

where f (Hz) is measured frequency and ΔB (T) is magnetic flux density distribution change. For water in-homogeneity according to fig.1 is value magnetic flux density distribution change from graph fig. 4 equal. ΔB=4,7μT. The frequency f_{max}=900Hz with maximum diagram value in fig. 4 on histogram according to relation (5) correspond to ΔB=21.15μT. This is the right results, because the difference of magnetic flux density from numerical results , fig.2 is approximately ΔB=15.0μT . The accuracy result was obtained from path solution. The numerical results are showed in fig.3. There is the difference of magnetic flux density ΔB=36.0μT. The better result can be done with the numerical result histogram solution.

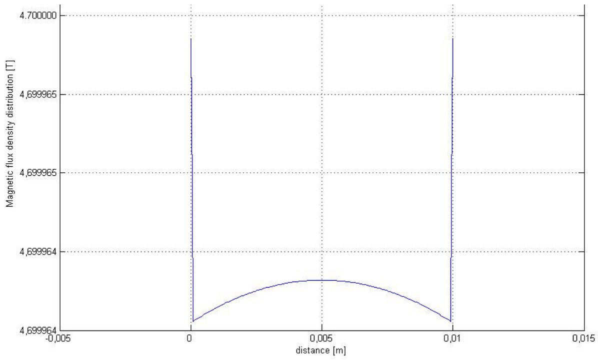

Fig.3. The magnetic flux density distribution change into water in-homogeneity ΔB=36μT, ANSYS numerical analysis results

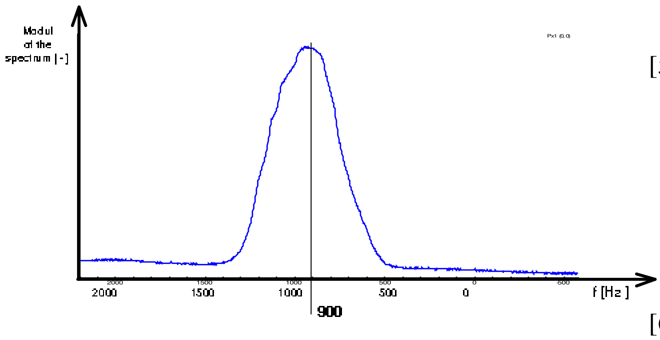

Fig. 4 The experimentally measured spectral characteristic into water in-homogeneity

4. CONCLUSION

The result showed, that it is possible use FEM modeling to the heterogeneous material analysis and use for the magnetic field deformation study into MR experiments. The mathematical experiments showed good results in surroundings of the heterogeneous objects with the complicated shapes.

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REFERENCES

[1] *Ansys User's Manual. Huston (USA): SVANSON ANALYSYS SYSTEM, Inc., 1994-2006.*

[2] Fiala, P., Kroutilová, E., Bachorec, T. *Modelování elektromagnetických polí, počítačová cvičení.* vyd. Brno: VUT v Brně, FEKT, Údolní 53, 602 00, Brno, 2005. s. 1 - 69 .

[3] Steinbauer, M. *Měření magnetické susceptibility technikami tomografie magnetické rezonance*. vyd. Brno: VUT v Brně, FEKT, Údolní 53, 602 00, Brno, 2006.

[4] Fiala, P., Kroutilová, E., Steinbauer, M., Hadinec, M., Bartušek, K. *Inversion Reconstruction of Signals Measured by the NMR Techniques.* PIERS 2007 Proceedings, www.piers.org, Praha, Czech Republic, 27.-30.8. 2007, ISSN: 1559-9450

[5] Steinbauer, M., Kroutilová, E. *Measurement of Weakly Magnetic Material Using New MR Technique*. In Applied Electronics 2006. Pilsen, Czech Republic: University of West BohemiaDepartment of Applied Electronics and TelecommunicationsUniverzitní 8306 14 PilsenCzech Republic, 2006. s. 87-91. ISBN: 80-7043-442-2.

[6] E., Steinbauer, M., Bartusek, *Measurement and simulation of material influence in MR tomography*. In Proceedings of the International Workshop ISEP - UTEE 3. - 6. 9. 2006 Paris. L'Institut Supérieur d'Electronique de Paris, Paris, France: L'Institut Supérieur d'Electronique de Paris, Paris, France, 2006. s. 87-92. ISBN: 80-214-3250-0.

[7] Hadinec, M., Fiala, P., Kroutilová, E., Steinbauer, M., Bartušek, K. *Magnetic field approximation in MR tomography*. Progress In Electromagnetics, 2007, roč. 1, č. 1, s. 1-5. ISSN: 1559-9450.

[8] Bartušek, K. *Speciální metody měření difúzních koeficientů metodami nukleární magnetické resonance*. n. n. Brno: VUTIUM, 2007. 21 s. ISBN: 978-80-214-3379-3.

[9] Bartušek, K., Dokoupil, Z. *Magnetic Resonance Diffusion Measurement Method in Heterogenous Systems*. In Nodern Development of Magnetic Resonance. 1. Kazan, Russian Federation: Zavoisky Physicel Technical Institute Kazan, 2007. s. 142-143.