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UTILIZATION OF NUCLEAR MAGNETIC RESONANCE FOR MAGNETIC SUSCEPTIBILITY MEASUREMENT

ING. MILOSLAV STEINBAUER.[1]
ING. KAREL BARTUŠEK, DRSC.[2]

Abstract: The paper deals with the magnetic susceptibility determination for materials giving no MR signal. The results obtained by Finite element method (FEM) modeling as well as data measured by MR tomography are introduced.

Keywords: MR tomography, magnetic susceptibility, FEM.

1 Introduction

The determination of magnetic susceptibility of weakly magnetic materials is simple for substances giving MR signal by comparison with substance, whose susceptibility is known [2]. In this paper we will discuss measuring technique suitable for substances with no signal in MR tomography.

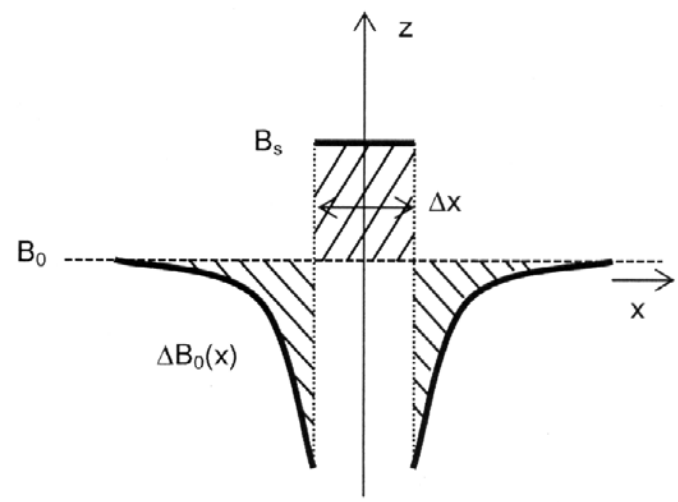

Fig. 1. Local deformation of magnetic field due to weakly magnetic specimen.

This method is based on constant magnetic flux in working space superconducting magnet. Inserting of the specimen with different value of magnetic susceptibility causes local deformation of homogeneous magnetic field – idealized example see Fig. 1. Using MR technique we can acquire image of the

[1] Department of Theoretical and Experimental Electrical Engineering, Faculty of Electrical Engineering and Communication, Brno University of Technology, Purkyňova 464/118, 612 00 Brno
[2] Institute of Scientific Instruments, Academy of Sciences of the Czech Republic, Královopolská 147, 612 00 Brno

magnetic field homogeneity in measured volume of specimen. From this image we derived a course of the magnetic induction module in the measured material. In our example the paramagnetic specimen of thickness Δx is inserted in homogeneous magnetic field with induction B_0 parallel with z-axis. Magnetic induction in the specimen with susceptibility χ_s increases to B_s

$$B_s = B_0 \cdot (1 + \chi_s). \qquad (1)$$

When material of the specimen gives no MR signal, the indirect method of induction B_s computation can be used. Assuming constant magnetic flux Φ thru normal area of cross-section S of the magnet working space

$$\phi = \iint_S B \cdot dS = const. \qquad (2)$$

Suppose the specimen has enough large length in y-axes direction, so we can neglect boundary effect and for z-x cross-section in the middle of the specimen Fig. 1 we can write

$$\int \Delta B_0(x) \cdot dx = 0, \qquad (3)$$

what means that sum of hatched areas bounded by curve in Fig. 1 with respect to the base value of induction B_0 is zero. If substance surrounding the specimen gives MR signal and we can determine the course of $\Delta B_0(x)$, we also can by use of (1) and known B_0 value identify B_s and χ_s values of the investigated specimen.

2 Numerical modeling

Several numerical tests were carried to verify the method mentioned above. In the 3D model, shown in Fig. 2, the three volumes with alternated magnetic susceptibilities were defined.

Numerical modelling was provided in Ansys 6.1 software. Using FEM the scalar magnetic potential Φ_m was computed by solving of Laplace equation $\Delta\Phi_m = 0$. Boundary conditions were set up as follows: $\Phi_m = const.$ on the surfaces Γ_1, Γ_2 and $\frac{\partial \Phi_m}{\partial n} = 0$ on the surfaces Γ_3, Γ_4.

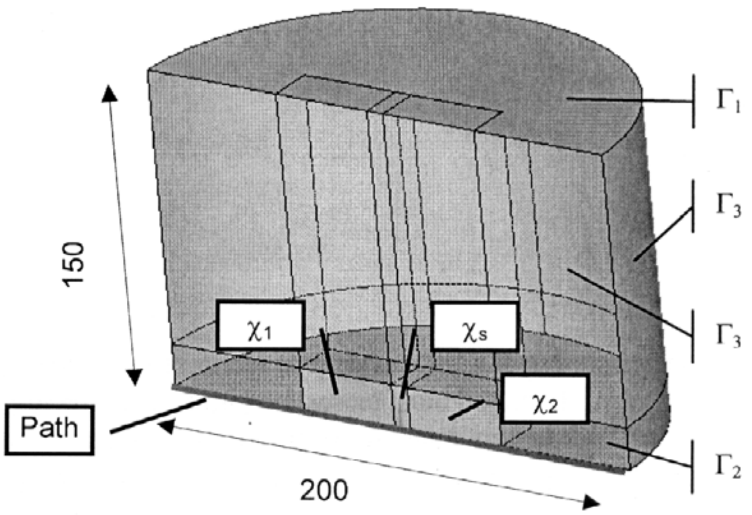

Fig. 2 Used Ansys model, dimensions in mm.

Model was meshed with 31642 nodes and 49775 elements of Solid96 type. Boundary conditions were adjusted so that induction $B_0 = 4{,}700$ T in *z*-axes direction. Module of magnetic induction *B* along the "path" marked in Fig. 2 is depicted in Fig. 3 for two cases A and B.

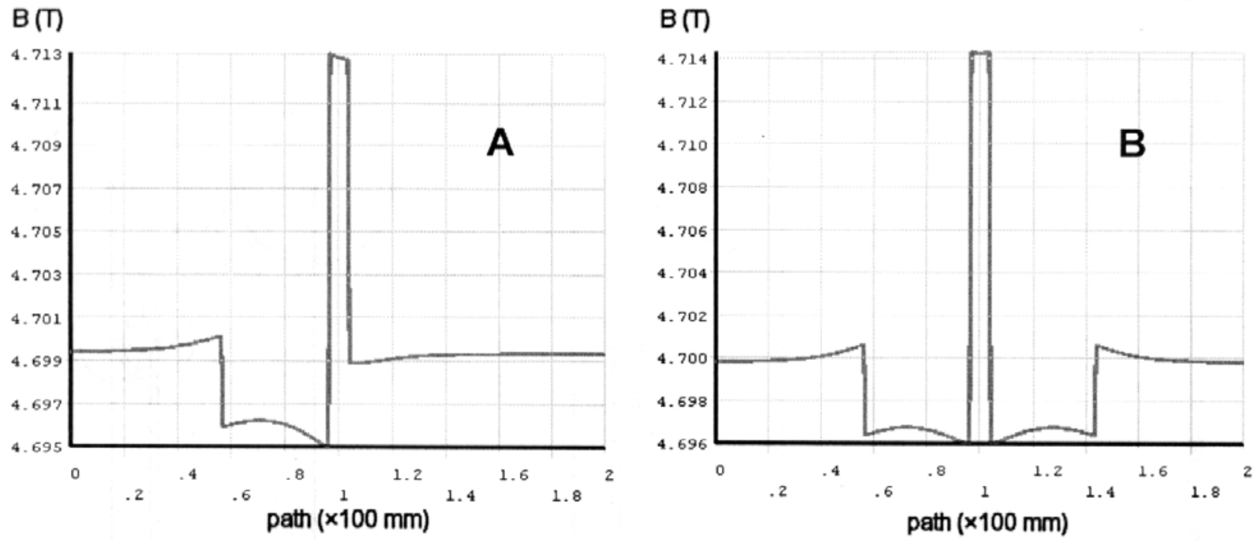

Fig. 3 The course of magnetic induction slony the path marked in Fig. 2
A) $\chi_1 = -9\cdot10^{-4}$, $\chi_s = 3\cdot10^{-3}$, $\chi_2 = 0$ B) $\chi_1 = -9\cdot10^{-4}$, $\chi_s = 3\cdot10^{-3}$, $\chi_2 = -9\cdot10^{-4}$

The data set from graph shown in Fig. 3A was numerically integrated and area bounded by the curve *B* and base level $B_0 = 4.700$ T was evaluated. Founded difference between areas over and below B_0 level was $9.16\cdot10^{-6}$ T.m. Relative deviation 9 % from initial estimation was caused due to numerical error.

3 Experiment

The method was experimentally verified with clay specimen on 200 MHz MR tomograph in ISI AS Brno. Reference substance giving the MR signal was water ($\chi_{H2O} = -9.04\cdot10^{-6}$) filled into cube vessel. The method of Gradient echo with echotime $T_E = 5.56$ ms [3] was used to acquire MR image with contrast corresponding to the magnetic field inhomogeneity. Experiment was treated one time with clay specimen of 7 mm thickness (Fig. 4A) and next only with water reference (Fig. 4B); basic field has magnetic induction $B_0 = 4.7$ T. Position of the specimen is depicted in Fig. 4A. Obtained image with phase-contrast (pre-processed in Marevisi program ISI) was further processed in Matlab. After de-noising by the limitation of signal the spatial deformation evoked by magnetic field inhomogeneity in specimen vicinity was eliminated. Acquired phase images were consequently subtracted to eliminate inhomogeneity of the basic field - Fig. 4C. By properly selected slice of this image we have the curve of phase change $\Delta\Theta$ of the water MR signal in the specimen vicinity, Fig. 4D.

For the used MR technique the phase change $\Delta\Theta = 2\pi$ rad response to magnetic induction change

$$\Delta B_0 = \frac{\Delta\Theta}{\gamma \cdot T_E}, \tag{4}$$

where γ is gyromagnetic ratio of water. In this way we can identify the course of magnetic induction change in water nearby the clay specimen.

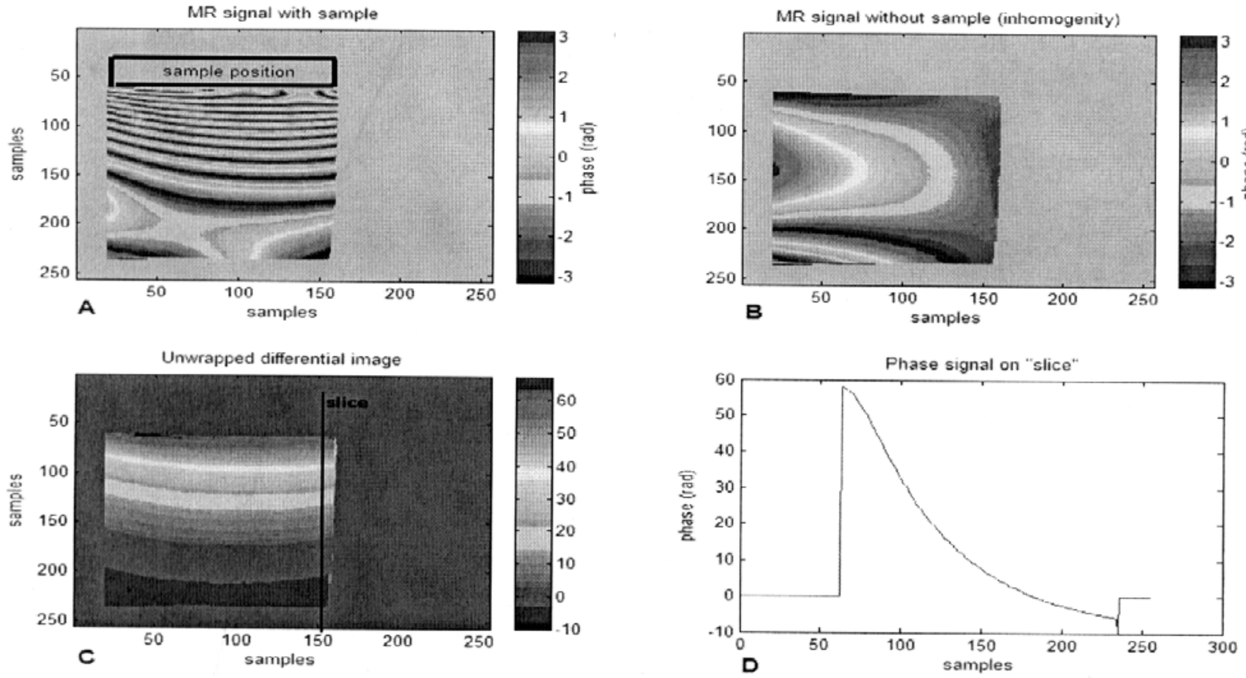

Fig. 4 Images obtain from MR experiment with 7 mm thick clay specimen placed on water filled vessel 40×35 mm. Processed in Matlab.

From known thickness Δx of the specimen and measured area ΔB_0 from (4), the susceptibility of clay specimen was finally calculated

$$\chi_S = \frac{B_S - B_0}{B_0} = \frac{-\int \Delta B_0 \cdot dx}{B_0 \cdot \Delta x} = \frac{2.656 \cdot 10^{-6}}{4.7 \cdot 7 \cdot 10^{-3}} = 8.07 \cdot 10^{-5} \,. \tag{5}$$

4 Conclusion

The method designed for magnetic susceptibility measurement based on MR tomography techniques is simple and enables to determine the magnetic susceptibility of such materials, which give no MR signal. After an optimalization this method can be used for investigation of the materials used in MR tomography as well as of biological tissues affecting quality of MR images.

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