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# CURRENT DENSITY DISTRIBUTION IN MAGNETIC STIMULATION OF THE BRAIN

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**Abstract.** We propose a method to solve the forward problem for analysis of the 3D spatial distribution of the electrical field induced in the head. We used an in-house developed software system including the following: module (A) to calculate magnetic vector potential of the alternating magnetic field, excited by external coils positioned in the air above the head; linking module (B) to introduce the calculated components of the external field as Dirichlet boundary conditions for the boundary regions of the module (C) - 3D realistic finite element model (FEM) of the head. Thus the complication of having to include current-carrying conductors in the FEM was avoided. The simplicity of the proposed method makes it convenient for various applications. For example, an optimization procedure may be considered for improving the efficacy of different external excitation coil configurations and placements.

**Key words.** Magnetic simulation, finite element modeling, current density, electric fields, brain non-homogeneous media.

## Introduction

Noninvasive transcranical electromagnetic stimulation is a routine technique for investigation of the brain function and for treatment of some psychiatric diseases [1, 2]. Improvement of efficacy by optimization of the stimulation system geometry and characteristics and adequate coil placement could be investigated by analysis of the 3D spatial distribution of the electrical field induced within the head.

## Method

The forward problem for evaluation of the induced currents distribution during magnetic stimulation of the brain was solved using in-house developed software modules and models. The module (A) was built using the software package Mathematica 4.0 (Wolfram Research, Inc.). It calculates the magnetic vector potential of the alternating magnetic field, excited by an external source (contours with pulsed current) with certain geometry and characteristics, positioned in the air above the head. Extensive review of the theoretical background concerning this problem was described in [3]. Using linking module (B) (FORTRAN dialect), the calculated components of the external field $A_x, A_y, A_z$ were introduced as Dirichlet boundary conditions for the nodes, which belong to the boundary regions of the designed 3D realistic finite element model (FEM) of the head. The FEM (C), shown in figure 1(a), was constructed using Ansys 5.7 (Ansys, Inc.), simulating the non-homogeneous anatomical structure of the head. We used the head and brain dataset [4] for the FEM reconstruction. Five tissue non-homogenities [5] were incorporated: skin $\rho_{M1} = 20\,\Omega m$ ), bone $\rho_{M2} = 177\,\Omega m$ ), cerebrospinal fluid $\rho_{M3} = 0.7\,\Omega m$ ), gray matter $\rho_{M4} = 2.2\,\Omega m$ ), white matter $\rho_{M5} = 6.8\,\Omega m$ ). The model consisted of 70,214 nodes and 396,285 tetrahedral 'solid 97' elements. The induced current density vector in the homogeneous sub-regions was determined in the FEM by the relation $\vec{J} = -\sigma(\partial\vec{A}/\partial t)$, taking into account the diffusion equation $\nabla^2\vec{A} - \sigma\mu(\partial\vec{A}/\partial t) = 0$ for magnetically homogeneous media $(\mu = const)$ with specific conductivity $\sigma = 1/\rho$.

## Results

The applicability and adequacy of the proposed method was verified with a simple example of particular coil position and geometry – eight-sided coil, positioned horizontally 1 cm over the head. The excitation current for the coil was generated by RLC-contour capacitor discharge $\mathrm{R} = 1.75\Omega$, $\mathrm{L} = 5.146\mu\mathrm{H}$, $\mathrm{C} = 32\mu\mathrm{F}$ ), with $\mathrm{I} = 1000\,\mathrm{A}$ (peak current). The initial current slope $(di(t)/dt)_{t=0}$ was assessed to be 10 $A/s$, at $\mathrm{f} = 10\,\mathrm{kHz}$ approximate equivalent frequency in stationary sinusoidal mode. The magnetic vector-potential distribution on the upper surface of the 3D head model is shown in figure 1(b). The distributions of the induced eddy currents in the skin, the cerebrospinal fluid, the gray and white matter, are represented in figure 2 (a)-(d), respectively.

## Discussion and Conclusion

The relatively complicated introduction of stimulation coil currents in the basic FEM software module is avoided. The solution of the 3D field problem by modeling the non-homogeneous head structure allows simulation of the real current density distribution profile within the brain tissue. This distribution, including the module and the direction of the induced current vector $\vec{J}$, is an important element for improvement of the diagnostic and therapeutic procedures. Focusing the stimulation in deep brain structures could be also studied.

The simplicity of the proposed method makes it applicable to be integrated in an optimization procedure for improving the efficacy of various external excitation coil configurations and placements.

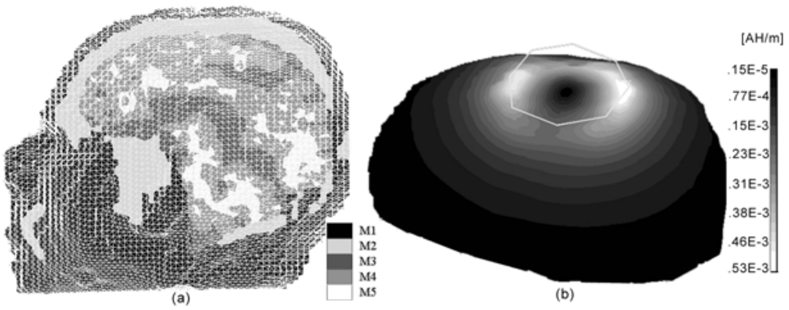


Figure 1. (a) – FEM model of the head, with five tissue structures: M1 - skin, M2 - bone, M3 - cerebrospinal fluid, M4 - gray matter, M5 - white matter; (b) – Excitation contour placement and induced magnetic vector-potential distribution on the upper surface.

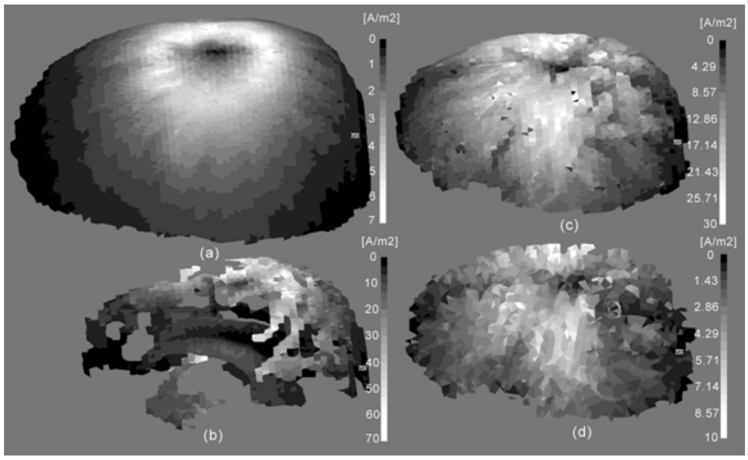


Figure 2. Current density distribution in (a) - the skin, (b) - the cerebrospinal fluid, (c) - the gray matter, (d) – the white matter.

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**РАСПРЕДЕЛЕНИЕ ПЛОТНОСТИ ТОКА ПРИ МАГНИТНОЙ СТИМУЛАЦИИ ГОЛОВНОГО МОЗГА**

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Мы предлагаем метод решения прямой задачи трехмерного пространственного распределения электрического поля, индуктированного в голове. Мы использовали собственную программную систему, содержащую:

модуль (A) - для расчета магнитного вектор-потенциала переменного магнитного поля, возбужденного внешними контурами, расположенными в воздухе выше головы;

связующий модуль (B) - для введения расчетных компонентов внешнего поля в виде предельных условий Дирихле для граничных областей;

модуль (C) - трехмерная модель для расчета методом конечных элементов (МКЕ) индуктированного поля в голове.

Таким образом, преодолены сложности включения токонесущих контуров в МКЕ. Простота предложенного метода делает его удобным для различных приложений. Например, в процедуре оптимизации для определения различных конфигураций контуров возбуждения, с целью улучшения эффективности стимуляции головного мозга.

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