Chapter 13

Integral Equation Formulations and Related Numerical Solution Methods in Some Biomedical Applications of Electromagnetic Fields:

Transcranial Magnetic Stimulation (TMS), Nerve Fiber Stimulation

Dragan Poljak
University of Split, Croatia

Mario Cvetković
University of Split, Croatia

Vicko Dorić
University of Split, Croatia

Ivana Zulim
University of Split, Croatia

Zoran Đogaš
University of Split, Croatia

Maja Rogić Vidaković
University of Split, Croatia

Jens Haueisen
Technical University Ilmenau, Germany

Khalil El Khamlichi Drissi
Blaise Pascal University, France

ABSTRACT

The paper reviews certain integral equation approaches and related numerical methods used in studies of biomedical applications of electromagnetic fields pertaining to transcranial magnetic stimulation (TMS) and nerve fiber stimulation. TMS is analyzed by solving the set of coupled surface integral equations (SIEs), while the numerical solution of governing equations is carried out via Method of Moments (MoM) scheme. A myelinated nerve fiber, stimulated by a current source, is represented by a straight thin wire antenna. The model is based on the corresponding homogeneous Pocklington integro-differential equation solved by means of the Galerkin Bubnov Indirect Boundary Element Method (GB-IBEM). Some illustrative numerical results for the TMS induced fields and intracellular current distribution along the myelinated nerve fiber (active and passive), respectively, are presented in the paper.

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1. INTRODUCTION

While human exposure to radiation from different electromagnetic interference (EMI) sources has initiated a number of questions regarding potential adverse effects, particularly for the brain and eye exposure to high frequency (HF) radiation, some biomedical applications of electromagnetic fields are of particular importance, as well. Thus, the electromagnetic fields are applied in medical diagnostic and for therapy purposes featuring the use of techniques such as: transcranial magnetic stimulation (TMS) (Cvetković & et al., 2015; Garvey & Mall, 2008; Rajapakse & Kirton, 2013, Yamamoto & et al., 2016), percutaneous electrical nerve stimulation (PENS), transcutaneous nerve stimulation (TENS) (Frijnas & ten Kate, 1994; Rattay, 1999; Zulim & et al., 2015), or intraoperational methods such as transcranial electrical stimulation (TES) and direct cortical stimulation (DCS). Transcranial magnetic stimulation (TMS) is a noninvasive and painless technique for excitation or inhibition of brain regions, and in last few decades is an important tool in preoperative neurosurgical diagnostic/evaluation of patients (Picht & et al., 2013; Deletis & et al., 2014; Rogić & et al., 2014). TMS is also used in therapeutic purposes (i.e. depression), and is subject of interest in neurophysiologic research. Various efficiency aspects of TMS stimulation have been primarily stressed out primarily due to differences in relevant stimulation parameters such as pulse waveform, frequency, intensity of treatment, etc. The choice of optimal stimulation intensity is still investigated in many TMS studies.

The coil orientation and positioning appreciably influence the misalignment from the targeted brain region, thus reducing the TMS efficiency, although by using navigated TMS, this problem could be somewhat alleviated. In addition to the stimulation parameters, being adjustable to the requirements of the TMS operator, to a certain extent, the difference in individual brain morphology, due to age, gender or health status and the biological tissue parameters appreciably influence the distribution of the induced fields in the brain. Most of the parameters are obtained under different measurement on ex vivo animal and human tissues, and usually exhibit large variations from their average values. The level of uncertainty in the values of the brain conductivity and permittivity, is even more pronounced at low frequencies.

Modeling and computer simulation of TMS phenomena could be rather useful in determining the exact location of stimulation, in the interpretation of experimental results as well as in designing some more efficient stimulation setups. Realistic TMS models can also provide a more reliable prediction of the distribution of internal fields and currents by taking into account the variability of the various input parameters.

Furthermore, techniques such as PENS, electro-acupuncture, or TENS are widely used in a treatment of neurological disorders. Basically, there are two types of electric potential occurring in the stimulated nerve cells; the electrotonic potential and the action potential. The electrotonic potential existing due to the local changes in the ion conductivity decays along the fiber, and the passive membrane then shows linear nature which satisfies Ohm's law. The action potential is initiated when the threshold potential to which the membrane potential must be depolarized, is achieved. Studies on electrical excitation of nerves, among other aspects involve: nerve excitation using stimulating electrodes, nerve conduction velocity tests or non-invasive stimulation of nerves. The exceptional nervous system complexity, particularly nerve cells as its basis, and widespread neurological disorders and a need for better insight into complex functioning of the nervous system have been continuously motivating researchers (Golomolzina & et al., 2014) to carry out an efficient and accurate nerve fiber modeling. Thus, such computational models of nerve fibers could provide a study of the nerve fiber response to different stimulus waveforms, often used