

Possible Interactions Between Stent and Electromagnetic Field

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Abstract

Over the past years, an increase in the amount of the electromagnetic sources could be observed. Model presented in this article is limited to the impact of low frequency fields generated by the e.g. electrical power lines or magnetic coils in a bone fractures therapy. Particularly, the effect of the magnetic component of the electromagnetic field on stents will be evaluated. The conductivity of human tissues will be investigated. Yielded results will be used to simplify complicated, three-dimensional problem of the current distribution in stent branches, to one-dimensional one. The merits of the paper is proposing, implementing and using for analysis a numerical model of the stent in magnetic field. The impact of frequency and positioning of stent in the magnetic field will be investigated and current distributions found.

Keywords: Magnetotherapy, Stents, Biomedical devices, Power lines

Introduction

In recent decades, a significant increase of electromagnetic field sources can be observed. These sources are characterized by different frequencies, and may impact human bodies in various ways. Sources can be divided into groups, where two are very characteristic and of different destinations. One is the group of sources of industrial origin, and includes especially power lines [1, 2] and base stations of mobile telephony [3]. This group is the subject of wide public interest. The second group are sources used in medicine, associated with the dynamic development of innovative devices and technologies. Model presented in this article is limited to an impact of low frequency fields. The influence of electrical power lines and magnetic coils in therapy of bone fractures will be evaluated. Particularly, the effect of the magnetic component of the electromagnetic field (EMF) on stents – implantable to the human body, usually to ensure the patency of veins and arteries [4], will be investigated. Magnetic Field (MF), during magnetotherapy sessions [5], substantially exceeds the level propounded in state orders and/or recommendations [6, 7]. Every case should be considered separately, according to the specific, individual contraindications.

Materials and Methods

Problems and methods of evaluation possible impact of MF on stents is divided into two groups. At the beginning, the model has to be suited to character of pulsating magnetic field and has to comply to specific material properties of both human tissues and stent itself.

Human tissues in MF

Considering potential influence of MF on stents, tissues adjacent to a stent should be discussed – particularly their electrical conductivity. To separate individual tissues found within the human body, the model from Virtual Family [8] was used, which is based on MRI scans of a 26-year-old woman, 1.63 meters in height (Fig. 1). Leaving aside legs and upper limbs, the model stands out 34 different tissues, organs and structures. Among them, there are: oesophagus, diaphragm, small intestine. Some structure like cartilage or kidney medulla occupy less than 0.5 percent of the entire body volume. Others, in turn, occupy the dominant part of the body, to list in descending order: muscles,

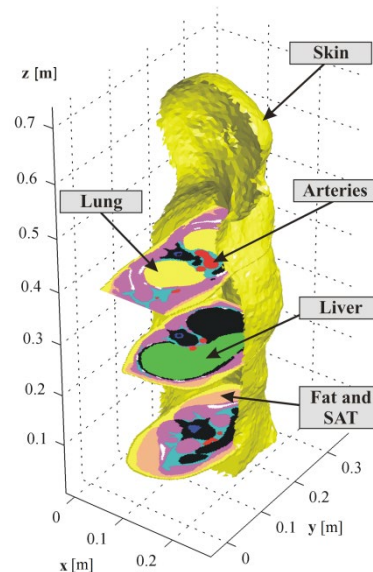


Figure 1. Virtual Human Model. Head and torso with selected cross-sections up to the chest height

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subcutaneous adipose tissue (SAT), lung, fat, connective tissue, skin. Among the listed, no blood vessels are found. However, within the chest, where stents are most often placed, the blood vessels are already a certain percentage of the local volume. In the highlighted sections at heart level, a significant part of the cross-section are: heart lumen and heart muscle. Arteries and veins are an important part of these sections (Fig. 2).

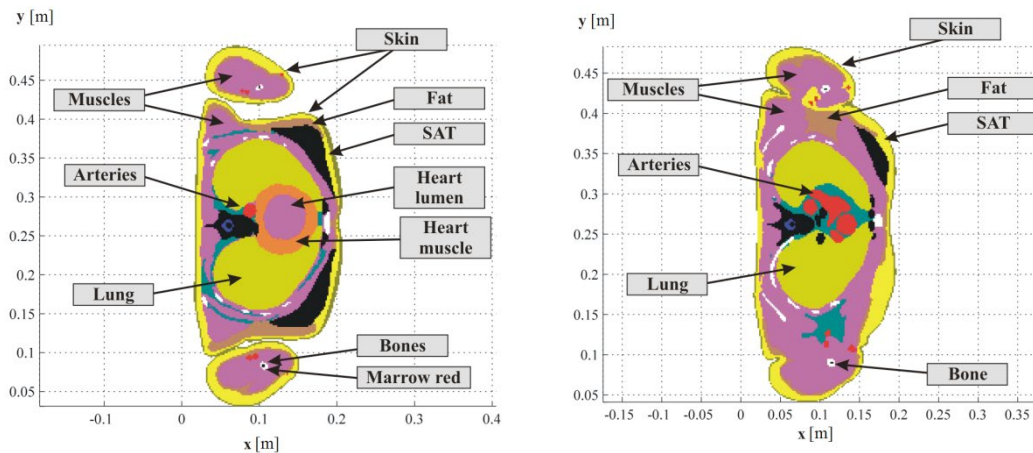


Figure 2. Two cross-sections on heart level. Shifted each other by 40 millimetres

In table 1, electrical conductivities of tissues, according to [9–11] are listed. The important conclusion can be made: conductivity of metal is about 7 orders of magnitude higher than the conductivity of human tissues. Electric field varies in time, as a result of variable MF. Since the current density is proportional to electric field and material conductivity, the current is concentrated in stent branches. It involves radically less computational time, by the possibility of using a peripheral model instead of field based, three-dimensional model. The second benefit of metal-tissue conductivities ratio is the evaluation of risk in term of prospective temperature increase. A relatively small cross-section of stent’s branch (wire) compared to a huge volume of surrounding tissues, results in temperature increase in stent only.

Table 1. Tissues electrical conductivities at extremely low frequency

Tissues/Organs	Percent of introduced volume	Electrical conductivity [S/m]
Muscle	27.4	0.15 – 0.35
SAT	10.3	0.12 – 0.78
Lung	10.2	0.07
Fat	7.7	0.12 – 0.78
Arteries and veins	1.03	0.70

Stent’s current

As was already stated, instead of complicated three-dimensional field calculations model can be simplified. The system must be presented in two different ways. Firstly, using an electric circuit model, represented by the grid of resistive elements and magnetic mutual inductance related to both magnetic field

applicator and branches of the stent wires, magnetic couplings will be modelled as voltage sources controlled by corresponding branch currents. Secondly, stent will be presented as infinitely thin wires located in the space. This approach will be necessary to determine mutual inductances between stents branches and the outer source of magnetic field. The basic method for solving the circuit model is the modified node voltages method and Kirchhoff’s current law [12]. The exemplary stent-like structure interpreted as an electric circuit is presented below (Fig. 3)

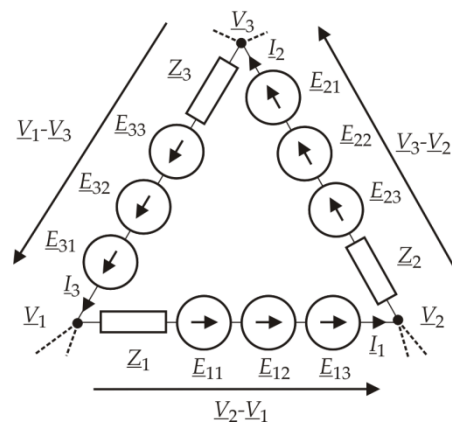


Figure 3. Schematic of a simple stent-like structure

$$\underline{V}_k - \underline{V}_l = \sum_i \underline{E}_{ij} - \underline{Z}_i \underline{I}_i \quad (1)$$

As mentioned before, magnetic coupling is modelled as voltage sources controlled by corresponding branch currents:

$$\underline{E}_{ij} = j\omega M_{ij} \underline{I}_j \quad (2)$$

The paramount operation is to determine the mutual inductances between two wires, as presented by the integral Neumann's formula [13,14].

Results and Discussion

Figure 4a presents investigated stent topologies [15]. In both cases the influence of the field frequency on the maximum current across all branches was investigated (Fig. 5a). Additionally the topology A was investigated for the influence of the rotation angle along the x axis on the maximum branch currents (Fig. 5b). On the fig.4b the distribution of currents of (from left to right) topology A, topology B, topology A rotated by 90° is presented. The field is of the frequency of 50Hz and magnetic flux density of 100mT. The field is applied along the z-axis. In general it can be seen that the bigger the contour penetrated by the magnetic field, the bigger the induced voltage and thus, current.

Conclusions

To summarize the numerical stent model results, the following conclusions were drawn. Because of the low conductivity of human tissues the model can be simplified as proposed. For low frequencies the model is accurate (there is no need to include the phenomena typical for high frequencies – like parasitic capaci-

tances) and the dependency between maximum induced current and frequency is linear. The positioning of the stent according to the MF vectors has tremendous influence on branch currents – the difference of up to 3 times was observed for analysed topology.

Further investigations should be focused on other devices, e.g. coils developed and used in Transcranial Magnetic Therapy – intensively developed subject [16] – due to extremely high magnetic component of EMF.

Analyzing the results, one conclusion can be inferred: magnetic field of levels used during magnetotherapy and of levels reached under power lines seems to be safe for people having stents implanted. It is conclusion set conditionally if frequency doesn't exceed radically 50 Hz and other fields from other frequency bands are negligible.

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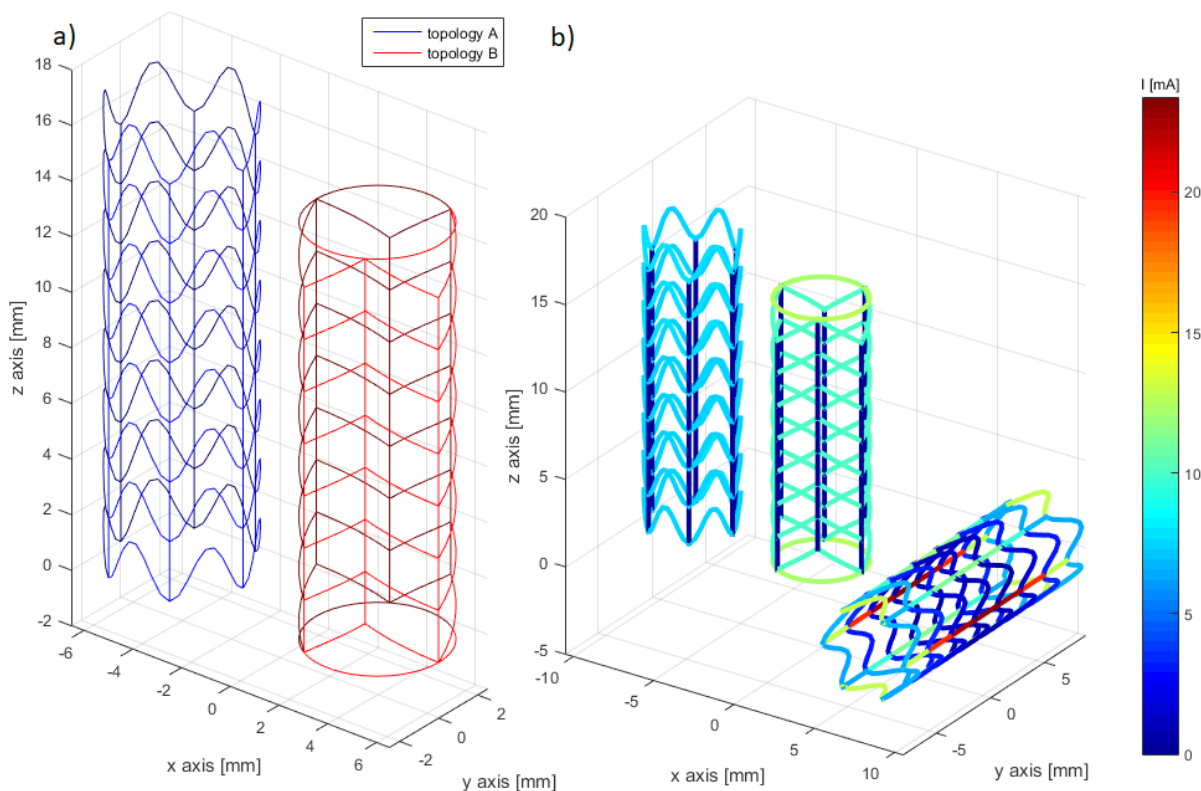


Figure 4. a) Investigated topologies of stent. b) Current distributions for: topology A, topology B, topology A (rotated by 90°), for BRMS=100mT, f=50Hz

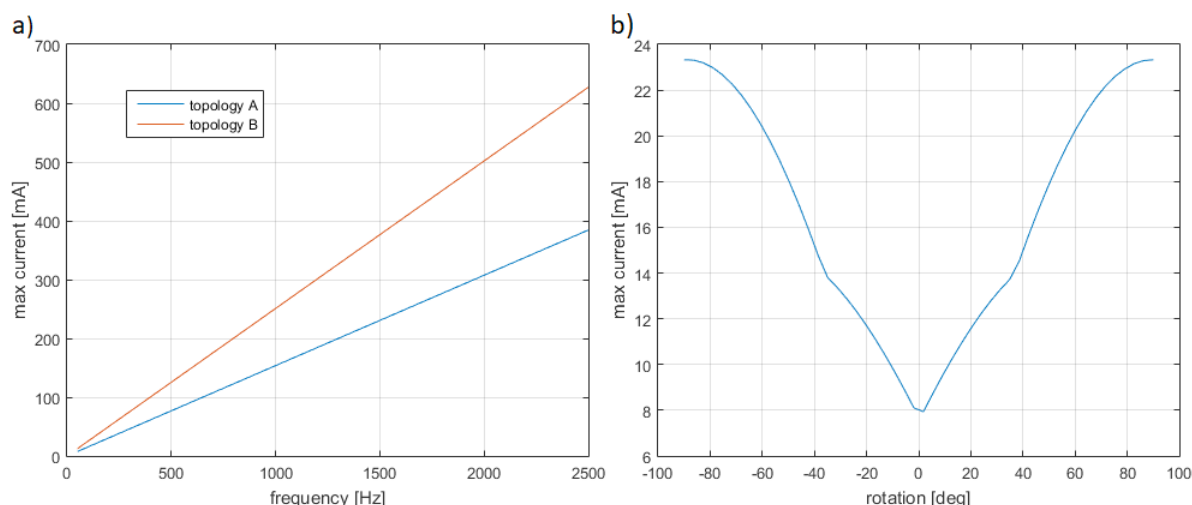


Figure 5. a) Dependency between maximum branch current and field frequency, $B=100\text{mT}$, for both topologies. b) Dependency between maximum branch current and rotation for $BRMS=100\text{mT}$, $f=50\text{Hz}$, for topology A

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