

Computer visualization of space configuration of a low-frequency magnetic field using experimental data in physiotherapy and engineering education

Vladimir Nikolov ¹, Kalin Dimitrov ²

Abstract – In the paper we demonstrate the step-by-step implementation of the application that allows us to calculate and visualize the magnetic field generated by out-of-line coils in arbitrary disposition. The application performs calculations by model equations in a given area. We have used various types of interpolations to reduce calculations. The program system is a useful tool for both the engineers and physicians who can choose an appropriate regime to increase the effectiveness of magnetotherapy treatment.

Keywords – low-frequency, medical applications, magnetic field, physiotherapy.

I. INTRODUCTION

Physiotherapy, and particularly magnetotherapy, is one of widely used treatment methods. Therapeutic action of magnetic field is used when treating a broad spectrum of pathologies. The use of magnetotherapy improves the dynamics of the blood-vascular system and immunity. It should be noted that in numerous researches, no negative side-effects when using magnetotherapy were detected. The magnetotherapy method using low frequency field is in a good accordance with traditional medicine means.

The impact of the low-frequency magnetic field with low intensity may be considered as low and ultralow doses of radiation. The mechanism of ultralow doses effect is rather complex and at the moment there are no complete theoretical results. One of the known models explaining this phenomenon was proposed by L.N. Gall [4].

We have to solve the so-called inverse problem: given results of system functioning (or measurements) to analyze the system behavior, where “to analyze” means to obtain some characteristics and interpret them. To analyze the results of ultralow effects one can use bio tests (for example blood analysis, thermal imager data). It is the analysis of digital images that opens up possibilities to apply mathematical and computer methods to obtain comparative characteristics and classification signs of the images [2].

The axis of these coils can be parallel or not parallel. Usually a system for magneto-therapy contains one microprocessor unit which, according to the special software,

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can switch different coils: define the number of “active” coils and their space dispositions so that they would be different in every moment during the process of therapy.

II. THEORY

1. Presentation for courses of bioengineering on the influence of a low-frequency magnetic field

In most cases, in practice the required space configuration of the magnetic field is created by means of one or more air coils, which are appropriately arranged in the space. For a coil there is a linear relationship between the magnetic flux density of the excited magnetic field and current in the coils. It is assumed that the environment, in which the space-time configuration of the magnetic field is considered, is linear. The resulting field is the superposition of the fields of the individual coils, which forms a more complex time-spaced magnetic field. We suppose that the environment around the coils is homogeneous and the relative magnetic permeability is constant, i.e. $\mu_0(x, y, z, t) = const$

The results of mathematical, computer and experimental studies of the spatial configuration of the magnetic field excited by a cylindrical coil, one of the most common structures of the low-frequency excitation magnetic field, are described in [3]. Visualization was performed in the plane orthogonal to the base plane of the coil. Numerical experiments were also performed for two coaxial coils. In what follows we use Fig.1 [11] illustrating a base model in the

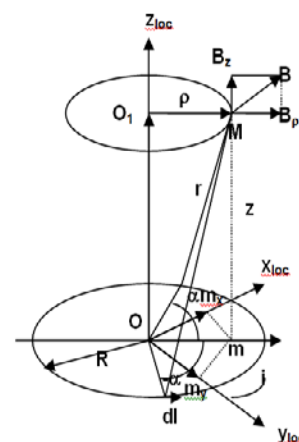


Fig.1 Local cylindrical and Cartesian coordinate systems of a coil

study of the spatial configuration of the magnetic field excited by a cylindrical coil.

2. Mathematical model for the base configuration

Every coil has its own coordinate system — a local cylindrical one. We denote this system by LC (with coordinates $\rho, z = z_{LC}$) and introduce the following notations:

- i — current value in a single current loop;
- R — radius of the current loop;
- O — the origin of the cylindrical coordinate system of the coil;
- M — an arbitrary point in which the magnetic induction is calculated;
- m — the projection of the point M in the plane of current loop;
- O_1 — the center of the circle lying in a plane parallel to the plane of the current loop and passing through the point M ;
- ρ — radius of the circle lying in the plane parallel to the plane of the current loop and passing through M ;
- dl — an elemental segment of the current loop;
- 2α — the central angle corresponding two symmetrical elemental segments;
- r — the distance from any of endpoints of $2dl$ segment to the point M .

It should be noted that on Fig.1 a current loop coincides with the base plane of the coil.

The vector of magnetic induction B in the point M has two components which can be calculated as the following [11]:

$$B_\rho = \frac{\mu_0 i}{2\pi} \frac{z}{\rho \sqrt{(R+\rho)^2 + z^2}} \left(\frac{R^2 + \rho^2 + z^2}{(R-\rho)^2 + z^2} L - K \right),$$

$$B_{z,LC} = \frac{\mu_0 i}{2\pi} \frac{1}{\sqrt{(R+\rho)^2 + z^2}} \left(\frac{R^2 - \rho^2 - z^2}{(R-\rho)^2 + z^2} L + K \right), \quad (1)$$

where K and L are complete elliptic integrals of 1 and 2 sort as functions of k and

$$k^2 = \frac{4\rho R}{(R+\rho)^2 + z^2}.$$

An example of visualization of magnetic induction for one coil is given below.

3 Model for out-of-line coils

The real problem is to calculate and visualize in a 3D magnetic field (in a given space area) generated by several coils, which are in an arbitrary disposition [1, 5, 6].

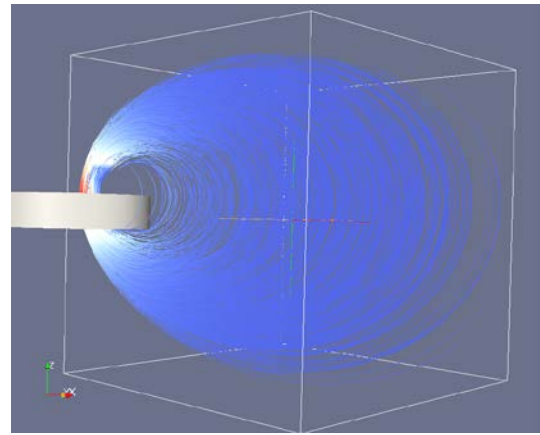


Fig.2. 3D visualization of the magnetic field for one coil. The given space area is bounded by parallelepiped.

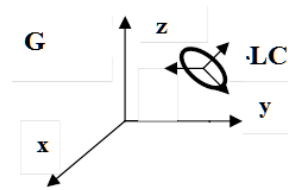


Fig.3 Global coordinate system (G) and local cylindrical system (LC) of a coil.

To do it, for a coil we consider a global coordinate system (G) with the origin O_G , a local rectangular coordinate system (LR) with the origin O_L and local cylindrical coordinate system of the coil. The calculation of the total magnetic field for several coils is performed in the area bounded by a rectangular parallelepiped. The area is divided into cells with the same size, which are also rectangular parallelepipeds. The calculation is performed in the nodes of the constructed mesh. The origin of G is supposed to be in the left bottom angle of the area.

Coils may be located both inside the area and outside it. Magnetic field values are calculated only inside the area. The direction of the coil axis is defined in accordance with the direction of current.

For every coil we use an auxiliary local rectangular coordinate system (LR) to reduce calculations, because the transition from one Cartesian coordinate system to another is coordinate shift and multiplication on a transition matrix. In this way for every coil the transition and inverse transition matrix can be calculated only once.

So, for given coordinates of a coil in G the sequence of calculation is the following:

1. $G \rightarrow LR$
2. $LR \rightarrow LC$, calculations by (1)
3. $LC \rightarrow LR$
4. $LR \rightarrow G$.

The magnetic induction should be calculated in many points around the coils. The number of these points depends on the resolution of computer images and the space configuration of the field of magnetic induction. It is clear that the increasing of resolution of computer images would need increasing of number of points. To optimize the running time, a variant of the algorithm using parallel calculations has been implemented: for every coil, the calculation of magnetic induction has been performed in a separate flow. The results of experiments are described in [1] and show that such an optimization leads to significant decreasing of the running time.

An example of visualization of results of calculations for 3 given out-of-line coils is shown below (fig.4).

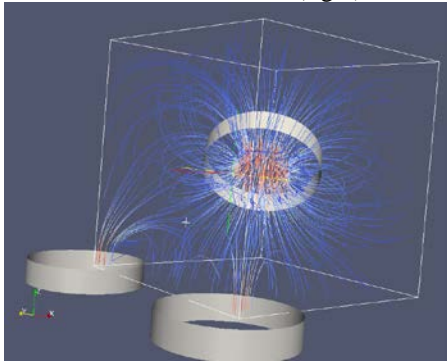


Fig.4. Magnetic field generated by 3 out-of-line coils. Parallelepiped shows the area where magnetic induction is calculated.

4 Interpolation as a method for reducing running time

The described algorithm of calculation of magnetic induction may be optimized by combining calculation in some base points of the area with interpolation in the rest of the points.

In [7, 8] we used values obtained by calculations as the base ones. We consider the following methods: 1) 3-dimensional linear interpolation, 2) one-dimensional quadratic Lagrange interpolation and 3) coordinate-wise cubic spline. Numerical experiments show that any of these methods reduces the running time considerably and does not lead to a loss of accuracy. For example, the results of experiments given in [7] show that the 3D linear interpolation is more effective than the 1D Lagrange interpolation and it decreases the running time nearly 9 times for the number of nodes 2.5×10^6 .

5 Interpolation by using experimental data

For a special magnetotherapy device (magnet bed, fig.5) the solution the problem of magnetic field interpolation by using experimental data was presented in [9]. In such a configuration at any moment only one pair of coils is active. In the process of the system functioning every pair of coils is active by turns, and a movement of magnetic field occurs.

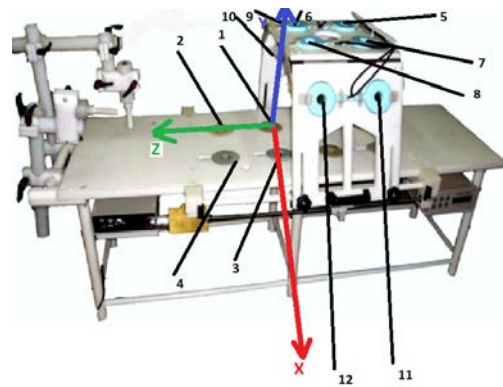


Fig. 5. Magnet bed, the coils and the coordinate system XYZ

For every given pair of coils the magnetic field was measured in the centers of coils and the middle of the interval between the centers. The measurement of magnetic induction is on the basis of a special algorithm implemented in a microprocessor. The values of magnetic induction are scalars (i.e. the module of the induction was measured). The interpolation of magnetic induction value in a given segment connecting centers of the coils (pair) and visualization of results have been performed. The order of the choice of pairs of coils is defined by a data table which also contains the coordinates of every measurement point.

We use one-dimensional quadratic Lagrange interpolation. As the electromagnetic induction value continuously depends on the point position, for any given pair of coils we at first calculate the induction value in all the points of the segment by a step of 1 mm (base points). Then we show the obtained distribution of the induction values in a special area in the interface in accordance with the following scheme (B denotes the induction value): $B \in [0, a]$ –blue, $B \in [a, b]$ –lightblue, $B \in [b, c]$ –yellow, $B \in [c, d]$ –orange, $B > d$ – red.

The user can choose the values of parameters a, b, c, d defining the color distribution. In this implementation the segment $[0, d]$ is partitioned into 5 equal parts, where d is the maximal value of induction in the base points. Thus the diagram of color distribution is in agreement with the position of the point the user chooses as the interpolation one (fig.6).

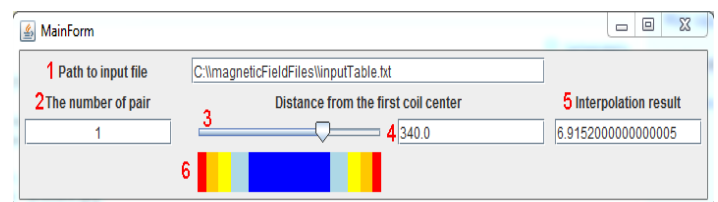


Fig.6. User interface for interpolation by experimental data.

The user gives the path to the input file (in .txt format) that contains experimental data. In field 2 one can choose a pair of coils (row number in the data table). Elements 3 and 4 are for input of the interpolation point. In 3 we select a point by using a slider, and when using 4 we should point a distance from the left end of the segment to the interpolation point. When changing data in 3 or 4 the result of interpolation is shown in 5 in real time. Note that the color distribution diagram is

drawn in element 6 immediately after the choice of coils; in doing so, the position of the slider corresponds the diagram.

III. RESULTS

For the visualization of calculation results, the Para view [10] package was used. One can compare the magnetic field intensity for various values of the current. As the magnetic induction linearly depends on the current (see (1)), we see that the intensity of the magnetic field in an area of interest increases gradually. The following pictures show the visualization of the field when we change the current from 0.5A to 2.5A (figs.7,8,9). It should be noted that Para view has a wide spectrum for transforming of obtained images, in particular it allows showing coordinates of a given point and the induction value.

IV. CONCLUSION

The paper is devoted to the presentation of methods of investigation of the influence of a low-frequency magnetic field on the human body. Usually a system for magnetotherapy contains one microprocessor unit which can switch different coils according to the special software during the process of therapy.

The visualization of the obtained magnetic field is a base for the engineering explanation of the process of therapy and for engineers designing magneto-therapy systems.

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REFERENCES

- [1] N. Ampilova, D. Dimitrov, B.Kudrin. Mathematical modeling of low frequency magnetic field in systems for magnetotherapy .Proc. 8 Int. Conf. CEMA13, 17-19 Oct. 2013, Sofia, Bulgaria. p.48-51.
- [2] N. Ampilova, I. Soloviev, E. Gurevich. Computer Methods of Investigation of Ultralow Doses Effects in Biomedical Applications. Proceedings of the International Conference on Biomedical Engineering and Systems, Prague, Czech Republic, August 14-15, 2014. p.67-1-67-7. Available at http://avestia.com/ICBES2014_Proceedings/papers/67.pdf. ISBN : 978-1-927877-08-1.
- [3] D. Dimitrov. Medical Systems for Influence of Electromagnetic Field on the Human Body (in Bulgarian), Sophia, Technical University, 2008.
- [4] L.N. Gall. Physical principles of functioning of a live organism matter. SPb, 2014 (in Russian)
- [5] B.Kudrin, A.Dimitrov. An algorithm for visualization of low-frequency magnetic signals in systems for magnetotherapy. Proc. 8 Int. Conf. CEMA13, 17-19 Oct. 2013, Sofia, Bulgaria. p.31-35.
- [6] B.Kudrin, A.Dimitrov. Computer visualization of low-frequency magnetic signals in systems for magnetotherapy with variable parameters. Proc. 8 Int. Conf. CEMA13, 17-19 Oct. 2013, Sofia, Bulgaria. p.36-39.
- [7] B.Kudrin, I.Soloviev On interpolation methods of low frequency magnetic field in systems for magnetotherapy. Proc. 9 Int. Conf. CEMA14, 16-18 Oct. 2014, Sofia, Bulgaria. p.154-157.
- [8] B.Kudrin,V.Nikolov. Algorithms of interpolation and visualization of low frequency magnetic field using experimental data. Proc. 9 Int. Conf. CEMA14, 16-18 Oct. 2014, Sofia, Bulgaria. p.43-45.
- [9] B.Kudrin,V.Nikolov. On the mathematical model of interpolation of low frequency magnetic field using experimental data. Proc. 9 Int. Conf. CEMA14, 16-18 Oct. 2014, Sofia, Bulgaria. p.80-84.
- [10] ParaView Tutorial - <http://paraview.org/>
- [11] K.Brandiski, G.Georgiev, V.Mladenov, R.Stancheva Theoretical Electrical Sofia, Bulgaria

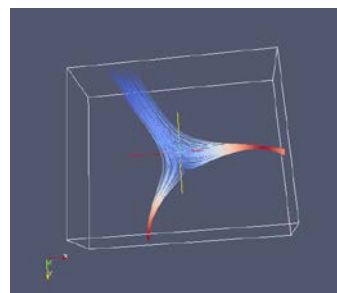


Fig.7 I=0.5A

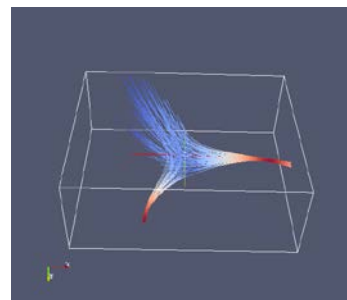


Fig.8 I=1A

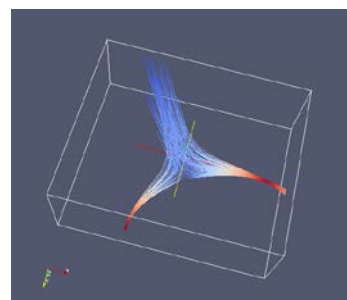


Fig.9 I=2A