

Visualization of a Low Frequency Magnetic Field, generated by Girdle Coil in Magnetotherapy

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Introduction

It's well known that the space configuration of low frequency magnetic field in the patient's area is very important in the process of magnetotherapy. Therefore the precise calculations of low frequency magnetic field as well as an easy-to-understand visualization of field distribution over the patient's area are of great importance for the reliability and predictability in the process of experimental measurement of magnetic induction of the constructed electromagnetic device.

An electromagnetic device (girdle coil) has been constructed for use as a therapeutic tool in magnetotherapy. The presented software decision exposes a low frequency magnetic field solver that allows evaluating the field strength throughout the volume influenced by the coil. A developed visualization tool provides both the histogram and a colored map of a low frequency magnetic field distribution that demonstrates the effectiveness of this coil with big sizes (Fig. 1a)

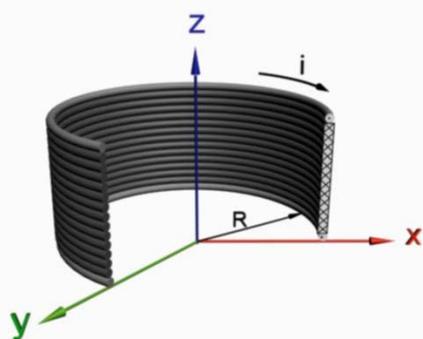


Fig. 1a. Girdle coil for magnetotherapy

Design Stage

The evaluation of the low frequency magnetic field distribution and its visualization is a difficult task and usually requires a lot of time depend on the environment geometry and applied visualization techniques [1,2]. Additionally fields are often represented as large sums of

field contributions of individual current turns. The calculation of field in space (off-axis form) requires field formulas that involve elliptic integrals or other complicated expressions that have to be approximated somehow [3,4].

In the particular case the task is to evaluate the values of magnetic field induction at each point of the area of space enclosed into the coil with sizes according to the above Fig. 1. For the axial symmetry of the generated low frequency magnetic field the calculations can be performed only for the section perpendicular to the coil plain and going through the center of the coil.

To achieve better effectiveness of the calculations as well as to decrease the memory necessary to store the results, the values of magnetic induction are evaluated only for one half of this section (right half).

The same restriction is applied to the visualization of filed distribution be default. But the user can obtain the full image – low frequency magnetic field distribution in all 2D area without great increasing of the execution time. Magnetic induction \mathbf{B} is stored together with its two ingredients – radial component \mathbf{B}_ρ and axial component \mathbf{B}_z for a future use to obtain vector form of accumulated field data. The magnetic induction \mathbf{B} generated by a separate turn with radius R at an arbitrary point M in the girdle coil (Fig. 1b) is calculated using a method based on magnetic vector-potential [5,6].

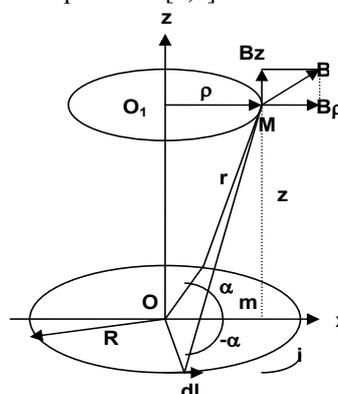


Fig. 1b. Calculation of magnetic induction around the girdle coil for magnetotherapy

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

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

$$B = \sqrt{B_{\rho}^2 + B_z^2}, \quad (3)$$

where K and L are full elliptical integrals; R is the radius of the girdle coil (Fig. 1b); ρ is the radius of an imaginary turn of the arbitrary point M (Fig. 1b); z is the vertical axis (Fig. 1b); i is the value of current in the girdle coil; μ_0 is the absolute magnetic permeability.

The key equations used to calculate the two components B_{ρ} and B_z of magnetic induction B in an arbitrary point in the girdle coil are (1), (2) and (3): For calculations optimization the area of plain that is enclosed (influenced) into the coil is divided into a number of vertical lines. Distance between the vertical lines determines the level of detail of the magnetic field image. This distance is a parameter, named **offsetHor** and is entered interactively by the user. The number of vertical lines **nVertLines** is calculated through dividing the radius of the coil (**RCoil**) by the **offsetHor**. Each vertical line is defined as a collection of points at which the magnetic induction values have to be calculated. The distance between points that belong to each vertical line can be specified interactively by the user and determines the precision of field calculation as well as the quality (level-of-detail) of the field image; this distance is a parameter named **offsetVert**. The algorithm for evaluating the magnetic field for the planar area of spaced influenced of a field can be seen in Fig. 2.

The field is visualized as a histogram [2,3]. The histogram consists of a number of boxes with the same gray color but with different size in X-axis that is proportional for each box to the value of magnetic induction B calculated at the low left corner of the box. The proportion is formed as:

$$((B - \min B) \cdot \text{coef}) \cdot xScale, \quad (4)$$

converted to integer data type, where: $\text{coef} = 1.0e+9$. $xScale$ is calculated on-fly as

$$xScale = \text{offsetHor} / (\max B - \min B). \quad (5)$$

For the coil consists of a lot of turns the magnetic induction B into each point of each vertical line have to be calculated as a superposition of partial magnetic inductions generated by all the ingredient turns. For their evaluation the values of ρ and z parameters are required. Value of ρ parameter does not change for the particular vertical line; between the consequent vertical lines this parameter increases by value of **offsetHor** parameter, specified by the user. The main task is to determine the value of distance on z axis (**zDist** parameter) from the selected point to each turn in the coil. For this purpose the special algorithm is created. First step is to determine the sequential number of the turn to which the selected point belongs (*current turn*) and the offset of the selected point into *current turn* the corresponding **zDist**-value:

$$\text{numTurn} = \text{selectedPoint} / d\text{Turn}$$

$$\text{offsetIntoTurn} = \text{selectedPoint} \% d\text{Turn}.$$

Then for the *current turn* the value of **zDist** parameter is evaluated as:

$$\text{zDist} = \text{offsetIntoTurn} - r\text{Turn}.$$

Next for each turn that occupies position into the coil over the *current turn* the value of **zDist** parameter is calculated as:

$$\text{for}(k = \text{numTurn} + 1; k < h\text{Coil}/d\text{Turn}; k++) \\ \{ \text{zDist} = k * 10 + r\text{Turn} - \text{selectedPoint}; \dots \}.$$

At last for each turn from turn $N 0$ up to *current turn* (without *current turn*) the value of **zDist** parameter is calculated as:

$$\text{for}(k = 0; k < \text{numTurn}; k++) \\ \{ \text{zDist} = \text{selectedPoint} - k * 10 - r\text{Turn} \dots \}.$$

For each calculated **zDist** the corresponding value of magnetic induction is evaluated and added to the final value for the *selected point*. Algorithm for magnetic induction superposition for a *selected point* is shown in Fig. 3.

Implementation

The magnetic induction value can be calculated at each point in the space using the **BEveryWhere()** method exposed by the **FieldCalc** class.

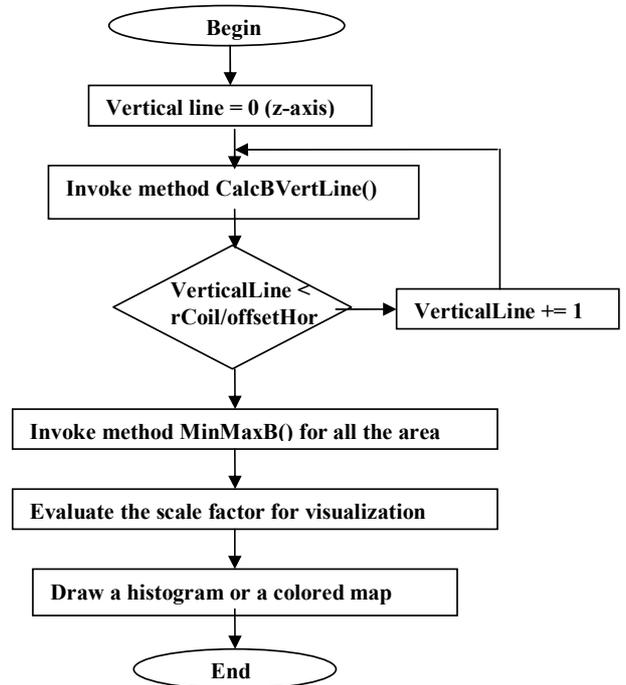


Fig. 2. Algorithm for magnetic field evaluation

The field distribution (histogram) is visualized into a Windows Forms control. For this **Panel** control a graphics object is created and a transform is applied as shown in Fig 4. The goal of the transform is to move the center of the coordinate system at the low end center of the coil in order to decrease the memory needed to store the program's

data. To perform the transformation needed a transformation matrix of the following form is created:

$$gr.Transform = new Matrix(1,0,0,1,panell.size.Width/2,(panell.Size.Height-1)) .$$

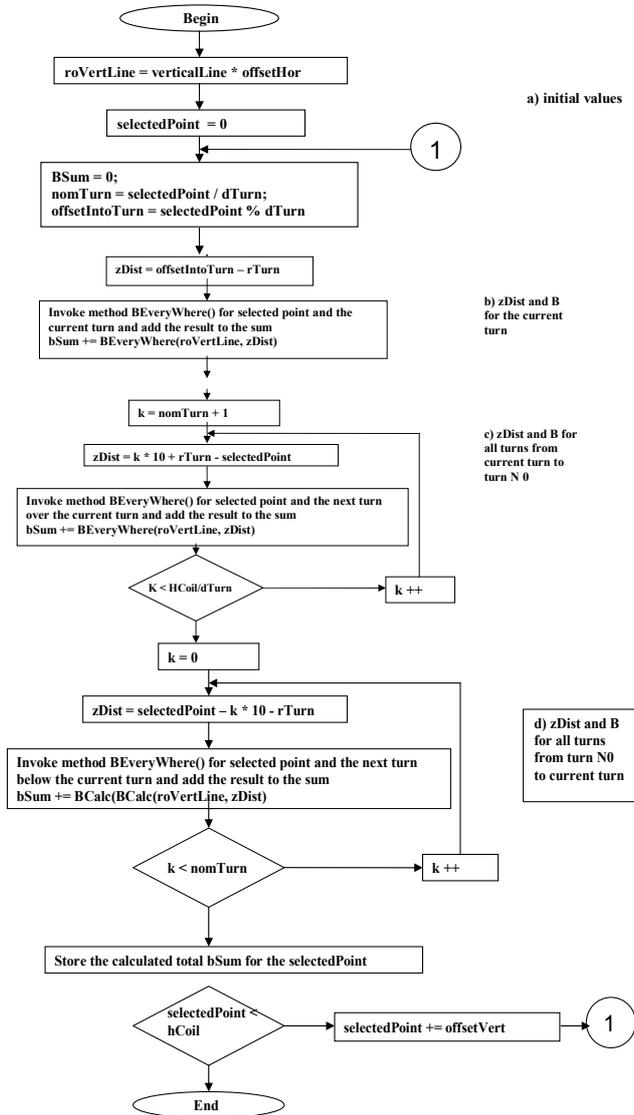


Fig. 3. Algorithm for calculating the final value of magnetic induction for selected point of an arbitrary vertical line

After the transform there is no more need to store the (x,y)-coordinate pairs of the points; x-coordinate is equal to the sequential number of vertical line and y-coordinate is calculated on-fly by adding *offsetVert* parameter value. The main data structure of the program is the *bList* collection each element of which is a separate collection as shown in Fig. 5.

The number of elements of *bList* collection corresponds to the number of vertical lines. The collection for each vertical line contains elements that are objects of *MemberB* class; number of elements corresponds to the number of points into which the magnetic induction has to be calculated and stored. *MemberB* class is a simple type that consists of two private fields to store the magnetic induction calculated and the corresponding color, a constructor and properties.

Experimental results

The presented article illustrates one approach to calculate and visualize a low frequency magnetic field distribution in 2D. The field is used for therapeutic purposes in magnetotherapy and is generated by a coil with a radius R into the range 200mm – 300mm. The coil consists of a number of current turns with the radius 1 mm.

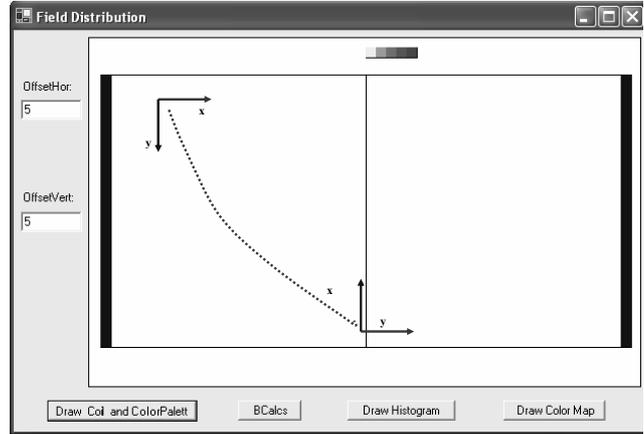


Fig. 4. The transformation applied to the Panel control

For field calculation are adopted formulas and method described in [1]. These formulas allow the magnetic induction *B* to be evaluated at an arbitrary point. Two algorithms are created that concern:

- The generation of points of interest (points at which the magnetic induction will be evaluated) by subdividing the area influenced by the field;
- The superposition of local fields generated by the individual turns to obtain the sum value of *B* at each point selected.

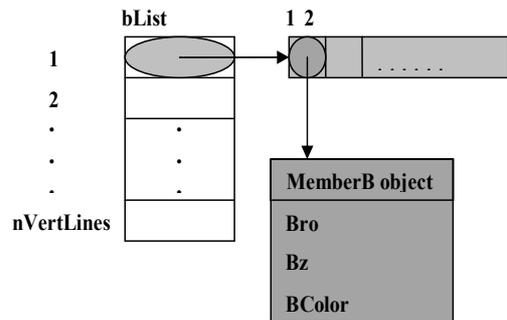


Fig. 5. Data storage retrieval

Additionally, the second algorithm presented is designed in such a way to allow regulation of the precision, expressed as pixels per turn, for the field calculation and visualization.

The algorithms are implemented in C# programming language using .NET environment. Field calculations are performed only for the right half of the section, perpendicular to the coil plane, which passes through the Z-axis. The results of field calculation (magnetic induction ingredients and a magnitude) are stored into a “collection of collections” data structure as shown in Fig. 5.

Results of field calculations are visualized as a histogram (Fig. 6) with a level of detail specified by the user.

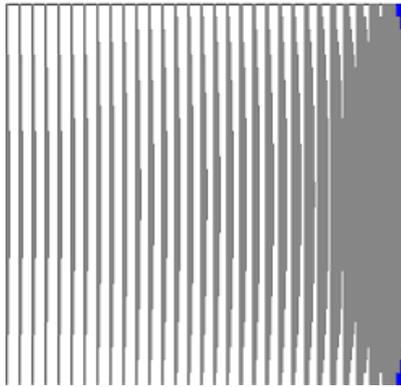


Fig. 6. Histogram of value of magnetic induction in the right half of girdle coil

Conclusions and future work

Visualization and calculation of the space configuration of low frequency magnetic field in the patient's area is of great importance as preliminary result not only for the process of experimental measurement of the value of magnetic induction in magnetotherapy, but for evaluation of the effectiveness of developed electromagnetic devices, also. Additionally these two processes can be used to assist the design of such devices. Into the particular case of therapeutic magnetic field the calculation and visualization are intended to allow the user

visually evaluate the strength of the field into the influenced area of space.

The presented algorithms are developed in such a way to allow performing of more common evaluations in cases of field generated of multiple coils along the same z-axis.

The data structures developed for geometric and calculated data representation are designed to store both radial $B\rho$ and axial Bz components of magnetic induction for future visualization of a vector field in 2D and 3D. At the implementation stage the data structures are chosen in such a way to allow data to be shared between different applications and transferred through Internet.

References

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4. **Todorova V.** 3D Computer Simulation of the Static Magnetic Field Distribution over the Virtual Human Body // *Information Technologies and Control*. ISSN 1312-2622. – 2005.
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D. Tz. Dimitrov. Visualization of a Low Frequency Magnetic Field, generated by Girdle Coil in Magnetotherapy // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 6(78). – P. 57–60.

The goal is to present algorithms for calculation and visualization of a low frequency magnetic field, generated by a girdle coil, which is used in magnetotherapy. The algorithms concern the selection of points in the patient's area and the superposition of the magnetic induction induced in each point from all the turns of the coil. Algorithms are implemented using C# programming language and .NET environment. The implementation illustrates an approach to minimize the memory needed to represent field's data and to separate the calculations and the visualization of the field into relatively independent modules. The implemented user interface allows to perform some measurements – to obtain values of magnetic induction at specified points of the patient's area or to obtain average value of magnetic induction in the selected sub-area. Ill. 6, bibl. 5 (in Lithuanian; summaries in English, Russian and Lithuanian).

Д. Ц. Димитров. Визуализация низкочастотного магнитного поля цилиндрической катушки в магнитотерапии // Электроника и электротехника. – Каунас: Технология, 2007. – № 6(78). – С. 57–60.

Цель – представить алгоритм для вычисления и визуализации низкочастотного магнитного поля цилиндрической катушки, которое используется в магнитотерапии. При помощи предлагаемого алгоритма можно обеспечить вычисление стройности магнитной индукции в произвольном точке области пациента. Предлагаемый алгоритм реализован при помощи программного языка C# и платформы NET. Применение предлагаемого метода иллюстрирует возможности минимизировать применяемую память во время вычислений. Применение потребительского интерфейса позволяет вычислить стройность магнитной индукции в каждой точке области пациента и получить интервал изменений стройности магнитной индукции. Ил. 6, библи. 5 (на литовском языке; рефераты на английском, русском и литовском яз.).

D. Tz. Dimitrov. Magnetoterapijoje naudojamos žiedinės apvijos generuojamo žemojo dažnio magnetinio lauko vizualizavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 6(78). – P. 57–60.

Tikslas – pateikti algoritmus, taikomus magnetoterapijoje naudojamos žiedinės apvijos sukuriama žemojo dažnio magnetinio lauko skaičiuoti ir vizualizuoti. Algoritmas apima taškų parinkimą paciento zonoje ir kiekvienos vijos kuriamo lauko magnetinės indukcijos superpoziciją kiekviename erdvės taške. Algoritmas praktiškai sukurtas naudojant programavimo kalbą C# ir .NET programavimo aplinką. Parodyta galimybė minimizuoti lauko informacijai atvaizduoti reikalingą atminties kiekį ir atskirti lauko skaičiavimo ir vizualizavimo procedūras į atskirus programos modulius. Naudojantis sukurtą vartotojo sąsaja, galima apskaičiuoti magnetinės indukcijos vertes pasirinktuose paciento zonos taškuose arba apskaičiuoti vidutinę magnetinės indukcijos vertę pasirinktoje konkrečioje zonoje. Il. 6, bibl. 5 (lietuvių kalba; santraukos anglų, rusų ir lietuvių k.).