

# AN ALGORITHM FOR VISUALIZATION OF LOW-FREQUENCY MAGNETIC SIGNALS IN SYSTEMS FOR MAGNETOTHERAPY

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## Abstract

*It's well known that mathematical description of magnetic field created by several non-coaxial coils is enough complicated. Therefore the calculation of magnetic induction of this magnetic field in different points is also complicated. Because of that digital methods for calculation of magnetic induction around the coils would be more user friendly. An algorithm for simulation and visualization of magnetic induction in different points of magnetic field generated by several non-coaxial coils is described in the paper. The package Para View has been used for computer calculation of magnetic induction as one convenient software. Some results of numerical experiments and the optimization by using parallel computations are given in the paper, also.*

## 1. INTRODUCTION

Visualisation of space temporal configuration of the vectors of magnetic induction around and in the human body is very important requirement for obtaining of good results in magneto-therapy. This visualisation can be obtained using one preliminary mathematical description of space temporal configuration of the vectors of magnetic induction around and in the human body.

As first step we should use mathematical description of the vectors of magnetic induction around and in the human body in the case of magnetic field created by single coil. Then we use mathematical description of the vectors of magnetic induction around and in the human body in the case of magnetic field created by several coils with parallel axis (or/and non-parallel axis).

The basic mathematical formulas (1) and (2) for calculation of components of magnetic induction of single coil in cylindrical coordinate system are well known [1], but they are too complicated:

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

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

Here

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

$$k^2 = \frac{4\rho R}{(R+\rho)^2 + z^2} \quad (3)$$

*i* - current value in the present single current loop;

*R* - radius of the current loop;

$\mu_r(x, y, z, t) = \text{const}$  is relative magnetic permeability;

$\rho$  - radius of the circle lying in a plane;

*z* – this is *z*-coordinate of the point

As the second step we should use mathematical description of the vectors of magnetic induction around and in the human body in the case of magnetic field created by several coils. As the coordinates of any point **M** both in GCS (global coordinate system) and LCCS(local coordinate system) are uniquely determined, it is possible to choose an arbitrarily LRCS. The same coordinates **ρ** and **z** of **M** can be used for the transition chain GCS → LRCS → LCCS and in the case of vice versa, for the chain LCCS → LRCS → GCS the same coordinates in GCS can be obtained.

It's should to be considered that such a LRCS results in the reducing of calculations because the transition from one Cartesian coordinate system to another is coordinate shift and multiplication on a fixed transition matrix. In this way the transition and inverse transition matrix can be calculated only once for every coil.

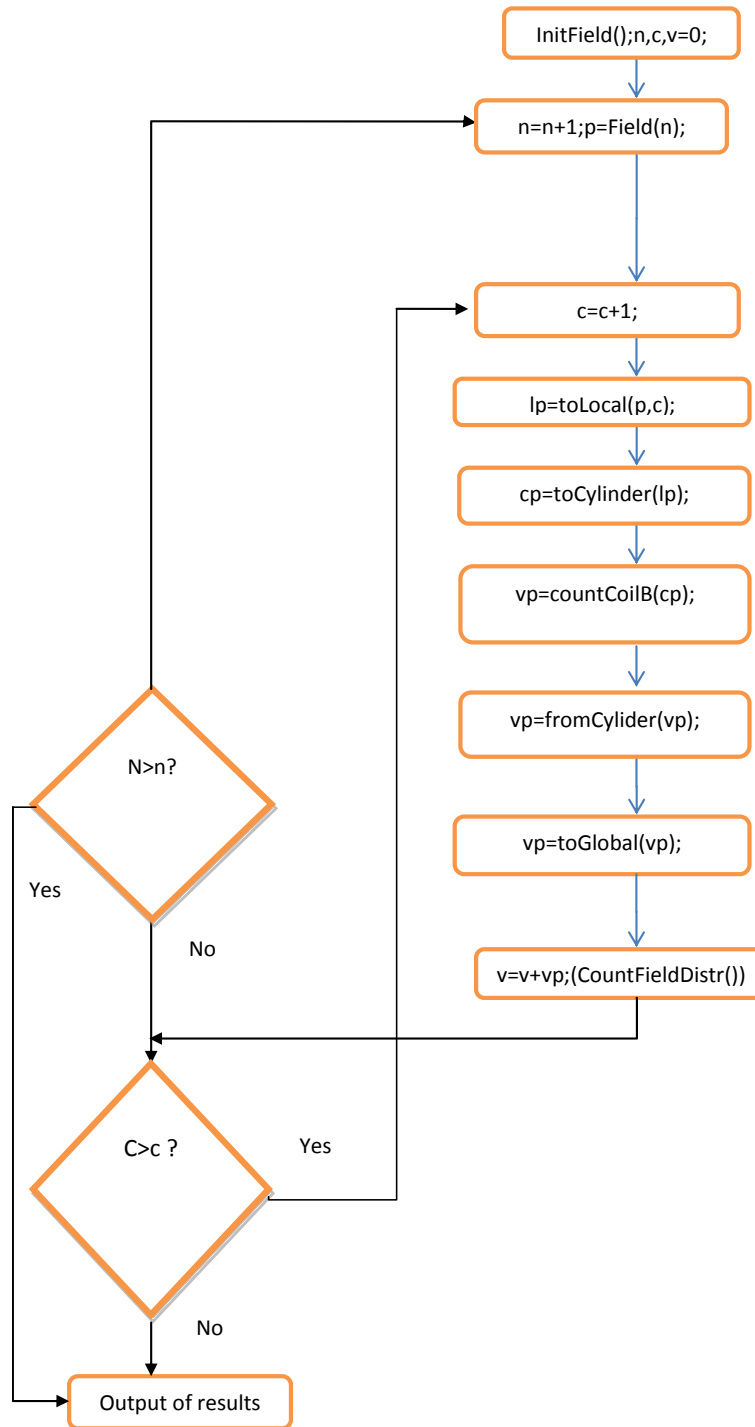


Fig. 1

The transition matrix has the form (1):

$$T = \begin{pmatrix} x1 & x2 & x3 \\ y1 & y2 & y3 \\ z1 & z2 & z3 \end{pmatrix} \quad (4)$$

Here columns are basis vectors of LRCS in the GCS basis (

$$\mathbf{O}_x=(x_1,y_1,z_1), \mathbf{O}_y=(x_2,y_2,z_2), \mathbf{O}_z=(x_3,y_3,z_3)).$$

The main parts of algorithm for this calculation dur-

ing the process of transition chain GCS ->LRCS for the point  $M$  of the mesh are the following:

1. Transition chain GCS->LRCS;
2. Transition chain\_LRCS ->LRCS;
3. Calculation of module of magnetic induction  $B$ ;
4. Transition chain LRCS->LRCS;
5. Transition chain LRCS->GCS;

## 2. ALGORITHM –PROGRAM DESCRIPTION AND SCHEME

The algorithm (Fig.1) has been implemented on Java language. To visualize results the package ParaView was used. The program contains the following classes and methods:

**Main** – the class that contains the method `main()`, where all the methods for calculation of magnetic field and output of results into a file \*.vtk (for the following visualization by ParaView) are called.

**I** – contains the methods `eK()` and `eE()` to obtain interpolated values of elliptic integrals. Tabular data and finite differences are in a text file.

**MainForm** – contains methods for a work with the graphic interface and corresponding event handlers.

**Coil** – the class of coil that contains the following methods:

`Coil()` – this is the constructor of the class. It has parameters such as the direction of the coil axis, the origin of local coordinate system of the coil, current value, the number of contours etc. The coil axis is taken as Oz. When a copy of coil is created an arbitrary vector is chosen, and the vector product of the vector and Oz is taken as Ox, then vector product of Oz and Ox is taken as Oy. Basis vectors are normalized. In the copy of coil direct and inverse transformation matrix (from global to local coordinate system and inversely) are calculated and saved.

`toLocal()`– transformation from global coordinate system to the local one;

`toCylinder()`–transformation from local coordinate system to the cylindrical one;

`fromCylinder()` — transformation from cylindrical coordinate system to the local one;

`toGlobal()` —transformation from local coordinate system to the global one. The library Java3D is used.

`countLoopB()`– calculation of electromagnetic induction vector in cylindrical coordinate system for one contour of the coil;

`countCoilB()` – calculation of electromagnetic induction vector in cylindrical coordinate system for a given coil (in a given point of space) as the superposition on all the contours.

**Counter** – contains method `initField()` to initialize 3-dimensional array of values of electromagnetic field vectors and `countFieldDistr()` that calculates the vector of electromagnetic field for a given point as the superposition on all the coils in the configuration. (For one coil there is the method `countCoilFieldDistr()` that calculates electromagnetic induction in every point of the given array of points.)

Introduce the following notations: *Field* -the 3D array of points in which the calculation will be performed;

*N* – the number of points in *Field*;

*C* – the number of coils;

*p* – a current point of the lattice;

*c* – the current coil number;

*lp* – local coordinates of the point;

*cp* –cylindrical coordinates of the point;

*vp* – value of magnetic induction (MI) in a given point relative to the current coil;

*v* – the sum of vectors of magnetic induction created by all the coils in the current point.

## 3. OPTIMIZATION RESULTS

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 running time a variant of the algorithm using parallel calculations has been implemented: for every coil calculation of magnetic induction has been performed in a separate flow. The results can be seen in the Table1 and on Fig.2 and Fig.3. The time includes running time and the result file generation time.

Table 1

№	Number of coils	Number of points	Time (sec)	Optimization time (sec)
1	1	400000	21	21
2	2	400000	35	21
3	3	400000	50	24
4	4	400000	64	29
5	5	400000	78	32
6	6	400000	92	35
7	7	400000	107	55
8	8	400000	121	61
9	9	400000	135	46
10	10	400000	150	48
11	2	100000	9	6
12	2	200000	18	11
13	2	300000	26	16
14	2	400000	35	21
15	2	500000	44	26
16	2	600000	53	32
17	2	700000	61	37
18	2	800000	71	42
19	2	900000	79	47
20	2	1000000	88	57

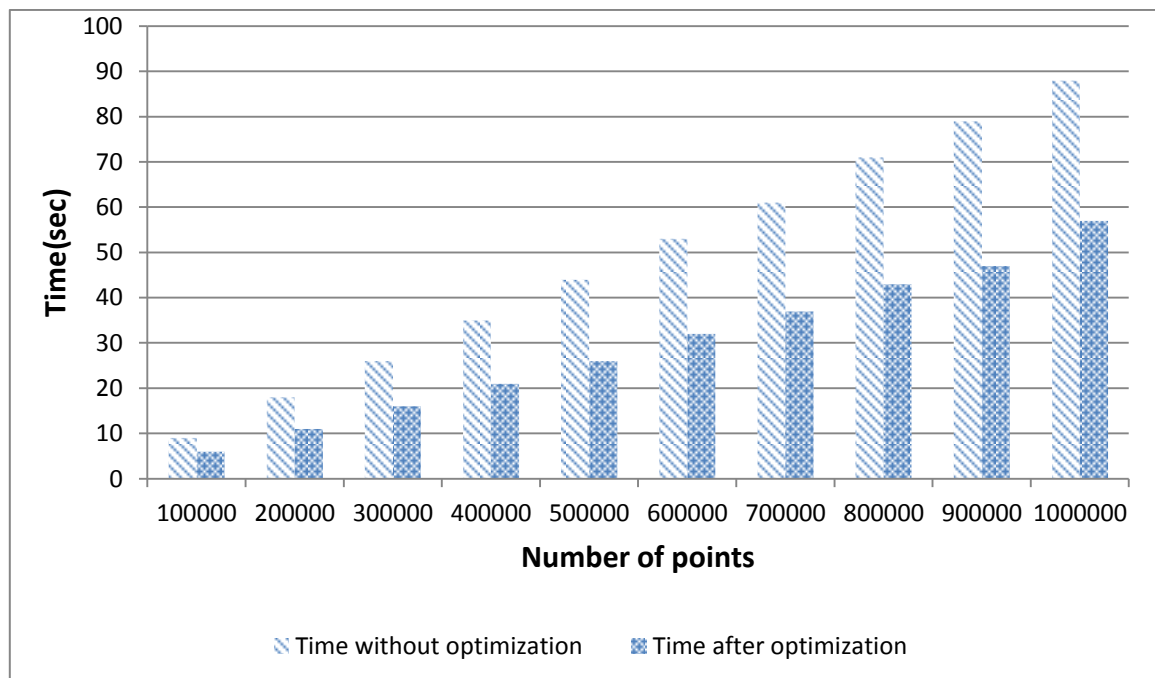


Fig. 2. Optimization results for two active coils

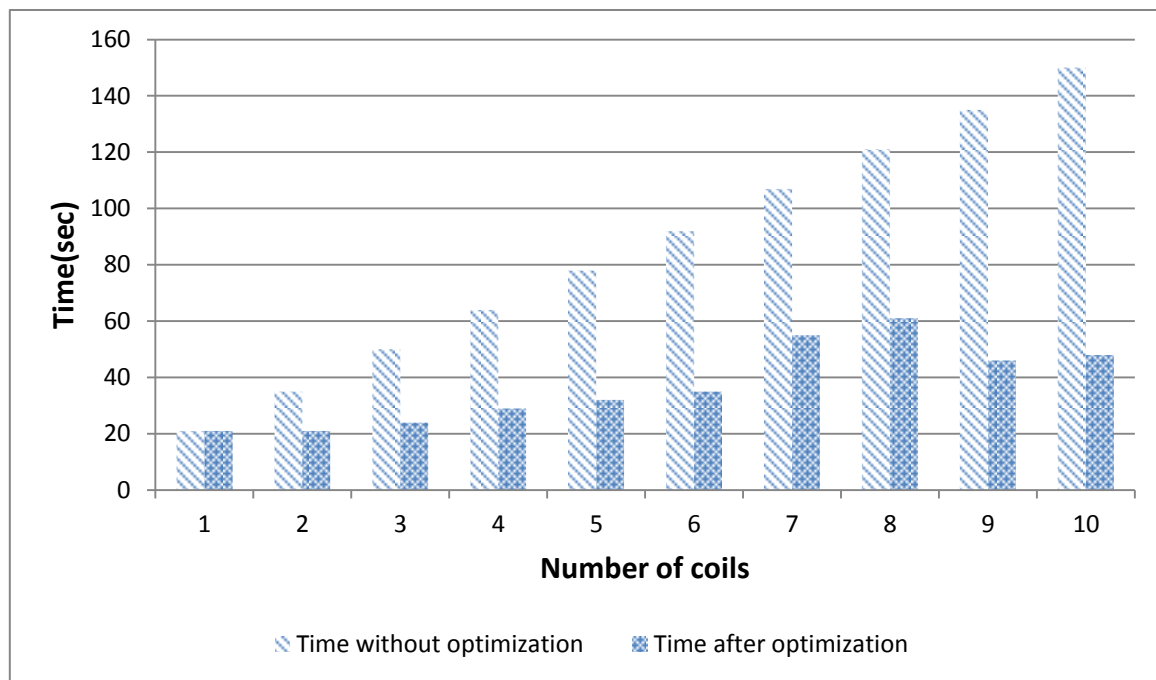


Fig. 3 Optimization results for 10 coils

#### 4. CONCLUSION

An algorithm for calculation of the values of magnetic induction of low frequency magnetic field around and in the human body in the process has been created. Some results of optimisation of the time for calculation of space configuration of magnetic field in the patient's area are also presented. The optimisation has been done both for different numbers of coils for calculation of magnetic induction and for different number of points of the space lattice.

#### 5. ACKNOWLEDGMENTS

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#### References

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