Control over influence of the magnetic field parameters on a biological object

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Abstract

This article is devoted to the problem of evaluation methods for control over influence of the magnetic field on a biological object during magnetic physiotherapy procedure. In this paper, we carry out a research into a mathematical model of interaction of the magnetic field parameters with a biological object, which depends on values of magnetic induction, its form and time of the field effect on sections of the biological tissue.

1. Introduction

In physiotherapy, i.e. when the biological object (hereinafter BO) is subjected to the magnetic field (hereinafter MF), it is important to calculate properly a final, effective result of the procedure. It means the doctor fixes certain MF parameters having influence on the patient, but the influence strength is different and depends on the patient's condition. The analysis of experimental research and practical use of MF in medicine is an important part in the development of modern physiotherapeutic equipment. Based on these data, best principles of magnetic physiotherapy apparatuses and their parameters are selected. The main problem of improvement of magnetic physiotherapy apparatuses (MFTA) remains the issue of MF dosage control during physiotherapy. This problem has the following areas:

- evaluation method of the MF impact on the biological tissue;
- choice of parameters and form of the MF output signal.

Previous works proposed efficient generation methods and construction principles as well as algorithms of high-precision sources of changeable magnetic field [1] that provide a stable value of the magnetic induction taking phase and amplitude correlations into account. Also, provision of standardized values of magnetic induction, frequency and fields form with possibility to adjust fixed therapeutic parameters [2].

Control and evaluation parameters of influence of the magnetic field on the biological tissue is crucial in the study of these areas, as it enables to monitor and evaluate the progress of interaction of the magnetic field and biological structures with standardized parameters in real time.

So research and obtaining appropriate mathematical models of influence of biophysical processes and effect of the magnetic field parameters on the biological tissue allows:

- to investigate a temperature control method of the magnetic field on the biological tissue in real time;
- to work out new principles of making an apparatus of standardized therapy with automatic control system;
- to increase strength of the magnetic field during therapeutic procedure.

Creation of a universal apparatus of magnetic physiotherapy [3], which allows to study in real time the impact of physiotherapeutic factor with possibility to change parameters of the magnetic field in order to obtain standardized and planned dose, is essential for physiotherapeutic procedures and achievement of the most effective impact from them.

2. Mathematical simulation of the effects of an external magnetic field on biological objects

At present, much attention is paid to the impact on the human body and MF biological objects. Influence of even weak low frequency electric and magnetic fields causes biological effects that can lead to health problems [4].

Today scientists have determined two mechanisms of influence (Fig.1) external MF influence on the human due to electric currents induced in his body [5,6]:

1) changes in the potentials' difference between external and internal surfaces of cell membranes, which affect the exchange processes between the cell and the environment that surrounds it;

2) heating the tissue under the influence of apparent density of Joule's losses.

$$B_x(t) = B_0 e^{-\mu x t}$$

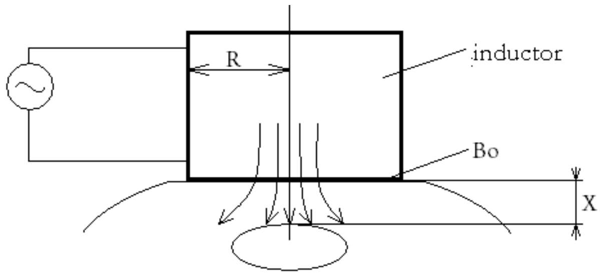

Fig.1 Effect of external MP for biological object

Background information for conducting medical research and proof of accuracy of previous standards is a picture of distribution of the electromagnetic field and current density in the human body, which was obtained with the highest possible reliability taking complex human internal structure and specific sources of external field into consideration.

The aim was to consider the peculiarities of numerous calculations of electromagnetic processes in the biological environment subjected to external MF, imagining it in a leading heterogeneous environment with a complicated microscopic structure and using approaches as those to be used for processes of composite materials [7]. It is proposed to solve the problem in two stages:

1) finding a picture of the averaged field throughout the biological object, and in the human body, in particular.

2) obtaining distribution of the local field in a small area that represents the greatest interest in terms study of biological effects by using the available data.

2.1 Electromagnetic parameters and electrical properties of biological tissues

Typical dimensions of tissue structures, affecting potentially the character of electromagnetic processes and effective electromagnetic properties of the biological environment are divided into, at least, four modes - from the cell structure (10 μm to the borders between different organs (10 cm) [7].

Biological tissue is characterized by two important electrical properties [8]:

1) First, there are free current carriers in it, therefore it can be considered an electrical conductor with a conductivity value that ranges from 0,1 to 10 $(\Omega\cdot m)^{-1}$.

2) Second, bio-tissue also contains bound charges, which cause dielectric effects, specifically, to the rise in the external electric field, electric polarization, which is characterized by dielectric permeability, whose value varies widely - its relative value ranges within 10^1-10^7. Magnetic properties of the bio-tissue are characterized by magnetic permeability, the value of which must be equal $\mu=\mu_0=4\pi\cdot10^{-7}$ H/m.

The behavior of structural elements of the bio-tissue depends considerably on the frequency of changes in the external field, which is manifested in the form of dispersion macroscopic dielectric permeability and conductivity [7].

The following typical time intervals are the subject of the analysis of interaction between the external electromagnetic field and a biological object [7]:

$\tau_e = \dfrac{\varepsilon}{\sigma}$ - relaxation time of bulk electric charge;

$\tau_m = \sigma\mu_0 L^2$ - magnetic field diffusion time at a distance L (for L we mean a typical size of the biological object;

$\tau_{em} = \dfrac{L}{c}$ - electromagnetic wave passage time of distance L.

When a biological object is exposed to external MF (B-field), whose frequency is f<10 kHz, which corresponds to the dimensionless parameter $\omega\tau_m<<1$, electric currents induce in the body of a biological object. And MF created by these currents is much less than the external MF. This greatly simplifies the solution of the field-effect task of finding distribution of current density in the bulk BO[7].

In the case of low frequency changes in the external MF (f<<10 kHz) the main parameter, which characterizes the electromagnetic processes in the biological environment, is the value of specific conductivity (because the condition is fulfilled $\omega\tau_e<<1$ dielectric properties of the environment can be omitted).

The value of the organs anatomical location in the human body and their conductivity values are the background information for drawing up and solving field-effect task in order to study the influence of MF on the human.

2.2 Features of the numerical fulfillment of the task

When a person is exposed to the external MF $B_0(r)$ of low frequency in the biological environment characterized by a conductivity values $\sigma(r)$ that depends on this point, currents induce, and their density distribution can be found from the solution of field-effect task. The system of differential equations written in the variables (A, φ) and which describes the electromagnetic processes in the human body subject to low frequency MF (when neglecting electric induction currents), is as follows [7]:

$$\begin{cases} \dfrac{\partial A}{\partial t} + \dfrac{1}{\sigma}\nabla\cdot\dfrac{1}{\mu}(\nabla\cdot A) + \nabla\varphi = 0 \\ \nabla\cdot\left[\sigma\left(-\dfrac{\partial A}{\partial t} - \nabla\varphi\right)\right] = 0 \end{cases} \qquad (1)$$

In this case we solve a set of equations with an equation for vector A in the outer area in relation to the biological object:

$$\Delta A = -\mu_0 J_0, \qquad (2)$$

where J_0 – known value of current density of the external MF.

In the case of low frequency f<10 kHz vector potential A(r) in the human body can be considered a known value, which coincides with the vector potential of external MF A_0(r), which was calculated without biological environment. In this case, system (1), which is specified by the Harmonic Law, changes in time of the external field will be simplified take the form of [7]:

$$\nabla \cdot [\sigma(r)\nabla\varphi(r)] = -i\omega\nabla \cdot [\sigma(r)A_0(r)] \qquad (3)$$

The following boundary conditions on the surface of the body are fair, they result from the condition of the fact that a standard component of the current density on the border of the environments is equal to zero:

$$n \cdot \sigma(r)\nabla\varphi = -i\omega n \cdot \sigma(r)A_0 \qquad (4)$$

Equations (3) and (4) represent the mathematical description of the internal problem of calculation of the electric potential φ distribution in the heterogeneous environment of the bio-tissue when exposed to external low frequency MF.

Then the density of induced current

$$J \cong \sigma 2\pi f \cdot B_K , \qquad (5)$$

where B_K – magnetic potential module.

Magnetic potential module is:

$$B_K = \frac{B_x}{\mu} \cdot R , \qquad (6)$$

where R – radius of the inductor

$\omega = 2\pi f$ - phase rate

Let's consider the biological tissue (as a composite magnetic environment),which is in a diamagnetic liquid phase with paramagnetic particles, which is influenced by an external changeable MF with induction

$$B_x(t) = B_0 e^{-\mu x t} \qquad (7)$$

The concentration of paramagnetic particles is so small that the behavior of these particles can be seen as separately isolated ones.

The value of heat losses, which are released in the unit of the biological tissue magnetic potential module can be calculated in the formula [9]:

$$P = \mu_0 \pi \chi f \left(\frac{B}{\mu\mu_0} \right)^2 , \qquad (8)$$

where f – changeable frequency of the magnetic field.

The value of current density, directed to the biological tissue can be calculated by an equation

$$J_{B_x} = \pi R \gamma f B , \qquad (9)$$

where γ – conductivity of the biological tissue;

R – radius of the area of biological tissue under consideration.

Dependence of the necessary time of MF effect to achieve the desired therapeutic effect can be determined from the formula (7) taking a logarithm

$$-\mu x t = \ln \frac{B_x(t)}{B_0} , \qquad (10)$$

Time t of the magnetic induction effect $B_x(t)$ to achieve the desired therapeutic effect with a value of B_0 on the border of environments

$$t = \frac{1}{\mu x} \ln \frac{B_x(t)}{B_0} \qquad (11)$$

Magnetic induction B_0 can be measured on the surface of the biological tissue.

While developing and serial producing inducers of magnetic physiotherapy apparatuses, the value of magnetic induction on the surface of the inductor coil or in its geometric center. So it is possible to calculate the value of magnetic induction for inductors made on the basis in the form of Helmholtz's rings

$$B = K_B I , \qquad (12)$$

where K_B – constant of Helmholtz rings fixed by the magnetic induction,

I- current value.

When the alternating current flows in the Helmholtz rings, the value of a variable magnetic field can be calculated

$$B(t) = K_B I(t), \qquad (13)$$

where $I(t)$- value of the alternating current.

Thus, the value of magnetic induction coil can be calculated by formulas (12) and (13) or measured by a precision teslameter.

The value of magnetic induction that has its effect on the biological tissue can be measured on the surface of BO, or calculated by formula (7), and at the depth x, for value $B_x(t)$, duration of the therapeutic procedure t is to be calculated according to the formula (11).

The amount of heat, which is released in the biological tissue (hereinafter BT) subjected to the magnetic field, is equal to [10],

$$Q_B = 2 \cdot 10^{-16} g_{cp} f^2 H^2 , \qquad (14)$$

where g_{cp} - a generalized density of BT;

H- magnetic field intensity.

In view of the fact that the magnetic induction B is related to intensity *H* by the equation

$$B = \mu\mu_0 H , \qquad (15)$$

where μ_0 – magnetic constant of the vacuum;

μ – magnetic constant of the environment.

We come to the dependency of heat amount in the biological tissue obtained by exposing it to MF

$$Q_B = 2 \cdot 10^{-16} g_{cp} f^2 \left(\frac{B}{\mu\mu_0}\right) \qquad (16)$$

in this case this current density is described in [10]

$$i_B = 1{,}3 \cdot 10^{-11} f \frac{B}{\mu\mu_0} \quad (17)$$

and heat absorption is equal

$$P = i^2 g_{cp} \quad (18)$$

3. Experiment

Tab.1 shows the data on changes in temperature when "MIT-11" is on, but without its contact with BT, with given values of the magnetic induction 12, 15, 18 mT.

Measurements (Tab.1) were conducted by the following equipment: “MIT-11”, camera IR MoblR.

Figure 2 shows a summarized graph of changes in temperature and time in case "MIT-11" apparatus is installed, values of the magnetic induction 12,15,18 mT. Temperatures on the inductor apparatus are changed under the law similar to exponential one. When fixed 18 mT, a value of magnetic induction, the temperature is changed faster than values of magnetic induction given by the apparatus installed on the values of magnetic induction 12, 15 mT.

Tab.1

Temperature dimensions

Time, s	Temperature on the inductor coil of the apparatus in various modes without its contact with BO, ºC		
	12 мТл	15 мТл	18 мТл
5	24,6	25,2	26,4
10	24,8	25,4	26,6
30	24,9	25,8	26,9
60	25,1	26,2	27,8
90	25,4	26,6	27,9
120	25,6	26,9	28,6
180	26,0	27,9	28,9
210	26,4	28,1	29,6
240	26,5	28,8	30,8
300	26,9	29,6	31,8

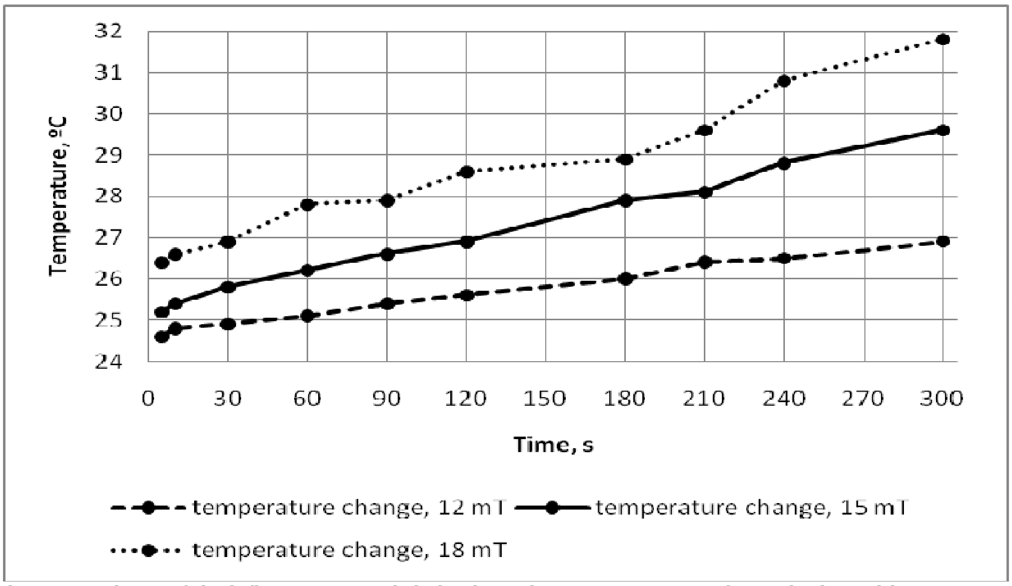

Fig.2 Dependency of the influence magnetic induction value on temperature change in time without contact with BO.

Tab.2 shows the data on temperature change when "MIT- 11 " is on, and in contact with BO at the set values of magnetic induction 12,15,18 mT

Figure 3 shown the total graph of temperature and time for installation on device "MIT-11" values of magnetic induction 12,15,18mT. Temperatures on the inductor apparatus for changing the law close to exponential. When installed on a unit value of magnetic induction 18 mT temperature changes faster than the devices installed on the values of magnetic induction 12 15 mT.

Tab.2

Temperature dimensions

Time, s	Temperature on inductor apparatus in various modes in contact with BO, ºC		
	12 мТл	15 мТл	18 мТл
5	34,7	34,8	34,9
10	34,9	35,0	35,2
30	35,1	35,2	35,3
60	35,4	35,5	35,9
90	35,6	35,8	36,2
120	35,8	36,2	36,8
180	36,5	36,6	37,5
210	36,9	37,5	38,3
240	37,2	38,2	39,3
300	37,5	38,9	39,8

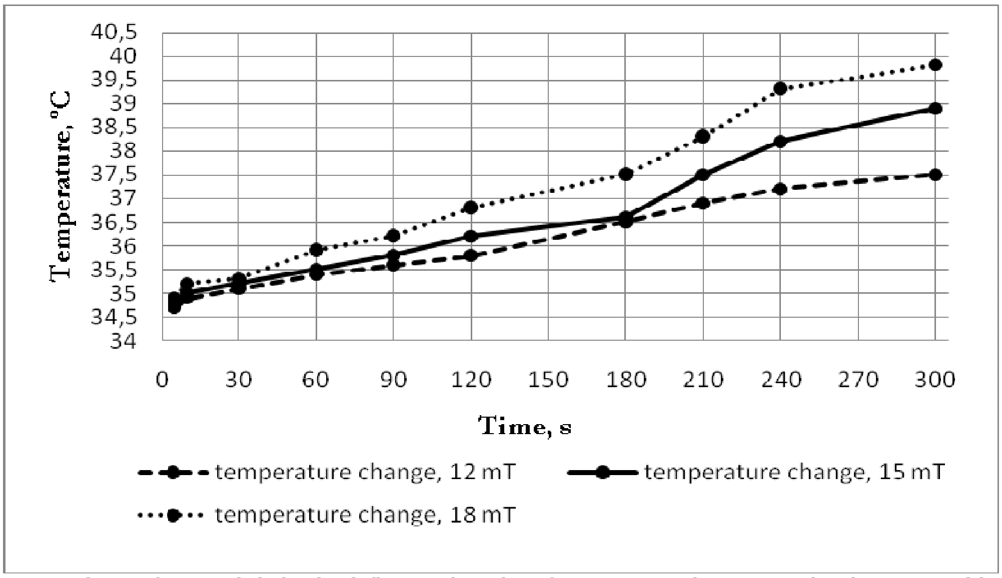

Figure 3 Dependence of magnetic induction influence the value of temperature change over time in contact with BO.

Conclusions

Based on the considered model of interaction of the biological tissue with magnetic field, a practical method for control efficiency of the effect of the magnetic field on biological objects [3] has been developed; it includes a functional diagram of an automated device and an algorithm with feedback. The proposed implementation allows:

- toincrease the effectiveness of treatment, and in some cases to eliminate lack of therapeutic effect, caused by uncontrolled ultrasonic effect or its absence during physiotherapy.
- to provide a magnetic physiotherapy effect on organs and tissuesby a signal that is adjusted and controlled in real time according to a prescribed dose of the magnetic induction during the procedure.

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