The temperature method of control in a magnetotherapy

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Abstract

The article is devoted to the problem of the temperature control of a biological object in the magnetotherapy. In this work was devised the mathematical model of influence the magnetic fields on a biological object with the control of the temperature variation the surface epidermis spheres. It was conducted an experimental researches of temperature variation of a biological object with magnetotherapy apparatuses "MIT-11" and "POLUS-4".

1. Introduction

Magnetotherapy is a leading method of physiotherapy based on a medical - prevention and anesthetic action of the low-frequency magnetic and electromagnetic fields during the rehabilitation, recovery and treatment of tissues, organs and systems of the human organism. When the conducting of the magnetotherapy procedure are used, as a rule, an impartial diagnostic of diseases, based on studying of the heat products and heat transfer processes. It uses three main methods for obtaining the information [1]: a thermometry, thermography, calorimetry. Thermography is an effective secure noninvasive method for registration of the human body infrared radiation in order to diagnose the various diseases. An important problem, in the thermal control of biological tissue (BT), while working the magnetotherapy apparatuses (MTA), is the developing of the experiment methods, analysis of the results and equipment selection. The data analysis of thermography includes qualitative and quantitative estimate, and processing of obtained information using professional software. The perspective type of the physiotherapy apparatuses is MTA with feedback that allows to adjust the parameters of magnetotherapy effects before treatment session and to change them during the procedure to achieve the maximum therapeutic effect. Using MTA with feedback allows to create the given forms of magnetic field (MF) with high precision, to create an operational diagnosis and optimization during the therapeutic procedures, to vary the biotropic parameters, to be universal in functionality, to ensure stable values of magnetic induction. These qualities allow to increase the efficiency of influence MF on BT.

The temperature of BT is an important parameter of an estimation the influence and the efficiency of the MF action on the human organism. To increase the using effect, selection of the optimum modes, to ensure the control of the MTA functioning, in the scientific articles [2,3], we proposed and approved the contactless temperature method of control the MF parameters during the physiotherapeutic procedure with providing a high efficiency due to the feedback, that has allowed to control and automatically select the MF mode, needed to achieve an effective field action due to the temperature measuring of the biological object (BO), to form normalized, exactly measured action of the MF on the BT.

The offered in patent method influence on the organism [3] by MF implemented a temperature measuring of BO before, during and after completion of the magnetotherapy session, with the formation of database at the same time, their control and processing the obtained values. This has allowed to raise an efficiency of magnetotherapy procedure.

The most works on magnetotherapy [1, 4-9] are devoted not so much revealing the thermal effect of MF action on BT, as describing the finished effect.

Therefore, the actual problem is a modeling of the MF influence at the temperature variation of the surface or deep epidermis spheres and other BT, and holding the experimental studies of BT temperature modes variation during magnetotherapy procedure.

2. Mathematical modeling of the magnetic field influence at the temperature variation of the epidermis surface spheres

The action of variable MF at BT first of all is associated with depth penetration and energy release (thermal effect). MF may cause a change of the ion spectrum vibrations inside the macromolecule. This increases the possibility of transiting the energy from neighboring atoms and complexes inside the macromolecules. As a result, it can cause the changes of energy of the ion thermal motion, which is consist several or even tens percent from its initial thermal energy, which is equivalent to shifting the temperature to ten degrees. It is enough to run the process of changing the ions properties in macromolecules and their conformational state.

The mathematical model of the BT electromagnetic energy absorbed dose is determined by the parameters of the absorbed dose of an electromagnetic radiation (its magnetic component). When passing the electromagnetic waves through the organism tissue, a part of the energy of electromagnetic waves is converted into heat through the conductivity of tissue. The mechanism medical action of the low-frequency magnetotherapy is not due to the magnitude of the excreted heat (it was small due to low frequency fields), but its irritant, stimulant effect.

One of the factors and the action mechanisms of electromagnetic oscillations on the body is the excretion of Joule heat Q. Under the action of MF in BT an eddy currents are induced I. These currents can be used for heating the BT layers and organs. Let's review the thermal effects that are defined by the given currents.

To calculate the specific heat effect that is created by eddy currents, we can use the Joule - Lenz formula [5]:

$$Q = I \cdot U \cdot t, \tag{1}$$

where U - is the voltage of the electric field induced in BT, t - is a unit of time.

But the parameters of heat *Q (t),* eddy current *I (t)* and voltage *U(t)* changes in time *t*. Therefore, throughout a time, heat quantity has such form

$$Q(\mathrm{t}) = I(\mathrm{t}) \cdot \mathrm{U}(\mathrm{t}) \cdot t, \tag{2}$$

where *I (t)* – is a value of eddy currents at the present time, *U(t)*- is a voltage of electric field induced in BT during the time t.

The quantity of heat that is excreted per unit volume V per unit time t can be estimated by the specific thermal effect (heat products) q [5]:

$$q = \frac{Q}{V \cdot t}. \tag{3}$$

Including that the volume is calculated as $V = S \cdot l$, the current is $I = j \cdot S$, and $E = j \cdot \rho$ - is electric field intensity; so we obtain a formula for determining the heat quantity

$$q = j^2 \cdot \rho. \tag{4}$$

The formula (4) shows that at a given current density j the greater quantity of the heat will be allocated in tissues with a large specific electric resistance ρ.

For the eddy currents it is possible to write down [6]:

$$I = -\frac{S}{\mathrm{R}} \cdot \frac{dB}{dt}, \tag{5}$$

where

$\frac{dB}{dt}$ - is a gradient (speed) of the change the MF induction values,

S - the area of a contour section with a length l,

R - BT resistance.

Express resistance R through the formula of specific electric resistance:

$$\mathrm{R} = \frac{\rho \cdot l}{S}. \tag{6}$$

Get the values of the eddy currents

$$I = -\frac{S \cdot S}{\rho \cdot l} \cdot \frac{dB}{dt} = -\frac{S^2}{\rho \cdot l} \cdot \frac{dB}{dt}, \tag{7}$$

or

$$I = -\frac{k_1}{\rho} \cdot \frac{dB}{dt}, \tag{8}$$

where $k_1 = \frac{S^2}{l}$ - coefficient that depends on geometrical sizes of the area (of tissue)

Let's admit that the MF induction are changing under the harmonious law

$$B = B_0 \cdot \cos(\omega t), \tag{9}$$

where B_0 - an amplitude of MF induction, ω - angular frequency, then

$$\frac{dB}{dt} = -B_0 \cdot \omega \cdot \sin(\omega t). \tag{10}$$

Let's substitute (10), (8) in (4) and get the goal formula for the calculation the values of the specific thermal effect MF action on BT

$$q = k \frac{B_0^2 \cdot \omega^2 \cdot \sin^2(\omega t)}{\rho}, \tag{11}$$

where q - is a heat quantity which is allocated for 1 second in the unit of volume, $k = \frac{k_1^2}{S^2}$.

Thus, as follows from the formula (11), the value of the heat quantity which is released in the tissues, in proportional to the square of the frequency and induction of variable MF and inversely proportional to the resistivity. So the tissue which contain many vessels such as muscle, will heat up more than such tissue as fat.

The increment of the body temperature T due to the transfer him the heat q equals [7]

$$dT = \frac{1}{C_{\mathrm{q}}} dq, \tag{12}$$

where C_{q} - the heat capacity of the volume unit.

Taking the time derivative from this equality, we obtain as a criterion of biological relevance of tissue heating the temperature increasing with a speed:

$$T_t^{/} = \frac{1}{C_q} \cdot \frac{dq}{dt} . \qquad (13)$$

From (11) follows the gradient equation of heat quantity

$$\frac{dq}{dt} = k \frac{B_0{}^2 \cdot \omega^3 \cdot \sin(2\omega t)}{\rho} . \qquad (14)$$

Let's substitute (14) in (13) and obtain the formula that helps to calculate the speed of temperature increasing of the surface layer of BO

$$T_t^{/} = k \frac{B_0^2 \cdot \omega^3}{C_q \cdot \rho} \qquad (15)$$

Taking into account the circular frequency $\omega = 2\pi f$ we obtain an estimated formula of the gradient temperature

$$T_t^{/} = k \frac{8\pi^3 \cdot B_0^2 \cdot f^3}{C_q \cdot \rho} . \qquad (16)$$

Let's conduct the graphical research of the dependence $T_t^{/}$ from magnetic induction B (fig. 1) and the frequency f (fig. 2). We accept the following BT parameters and the sample sizes [8]: the conduction of environment σ =0,125 (Om·m)$^{-1}$, heat capacity of the volume unit C_q =3352 (J ·kg·1°C·s^{-1}), radius of the influence zone r =0,25 sm.

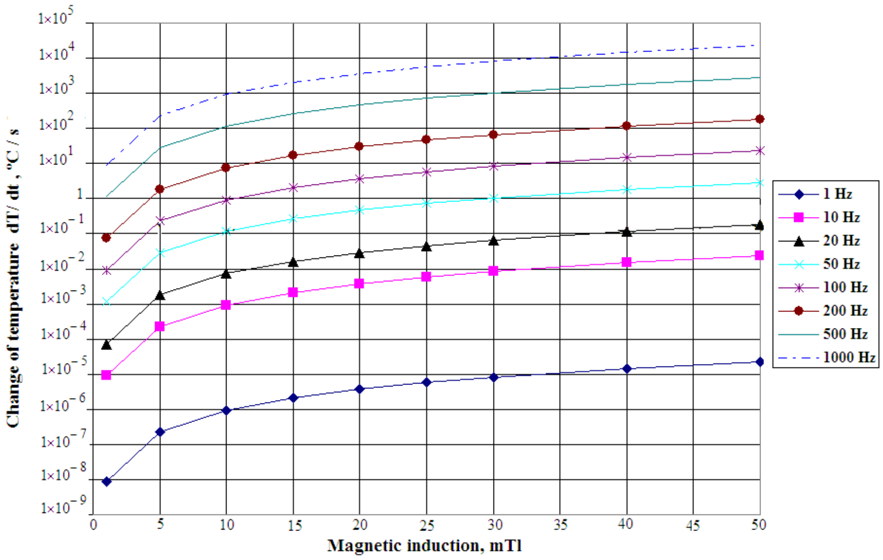


Fig. 1. The speed of temperature variation dependency on magnetic induction

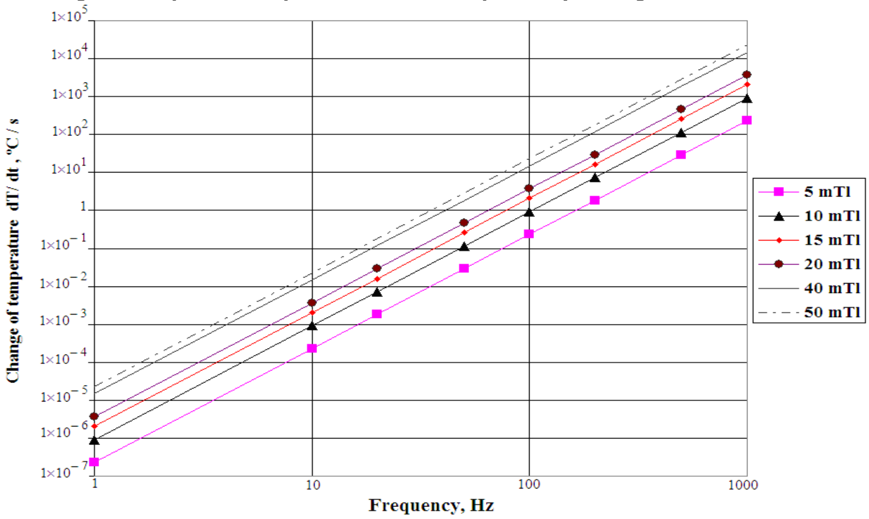


Fig. 2. The speed of temperature variation dependency on the frequency.

According to the results of theoretical and experimental researches of influence of the MF parameters on BO it has been received the formula (17) for calculating the temperature $T(°C)$ in MF acting zone, with empirically method. The results of researches indicate that the temperature in the zone of MF action is directly proportional to the magnetic induction $B(t)$ and the time of action t and inversely proportional to BO impedance Z, heat capacity of the volume unit C_q, environment conductivity σ, the square of the zone local action S.

Thus we get a formula of temperature dependence of the BO surface layers from the object parameters and operating factors:

$$T(°C) = \frac{K_m \cdot K_{BÒ} \cdot K_f \cdot B(t) \cdot t}{Z \cdot C_q \cdot \sigma \cdot S}, \qquad (17)$$

where $K_{BÒ}$ - a coefficient for multilayer BT, K_m - a conversion coefficient of the source signal of magnetic induction, K_f - a depending coefficient on the frequency for a specific type of BT.

The formula (17) allows to estimate the MF influence and action on the temperature values T and heat capacity of BT volume unit. There are presented the results of the theoretical researches of the thermal field by the formula (17), on the fig. 3 and fig 4.

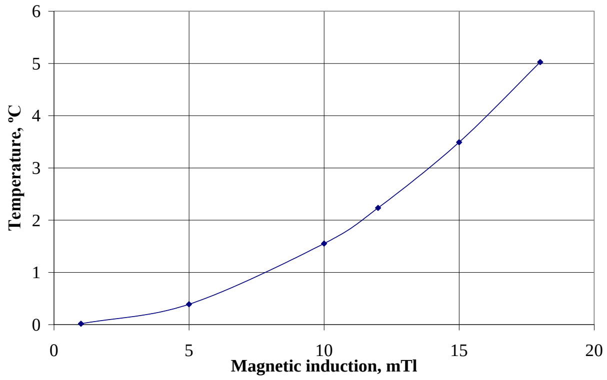


Fig. 3. The temperature dependence on the magnetic induction

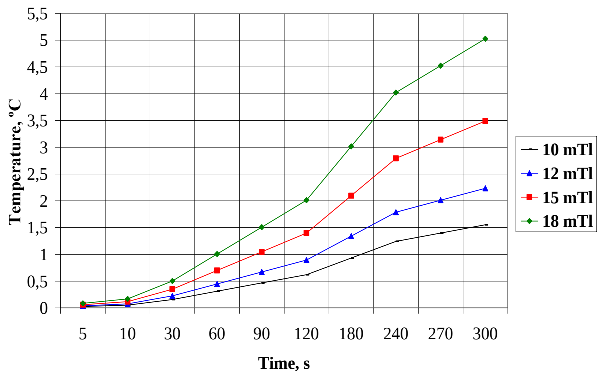


Fig. 4. The temperature change dependency on the time at the different modes operation of the magnetotherapy apparatus.

As we can see from the fig. 3, the temperature of the BT superficial sphere at the magnetotherapy procedure, is changing by the law, similar to the exponential, and increases the temperatures difference ΔT from 0,015ºC at B=1 mTl to 5,02 ºC at B=18 mTl (during 300 s). Using the formula (16) for temperature prediction it's necessary to choose the coefficient k, which depends on geometrical sizes of the area (of tissue).

Let's compare the graphs in fig. 1-4 and with a method of the k coefficient selection we will provide convergence of formulas results (16) та (17).

The optimal values of the radius of MF area action $k = r^2 = 0{,}00000625$ m² at a frequency $f = 1000$ Hz.

3. The experimental researches

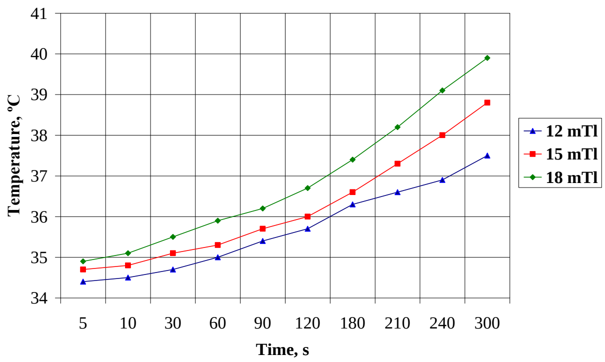
With the help of multifunctional precision infrared camera "MobiR M3" (fig. 5) it has been carried out the measurements of the temperature in the zone of MF action at the contact the MTA inductor with BT, and with a universal teslameter 43205 - the measurements of values the magnetic induction.

The experimental researches were spent with MTA "MIT-11" (operating modes 12, 15, 18 mTl) and "POLUS-4" (operating modes 5, 10, 15 mTl).

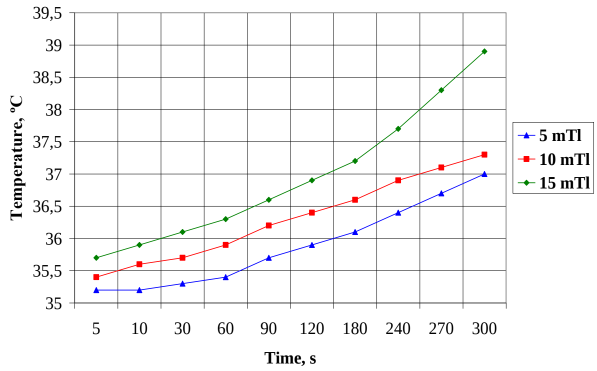
Fig. 5. The infrared camera "MobiR M3", the temperature informational table and the universal teslameter 43205.

Using the full-screen precision temperature measurement allows to provide with a high-precision the distribution of BT thermal field with MTA during the procedures of magnetotherapy

The advantages of the infrared camera are a precise radiometric thermal radiation, a modern integrated processing of thermal images, an integrated signal system, a professional software. Based on the informational temperature tables, it was constructed the graphs of depending temperature changing with time at the contact the inductor with BO for apparatuses "MIT-11" (fig. 6a), "POLUS-4" (fig. 6b).



a)



b)

Fig. 6. The experimental researches of temperature variation of biological object with magnetotherapy apparatuses "MIT-11" (a) and "POLUS-4" (b).

The results of theoretical calculations by formulas (16) and (17) (accordingly ΔT_1 and ΔT_2) and the experimental results of the temperature speed change on the MTA "MIT-11" (ΔT_3) (for the apparatus operating modes 12, 15, 18 mTl) and "POLUS-4" (ΔT_4) (for the apparatus operating modes 10, 15 mTl). The table 2 shows the absolute $\Delta_{ij} = \left|\Delta T_i - \Delta T_j\right|$ and relative δ_{ij} $(i, j = 1,2,3,4)$ errors of the theoretical and experimental researches of the speed temperature change $T_t^{/}$.

Tab. 1.

The comparison of predicted and experimental researches of the temperature variation

Magnetic induction B, mTl	The predicted temperature variation ΔT, °C / s		Experimental researches, ΔT, °C / s	
			"MIT-11"	"POLUS-4"
	ΔT_1	ΔT_2	ΔT_3	ΔT_4
10	0,005772	0,00517		0,00644
12	0,008312	0,007445	0,0105084	
15	0,012988	0,011633	0,013898	0,010847
18	0,018702	0,01675	0,016949	

Tab. 2.

The comparison of the absolute (Δ_{ij}) **and relative errors** $(\delta_{ij}, \%)$ **the predicted and experimental temperature variation.**

Error	Magnetic induction, mTl			
	10	12	15	18
Δ_{12}	0,000601	0,000867	0,001355	0,001952
Δ_{13}		0,002196	0,000909	0,001753
Δ_{14}	0,000668		0,002141	
Δ_{23}		0,00306	0,00226	0,000199
Δ_{24}	0,00127		0,000786	
δ_{12}	10,4	10,4	10,4	10,4
δ_{13}		20,8	6,5	9,3
δ_{14}	10,3		16,4	
δ_{23}		29,1	16,2	1,1
δ_{24}	19,7		6,7	

The relative error of the calculation comparison of temperature variation ΔT by the formulas (16) and (17) is equal to 10,4%. The comparison of the calculation results by proposed formula (16) and the experimental research results of the temperature variation on the "MIT-11" and "POLUS-4" apparatuses, shows the least relative error $\delta = 6,5\%$ for apparatus "MIT-11" for an operating mode $B = 15$ mTl and $\delta = 10,3\%$ for apparatus "POLUS-4" for an operating mode $B = 10$ mTl.

According to V. E. Ilarionov [9] data at $40°C \le T \le 42°C$ are violated the indication modes of acoustic and electromagnetic radiation of chromosome continuum of the biological systems, there are the obstacles for the "soliton" conductivity of DNA, RNA, protein and water environments. In the fig. 7 , the 1,3,5,7,9 curves show the time of achieving the predicted, according to the formula (17), and 2,4,6,8,10 curves according to the formula (16), a critically acceptable level of temperature $(T = 40°C)$ for different modes of MTA (accordingly 10, 12, 15, 18, 20 mTl). The initial temperature $T_0 = 34,3°C$ is taken from experimental researches - fig. 6 (a).

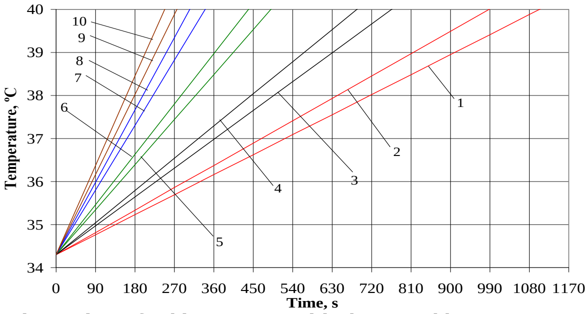


Fig. 7. Time of achievement a critical acceptable temperature level by the formulas (16) and (17).

Experimental research data from the "MIT-11" (Fig. 6 (a)) shows that for mode 18 mTl, a critical acceptable temperature level is achieved in excess of time $t = 300$ s.

The results of prediction of time achieving critical acceptable levels of temperature (fig. 7), at mode MTA 18 mTl show that critical acceptable temperature level is achieved at time $t = 304{,}7$ s according to the formula (16) (curve 8) and $t = 340{,}2$ s with the formula (17) (curve 7).

4. Conclusion

On the basis of experimental and theoretical researches was devised the system of temperature control and directed of MF on BT acting a precisely dosage, which provides a precise control and a high efficiency of the MF therapeutic effects, of the required forms, on BT due to the measuring of temperature gradient during the magnetotherapy procedure.

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