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Computer simulation of processes of radiation-thermal heating[1]

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Abstract. In this work we present results of computer simulation of radiation-thermal heating of magnetic materials to change their structure. The energy source is a pulsed electron accelerator. The simulation results are presented in the form of the temperature distribution in the irradiated material, depending on the pulse duration, pulse repetition rate and the parameters of the material.

1. Introduction

Synthesis of ferrites beams of accelerated electrons is discussed in [1-3]. The radiation source produces a stream of electrons perpendicular to the flat object specified thickness. The distribution of energy losses of electrons on the thickness of the object is described by a Gaussian function. Thermal radiation and heat transfer is discussed in [4]. A mathematical model of a computer program is the heat equation [5, 6]. For the numerical solution of the equations used explicit template finite-difference schemes for one-dimensional case:

$$T_i^{n+1} = \frac{\lambda\,\Delta t}{\rho\,c\,h^2}\left(T_{i+1}^n - 2\cdot T_i^n + T_{i-1}^n\right) + T_i^n + \frac{P_i^n \Delta t}{\rho\,c\,h^3},$$

where P_i^n - is the power density of the radiation source in n - including the temporary layer, h is the grid spacing, $T=T(x,t)$ - the temperature pressure, λ - the thermal conductivity, ρ - the density of the heated substance, c - is the heat capacity of the substance.

2. The main parameters system computer simulation

The mathematical model is implemented in a software system with the interface presented in figure 1. The main window of the program includes tools for setting and changing parameters of the model. The main parameters of the system are: E_e - the energy source; Z - the number of the main chemical element; A_e - its atomic mass; R_e - extrapolated mileage of electron flow; J_{imp} - current source; d_{ti} - pulse duration; F_i - pulse frequency; N- number of pulses; G - the pulse energy; D - the power absorbed dose; T_{max} - maximum temperature; T_{cp} - average temperature; D_x - the thickness of the heated material. The simulation results can be observed in the main window. The received data can be saved in files.

3. The results of computer simulation

[1] Work carried out in the framework of the increase of competitiveness of Tomsk State University

The purpose of computer simulation is to obtain the temperature profile in the radiation-thermal heating in the process of synthesis and sintering of magnetic materials, and comparison with experimental results. The objective of the simulation - optimization procedures, radiation-thermal heating, energy and time costs and the devices used. This task can be solved by variation of the variables in the parameter space of the system.

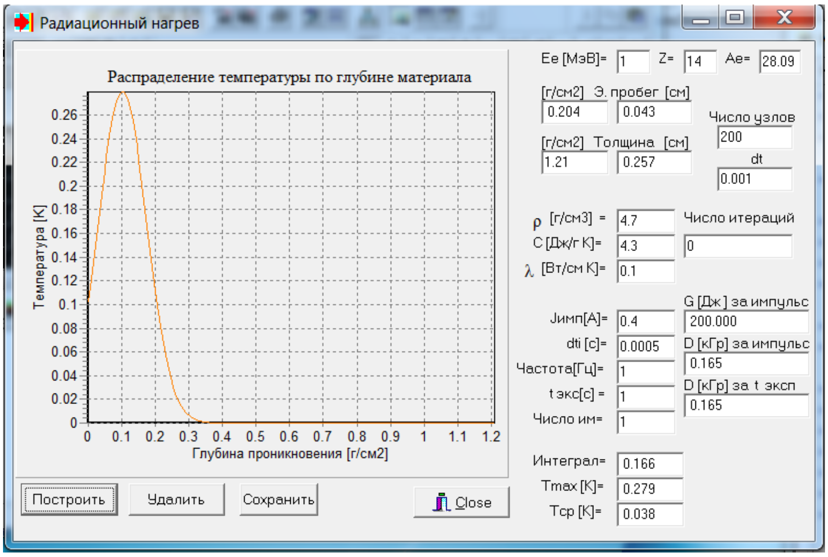

Figure 1. A fragment of the main window

An important characteristic is the distribution of energy losses of the incident electrons, the depth of the material from one pulse (with specified energy E_e and pulse duration J_{umn}). Figure 2 presents the distribution of energy losses of electrons.

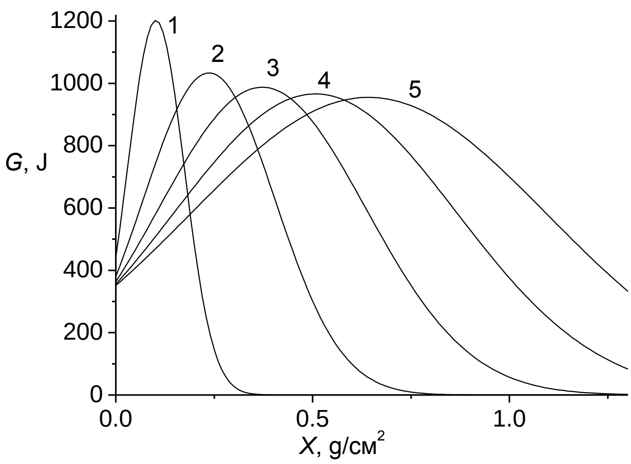

Figure 2. The distribution of energy losses of electrons in the bulk material. Curve 1 corresponds to E_e = 1 MeV, 2 - 2 MeV, 3 - 3 MeV, 4 - 4 MeV, 5 - 5 MeV.

Figure 3 presents the temperature distribution in the material for different time intervals of exposure, after the action of one pulse. The results are presented for the energy flow E_e = 1 MeV, for a material with physical characteristics: R_e = 0,204 g/cm^2, D_x = 0,204 g/cm^2 (is equal to the extrapolated mileage), λ = 0.1 W/(cm * K), ρ = 4.7 g/cm^3, c = 4.3 J/(g * K), $J_{имп}$ = 0.4 A, d_{ti} = 500 μsec, the time t_{exp} was changed from d_{ti} to 0.4 seconds.

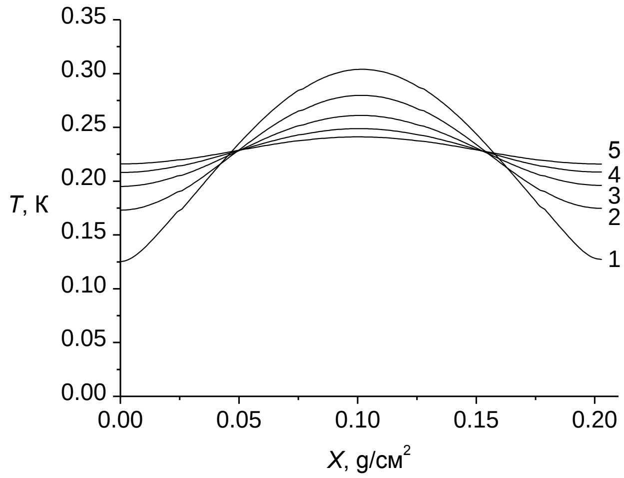

Figure 3. The temperature distribution along the depth of the sample from the time of the observation. Curve 1 corresponds to t_{exp} = 500 μsec; 2 - 0.1 sec; 3 - 0.2 sec; 4 - 0.3 sec; 5 – 0.4 sec. The thickness of the material equal to the length of the extrapolated path.

There is interest in studying the effect of electron energy on the temperature distribution along the thickness of the material. As we know with increasing beam energy increases the extrapolated path of the electron. At a small thickness of material, you can get a situation where a small fraction of the energy loss of the beam will occur in the material. Figure 4 shows the temperature distribution along the depth of the material for different beam energy and a fixed time interval of exposure. The results are presented for the following parameters: material thickness varied from D_x = 0.3 g/cm^2 to D_x = 1.1 g/cm^2 . Exposure time t_{exp} = 0.1 sec.

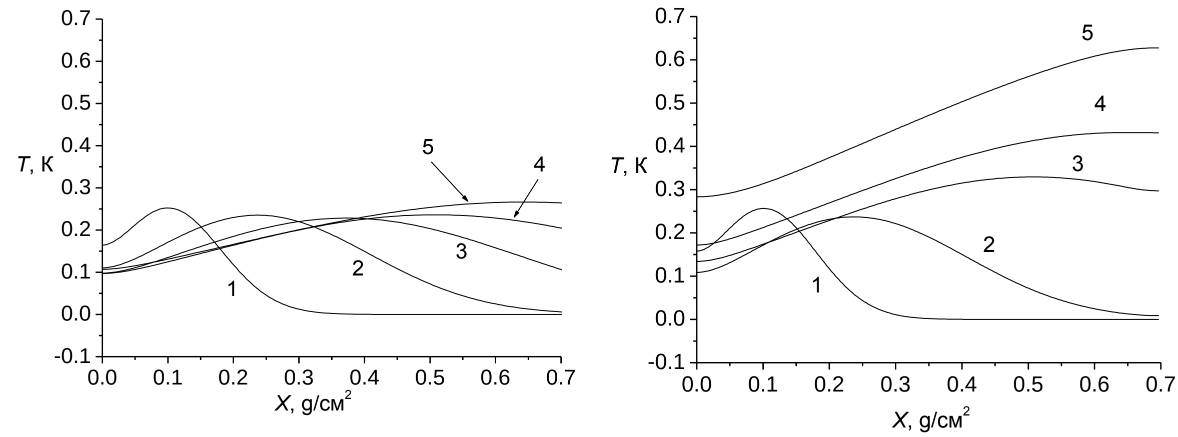

Figure 4. The temperature distribution along the depth of the sample from the electron energy (when the beam current pulse is 0.4 A, a pulse duration of 500 μsec and a fixed exposure time). Curve 1 corresponds to E_e = 1 MeV; 2 - 2 MeV; 3 - 3 MeV; 4 - 4 MeV; 5 - 5 MeV. Sample thickness: D_x = 0.7 g/cm^2 - left graph; D_x =1.1 g/cm^2 - right graph.

Values extrapolated path of the flow of electrons R_e and the average temperature T_{cp} presented in the table 1:

Table 6. Values extrapolated path.

E_e [MeV]	D_x = 0.3 g/cm^2		D_x = 0.7 g/cm^2		D_x =1.1 g/cm^2	
	R_e	T_{cp}	R_e	T_{cp}	R_e	T_{cp}
1	0.204	0.155	0.204	0.066	0.204	0.042
2	0.474	0.310	0.474	0.133	0.474	0.085
3	0.744	0.465	0.744	0.199	0.744	0.127
4	1.014	0.620	1.014	0.266	1.014	0.169
5	1.284	0.775	1.284	0.332	1.284	0.211

The main task of computer simulation is to obtain the temperature profile in the radiation-thermal heating in the process of synthesis and sintering of a number of magnetic materials and the determination of the temporal parameters of the heating process.

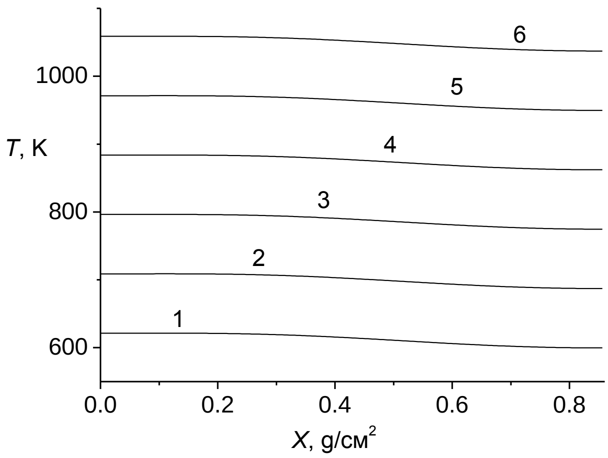

Figure 5. The temperature distribution along the depth of the sample from the time of exposure (when the beam current pulse is 0.25 A, the pulse duration of 500 μsec and pulse frequency of 10 Hz). Curve 1 corresponds to t_{exp} = 140 sec, 2 - 160 sec, 3 - 180 sec, 4 - 200 sec, 5 - 220 sec, 6 - 240 sec.

For the experimental studies were calculated source parameters for heating materials with the following characteristics: λ = 0,063 W/ (cm * K), ρ = 3÷4.7 g / cm^3, c = 0.8 J / (g * K). These settings correspond to the ferromagnetic material which was heated by the electron accelerator. The beam energy E_e = 2.4 MeV, current $J_{имп}$ = 0.25 A, d_{ti} = 500 μsec. Material thickness 2 mm. Figure 5 shows the temperature distribution along the depth of the material for different time intervals of exposure, frequency source F_i = 10 Hz. Temperature values when changing the frequency of the source is presented in the table 2:

Table 2. The temperature dependence of the frequency.

F_i [Hz]	t_{exp} [sec]	T_{cp} [K]
11	180	870
13	180	1040
15	180	1170
17	180	1360

4. Conclusion

Created a computer program to simulate the heating of the object stream of accelerated electrons. We have compared the simulation results with experimental results. In real experiments the temperature in 1200^0C was obtained when F_i = 10 Hz, with an error of less than 3% corresponds to the results of computer simulation. The program can be effectively used to solve optimization problems of the processes of obtaining materials with specified characteristics.

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5. References

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