Numerical simulation of induction heating of a carburizing container with a titanium sample

A Voyko¹, M Fomina¹, A Shumilin¹, I Rodionov¹, S Kalganova¹, I Artyukhov¹, A Fomin¹
¹Yuri Gagarin State Technical University of Saratov, Saratov 410054, Russia

Abstract. Induction heating of a carburizing container using induction heating was studied. The dependency of heating up to the temperature of 1660 ºC was determined depending on the current values \( I \) from 0.5 to 2 kA on the inductor at the frequency of 112.5±2.5 kHz. Experimental results were compared to the data of numerical simulation of heat transfer in the carburizing container.

1. Introduction

Induction heating is widely used in the treatment of metals, e.g. in heat treatment of steel, aluminium and titanium [1-3]. Simulation of the physical processes is frequently applied when it is necessary to assess the distributed parameters in the elements of sensors, electronic components and devices [4-7].

Control of technological parameters is an important component of any technology. For example, in the production of micron-sized particles by granulation, monitoring and control of treatment parameters is important [8-10]. Tasks regarding the determination of the physical fields distribution are quite frequent and they can not be investigated by the direct methods. In this case, theoretical methods of system analysis are applied, in particular numerical methods of calculation. The initial information is the process data, e.g. power consumption, inductor current and frequency, as well as the temperature on the surface of the technological volume, i.e. the container for chemical-thermal processing (carburization).

The carburization process using a solid carburizer (carbon-containing medium) is performed in sealed chambers made of refractory metal. Products after carburization are characterized by higher hardness and changes in the chemical composition of the surface, in particular the appearance of carbides. In this paper, the effect of induction heating on a metal (titanium) container containing metallic samples and a carburizer is investigated.

2. Methodology

The technological area elements included an inductor, a dielectric chamber, a carburizing container and heat-insulating limiting parts. The current on the inductor changed from 0.5 to 2 kA on the inductor at the frequency of 112.5±2.5 kHz [11].

Numerical simulation was performed using "Elcut 6" software. In this program the geometry of the "inductor – carburizing container" system was drawn, further a finite element mesh was generated and AC magnetic field distribution and non-stationary heat transfer were modeled depending on the peculiarities of heat source and heat loss due to convection and radiation (Figure 1). As the main elements of the "inductor – carburizing container" system were selected: an inductor (1); water (2); a quartz chamber (3); a metal container (4) with the outer diameter of 14 mm; a stopper (5); dielectric inserts (6); carbon-containing medium (7); titanium samples-disks (8) with the diameter...
of 6 mm. The following values and indices were determined in the simulation: the distribution of the current density \( j \) and the temperature \( T(t) \) at different time \( t \).

3. Results

Modeling the current density \( j \) and the temperature field \( T \) showed that the optimum current \( I \) for heating the container in the "inductor – carburizing container" system was the current \( I = 1.5 \) kA, since this value provided the required temperature for the carburizing process.

![Figure 1(a,b). Geometric model of the "inductor – carburizing container" system (grid spacing 1 mm) (a); finite element grid (triangular shape) (b).](image)

The obtained model of the current density distribution showed that the current density in the inductor reached a maximum \( j = 7 \times 10^7 \text{A/m}^2 \) (Figure 2).

![Figure 2. Distribution of the current density \( j \) in the elements of the "inductor – carburizing container" system at a current on the inductor \( I = 1.5 \) kA (container diameter 14 mm).](image)
In the container, three regions with different current density were distinguished, which correspond to the titanium samples and carbon-containing medium (Figure 3). The current density in the carbon-containing medium reached a larger value \( j = 0.85 \times 10^7 \text{A/m}^2 \) (Figure 3a). Thus, in these areas more heat was emitted compared to the titanium elements of the system (Figure 3b). It is reasonable to assume that during the induction heating the core of the container will be heated to a higher temperature than its surface. The current density difference in the carbon-containing medium and titanium was clearly shown on trajectories \( L \) from the periphery to the center of the container (Figure 2,3). The obtained graphs characterize the substantial non-uniformity of the current density \( j \) in the elements of the system.

![Figure 3(a,b). Graphs of the current density \( j \) as a function of the depth \( L \) in the container and in the carbon-containing medium (a); in a titanium container and a sample disk (b).](image)

The current density in the container wall (section \( L \) from 0 to 4 mm) was characterized by a small value. In the region of the carbon-containing medium (section \( L \) from 4 to 7 mm), the current density was an order of magnitude higher and amounted to \( j = 6.5 \times 10^6 \text{A/m}^2 \). The current density on the container surface reached \( j = (2.6–2.8) \times 10^5 \text{A/m}^2 \) and at a depth \( L = 2.6 \text{ mm} \) it was minimal \( j = 0.8 \times 10^5 \text{A/m}^2 \).

The results of the preliminary experiment and modeling of the temperature field showed that the temperature in the container was distributed uniformly (Figure 4).

4. Conclusions

Thus, the simulation data on induction heating at 0.6–1.5 kA corresponded to the experimental results. At a minimum inductor current of 0.6 kA, the carburization temperature was reached (about 900–950 °C), however, for a higher rate of carburization of small-sized products, it is advisable to provide a current value of the inductor of at least 1.5 kA. At the inductor current \( I = 1.5–2 \text{ kA} \), there was a rapid heating of the container up to the melting temperature \( T \geq 1660 \text{ °C} \). This processing mode can be used only for accelerated heating of the container, however, it is recommended to perform the exposure at the inductor current \( I = 0.6–1.5 \text{ kA} \).
**Figure 4(a, b).** Arrangement of the elements of the system including an inductor (1), a dielectric chamber (2), a carburizing container (3) and heat-insulating limiting parts (a); the result of the thermal field numerical simulation at $I = 1.5$ kA and $t = 300$ s (b).

**Acknowledgments**

The research was supported by the Russian Science Foundation (project No. 18-79-10040). A. Fomin expresses his gratitude to the company “TOR” for the test access to “Elcut” software.

**References**

[1] Demidovich V B, Chmilenko F V and Rastvorova I I 2015 Acta Tech. CSAV. 60 107
[2] Kuvaldin A B, Lepeshkin S A and Lepeshkin A R 2014 Acta Tech. CSAV. 59 279
[3] Fomin A, Dorozhkin S, Fomina M, Koshuro V, Rodionov I, Zakharevich A, Petrova N and Skaptsov A 2016 Ceram. int. 42 10838
[4] Aman A, Majcherek S, Schmidt M-P and Hirsch S 2014 Procedia Eng. 87 124
[5] Aman A, Majcherek S, Hirsch S and Schmidt B 2015 J. Appl. Phys. 118 164105
[6] Majcherek S, Aman A and Fochtmann J 2016 J. Micromech. Microeng. 26 025013
[7] Aman S, Aman A and Morgner W 2013 Compos. Sci. Technol. 84 58
[8] Bück A, Palis S and Tsotsas E 2015 Powder Technol. 270B 575
[9] Palis S and Kienle A 2014 J. Process Control. 24(3) 33
[10] Palis S and Kienle A 2013 Ind. Eng. Chem. Res. 52 408
[11] Fomin A A, Fomina M A, Steinhauer A B, Petrova N V, Poshivalova E Yu and Rodionov I V 2014 Proc. 55th Int. Sci. Conf. on Power and Electrical Engineering of Riga Technical University (Riga), (Riga: IEEE) p 111