The influence of power consumption and current in the inductor on the temperature of heated titanium samples

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Abstract. The measurement results for power consumption and current in the inductor and heating temperature of titanium disc-shaped and cylindrical samples when treated with high frequency currents within 90 to 120 kHz have been presented. The influence of the current in the inductor in the range of 0.3 to 8.5 kA on the heating kinetics of disc-shaped samples within 800 °C to 1500 °C in the air has been identified. A regression model describing the temperature change depending on the power consumed by the heat treatment device as well as its duration has been built.

1. Introduction

Determination of the current-voltage and watt-ampere characteristics of various electronic devices and electrotechnological processes, e.g. the ones accompanied by the occurrence of gaseous electrical discharges (electric arc welding, magnetron sputtering, electric spark alloying, plasma spraying) or high-frequency treatment by electromagnetic waves is important for the development of technological recommendations and optimal modes [1-3]. In order to investigate various systems such as sensor modules the characteristics of the transformation of the input-output signal should be studied as well [4]. When the system "inductor-product" is studied the transfer characteristics of the device for heating with high frequency currents (HFC) are determined together with those of the heat treatment process. The current in the inductor is necessary to develop the technological process with the use of HFC heating devices having the parameters different from the ones described in this work [2]. However, in this case a technological parameter should be used – the consumed power, which is determined by the product of voltage on the laboratory transformer output by consumed effective current. The aim of this work is to establish the dependence between the power consumed by the HFC heating device and the current in the inductor as well as to determine the heating kinetics at different power values.

2. Methodology

To heat the titanium samples (mass 1.1–1.3 g) of the disc-shaped (diameter 14 mm, length 2 mm) and cylindrical (diameter 3.5–4 mm, length 10–13 mm) products special designs of inductors of a cylindrical spiral shape were used [2].

Clamp meter "UT 205" (Uni-Trend Group Ltd.) was used to measure the current in the inductor $I$. This clamp enables the measurement of the effective current $I$ from 0 and 4 kA in the high frequency range (within 150 kHz) (Figure 1a). This meter enables the increase of the measurement range from 4 to 10 kA in the short-term use. Current clamp 2 was located close to the inductor so that the water-cooled copper conductor line $I$ passed through the measuring part (clamp) of the device (Figure 1b).
Figure 1(a, b). Measurement of the inductor current (the actual value on the indicator is about 3.7 kA) (a); position of the measuring part of the current clamp from the side of the heated disc sample (b).

The temperature $T$ of the heated samples in the range from the room +20 ºC to +1100 ºC (+1650 ºC) was controlled by a non-contact method with the use of infrared (IR) pyrometers "DT-8828" (CEM Instruments) and a high-temperature one – "MS6550B" (Precision Mastech) [2] (Figure 2).

Figure 2. Non-contact measurement of the sample temperature.

The disc sample 2 located in the inductor 1 with an insulating cover and water-cooled copper current-carrying parts 4 were located at a sufficient distance from the pyrometer 3 in order to exclude its damage (Figure 2).

3. Results

The applied circuit design of the HFC device allowed regulation of the amount of the consumed electrical power $P$ with the help of voltage $U_c$ (Figure 3a). At the input of the device the value of the consumed current $I_c$ was also controlled.
Figure 3(a, b). Volt-ampere characteristics of the device for treatment with HFC with various systems "inductor–product" (a); dependency of the current in the inductor on the power (b).

When the technological modes of the treatment with HFC are determined it is necessary to know the current in the inductor $I$ (Figure 3b). The dependency of the current $I$ on the consumed power $P$ was received for different systems "inductor-product": 1 – for titanium disc-shaped samples (mass 1.1–1.3 g); 2 – for cylindrical products with a smaller (less than 4 mm) diameter (mass 1.0–1.2 g); 3 – for a product with a mass 80 times bigger compared to the disc-shaped sample.

Approximation of the experimental data on the temperature dependence $T(P,t)$ on the consumed electric power $P$ and the treatment duration $t$ for the considered temperature range was presented in the polynomial form (1).

$$T(P, t) = -1700,15 + 315,67\times\ln(P) + 64,85\times t - 2,27\times t^2 + (0,04\times10^{-2})\times t^3 - (3,4\times10^{-4})\times t^4 + (1,1\times10^{-6})\times t^5,$$

(1)

This type of model made it possible to establish a direct-proportional temperature dependence on the natural logarithm of the consumed electric power $P$ (coefficient of multiple determination $R^2 \approx 0.91$). In the graphical form the regression model $T(P,t)$ was characterized by the presence of heating and exposure areas (Figure 4).

Figure 4. Heating kinetics at different power values.
Knowing the watt-ampere characteristics of the device for the heating with HFC the technological modes for these types of the treated disc-shaped samples and cylindrical products can be determined. When the modes of treatment of titanium products using HFC are determined the kinetic curves of heating at the chosen consumed power \( P \) should be received if the developed device for the treatment with HFC is applied.

4. Conclusions

The summarized data on the technological parameters (power \( P \) and current in the inductor \( I \)) and kinetic temperature characteristics \( T(P,t) \) allow the development of the technological recommendations for the treatment of small-sized titanium products with the use of HFC.

According to the previously obtained data on the composition, structure, and physico-mechanical properties of oxide coatings produced on commercially pure titanium, the application of temperature range from 800 to 1000 °C appears to be most reasonable [5]. The samples should be heated to the given temperatures at the current in the inductor around 7.3±0.2 kA, which corresponds to the device power 1.25–1.3 kW. The exposure at temperature \( T = 800±10 \) °C should be performed at the power values of 0.28–0.3 kW and current on the inductor of 3.2±0.1 kA whereas for \( T = 1000±20 \) °C it is necessary to use a mode with parameters \( P = 0.36–0.4 \) kW and \( I = 3.9±0.1 \) kA.

Acknowledgments

The research was supported by the Ministry of Education and Science of the Russian Federation in the framework of the Program of Scientific Research in Universities (project No. 11.1943.2017/PP).

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