Approaches to Modernize Induction Heater for Purpose of Heat Treatment of Titanium Alloys

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Abstract— **Through heating of titanium before plastic deformation is energy and time-consuming process. The main problem carrying out the process is used resistance furnaces which require a lot of time and power. The paper suggests implementing induction heating for purpose of reducing treatment time and power. In order to realize it, the authors are considering several approaches of optimization to find out optimal modes of operation. The proposed ways to optimize heater is shape and topology optimization. The ways are implemented to Comsol Multiphysics and based on obtaining results of finite element analysis. It also discusses what geometric parameters and to what extent affect the technological mode.**

Keywords— Optimization techniques, induction heating, uniformity of temperature, numerical analysis, FEM, FEA

I. INTRODUCTION

Titanium is one of the main structural materials used in aircraft construction, military industry, shipbuilding and a number of other industries, requiring high quality materials due to safety requirements. Therefore, each step-in creating titanium products for these areas requires increased attention and the use of the latest technologies. This work is devoted to the heat treatment of titanium billets before plastic deformation.

II. FORMULATION OF THE PROBLEM

A. Finite element formulation of the problem

The process of induction heating can be presented as a doubly coupled electromagnetic-thermal problem. The 2D axis-symmetric problem of magnetic field may be described in terms of magnetic vector potential $\underline{\mathbf{A}}$ using complex numbers as shown below

$$\mathrm{curl}\,\mathrm{curl}(\underline{\mathbf{A}}) + j \cdot \omega\gamma\mu\underline{\mathbf{A}} = \mu\underline{\mathbf{J}}_{\mathrm{ext}}, \qquad (1)$$

where $\omega = 2\pi f$ denotes the angular frequency γ is the electric conductivity, μ is the magnetic permeability.

The complex current density of coil domains is written as

$$\underline{\mathbf{J}}_{\mathrm{ext}} = \sigma\left(j\omega\underline{\mathbf{A}} + \frac{U(T)}{\mathbf{l}}\right) \qquad (3)$$

где, $\mathbf{l}$ is the vector of the coil length and voltage $U(T)$ is defined as following

$$U = K_p(T_g - T_m) + K_i\int_0^t (T_g - T_m)\,dt + K_d\frac{dT_m}{dt}. \quad (4)$$

The equation is dependent on the temperature T_m which is measured at a point of workpiece surface in the middle of its length and the given temperature T_g. Control is realized by selecting factors K_p, K_i and K_d. And the temperature is calculated by classic heat transfer equation in the general form

$$div(\lambda(T)grad(T)) = \rho C_p(T)\frac{\partial T}{\partial t} - p. \qquad (5)$$

Here p is the dissipated Joule power, C_p is the heat capacity, λ is depicted thermal conductivity, ρ is the mass density.

The process of irradiation of heat from surface is taken into account by boundary conditions implemented in Comsol called «Surface-to-surface radiation».

B. Formulation of the problem t

The figure 1 is shown geometry of the installation and depicted the main changing parameters.

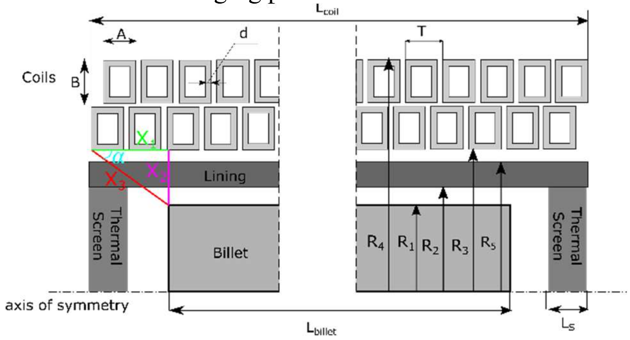

Fig. 1. Main geometry

III. RESULTS

In the classical theory of induction heating, «ideal» cases are considered in which heat losses due to radiative exchange, convective heat transfer, and also nonlinear physical properties of the heating workpiece in space are neglected. This theory also claims that the inductor overhang should be more than 15% of the workpiece length for uniform heating along the workpiece length, and maximum efficiency is achieved by reducing the gap between the inductor and the workpiece. These findings are usually obtained using analytical expressions or empirical experience. But in the process of optimizing the induction heater in [1], it was noted that in some cases, an increase in the gap leads to a decrease in the temperature difference at the end of heating.

Let us consider the two cases of "ideal" and "real". In the ideal case, we neglect any heat loss (radiation, heat transfer), but we take into account the uneven distribution of the magnetic field. In real cases, the exchange of radiation, heat transfer to the environment, the influence of the lining, etc. are taken into account. In order to conduct a correct comparison in all cases, the maximum current is the same, whom is changing dependent on the temperature at a certain point according to a similar law as in equation (4).

Analyzing figure 2, it can be concluded that with an increase in the length of the inductor (a negative overhang indicates that the length of the inductor is less than the length of the workpiece), both for the real case and for the ideal one, the temperature difference decreases. But for an ideal case, there is a range of minimum difference (extension length 200-250 mm) after which the temperature difference curve begins to increase again. An increase in the gap for both cases leads to an increase in the temperature difference in the volume.

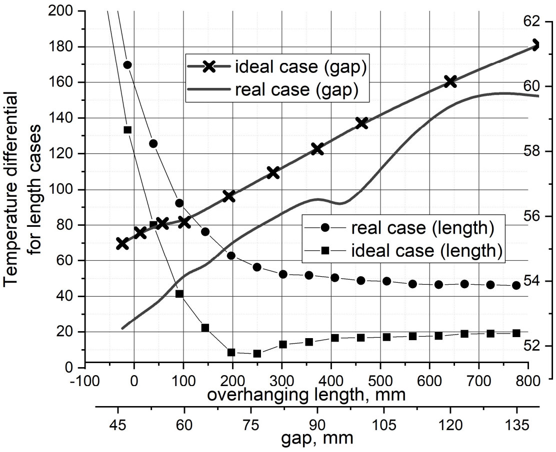

Fig. 2. The temperature difference at the end of heating for a real and idealized case depending on the departure and clearance

It is worth considering several cases with different ratios of the inductor offset and the gap. These results are shown in Fig. 3 for an ideal case and in Fig. 4. for the real case. Analyzing the data of the figures, it can be noted that with an increase in the length of the departure, a moment arises when a further increase in the gap leads to an increase in the uniformity of heating.

One explanation for the fact that there are optimal ratios of length and gap, and as a consequence of the angle between them, is the vortex nature of the magnetic field. In the center of the billet, the magnetic field can be considered almost solid, i.e. only the azimuthal component of the magnetic field prevails, and at the edges of the workpiece, the field has a vortex character and closes to itself through the edges of the workpiece (see Figure 5). The influence of field vortices can be weakened by changing the ratio of the inductor to the gap and the gap, and as a result, align the magnetic field in the workpiece.

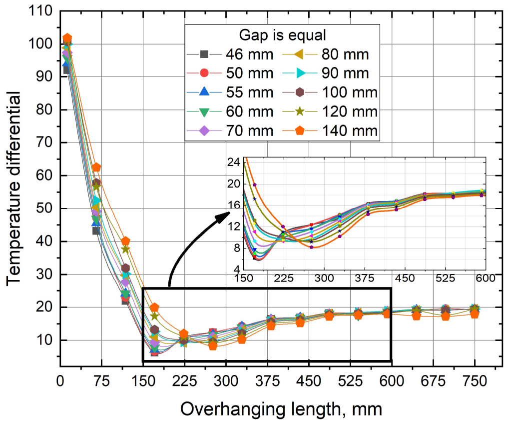

Fig. 3. Temperature difference at the end of heating for an ideal case depending on the inductor

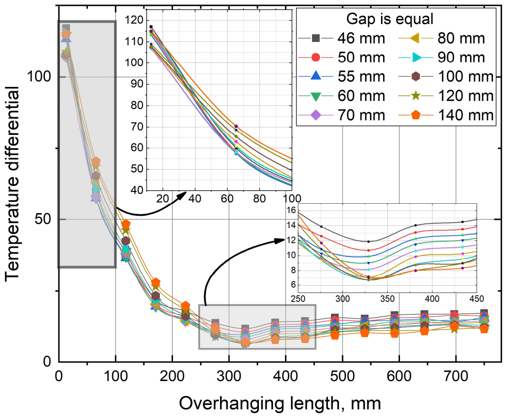

Fig. 4. The temperature difference at the end of heating for the real case

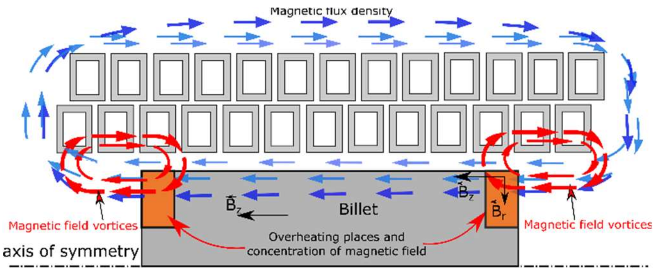

Fig. 5. Explanation of overheating of the marginal zones

IV. CONCLUSION

In the work will be considered approaches how to choose the most appropriate way in order heat up uniformly workpiece. Here, authors show briefly general results as ratio of lengths of inductor and workpiece influence on distribution of temperature along length. In full paper, the result will be added by optimization study and additional parametric explanations.

ACKNOWLEDGMENT

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