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FEM Investigation of Induction Heating System for Pipe Brazing

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***Abstract*—**The paper deals with determination of electromagnetic and temperature field distribution of induction heating system used for pipe brazing. The problem is considered as coupled – time harmonic electromagnetic and transient thermal field. It has been solved using finite element method. The detailed maps of electromagnetic and thermal field distribution have been obtained. The good understanding of the processes in the considered system ensures possibilities for control, management and increasing the efficiency of the welding process.

***Keywords*—**Electromagnetic field, temperature field, finite element method, induction heating, pipe brazing.

I. Introduction

THE technologies based on induction heating are widely used in the industry for thermal treatment of conducting parts. Induction heating has a variety of advantages - high efficiency, very good accuracy in heating of certain zones in a short time, clean operating conditions. Due to its effectiveness and capabilities, it is of permanent interest to the researchers both in the past [1] and nowadays [2]-[7].

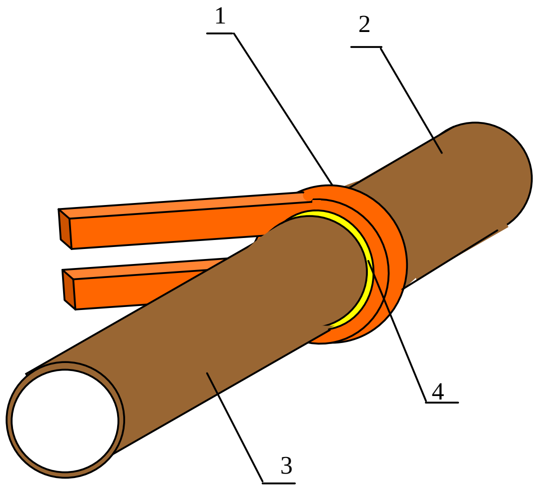
The motivation for carrying out the present work is necessity of real system development, used for socket brazing pipes. The main goal of the investigation is estimation of possible variants of such devices. The detailed coupled - electromagnetic and temperature field determination can be used in further work, concerning special requirements for temperature distribution in the heated details. So it is a first step for solving the optimization problem. The profound understanding of the induction heating processes in the system gives also good possibilities for estimation of the device efficiency, proper control and management of the brazing process.

II. Description of Investigated System

The principal geometry of the investigated system is shown in Fig. 1. The system consists of inductor 1, pipes subject to brazing - 2 and 3 and filler 4.

The system is designed for socket brazing pipes from 0.250 to 2.0 inch diameter, which covers the bulk of brazing. Wall thickness of pipes is between 0.06 ÷ 0.13 inches. Filler material is BCupand BAg. Maximum length of braze joint is 0.5 inches for 2 inch pipes.

The frequency range is 50÷200 kHz, the coil current - 600÷1000A and 6 kW maximal continuous output power.



1. inductor
2. copper pipe
3. copper pipe
4. BAg filler

Fig. 1 Geometry of the investigated system

The variant of investigated system is considered with 950 A applied current and 150 kHz frequency. The two copper pipe parts are with diameter D = 2 inch and thickness 0.1inch. The filler is BAg with size 0.1x 0.2 inch. Maximum heating time is 3 min and the end heating temperature is about 750 ^{0}C. The cooling water flowing inside the conductors is with temperature 40^{0}C. The temperature of ambient air and the initial temperature of the heated pipe is T_0=20^{0}C.

III. Mathematical Model of the Coupled Field

The field problem is considered as coupled - electromagnetic and thermal.

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The electromagnetic field is analysed as time harmonic and eddy current losses in conductive parts of the system are considered as heat sources in analysis of transient thermal field problem. The electromagnetic and transient thermal problems are solved in a domain consisting of the whole system and a wide buffer zone around it (Fig. 2).

A. *Region of Investigation*

The investigated region is shown in Fig. 2. It features axial symmetry and includes the following subdomains:

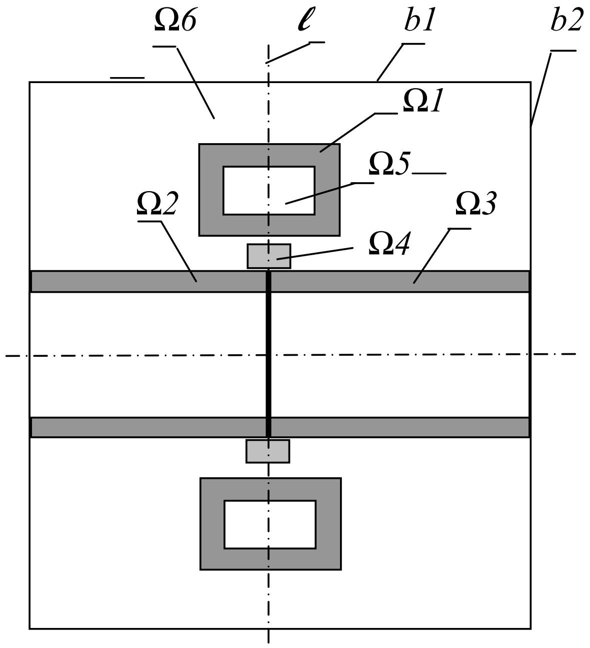

Fig. 2 Investigated region

Ω1- inductor;
Ω2, Ω3 – two copper pipes;
Ω4- filler;
Ω5- cooling water;
Ω6- buffer zone with air
b1, b2- boundaries of the buffer zone
l- line of the contact of the two pipes

B. *Governing Equations*

The time harmonic electromagnetic field is modelled by equation:

$$\nabla \times (\mu^{-1} \nabla \vec{A}) = \vec{J}_e - \sigma \frac{\partial \vec{A}}{\partial t} \quad (1)$$

where $\vec{A}$ is magnetic vector potential;
σ is electric conductivity;
μ is magnetic permeability;
and $\vec{J}_e$ is current density.

Flux-parallel boundary conditions are imposed on the boundaries *b1* and *b2* of the buffer zone.

The time varying electromagnetic field produces eddy currents:

$$\vec{J} = j\omega\sigma\vec{A} \quad (2)$$

The corresponding Joule losses are source of the heating in the region:

$$Q = \frac{[\sigma]^{-1} \vec{J}\vec{J}^*}{2} \quad (3)$$

The transient thermal field is modeled by equation:

$$\rho.C \frac{\partial T}{\partial t} + \nabla(-k \nabla T) = Q \quad (4)$$

where k is thermal conductivity;
T is temperature;
ρ is a density;
C is specific heat;
and Q is heat source, obtained in electromagnetic field analysis.

The convection boundary conditions are posed both for outer boundaries of the inductor and the pipe and water cooling of the inner inductor boundaries:

$$F_n = h(T - T_{\text{inf}}) \quad (5)$$

where h is the convection coefficient;
T_{inf} is the external bulk temperature;
F_n is the normal heat flux.

Radiation from the outer surfaces of the inductor, pipes and filler is also taken into account using

$$F_n = \beta K_{SB} (T^4 - T_{\text{inf}}^4), \quad (6)$$

where β is emissivity;
K_{SB} is Stefan-Boltzmann constant.
The initial temperature T(x,y,0) = T_0=20^0C.

IV. FEM Analysis – Numerical Simulations

Numerical simulation of the coupled - electromagnetic and thermal fields was carried out using finite element method (FEM) and QuickField 5.6 software package [8].

In Fig. 3 a part of finite element mesh in the investigated region is shown.

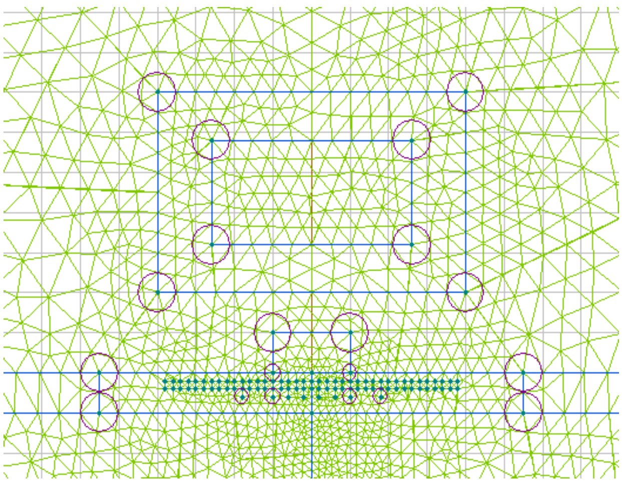

Fig. 3 Part of the FE mesh in the investigated region

Magnetic field lines and total current density distribution are presented in Fig. 4. In Fig. 5 the current density distribution in the filler and in the two pipes is shown. Estimation of eddy current distribution in the investigated region shows that it is rather non-uniform and, as it can be expected, the induced currents are concentrated at the surfaces. Special attention is paid on the pipe surface where the maximal values of current density are about $10^8 A/m^2$.

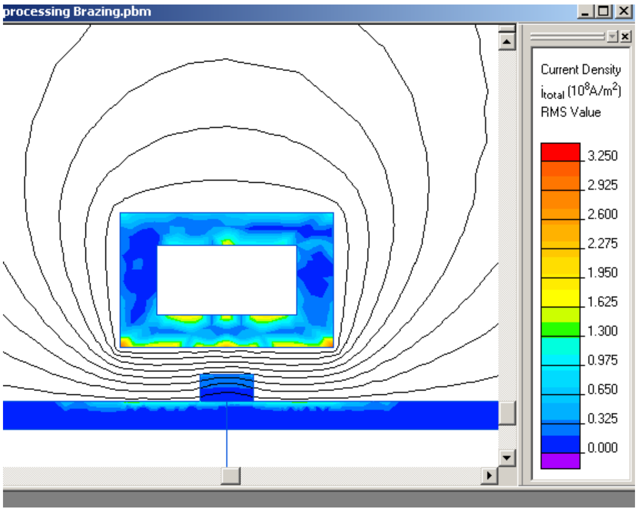

Fig. 4 Magnetic field lines and total current density distribution in investigated region

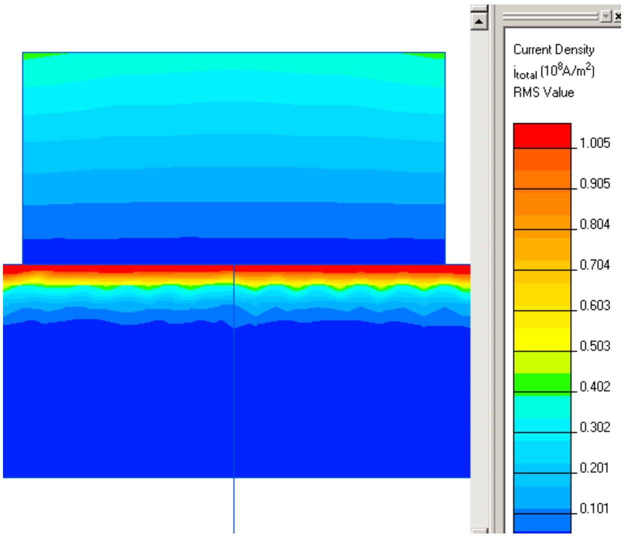

Fig. 5 Current density distribution in the filler and in the pipes

The transient thermal field of the modeled system has been studied during 3 minutes induction heating. The process of temperature change is illustrated in Fig. 6 and Fig. 7. The maximal achieved temperature is about 780^{0}C. In Fig. 6 is shown the temperature distribution for three different moments (t_1=1min, t_2=2min, t_3=3min). The maximal values of the temperature are: at t_1=1min, T_1max=460^{0}C, at t_2=2min, T_2max=635^{0}C and at t_3=3min, T_3max=780^{0}C.

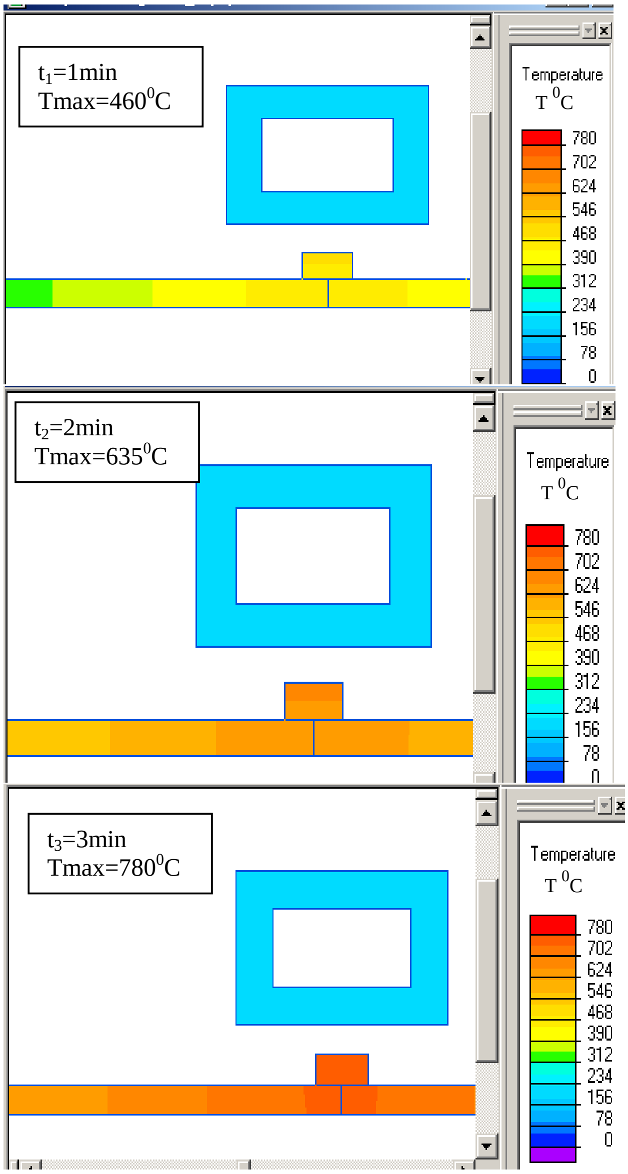

Fig. 6 Temperature change after 1, 2 and 3 minutes heating

The process of temperature increase in the point of maximal temperature during 3 minutes heating is shown in Fig. 7.

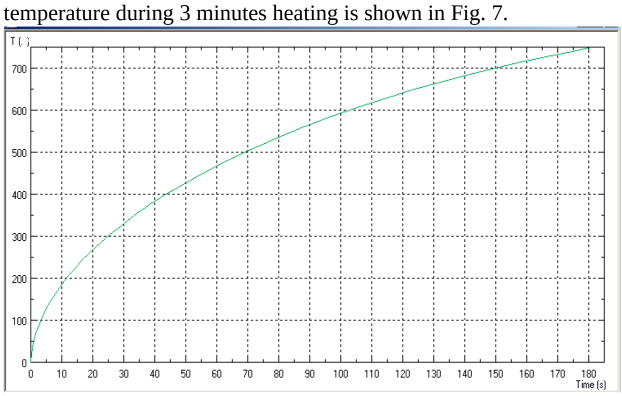

Fig. 7 Temperature increase in the point of maximal temperature during 3 minutes heating

V. Conclusion

Determination of electromagnetic and temperature field distribution of induction heating system used for pipes brazing was obtained. The problem was considered as coupled – time harmonic electromagnetic and transient thermal field. It has been solved using finite element method and QuickField 5.6 software package. The detailed maps of electromagnetic and thermal field distribution have been obtained. The results can be used in the next work, concerning special requirements for temperature distribution in the heating details. So the presented investigation is a base for solving of the optimization problem and gives good possibilities for estimation of the device efficiency, proper control and management of the brazing process.

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