EXPERIMENTAL STUDY OF THE INDUCTION HEATING IN THE MANUFACTURING OF METALLIC TUBES BY LONGITUDINAL WELDING PROCESS

A. SPAHIU[1]

Această lucrare tratează studiul experimental al încălzirii prin inducție, în înaltă frecvență, folosită în procesul de sudare longitudinală prin presiune a țevilor metalice. Studiul parametrilor ce influențează distribuția temperaturii în tub este foarte important pentru optimizarea procesului de sudare. Acest studiu este completat de dezvoltarea şi exploatarea modelului numeric al ansamblului experimental. Prin urmare, articolul conține şi studiul magnetotermic al procesului de încălzire prin inducție.

This paper deals with the experimental study of high frequency induction heating in the longitudinal welding by pressure of the metallic tubes. The study of the parameters that influence the temperature distribution in tube is very important in the optimization of the welding process. This study is carried out by using the developing and results analysis of the numerical model of the experimental assembly. More, the article contains the magnetothermal study of the induction heating process.

Keywords: induction heating, longitudinal tube welding, magnetothermal coupling.

1. Introduction

The principle of the tubes welding by induction heating [1][2] deals with a flat metallic strip that is gradually bended in cylindrical shape by the action of mechanical forces, and is introduced into an inductor supplied in high frequency. The edges of the strip make a V shape whose vertex stands for the contact point. The magnetic field generated by the inductor causes the developing of the induced currents which pass through the most part of the tube surface covered by inductor, then pass along the edges to be welded, and finally are closed by the welding point, Fig. 1 [3]. However, a part of the induced current passes through the strip edges situated in the opposite direction with respect the welding point, and are closing by the inner surface of the metallic strip.

[1] PhD Student, Dept. of Electrical Machines, Electrotechnical Materials and Electrical Drives; PEM_NM laboratory, University POLITEHNICA of Bucharest, Romania

In order to reduce this component of the induced current it is necessary to place a magnetic circuit inside the cylindrical shaped strip. The magnetic circuit shall be made from a material characterized by high magnetic permeability and low losses in high frequency [4].

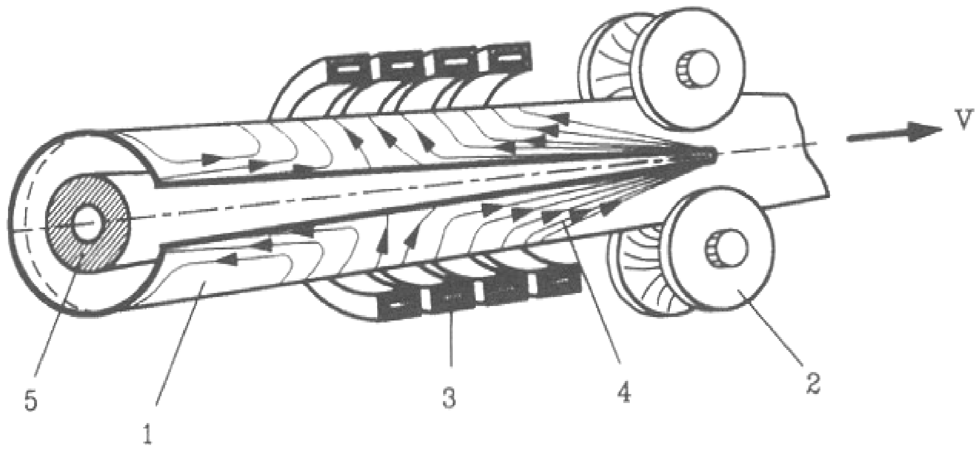

Fig. 1. Principle of the longitudinal tube welding using the induction heating process
1-metallic sheet; 2-forming rolls; 3-inductor; 4-usefull current; 5-impeder

A complete study of an electromagnetic processing device concerns in finding of the parameters that influence the distribution of the main quantities in the workpiece. Thus, by making a thorough study, an optimal set of values can be found so that the equipment to work at high efficiency.

The measurements performed on the experimental assembly have shown the influence on the temperature distribution of the:

- presence of the magnetic impeder;
- frequency and current of the supply source;
- inductor position with respect the welding point;
- impeder position with respect the welding point.

2. Experimental model

The experimental model of the tube welding assembly consists of a metallic cylinder containing a longitudinal slit, and an inductor supplied in high frequency, surrounding the tube, Fig. 2. Five thermocouples are welded along the slit starting from the welding point, Fig. 5.

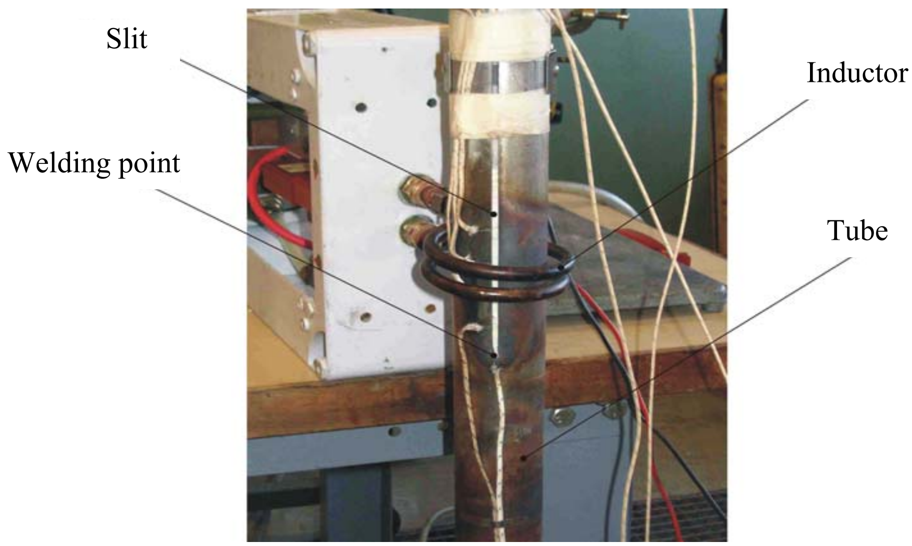

Fig. 2. Experimental model of the welding assembly

3. Experimental testing

3.1. Influence of the impeder presence

Here are compared two experimental tests the presence of the impeder.

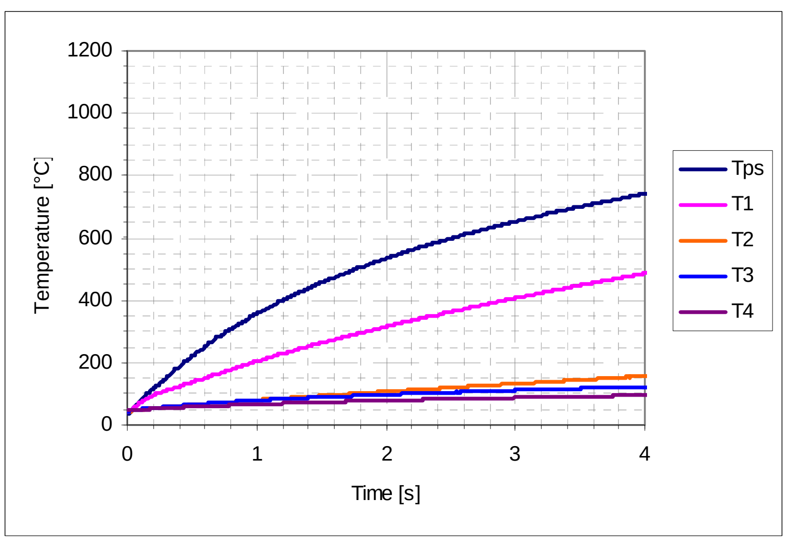

Fig. 3. Temperature evolution for the application without impeder

The application without impeder, Fig. 3, is characterized by the following data: frequency f = 378 kHz, inductor current I_{ind} = 372 A, and the power at the generator terminators P_{gen} = 3.35 kW.

The application with impeder, Fig. 4, has the following data: f = 359 kHz, I_{ind} = 327 A and P_{gen} = 3.32 kW.

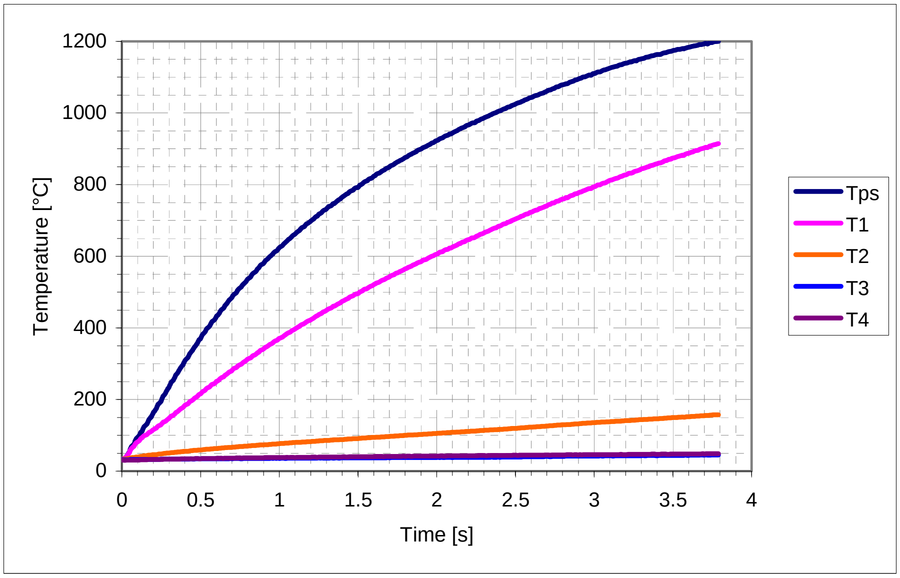

Fig. 4. Temperature evolution for the application with impeder

The above graphics show the following conclusions:

- the presence of the impeder within the tube forces the induced currents to close through the welding point area;
- though the values of the power at the generator terminals and of the inductor current are superior for the application without impeder, the heating rate in the welding point is higher for the application with impeder.

3.2. Influence of the inductor position with respect the welding point

In this section is studied the influence of the inductor position with respect the welding point. These positions and their notation are shown in Fig. 5.

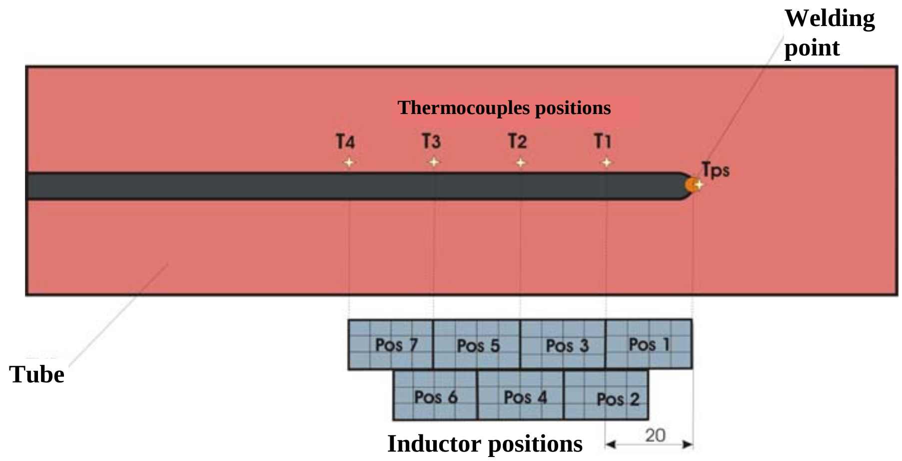

Fig. 5. Inductor positions with respect the welding point

The temperature evolution in these five thermocouples, Fig. 5, at the moment t = 2.5 s, depending on the inductor position with respect the welding point is depicted in Fig. 6.

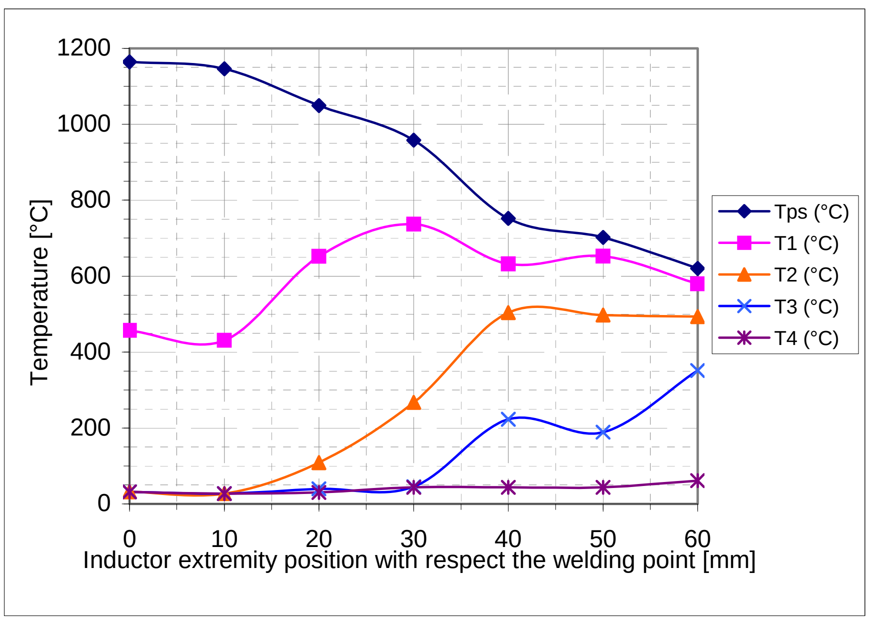

Fig. 6. Temperature at the moment t = 2.5 s for several positions of the inductor with respect the welding point

The analysis of the above results leads to the following remarks and conclusions:

- between the two extreme positions of the inductor, the frequency varies with 12 %; for no-load conditions, the value of the frequency decreases due to the reactive power that become important, and the capacity reactance remains constant. As the inverter is accorded to the resonance frequency, the frequency for no-load conditions will be lower than the frequency for the load regime. When the inductor is near to the welding point, we can say that the assembly operates under load conditions. As the distance between inductor and the welding point is increasing, the device working moves to the no-load conditions;
- the generator is built so that the power delivered is constant. Thus, the power at the generator terminals is almost steady, varying with 6 %;
- the current through inductor decreases with the increasing of the distance between inductor and the welding point. Thus, the difference between the extreme values is 30 %. By increasing the distance between inductor and the welding point the coupling between the inductor and the tube will get weaker, and thus the inductor current will decrease.

The evolution of the electrical parameters will tend to become steady when the distance between inductor and the welding point will surpass a certain value.

The variation of the three electrical quantities, as effect of the variation of the inductor position, influences the temperature values at the level of the five thermocouples, lead to the following results and conclusions:

- difference between the temperature registered by the welding point thermocouple is 46.73 % between the two extreme position of the inductor;
- influence of the inductor position on the tube temperature is emphasized by the suddenly increase of the temperature value at the moment $t = 2.5$ s;
- temperature in the five thermocouples starts to get uniform by moving away the inductor from the welding point.

In industrial applications it is necessary to heat the welding point to a temperature near melting in the shortest time, simultaneously being necessary the preheating of the tube edges near the welding tube at a temperature high enough to facilitate the welding process [2].

Consequently, the optimal position of the inductor with respect the welding point is between 10 mm and 30 mm with respect the welding point.

3.3. Influence of the impeder position

In this section is studied the influence on the tube temperature of the impeder position with respect the welding point.

Fig. 7 shows the positions of the impeder right hand extremity corresponding to different experimental applications.

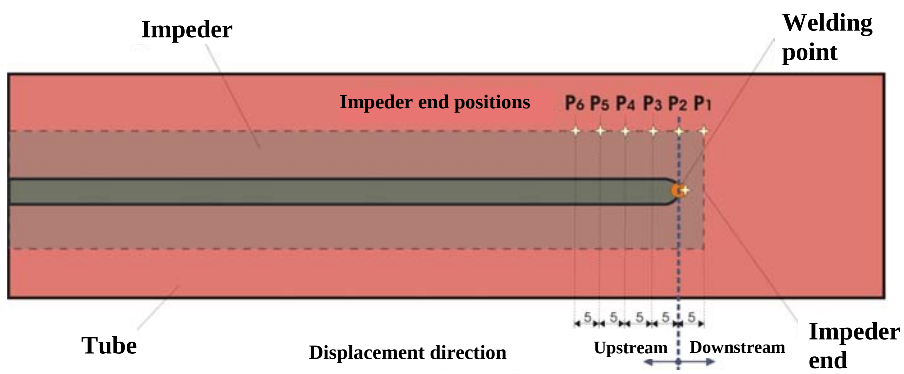

Fig. 7. Impeder position with respect the welding point

From the temperature evolution charts we can make the following conclusions:

- main electrical quantities characterizing the induction heating process have the following differences between the extremes of its values: frequency 1.5 % ; inductor current 7 %, and the power at the generator terminals 4.6 %.
- the set of graphs obtained shows that the upstream displacement of the impeder with respect the welding point, influences the heating rates (it is increasing) of the tube edges, that even exceed those of the welding point. Consequently, the best position of the impeder is at 5 mm downstream with respect the welding point.

4. Numerical analysis of the induction heating using the magneto-thermal coupling

This section deals with the numerical simulation of the induction heating in the welding process.

Here are treated not only the electromagnetic aspects of the heating process, but also, using the magnetothermal coupling, the interaction between the electromagnetic and thermal phenomena [5]. The magnetothermal coupling [6][7] allows the study of the thermal transient regime specific for the heating of the conducting workpieces placed in a.c. magnetic field. The generation of the induced currents within the workpiece heated by induction is described by Maxwell's equations, and the transient heating as results of Joule's effect of the induced currents by Fourier's equation.

4.1. Physical model

The physical model from the Fig. 8 is represented by the inductor – tube assembly from the Fig. 1, the inductor being placed in the position 3, Fig. 5. The inductor is composed of two turns and has the current I = 325 A, and the frequency f = 359 kHz.

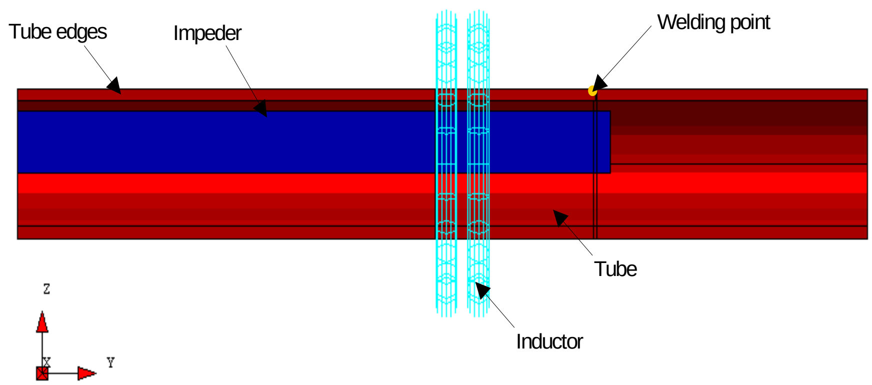

Fig. 8. Geometry of the welding by induction heating assembly (Ox view)

4.2. Numerical model

The computation domain of the electromagnetic and thermal fields is only half of the physical domain, Fig. 9, due to the symmetry with respect the plane z0y.

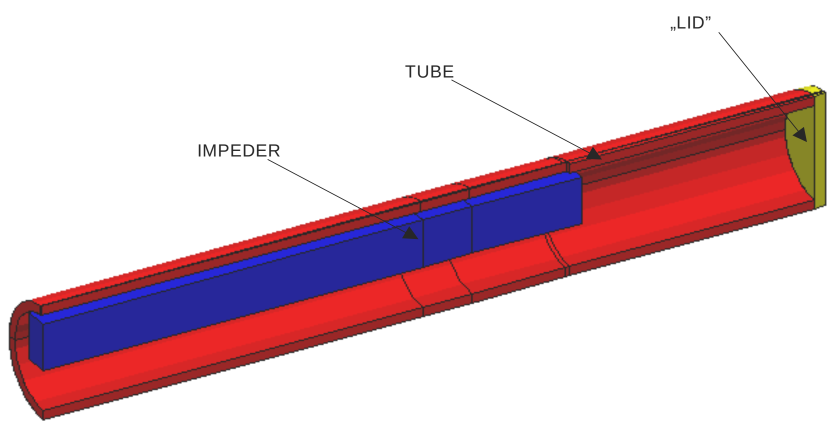

Fig. 9. Tube, Impeder and „Lid" regions of computation domain

The Tube region, Fig. 9, is composed of the tube already welded and of the part of the tube that contains the slit. The tube is a region of massive conductor type, the electromagnetic field being computed by means of the surface impedance formulation [6]-[8].

From thermal point of view, the tube is a thermal conductor type region [6]. The thermal field is computed in the volume of the tube region, and the thermal exchange with the surrounding medium at the tube surface level is defined by the coefficients of thermal exchanges by convection, $\alpha = 20$ and radiation, $\varepsilon = 0.9$. The material of tube is Inox 304L nonmagnetic steel.

The Impeder region, Fig. 9, is defined from electromagnetic point of view by using the magnetic scalar potential formulation Φ. From thermal point of view this region is inactive.

The “Lid” region, Fig. 9, is created for topological reason imposed by the transformation of the tube region in a simply connected domain. This is a region of massive conductor type, the electromagnetic field being defined by means of the surface impedance formulation associated to the regions of surface type. The resistivity of this region is 1000 times superior to the tube resistivity. From thermal point of view the “lid” region is of thermal conductor type. The thermal field is computed in the volume of the region. The "Lid" region material is characterized by the thermal conductivity $k = 0.01$ W/m·K and the specific heat $\rho C_p = 1000$ J/m^3·K. The thermal exchanges are defined as for the tube region.

The Inductor is of stranded conductor type and is composed of two turns supplied by 325 A at a frequency of 359 kHz.

The Air region is related with the air volume and with the inductor volume is defined by the reduced scalar potential formulation Φ_{red}, being inactive from thermal point of view.

4.3. Results of the numerical simulation

Chart of the temperature distribution at the end of the heating

The distribution of the temperature in tube at the end of the heating is shown in Fig. 10. This figure shows that the most important values of the temperature are reached in the tubes edges placed between inductor and the welding point.

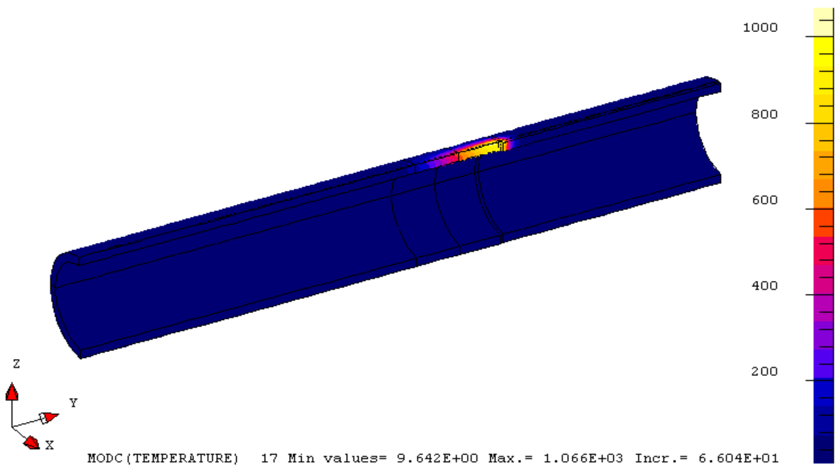

Fig. 10. Temperature distribution [°C] at the end of the heating process, t = 2.8 s

Evolution of the power induced in tube

The evolution of the power induced in tube during the transient heating process is shown in Fig. 11.

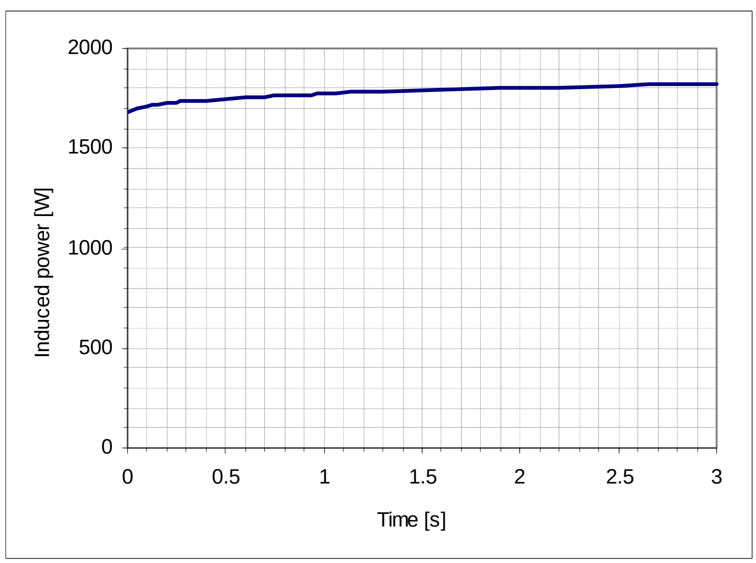

Fig. 11. Evolution of the power induced in tube during the heating process

We notice that this evolution slightly increases due to increasing of the tube resistivity with the temperature.

Temperature evolution

The temperature evolution in the welding point and in the thermocouple T1, Fig. 5, and the comparison with respect the values obtained for the experimental model are shown in the following figure:

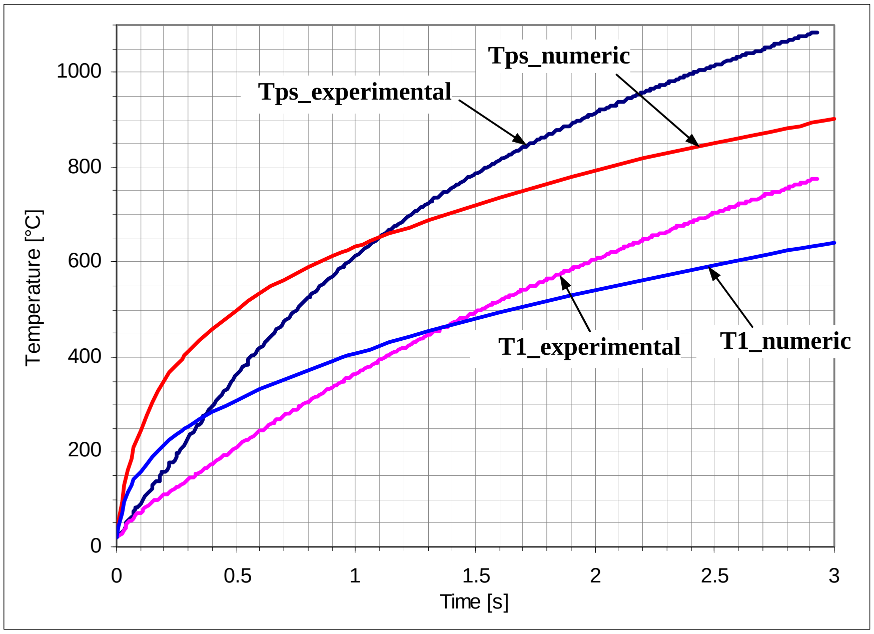

Fig. 12. Evolution of the temperature during the heating process

From the comparison between experimental study and the numerical one, of the temperature evolution in the two thermocouples, we conclude that:

- there are obtained acceptable differences despite the errors caused by the physical characteristics of the thermocouples and measuring devices, and taking into account the errors and approximations of the numerical model;
- the initial slope of the temperature evolution curves for the numerical model is higher because of the thermal inertia effect, that cause the delay of the thermocouples reaction.

5. Conclusions

The experimental study of the induction heating in the welding process of a metallic tube was carried out with the purpose of measurement of the temperature in the welding point and along the strip edges.

Thus, it was studied the influence on the tube temperature distribution of the impeder and of inductor position with respect the welding point.

It was found that changing the inductor position with respect the welding point has an important effect on the tube temperature distribution and on the electrical quantities due to the modification of the current path impedance.

As in the case of the impeder, the changing of the impeder position with respect the welding point will result an important variation of the tube temperature in the welding point and along the strip edges to be joined.

The analysis of the electromagnetic and thermal fields with the 3D numerical model of the experimental assembly had shown a good agreement with the experimental results.

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