Issues Concerning Ways to Optimize the Electrothermal Induction Systems using Informational Techniques

Teodor LEUCA*, Claudiu MICH-VANCEA**, Ştefan NAGY**

* University of Oradea, Academy of Romanian Scientists Technical Sciences Section,
1 Universitatii street, 410087 Oradea, Romania, E-Mail: tleuca@uoradea.ro

** Department of E.M.U.E.E.,
University of Oradea, Faculty of Electrical Engineering and Information Technology,
1 Universitatii street, 410087 Oradea, Romania, E-Mail: cmich@uoradea.ro, snagy@uoradea.ro

***Abstract* – This paper presents some aspects of the electromagnetic induction systems related to the possibility of optimizing the processes and devices used for the induction heating through informational techniques. We have analyzed the specific problems of the power supply installations for an inductor – product system, as the electrical energy conversion according to specific and optimal parameters of the induction heating process. The electromagnetic induction devices must be designed through the coupled numerical modeling of the circuit inverter and of the induction heating process because the product's properties and the electrical parameters of the heating device vary according to temperature. These methods together with the informational techniques are significantly improving the process: there are fewer superior disturbance harmonics, fewer losses of the static commutation elements during the commutation process, the uniform lengthwise heating of the semi-finished product.**

***Keywords:* electrothermal, induction, numerical modeling**

I. INTRODUCTION

The numerical modeling is very useful to the study of the electromagnetic induction heating device; with the help of its characteristic graphics we can observe the variation of the charge supply electrical parameters, the distribution of the electromagnetic and thermal field inside the semi-finished product which is being heated according to the charge supply electrical parameters, to the structure of the inductor – product system, as well as according to the material's properties [1], [2]. The world is using a greater range of products, the consumption level has also increased and the reserves of raw materials are not enough anymore; therefore it is necessary to quickly develop some technologies to process the raw materials and also to improve the quality of the product through optimization methods which mean lower costs for the induction heating devices building and operation. Nowadays, through the informational technology we can find new solutions and methods in order to optimize a phenomenon or a process.

The main advantages of the induction heating process are the high thermal efficiency, fast heating and easy control of its parameters in order to establish the heat level inside the semi-finished product, to repeat the process etc. [3].

The numerical modeling of the thermal and electromagnetic phenomena requires a solution for Maxwell's differential equations for the electromagnetic field and for Fourier's equation for thermal field [3]. The researches from the last decades aimed to find new adequate numerical techniques in order to offer a solution for these differential equations that have made possible the analysis of the complex field of electromagnetic phenomena. The approximation methods that are using the finite differences method and the finished element method are the most important studies nowadays.

In the specialized researches, they state that the induction heating has a greater efficiency than the charge (inductor-piece) supply at frequencies different from the industrial one. Therefore, it is necessary that the power supply device for an inductor be designed through informational techniques meant to provide an optimal working.

The electromagnetic induction heating of the semi-finished products is used in the industrial processes as an intermediary stage, called hot working; thanks to this hot working, the finished product will have a geometrical and dimensional shape of high quality. In order to accomplish these plans it is necessary that the inductor's power supply device transmit the optimal electrical parameters necessary for the heating process; it is also required that the semi-finished product be uniformly heated lengthwise through the geometry of the inductor-heated piece system or by using some active materials (magnetic field flux concentrators). In many cases, the practical experiments have shown that the thermal field is not uniform inside the product; this is the result of the induced electromagnetic field, which is weaker at the inductor's extremities. In this case we will optimally design the inductor-heated piece system by using the numerical modeling of the heating process; therefore we will find the optimal dimensions of the magnetic flux concentrators, in order to have an as uniform lengthwise heating as possible.

II. ASPECTS REGARDING OF THE OPTIMIZATION BY NUMERICAL MODELING

Nowadays the electricity consumption is higher due to the high productivity and to the higher economical efficiency of the electrothermal processes, which are the result of the automation of the electrothermal installations and of their greater power. That is why a wise design and use of the electrothermal installations require a good knowledge of all elements that are influencing the economical and energetic indicators, as these indicators are meant to improve the technological processes in what regards the quality of the products and the consumption of electricity. The energy flux between different electrical systems can be set with the help of the inductor's power supply devices.

The inductor's power supply devices are chosen depending on the application type (it may be continuous or intermittent), output power, inductor's supply voltage frequency, power change, adjustment devices, cooling methods, environment etc.

The advantage of the power supply devices for an inductor with intermediate circuit with direct current is that it diminishes the number of superior harmonics from the network electrical power supply. This kind of converter is working as described below: the three-phase industrial frequency power is conducted to an inductive or capacitive intermediate direct voltage circuit (through a converter) and then it is changed to a mid- frequency mono-phase power (through an inverter) which charges the inductor. The first types of converters were using two oscillating circuits (parallel and series) (hybrid converters); nowadays the power semi-conductive devices have become more performing and the equipments contain only one (charge) oscillating circuit, parallel or series.

The inverter (whose charge is the inductor and the semi-finished product to be heated) is a very important element in this system. The inverter is transforming the direct current to alternative current at the frequency, current and voltage parameters required by the technological process for the heating of the desired product. The output parameters depend on the desired heating process (volume heating when we desire the heat for forming, or the melting of the product; superficial heating for thermal treatments), on efficiency and on the size of the product, which is being heated.

In figure 1 it is shown the induction heating installation; it is connected to the industrial network and it is composed of an AC/DC converter, a filtering device, an inverter (DC/AC converter) and a charge.

Nowadays the design of the inductor's power supply devices is easier due to the development of the informational techniques; the numerical modeling of these devices is meant to improve their performance. A commercial soft (Matlab), which can be seen very often in the academic environment, makes possible the simulation of a converter or of an inverter.

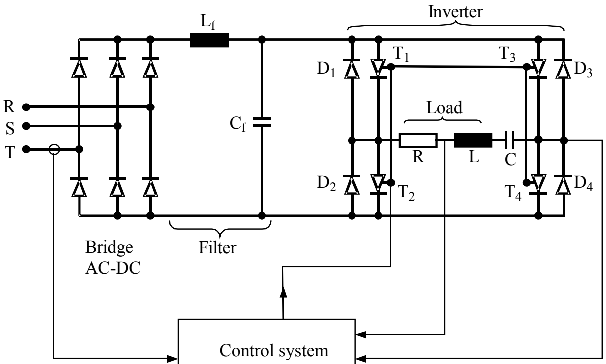

Fig. 1 – Electrical scheme of the induction heating installation.

The processes can be improved with the help of the modern calculation and simulation techniques that help us to choose the best solution, even since the project stage. The numerical modeling clearly shows the advantages and the disadvantages of one solution, with no need for previous experimental achievement.

In fig. 2 is present diagram of the coupled numerical modeling for power supply of inductor and heating process of semi-finished product. Parameters of the charge in numerical modeling of inverter are modified function of the temperature of heating process. The temperature and new values of the parameters of charge is calculated by the numerical modeling of the heating process. When we have the new values of the charge parameters, by control block of the inverter, using the PWM technique we can generate the optimum parameter of power supply of inductor to obtain the maximum efficiency of the heating process. In this way the numerical modeling is a method to approaching the real functioning of induction heating installations. The results obtained, in different phases of the numerical modeling, can be used for an advanced optimization process, which using genetics algorithms or stochastic methods [4].

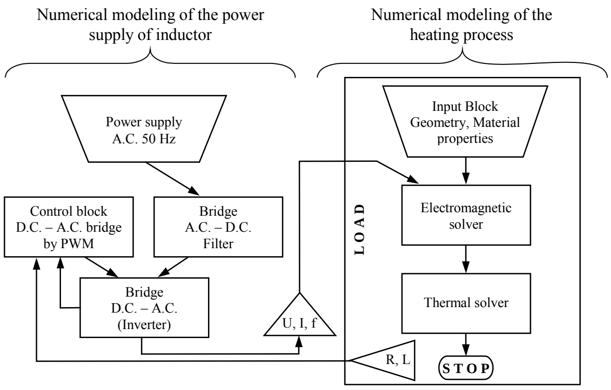

Fig. 2 – Diagram of the coupled numerical modeling for power supply and heat process.

III. THE HEATING PROCESS. THE INDUCTOR – PRODUCT SYSTEM

There appear two different phenomena during the induction heating process: the coupled electromagnetic and thermal phenomena. The coupled electromagnetic and thermal field is very useful for an optimal design of the inductor – product system. The electromagnetic phenomena expressed by Maxwell's differential equations and the thermal phenomena expressed by Fourier's equation can be easily solved through the approximation method; the most frequent is the finished element method. This method has been implemented in specific software, which is designed to offer a solution to the induction heating problems; this software is very useful for the inductor-heated piece system design for induction heating.

The volume induction heating process can be improved from many points of view; a very important aspect is the heating quality, as it is already known that the ends of the inductor are less heated; therefore, we have a non-uniform lengthwise heated semi-finished product. We may state now that the quality of the induction heating, that is the uniform lengthwise heating, represents an optimization problem of the induction heating process.

The solution for this problem requires the analysis of the equations of the induction heating phenomena in order to find proper optimization methods. In the case of volume induction heating the semi-finished product we may notice that the semi-finished product is heated according to the energy induced inside the product; the level of this energy is also depending on the geometry of the inductor – product system. We may conclude that the uniform lengthwise heating can be optimized if there is a correct distance between product and each turn of the inductor, and if the wrapping step of the inductor is appropriate [6].

The authors have achieved a study related to the volume induction heating of non-ferrous semi-finished products (aluminium bar) having the length L_2= 800 mm and the diameter ϕ_2 = 60 mm, where the temperature variation on the semi-finished product's length must not exceed 5% of the final heating temperature. In the case of a common situation, this temperature variation exceeds 5%. The numerical modeling of the induction heating process, with the help of the special software, makes possible the analysis of the elements that are causing the heating depending on duration and geometry of the inductor-heated piece system.

The two methods mentioned above for the improvement of the induction heating quality have been used for the installations that are in the project stage and for a given inductor-heated piece configuration; the results are not relevant for all types of configurations. In their researches the authors aimed to find a solution that can be applied to the already designed installations and to any configuration of inductor-heated piece system [7].

The authors recommend the use the magnetic flux concentrators at both ends of the inductor. The optimal geometrical sizes of the magnetic flux concentrators have been obtained in order to have a temperature variation lengthwise the semi-finished product less than 5% of the final heating temperature variation.

Because of the use of numerical modeling for the optimal configurations, the temperature variation lengthwise the product is under 5% (the semi-finished product has been uniformly heated lengthwise), the results can be seen in table 1.

The optimal variation of the inductor-heated piece distance is shown in fig. 3; this variation leads to the thermal distribution by induction heating like in figure 5.a. Figure 4 shows the inductor's optimum wrapping step that leads to the thermal distribution by induction heating as seen in figure 5.b. Figure 5.c., shows the distribution of the thermal field after the induction heating of the same piece through an inductor with constant diameter and wrapping step, and with magnetic flux concentrators at the ends. A third method was verified experimentally and the results are satisfactory as shown in figure 6.

Table 1 – The results of the three optimized cases of heating process.

	Initial case	With variable diameter	With variable wrapping step	With concentrator
Heating time [s]	30	30.3	31	28
Max temperature [^oC]	574.9	551.3	549.7	546.4
Min temperature [^oC]	440.0	513.9	504.3	499.3
Temperature difference per section [^oC]	134.9	37.4	45.4	47.0
Temperature difference lengthwise [^oC]	107.9	8.2	17.1	15.3
Percentage value of the lengthwise temperature variation [%]	18.7	1.4	3.1	2.8
Efficiency	37.7	38.9	37.9	37.3

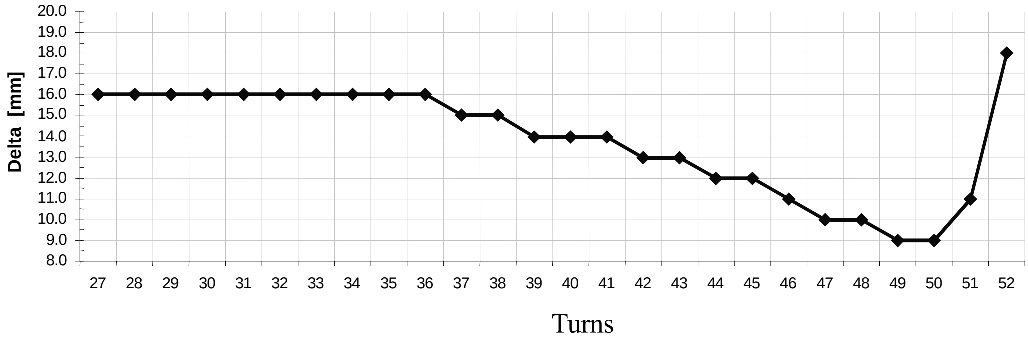

Fig. 3 – Variation of the inductor-heated piece distance from centre towards the ends.

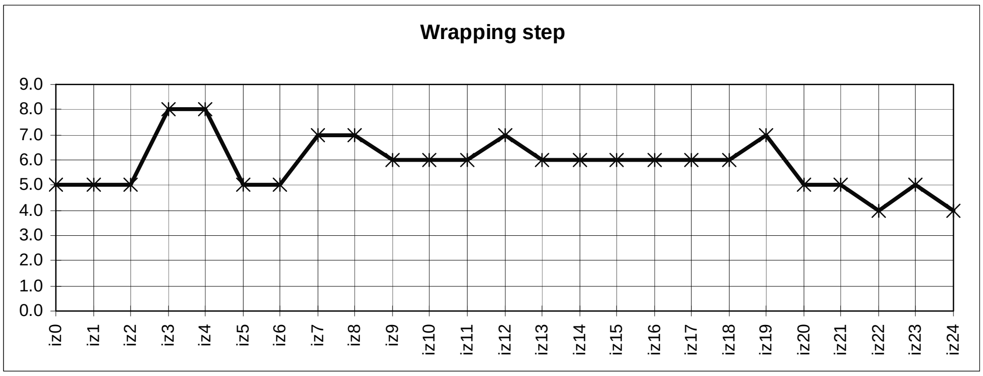

Fig. 4 – Variation of the inductor's wrapping step from centre towards the ends.

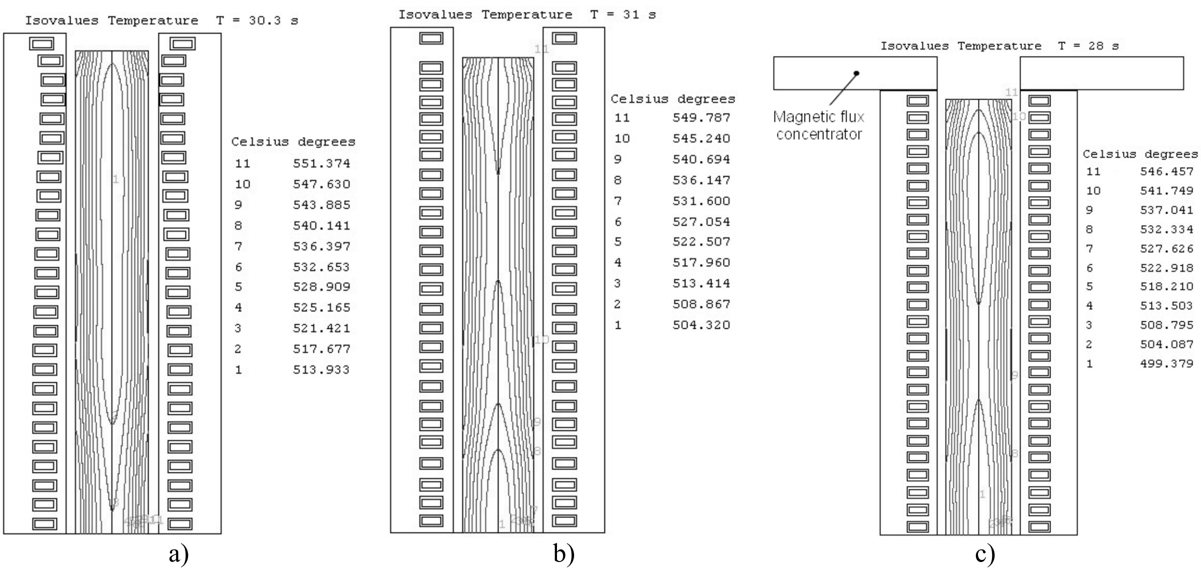

Fig. 5 – Thermal distributions in heated piece using optimizations method.

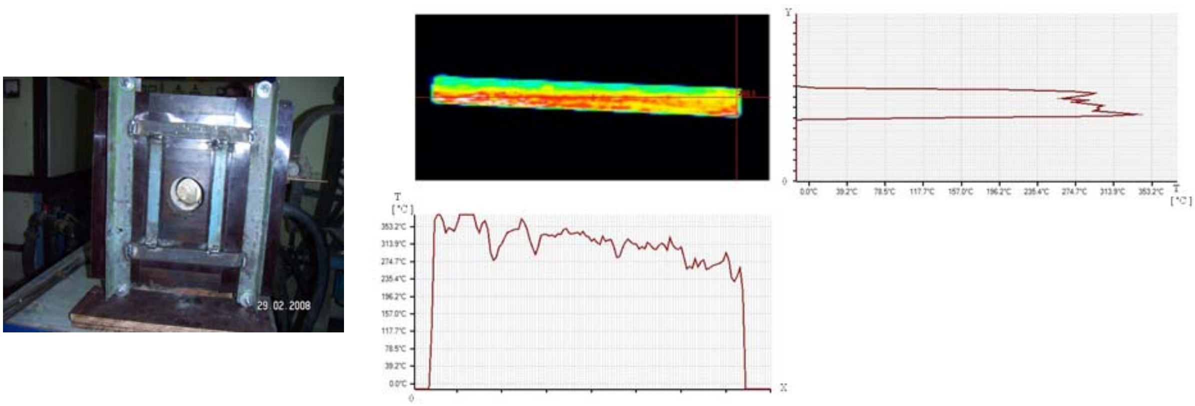

Fig. 6 – Experimental results. Thermal distributions in heated piece using magnetic field concentrator.

As can be seen from figure 6, in the case when we use the magnetic field concentrator, the distribution of the thermal field on the surface of piece is sufficiently uniform to conclude that the maximum difference of temperature on the surface piece is less than 5% from the final heating temperature. Variations of the temperature over the piece from figure 6 are due to deficiency in particular to reading the temperature with the thermal imaging camera (infrared) on the shiny surface of the piece (eg aluminium alloy - Anticorodal_100). To read the correct temperature on the surface of the piece is necessary to clouding the area, which was not done in to the practical stand.

IV. CONCLUSIONS

The numerical modelling design of installations and equipments through informational techniques is a new way to satisfy the market's needs for development. This method is by far the best designing solution: it offers high precision, and the parameters are depending on the initial information, heating time, product's geometry and properties.

The design of induction electromagnetic devices through informational techniques leads to an economical and technical improvement (cost reduction, better working devices and high quality final products). The optimisation of the inductor's power supply devices performance has as results the reduction of the disturbing superior harmonics, lower commutation losses of the static commutation elements etc., these agents are badly influencing the efficiency of the thermal-electrical energy conversion inside the semi-finished product. The improvement of the inductor – heated piece system geometry, as well as the use of magnetic flux concentrators at the inductor's ends, have as result the uniform lengthwise heating of the semi-finished products.

The results obtained and presented in this study are very useful for anyone who wants to improve the operational performances of an electromagnetic induction-heating device.

REFERENCES

[1] T. Leuca, C. Mich-Vancea, Carmen Molnar, *The numerical modeling of the electromagnetic and thermic phenomenon in the heating process of semi-finished products from non-ferrous materials*, International Symposium IGTE – Graz, 17-20 September 2006, 96505;

[2] T. Leuca, Şt. Nagy, C. Mich-Vancea, *The numerical modeling of the heating process for the semi-finished products made up of non-ferrous alloy*, Simpozionul Naţional de Electrotehnică Teoretică, SNET07, 2007, pp. 400 – 405, Bucuresti, Romania.

[3] F. Hănţilă, G. Preda, M. Vasiliu, T. Leuca, E. Della Giacomo, *The numeric computation of eddy currents*, Editura ICPE, 2001, ISBN 973 – 8067 – 31 – 6.

[4] T. Leuca, E. Vladu, M. Popa, *Using genetic algorithms in optimal design of electromagnetic devices*, Revue Roumaine des Sciences Techniques – Electrotechnique et Energetique, 49, 3, pp. 319-327, Bucarest, 2004;

[5] O. Biro, K. Preis, K.R. Richter, *Various FEM Formulations for the calculation of Transient 3D Eddy Currents in Nonlinear Media*, IEEE Trans. On Magn. Vol. 31, No 3, pp. 1307-1312, 1995.

[6] S. Galunin, M. Zlobina, Yu. Blinov, B. Nacke, et al, *Numerical optimization in design of induction heating systems*, Int. Symp. on Heating by EM Sources HES-04, 2004 June 23-25, Padua Italy;

[7] T. Leuca, C. Mich-Vancea, D.D. Betea, *The optimization of the heating process of non-ferrous semi-finished products by using concentrator*, 6th International Conference on Renewable Sources and Enviromental Electro-Technologies 8 – 10 June 2006, pp. 45 – 48, ISSN 1223 – 2106.