Numerical Simulation of Induction Through-Heater in Dynamic Operation Mode

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Abstract — The numeric model used in this paper is based on the finite element method and is aiming an inductive heating in volume of a cylindrical structure in a dynamic operation mode. Nowadays the induction through-heaters are usually designed to provide the required characteristics in “quasi” steady-state operation mode mainly. However, in industrial practice the heaters can operate under various disturbances more than half of time, so the transient process play significant role in effectiveness and quality of the heating. Investigation of dynamic characteristics of the heaters in dynamic modes can be only done by numerical modeling based on special algorithms providing a time loop additionally to coupling between electromagnetic and thermal analysis. Such numerical models have been developed and used for investigation of dynamic modes for heating billets. The results of numerical simulation can be used for design of induction through-heaters and improvement of their characteristics in dynamic operation modes.

Keywords: induction heating; numerical modeling; electromagnetic field and thermal field;

I. INTRODUCTION

One of the advantages of the induction through-heaters of various metal products is that they are wide spread used in industry because of their ability to be directly built into technological lines. Because of this, the through-heaters must be of high effectiveness not only in “quasi” steady-state operation but in different transient modes as well.

Investigation of dynamic characteristics of heaters in dynamic modes can be only done by numerical modeling. To simulate different kinds of transient modes in induction heating systems, a special group of numerical models is required to be developed. The models must simulate the heating process distributed not only in space but in time as well. For this reason the transient models of inductions through-heating should be based on special algorithms providing a time loop additionally to coupling between electromagnetic and thermal analysis. The electromagnetic induction heating installations bases on the penetration of the electromagnetic field in the conductive materials found in a variable in time magnetic field. The electrical eddy currents determined by the induced electromagnetic tensions, lead to the Joule-Lenz heating effect. The more the frequency increases, the more Joule losses, due to eddy currents. The general characteristics of induction heating applications are high efficiency, rapid heating and high performance temperature control. Therefore, induction heating installations can realize the needed fast heating of an electrically conductive material in a clean, efficient and controlled manner.

Numerical simulation of electromagnetic and thermal processes in induction heating lines can help to solve the problems in their dynamic behavior. Nowadays, we experience a fast development in IT and software dedicated to analyzing the thermal and electromagnetic phenomena, the optimization processes are done by numerical modeling.

Numerical modeling is very useful when studying the volume heating using electromagnetic induction, because it provides graphical representation of the electromagnetic and thermal field distribution in the half-products depending on the electrical input parameters, geometry inductor and material properties.

II. NUMERICAL MODELING OF THE PROCESS OF INDUCTION HEATING

In order to reach our purpose is necessarily to solve the Maxwell’s equations that describe the process of induction heating. For a faster solution, from efficiency point of view, the geometry model is axisymmetric, but the results are expanded with the tool that ANSYS has, for a better view.

The algorithm was developed in the commercial program package ANSYS based on Finite Element Method. The electromagnetic analysis is carried out in harmonic statement with temperature dependent material properties and thermal system includes only the heated billet without refractory material for radiation exchange between their surfaces. The thermal system can be extended if necessary. Numerical mesh is optimized in order to reach a compromise between good calculation accuracy and acceptable runtime of the model.
It is known that numerical models for simulation of induction through-heating process in dynamic operation mode have significant features compared to traditional models for "quasi" steady-state mode. For the dynamic mode, there have to be included coupled electromagnetic and thermal analysis but also taking into account the workpiece movement. [3]

Fig. 1. Algorithm for numerical simulation of dynamic modes

Besides this, very often these models should consider the system geometry changed in time. Such task, especially for 3D simulation, required development of very stable simulation algorithm shown in Figure 1. Usually in numerical simulation, continuously running physical heating process is replaced by big enough amount of time steps. For this kind of numerical simulation, at each time step the system geometry is assumed of no change. [2]

The algorithm is structured in two parts and it is done in APDL ANSYS language. The first part (block) of the algorithm includes creating all electromagnetic and thermal environments needed in the second part of the algorithm. For the first block referring to position of the workpiece we establish a parameter for positioning it inside the induction heater "up_billet" (Figure 2) and indirectly by this parameter, we set the movement of workpiece in dynamic modes. The created environments are saved in form of database and have all records necessary for solution like system geometry, numerical mesh and boundary conditions. The electromagnetic environments are only opened for actual temperature distribution for correction of material properties and for excitations in form of induction coil current or voltage as well frequency. [4,5]

Fig. 2. Extras of numerical simulation code with the defined moving billet parameter "up_billet" inside the inductor

Fig. 3. 3D model used for the induction heating

Induction installations for heating billets are wide spread in industry because of their numerous advantages.

Figure 3 shows the 3D model used for the induction heating in dynamic modes. The induction heating represents a coil of 29 windings of a rectangle 22x11x2 [mm] in cross-section and a cylindrical workpiece
having the diameter of 70[mm] and a length of 150[mm]. The material properties are temperature dependent as for electromagnetic problem but also for the thermal problem. [1]

The second part of the algorithm starts from a set of electromagnetic and thermal calculations at each time step of the heating process in the first inductor. Then this procedure is repeated for the heating process in the next induction coil. The results of electromagnetic and thermal calculations are saved at the end of each time step in results files for a proper reading and usage later on. The thermal environments read initial temperature distribution from the previous time step and the distribution of power density coming from the electromagnetic analysis. The algorithm reads the last temperature distribution for the workpiece, applies it as initial temperature condition for the current analysis and additionally read the heat generation, from the electromagnetic environment and applies it as load in the thermal environment.

III. RESULTS

For this study that was carried out, the temperature distribution in the heated part, represents one of the most important parameter that was followed along with the movement of the part inside the inductive heater. From one simulation to another the movement of the workpiece inside the inductor was of 0.01[m].

For a better efficiency, the numerical simulation was carried out in a 2D axisymmetric geometry and at the end the plotting results for the thermal field were expanded with the tools of ANSYS in a 3D visualization.

The magnetic field, for our numerical modeling, at starting position is more intense at the end of the workpiece that is more inside of the inductor, like in figure 4. We suppose that the electromagnetic losses due to their transformation in thermal energy and the thermal field distribution in piece have the same form as the electromagnetic field (figure 5).

Fig. 5. Distribution of temperature in the workpiece at position up_billet=0.005 m inside the inductor

Fig. 6. Distribution of temperature in the workpiece at position up_billet=0.06 m inside the inductor

Fig. 7. Distribution of temperature in the workpiece at position up_billet=0.1 m inside the inductor

As the workpiece is advancing inside the inductor the distribution of the temperature is getting homogeneous for the whole length of the billet.
IV. CONCLUSIONS

Dynamic operation modes play significant role in forming main characteristics of induction through-heaters. Dynamic behaviors of the heaters have been investigated by numerical modeling. Numerical models and results of investigated for the first start of through-heaters for billets have been presented. The simulation results can be used for design of induction through-heaters of billets and improvement of their characteristics in dynamic operation modes.

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REFERENCES


Fig. 8. Distribution of temperature in the workpiece at position \( u_{\text{p}, \text{billet}}=0.2 \text{ m inside the inductor} \)