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INDUCTION HARDENING OF LARGE DIAMETER PIPES AND ROLLS

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ABSTRACT

New approach of designing and control of induction heat treatment installations with utilizing of numerical models is developed. Models include two-dimensional simulation of coupling electromagnetic and temperature fields in cylindrical systems for processing of pipes and rolls. Also, thermal and structural tension during heating and cooling of pipes and rolls are simulated. These data allow defining structure, hardness, the size of grain and other properties of the pipes and rolls. They allow optimizing design and a choice of equipment, a heat treatment mode for achievement of the maximum quality and minimization of energy consumption. The developed models were used not only for the design of induction heat treatment systems of pipes and rolls, but also for a digital control of these complexes.

Key words: *Coupled Electromagnetic and Temperature Fields, Electromagnetic processing of metals, Induction heating, Multiphysics Problems*

I. INTRODUCTION

Induction heating technology is widely used in steel industry. Induction heating installations in the metallurgical industry have a power level that may exceed several hundreds of kilowatts or even tens of megawatts. The frequency range of used power sources is from tens Hz to MHz. In spite of the fact that induction hardening has successfully been applied in industry for many years [1], there is a growing demand in industry for a more precise process control. Also, it is necessary to develop new technology of induction heating of pipes and rolls for rolling mills with big diameter. Heat treatment of pipes and rolls is important stage in manufacturing of high quality steel products like lengthy pipes and rolls with big diameters for rolling mills. Hardening and annealing are main types of heat treatment of pipes and rolls. Modern heat treatment means strict observance of temperature evaluation during heating, controlled cooling and, probably, repeated heating. Using of computer simulation is a powerful and necessary approach for solving these problems.

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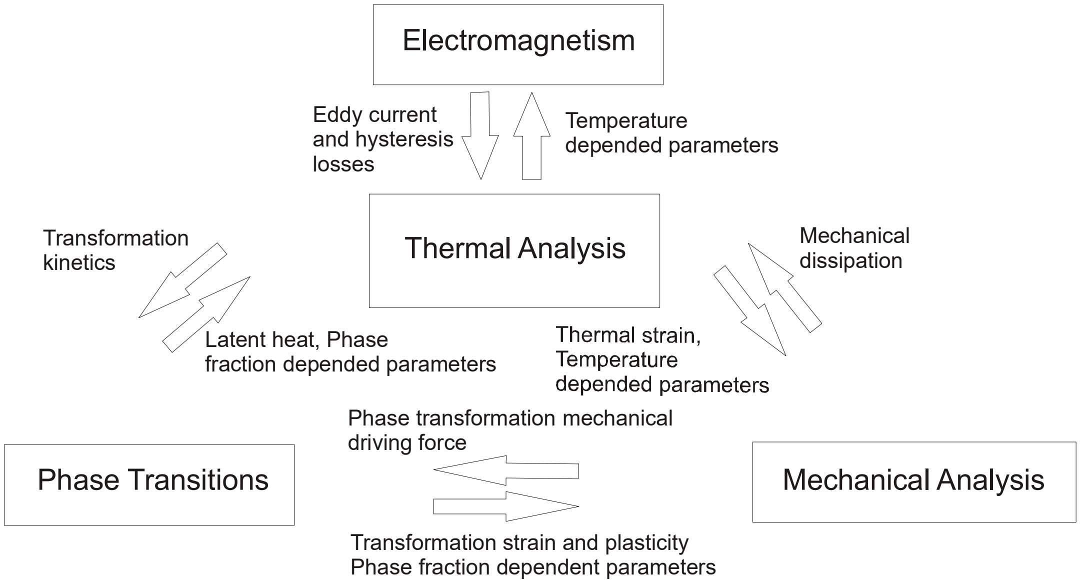

Fig. 1. Heat treatment physical phenomena

II. MATHEMATICAL MODELS

From the physical point of view the induction hardening is a very complicated process (Fig. 1). We should include all the significant phenomena to the mathematical description to achieve an acceptable calculation result. Moreover, it is very important to understand that all phenomena are coupled with each other.

It is obvious that induction hardening mathematical description should include the electromagnetic, thermal and phase transformations phenomena. But the resulting workpiece properties are strongly depend on stress-strain state (residual stress) due to summation stress effect with the external load. Moreover, stress is an additional driving force for the phase transformation (Fig. 1). That’s why it is desirable to describe this phenomenon too.

Effective numerical models of technological process of heat treatment are developed. They include two-dimensional modeling of electromagnetic and temperature fields in system [2]. Also, thermal tension during heating and cooling of pipes and rolls are simulated. These data allow defining structure, hardness, the size of grain and other properties of metal of the pipes and rolls.

The developed two-dimensional models were extremely effective not only at design of induction heat treatment systems of pipes and rolls, but also for a digital control these complexes. Using modular structure of induction heaters gives significant advantages in induction heating technology, since it allows optimizing the operation modes of equipment in relation to: energy consumption; scale formation; the ability to maintain a constant exit temperature.

III. INDUCTION HEAT TREATMENT OF PIPES

The heat treatment of pipes is important stage in production of high quality pipes with big diameters. Main types of heat treatment of pipes are annealing, normalization, aging, hardening etc. Dispersive hardening for two-phase (duplex) steel significantly improves properties of pipes.

Heat treatments of pipes usually carry out in gas-fired furnaces or electric furnaces. Gas-fired furnaces are not flexible due to big inertia. Besides combustion products contain gases which interact with metal that leads to deterioration of its quality and reduction of service life. Advantages of induction furnaces, such as absence of thermal inertia and high energy efficiency, are especially shown in the conditions of flexible change of temperature - time profile of the heat treatment. For pipes of small diameter, the greatest distribution was gained by induction installations of continuous action when the heating - cooling mode by direct placement of a zone of cooling behind the inductor is easily realized.

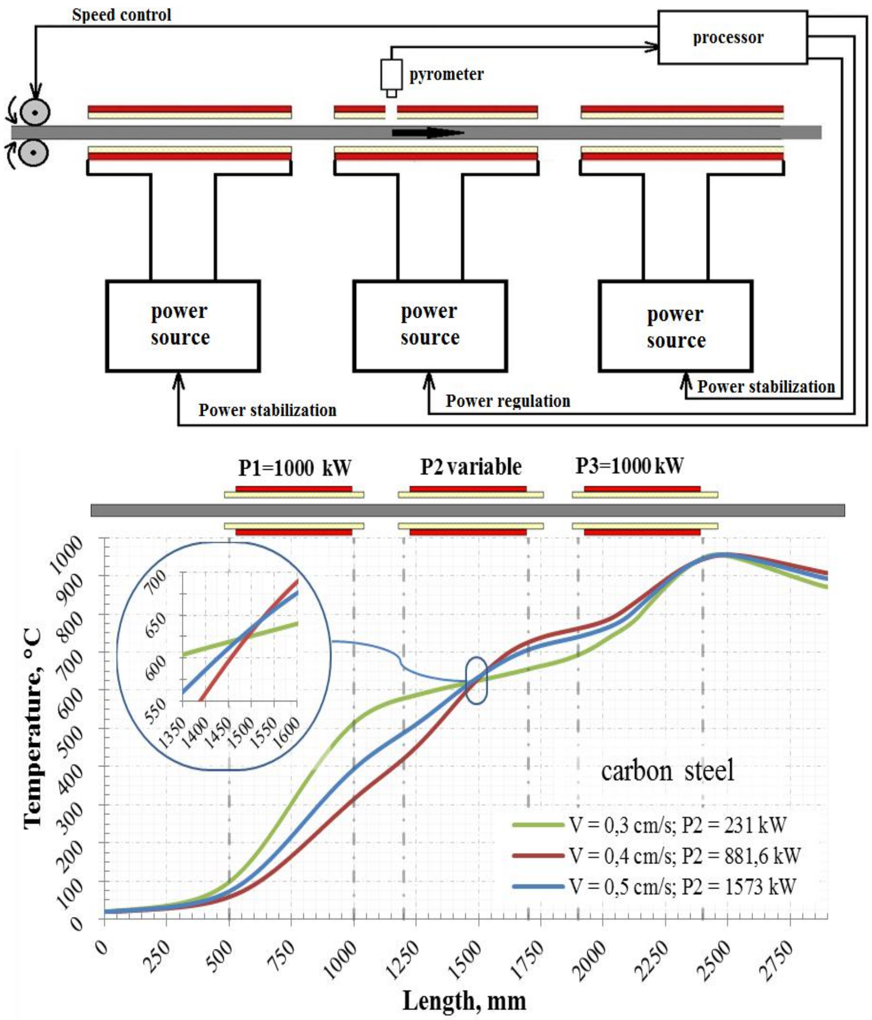

Fig. 2. Temperature control for a modular induction heater with a single control point

Advanced digital control allows effective processing of possible disturbances, such as: changes in the speed, diameter and initial temperature of the workpiece, and therefore to minimize the amount of rejects during heating [2].

To fully realize the advantages of modular induction units, an advanced digital control system should include control algorithms for stationary and non-stationary operation modes of the heater that occur during the initial start-up of a heater or when the technological lines stop and restart after a stop, with a change in the productivity of processing lines. Non-stationary modes can be characterized by a strong change in the temperature field of the load and the electrical parameters of the heater, and potentially can lead to a large percentage of rejects.

Investigation of the regulation of non-stationary operation modes of modular induction heaters was performed to determine the possibilities of reducing the changes in the temperature field of the load at the exit of the induction heater by means of an automatic control system with one temperature control point within the heater when controlling heating during the transient process, i.e. only one induction module (active zone).
The results of numerical modeling of the process of heating cylindrical billets using several modules with

independent frequency converters have shown a high efficiency of induction heaters with this configuration. They enable the creation of a highly efficient and reliable control system for an induction heater based on three or more modules. In the installation of the three modules, the heating control of the workpiece occurs only on the second module (the "active zone") along the pyrometer, the sighting point of which is located at a certain point inside the second inductor, while the power in the first and third inductor is maintained at a constant level (Fig.2).

Temperature curves for this type of control (Fig. 2) obtained for different velocity of pipes intersect at one point inside the second induction module and have the same temperature at the exit from the last module of the induction heater. For heated thin bodies with linear properties, the existence of this point was analytically proved [3].

For cylindrical nonlinear bodies, modeling showed that, while maintaining a constant temperature at the point of intersection of temperature curves, by creating a system of automatic power control of the generator with feedback on the temperature fixed by an optical pyrometer at the control point, this method of regulation allows almost completely to remove fluctuations in the temperature at the exit of an induction heating installation during the temperature transient processes.

However, realization of a necessary mode of heat treatment by space distribution of heating and cooling zones at a constant speed of movement of pipes in many cases is difficult to pipes of big diameter and demands unfairly big power of heating. And in this case, it is preferable to realize a stage induction heating of lengthy pipes that provides flexibility at realization of heat treatment. In this way heat treatment line consists of two separate zones: induction oscillating heating and quenching. After heating to the required temperature, the pipe quickly moves to the cooling zone.

Induction heating of pipes of big diameter possesses several features which need to be considered at equipment design.

1. For each diameter and thickness of pipes wall there is an optimum frequency of current with strong expressing of the maximum of electric efficiency. Therefore, a proper frequency choice is important at designing of energy saving induction heating systems.
2. In practice there is wide nomenclature of pipes diameters and thickness of a pipes wall. Procedure of a choice of number of replaceable inductors is developed for a guarantee of heating of any pipe with electric efficiency not lower than 10-15% from the maximum.
3. Special attention is paid to a lining choice at high-temperature heat treatment because of a big surface of thermal radiation. As temperature differences on thickness of a wall of pipes usually don't limit power, the choice of power of inductors is defined not only by productivity, but also achievement of high thermal efficiency.

Fig.3 – Stage hardening (two separate zones: induction oscillating heating and quenching)

IV. INDUCTION HEAT TREATMENT OF LARGE DIAMETER ROLLS

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The first use of induction heating for surface hardening of rolls was carried out in the early 1920s at the company Midvale Steel Company (USA) [1].

Rolls of rolling mills are made of steels with high hardenability. They must have a high strength of the surface layers and a uniform distribution of hardness along the length of the roll. At the same time, the rolls must resist strong shock loads and prevent the formation of cracks, chips, peeling both during the heat treatment and during the rolling process.

In order to meet these requirements, induction surface hardening is ideally suited for heat treatment of rolls. Along with the high quality parameters of the rolls, induction surface hardening allows to provide automation and repeatability of quenching, absence of deformations and high energy efficiency of heat treatment of rolls.

Due to the large dimensions of the rolls (length is up to several meters) simultaneous hardening is impossible due to the required considerable power and difficulty with water cooling. Therefore, continuous-sequential quenching with a vertical roll arrangement is used. Typical design of the roll and the machine for hardening are shown in Fig. 4.

To obtain the required distribution of the hardness and structure of the metal immediately before intense water cooling, the necessary temperature distribution over the section in the working zone of the roll must be in the interval:

$$1000\ ºC > T > 750\ ºC \qquad (1)$$

The distribution of the temperature over the roll section greatly affects the thermal stresses both during the heating before quenching and on the residual thermal stresses after quenching. It is also necessary to consider the time and intensity of cooling in order to avoid self-release.

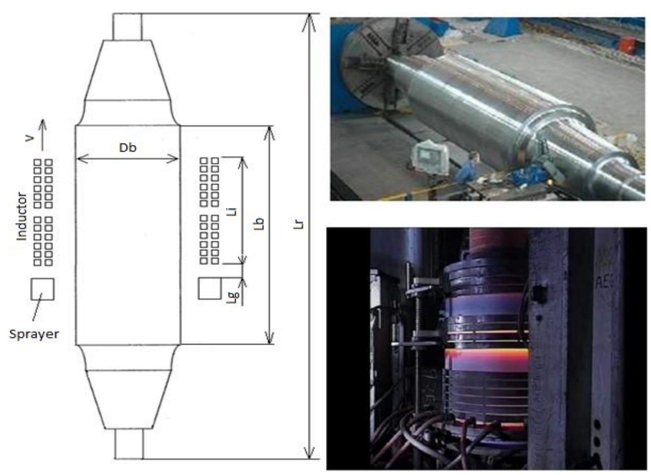

Fig. 4 – Induction hardening of large rolls

V. CONCLUSIONS

Induction heating technology is widely used in steel industry. In spite of the fact that induction hardening has successfully been applied in industry for many years, there is a growing demand in industry for a more precise control and quality assurance of the processed products.

New technologies for induction heat treatment of large diameter pipes (40"– 62") and rolls of rolling mills with a barrel diameter of up to 65" are developed. Developed computer control systems use specialized numerical models that provide high quality heat treatment and minimize residual stresses.

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