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ELECTROMAGNETIC FIELD ANALYSIS OF INDUCTOR-ROBOT-WORK-PIECE SYSTEM

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Preliminary Note – Prethodno priopćenje

The paper presents an analysis of the influence of the industrial robot located nearby an induction heater on the electromagnetic field distribution. The experiment consisted of numerical analysis and measurement verification. The analysis of the electromagnetic field distribution was conducted for low frequency (50 Hz) heater. Two variants which differed in the presence (or absence) of the robot were considered. As a result, the distributions of the electromagnetic field around the heater were obtained. The evaluation of the influence of the industrial robot location on the magnetic field intensity was presented and discussed.

Key words: induction heating, electromagnetic field, industrial robot

INTRODUCTION

The paper deals with the induction heating process. Induction heating is often used heating method in heat treatment and as a first stage of forging metals and for stirring metals [1-3]. Nowadays induction heating systems are more often equipped in feeders, manipulators or industrial robots. The induction heating system is a source of magnetic field characterized by such a value of field intensity which can be dangerous for the device operators [4]. It is necessary to check field values and, in some cases, limit magnetic field intensity in such working stands. Various kinds of protection devices can be applied, mostly shields. However, in some practical cases it is impossible to use such a solution due to technical limitations. In such cases industrial robots and/or manipulators were are often applied. The presence of so big a ferromagnetic body located close to an induction heater have usually causes changes in the electromagnetic field distribution and in the values of electric and magnetic field intensity, even for value which is dangerous for human beings. Too strong electromagnetic field could also cause disturbances influencing negatively on the industrial robot.

The paper presents calculations which evaluate the influence of the industrial robot presence on the electromagnetic field distribution. The Calculations were measurement verified.

TECHNICAL PROBLEM FORMULATION

Working in the steel industry usually involves exposure of a worker to a high health risks. Common threats are possibility of physical injury, high temperature and noise. Electrothermal appliances like arc furnaces, induction furnaces and heaters are more and more often used in the modern metallurgical industry. Their use increases the exposure of workers to the risks coming from electromagnetic fields.

The robots might be a solution in such a case as they can replace the people in the hazardous area, but placing the robot near the induction heating equipment changes the electromagnetic field distribution, and this change may cause that dangerous magnetic field strength will occur in some new places, different from those observed before, and thus pose a threat to the workers.

The study was conducted for the cylindrical induction heater supplied by the transformer with current of frequency f = 50 Hz (Figure 1).

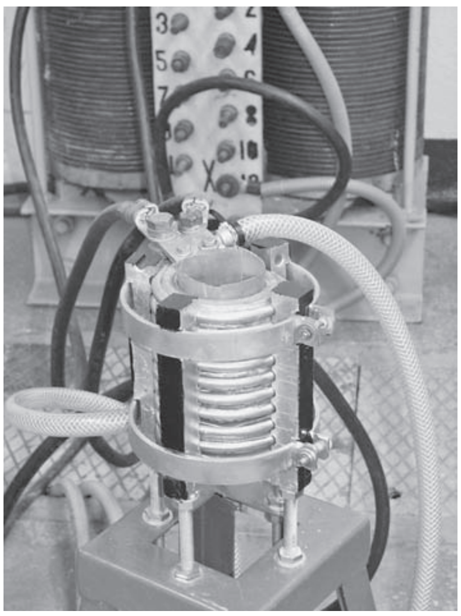

Figure 1 Induction heating system

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The robot used in this study was Kawasaki FS020N-FD40 (Figure 2).

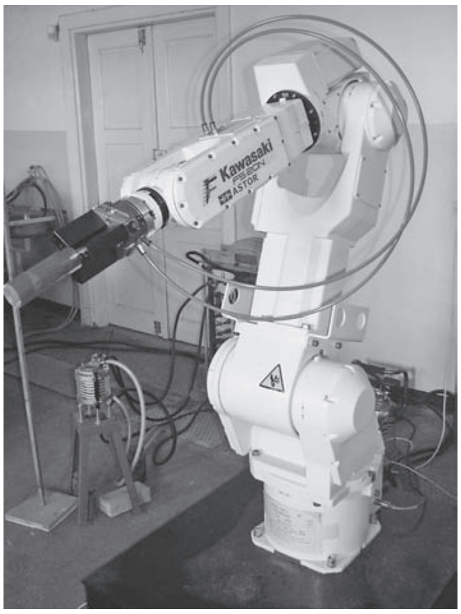

Figure 2 Robot Kawasaki FS020NFD40 – max payload 20 kg

The computations were done for the steel work-piece, where the grip, the grip fingers and robot arm were modelled as made of magnetic steel. Only the grip adapter was made of aluminium and modelled as such. Table 1 contains description of materials. Main dimensions of the system are as follows: inductor's diameter was 0,06 m, inductors length 0,127 m, work-piece diameter was 0,06 m and its length 0,15 m. Total length of the modelled system (shown in Figure 3), that is the work-piece, grip fingers, grip, adapter and robot TCP, was 0,380 m.

Table 1 **Materials properties**

Stystem component	Material	Conductivity S/m
workpiece	steel 4140	$3,69 \times 10^6$
grip fingers	steel 4340	$3,02 \times 10^6$
grip	steel 1010	$6,99 \times 10^6$
grip adapter	aluminium	$3,40 \times 10^7$
robot TCP	steel 1010	$6,99 \times 10^6$
inductor coil	copper	$5,60 \times 10^7$

For all steels non linear characteristic of B=f(H) curve was implemented.

The numerical analyses of the magnetic field distribution near the induction heater were done for the elements of geometry and material parameters identical to those of the real industrial objects. The only exception are the grip fingers. The Calculation model was made as a two dimensional one (axial symmetry), so it is impossible to model the three-finger grip. The fingers were modelled as a two parts of pipe without electrical connection between each other. It was possible because of using an electrical circuit coupled with the FEM model.

Measurement verification of the calculation results was carried out during the experiment. Measurements of rms value of induction were conducted using ELT 400 instrument.

NUMERICAL MODEL

The analysis of the electromagnetic field was carried out based on Maxwell's equations supplemented by the generalized Ohm's law equation. The calculations were simplified by the transition from time-domain analysis to the symbolic analysis. Electromagnetic field analysis was based on the expression using vector magnetic potential A, which is commonly used for steady-state electromagnetic problems [2, 5] and in 2D case reduces the number of state variables.

$$\nabla \times \left(\frac{1}{\mu} \nabla \times A \right) + j\omega\sigma A = J_s \tag{1}$$

where:

μ - magnetic permeability,
σ – electric conductivity,
ω – angular frequency,
J_s – source current density.

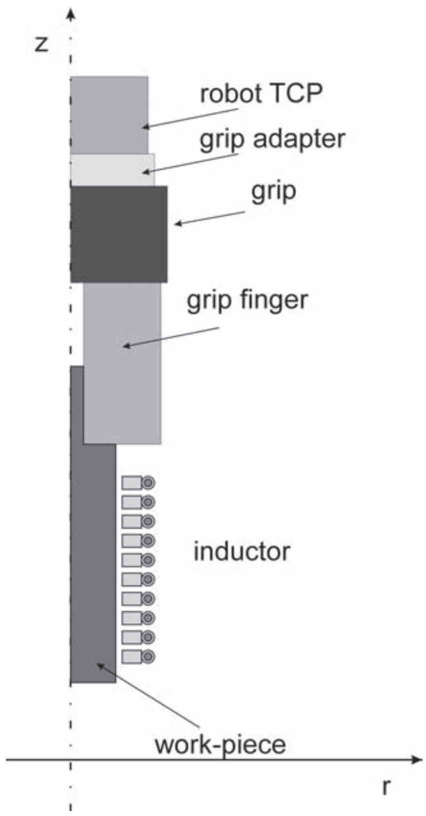

Figure 3 Calculation model

Electromagnetic induction B and field intensity H were determined from equation (1) after taking into account the following dependences:

$$B = \nabla \times A \tag{2}$$

$$H = \frac{1}{\mu} B \tag{3}$$

where:

H – magnetic field intensity,

B - magnetic induction.

In the numerical experiment, the inductor was supplied from current source (I_{rms} = 2 000 A). All conductive parts of the calculation system were modelled as massive conductors (with eddy currents). The Sketch of the model is presented in Figure 3.

EXPERIMENT RESULTS

During the investigations the steel work-piece was heated. Heating time was 120 s. Two variants of heating were considered:

a) the heated charge was kept by the robot grip;

b) the heated charge was kept by a special holder.

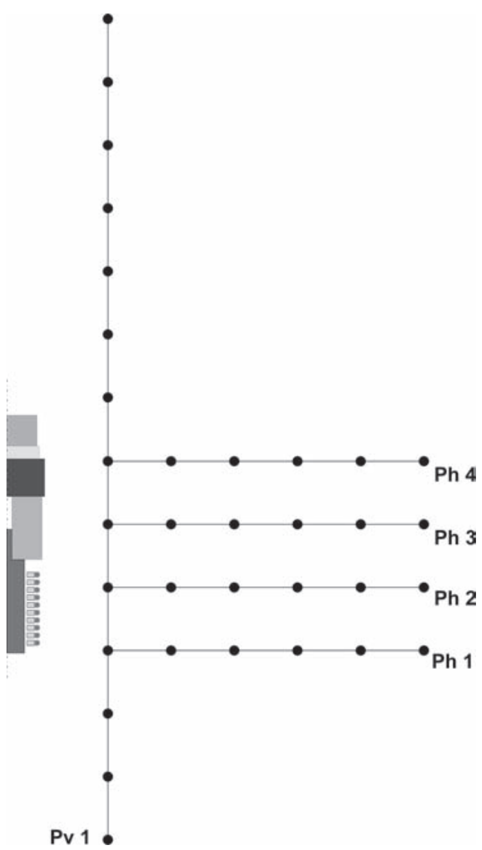

Figure 4 Measuring paths positions

Electromagnetic induction was monitored and its values were compared between different calculation variants. The results are presented as isolines of magnetic flux and also as the distribution of induction along 5 paths shown in Figure 4. For vertical path Pv1 radial coordinate was constant (r = 0,17 m) and vertical coordinates start from 0,2 m and reaches 1,5 m (every 0,1 m). For all the horizontal paths Ph 1 to Ph 4 radial coordinates change from 0,17 m to 0,670 m (every 0,1 m). Vertical coordinate for Ph 1 was 0,5 m, for Ph 20,6 m, for Ph 3 0,7 m and for Ph 4 0,8 m.

The distributions of the magnetic flux obtained from the calculations are shown in Figure 5. Field distribution differences are visible near the grip (detail A). The electromagnetic field penetrates the grip finger, the grip itself and, to some extent, the robot TCP.

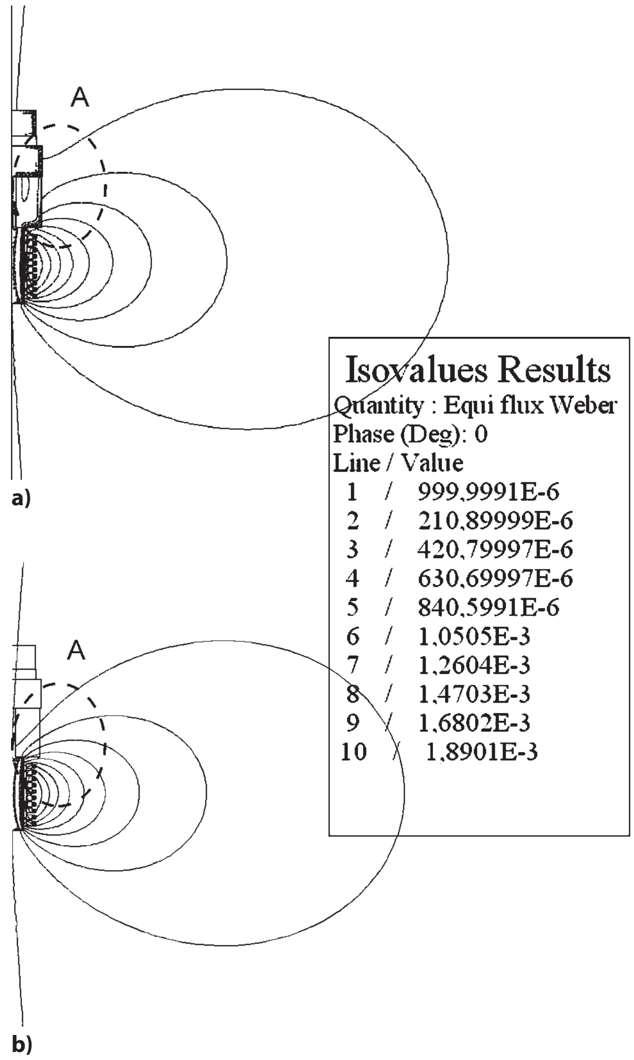

Figure 5 Magnetic flux distribution for: a) model with robot, b) model without robot

Figure 6 shows the differences in magnetic induction along the path Pv1 between the models with and without the robot. The most significant differences ap-

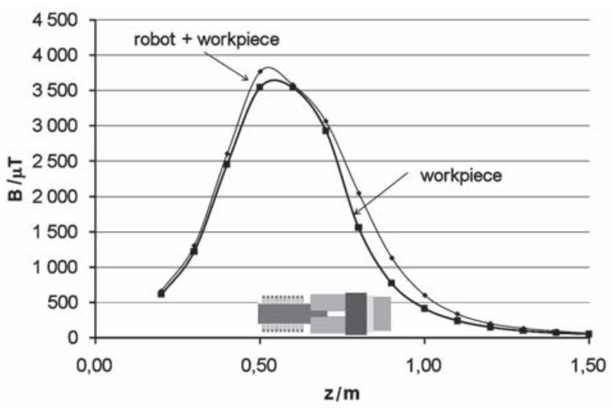

Figure 6 Induction distribution along the path Pv 1

pears at the ends of the inductor. The maximum value of the difference is 485 μT at the *z* coordinate 0,8 m. The influence of the robot's presence on the magnetic induction extend beyond the modelled part of the industrial robot and reached *z* coordinate 1,1 m. The values of induction for the model with the robot were higher then for the model without the robot along all the Pv 1 path.

The influence of the robot's presence on the induction distribution in the radial direction was monitored on the paths Ph 1 to Ph 4. Significant differences were observed for the path Ph1 and Ph 4 (Ph 4 shown in Figure 7).

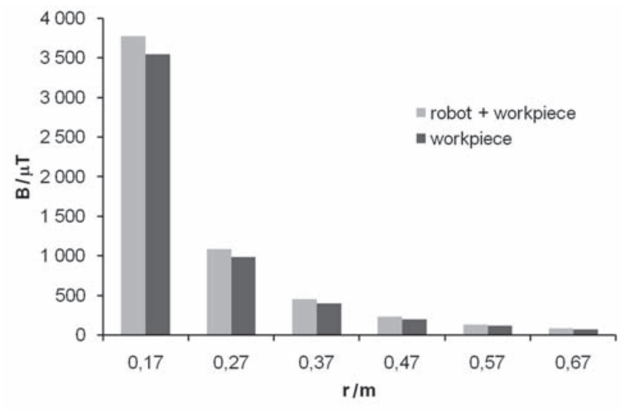

Figure 7 Induction distribution along the path Ph 4

As could be expected, the biggest differences appear close to the heating system, and it decreases quite rapidly. The maximum value of the difference is 481 μT and was observed for the first point of Ph 4 path.

Measurement verification was the last stage of our experiment. The measurements were carried out for both investigated models on two paths, Pv 1 and Ph 1. The convergence between the results obtained from the measurements and calculations was quite good. The differences did not exceed 11 %. The comparison of the results of calculations and measurements for the model consisting of the robot and work-piece is shown in Figure 8.

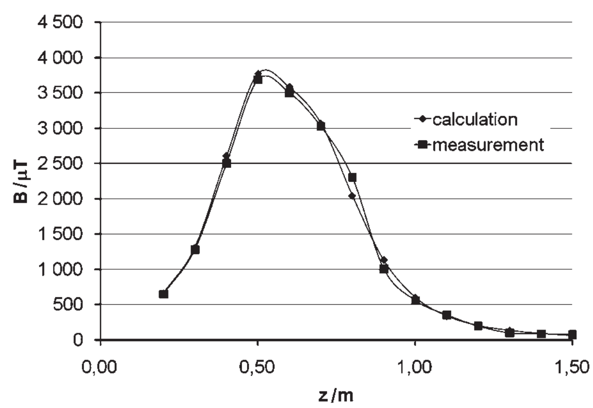

Figure 8 Comparison of the measurement and calculation results along path Pv 1 for the robot and work-piece system

CONCLUSION

The paper presents an analysis of the influence of the industrial robot located nearby an induction heater on the electromagnetic field distribution. Two variants differing in the presence of the robot were considered. During the experiment, field distributions around the heating system were monitored. Measurement verification of induction along two measured paths were performed. From the results obtained it can be concluded as follows:

- The presence of the robot increases the electromagnetic induction nearby the ends of the induction heater;
- In this experiment the increase of induction was up to 40 %;
- The presence of the robot increases the electromagnetic field induction in *z* axis of induction heater (Figure 6) especially in the robot arm direction;
- The growth of induction (bigger over 10 %) was observed at the distance of 1,30 m from the inductor.

The differences obtained in this experiment are similar to the results obtained in the experiment for medium and high frequency heaters described in [6], but for 50 Hz inductor the area of the robot's influence was larger, and the values of differences were higher, despite the fact that the tested induction heater has very low power (active power about 5,5 kW).

ACKNOWLEDGEMENTS

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Note: A. Przybyla is responsible for English language, Katowice, Poland