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COMPUTER SIMULATION OF INDUCTION CRUCIBLE FURNACE WITH SUPPLEMENTARY CONSTRUCTION ELEMENT

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ABSTRACT

In this paper the author deals with computer simulation which follows from the requirement of practice. Electromagnetic field distribution around a crucible induction furnace and changes in the distribution of this field using additional structural element (flat short-circuit thread) are solved here. Computer simulation was created in a commercial simulation program RillFEM 2D (RillFEM company, www.rillfem.com), which is based on the finite element method (FEM).

Keywords

Induction crucible furnace; computer simulation; electromagnetic field distribution; additional structural element; RillFEM 2D software

1. INTRODUCTION

Induction heating is often commonly used in many industrial applications. It is precisely because of its positive qualities - high density of the transmitted electromagnetic energy, high reliability, low energy consumption (compared with other methods of heating), ecological heating (heating causes no fumes), high speed and easy maneuverability heating. For most applications, induction heating is the most convenient and often the only way of heating.

2. COMPUTER SIMULATION OF THE ELECTROMAGNETIC FIELD DISTRIBUTION AROUND THE CRUCIBLE INDUCTION FURNACE

2.4. Problem definition

My goal was to determine the geometric distribution of the electromagnetic field around the induction crucible furnace, which heats cylindrical batch with crude iron (Table 1). My task then was to compare two geometrical arrangement of the furnace.

In the first case I simulate a device with simple single layer copper inductor with crucible and cylindrical charge (Fig. 1, Fig. 2). The induction unit is shielded with 32 bunches of transformer sheets, which are located on the outer circumference of the coil. In the latter case I will add the additional structural element (flat short-circuit thread) at the top of the furnace coil (Fig. 1). The objective of simulation is to verify the influence of an additional structural element on the distribution of the electromagnetic field around the monitored device.

Table 1 – ISTOL 700 Kg furnace parameters

Furnace parameters	ISTOL 700 Kg
Capacity of the crucible	700 Kg
Input power	500 kW
Frequency	900 – 1200 Hz
Number of coil threads	11
Input voltage	1300V
Current in one thread	4500A
Number of transformer sheets bunches	32
The alternative current layer current	70004 Az
Inductor design	single-layer inductor

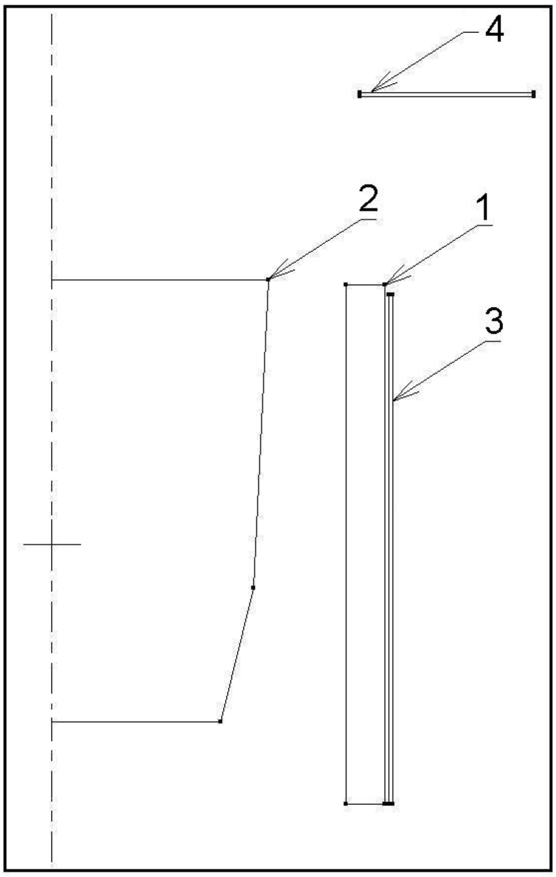

Figure 1 – Geometric situation of the problem in the plane rz cut, plotted in the program RillFEM 2D preprocessor, with a description of the components:
1 – inductor (alternative current layer), 2 – cylindrical charge, 3 – bunches of transformer sheets shielding (alternative layer), 4 – additional structural element - flat short-circuit thread.

Figure 2 – Sample inductor separated from the vacuum induction crucible furnace (1000 Hz, 1000 kg) with shielding transformer plates bunches

2.5. Basic theory of the induction heating problem

The electromagnetic field [1, 4] is described in the general case by Maxwell's equations, which describe the electromagnetic field with vector quantities *E*, *D*, *B*, *H*, *J*.

Based on the material relations:

$$\boldsymbol{D} = \varepsilon \boldsymbol{E} \tag{1}$$

$$\boldsymbol{B} = \mu \boldsymbol{H} \tag{2}$$

$$\boldsymbol{J} = \gamma(\boldsymbol{E} + \boldsymbol{E}_v) = \gamma\boldsymbol{E} + \boldsymbol{J}_v \tag{3}$$

and substitute the definition relations to the first and third Maxwell equations, we obtain the equations describing the electromagnetic field on the basis of potentials ***A*** and *Φ*.

$$\mathrm{rot}\frac{1}{\mu}\mathrm{rot}\,\boldsymbol{A} + \gamma\left(\mathrm{grad}\,\Phi + \frac{\partial \boldsymbol{A}}{\partial t}\right) + \frac{\partial}{\partial t}\varepsilon\left(\mathrm{grad}\,\Phi + \frac{\partial \boldsymbol{A}}{\partial t}\right) = \boldsymbol{J}_v \tag{4}$$

In the modeling of induction heating the electromagnetic field is considered quasistationary in all conductive areas of the equipment design, displacement current compared with the conductive current can be neglected.

$$\mathrm{rot}\frac{1}{\mu}\mathrm{rot}\,\boldsymbol{A} + \gamma\frac{\partial \boldsymbol{A}}{\partial t} = \boldsymbol{J}_v \tag{5}$$

2.6. Simulation results

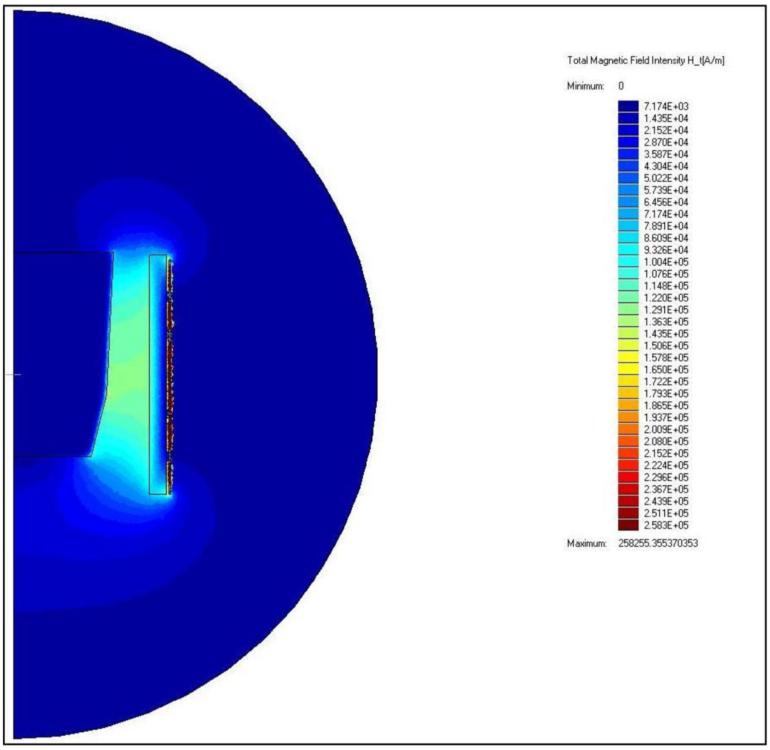

Figure 3

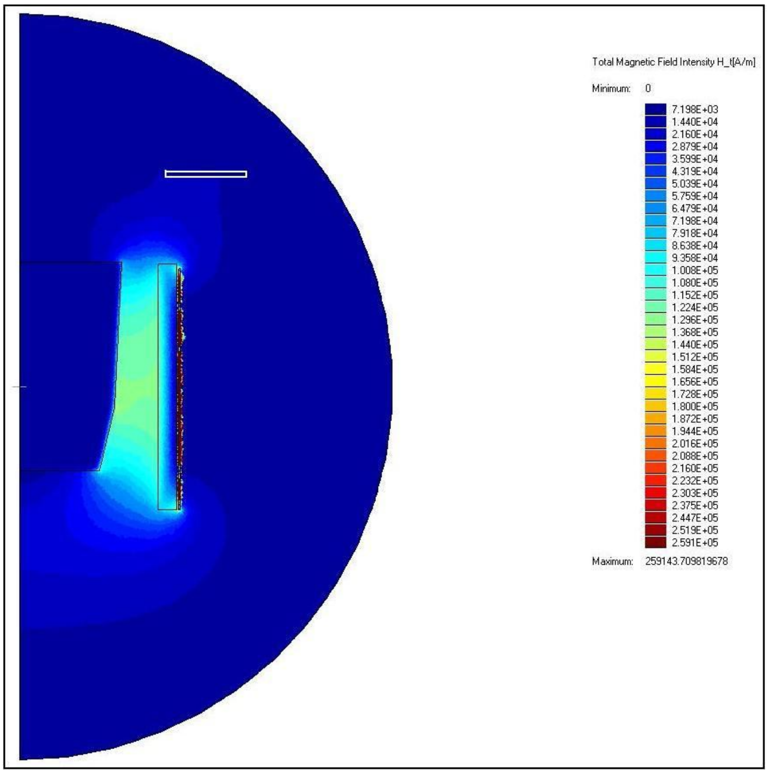

Figure 4

Figure 3, 4 – LEGEND: Size distribution of magnetic field intensity ***H*** [A/m] for the case itself crucible induction furnace (upper image - Figure 3) and induction furnace supplemented by an additional structural element in the form of flat short-circuit thread, which is highlighted in white for clarity (bottom figure - Figure 4).

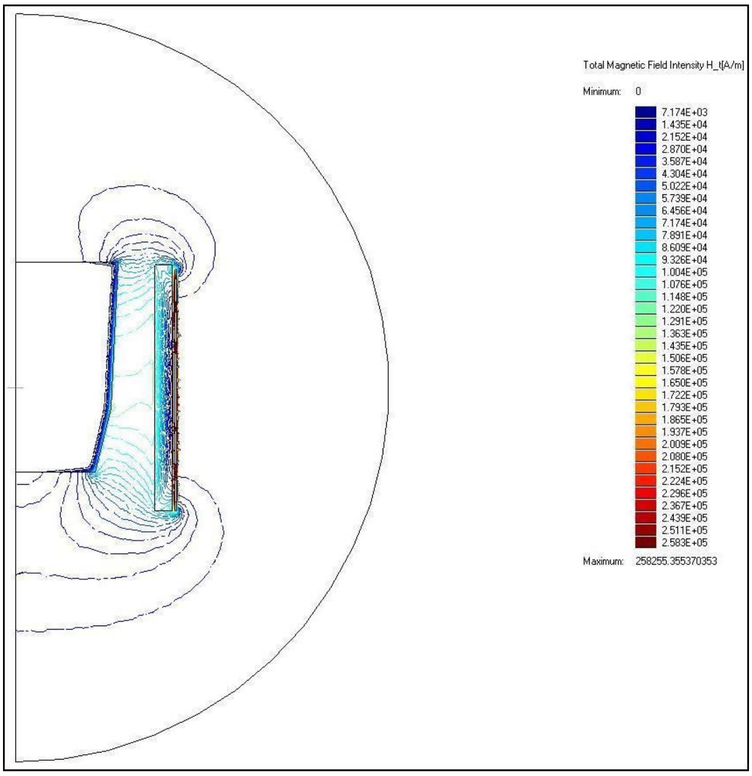

Figure 5

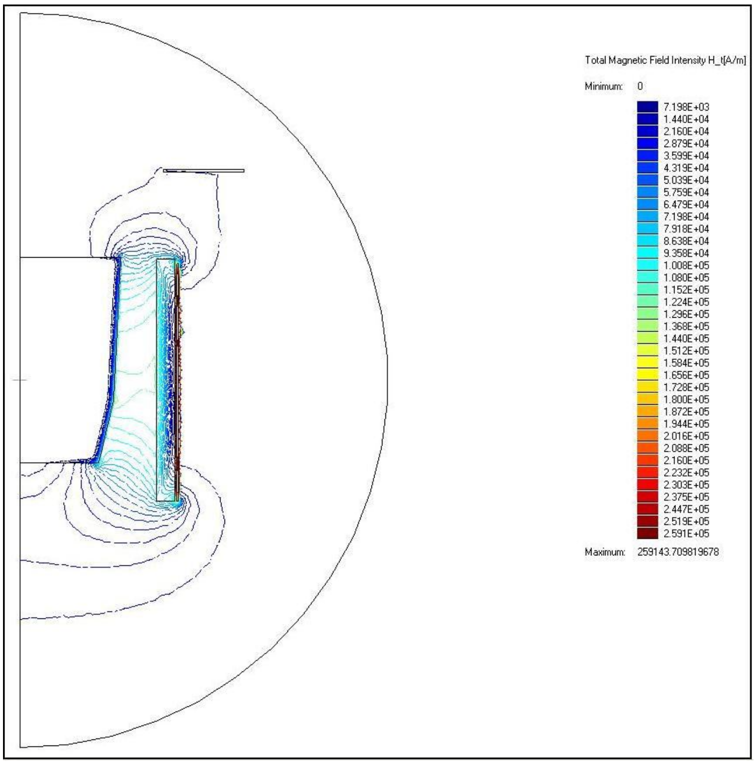

Figure 6

Figure 5, 6 – LEGEND: size distribution of magnetic field intensity ***H*** [A/m] in the form of contour lines (isolines) in case of an induction crucible furnace itself (upper image - Figure 5) and induction furnace supplemented by an additional structural element in the form of flat short-circuit thread, which is located above the upper end of the inductor (bottom figure - Figure 6).

3. CONCLUSIONS

Simulation of magnetic field intensity distribution shows the well-known shielding effect of shielding with transformer sheets bunches to reduce the leakage flux of the coil in the construction of the equipment. It also shows us in this case not very significant influence of the flat short-circuit thread on magnetic field intensity distribution change.

Further research confirmed the assumption that the size effect of the electromagnetic field depends on the geometric shape of an additional element and then especially on its distance from the powered inductor.

In this case I can say that the element distance from the top part of inductor is too large to have significant influence on the electromagnetic field distribution in this area and therefore in the construction of new induction furnaces I propose to reduce this distance based on pre-test carried out computer simulations.

I have shown in this example that modern computer programs allow you to reliably solve relatively complex technical problems with induction heating. When solving electromagnetic field we can also conveniently solve other types of fields.

REFERENCES

[1] *Kroupa, Oldřich*: Možnosti snížení energetické náročnosti ohřevů elektromagnetickou indukcí. Písemná práce ke státní doktorské zkoušce. ZČU v Plzni. Plzeň: květen 2011

[2] *Kroupa, Oldřich*: Example of induction heating computer simulation, Electric power engineering and ecology – Selected parts I. Pages 37-44. Published by BEN – Technická literatura. Praha 2011

[3] *Kroupa, Oldřich*: Indukční ohřevy v praxi. Elektrotechnika a informatika, část třetí – Elektroenergetika, str. 51 – 54. Západočeská univerzita v Plzni. FEL. Nečtiny 2008

[4] *Langer, Emil; Kožený, Jiří*: Elektrotepelná zařízení indukční. VŠSE. Plzeň 1982

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