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Flux 3D application package for the analysis of magnetic field in an induction heater for cylindrical workpiece

Streszczenie. *W pracy przedstawiono wyniki obliczeń rozkładu natężenia pola magnetycznego w procesie nagrzewania indukcyjnego wsadów cylindrycznych od wewnątrz. Wykonano obliczenia w programie FLUX 3D metodą elementów skończonych. Wzbudnik stanowi 5-zwojowa miedziana cewka, w pracy zasymulowana jako 5 pojedynczych cewek o przekroju prostokątnym. Rozkład pola magnetycznego wyznaczony został dla prądu o wartości skutecznej 2kA i częstotliwości 9835Hz.* ***(Zastosowanie programu FLUX 3D do analizy pola magnetycznego nagrzewnicy indukcyjnej wsadów cylindrycznych)***

Abstract*. The paper encloses the results of the numerical analysis of electromagnetic field in the induction heating device for cylindrical workpieces. The 5-turn inductor has been replaced with five single coils with rectangular cross section. Numerical simulation was made for three different value of the times. The magnetic field in the charge was calculated for current I=2000 A and frequency f=9835 kHz. Its distribution was simulated and analyzed in the FLUX 3D program by using of finite element method.*

Słowa kluczowe: Pole elektromagnetyczne, nagrzewanie indukcyjne, hartowanie indukcyjne.
Keywords: Electromagnetic field, induction heating, induction hardening.

Introduction

In the induction heating process, an alternating current is passed through a conductor, creating an alternating magnetic field. A workpiece placed within this field becomes part of the electromagnetic circuit. As a result, alternating current will be developed within the workpiece, with subsequent heating due to resistive and hysteresis losses. If a high-frequency current is used, (typically 50 to 200 kHz), the inducted current is not concentrated near the surface. In this paper presents an inductive heater with internal inductor used for annealing steel pipes. CAD model is presented on Fig. 1.

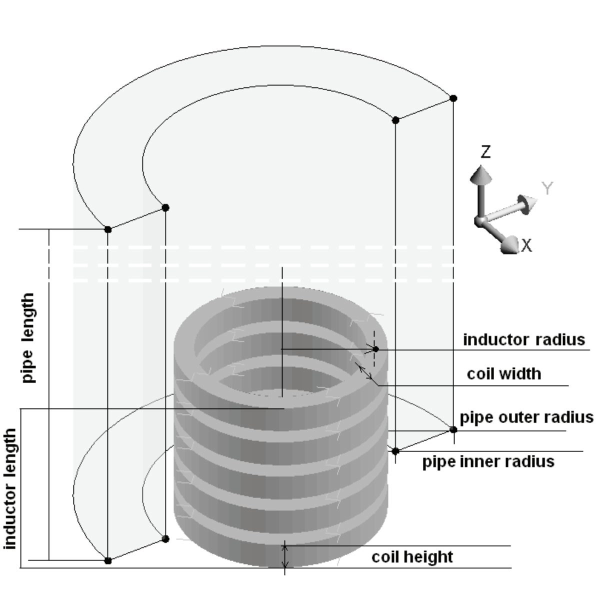


Fig.1. Cross-section of the workpiece with internal inductor.

Numerical methods development, for example the development of FEM (Finite Element Method) and of numerical simulation programs, can make possible the simulation of inductor behavior, before building the prototype and avoiding the designing errors [1, 9,14-16].

Construction of mathematical model

The model couples the volume formulations in vector electric potential $\boldsymbol{T}$ and scalar magnetic potential Φ in the conductive regions (magnetic or non-magnetic), with the Φ formulation in magnetic and non-conductive regions, and the Φ_r formulation in reduced scalar magnetic potential (non-magnetic and non-conductive regions).
Describe the magneto-harmonic electromagnetic field equations whose solutions were obtained for regions of eddy current related to the complex images of electromagnetic potentials [2-4]:

$$\mathbf{curl}\left[\frac{1}{\gamma}\mathbf{curl}\underline{\boldsymbol{T}}\right]-\mathbf{grad}\left[\frac{1}{\gamma}\mathrm{div}\underline{\boldsymbol{T}}\right]+\mathrm{j}\omega\mu\left(\underline{\boldsymbol{T}}-\mathbf{grad}\underline{\Phi}\right)=0 \quad (1)$$

and

$$\mathrm{div}\left[\mu\left(\underline{\boldsymbol{T}}-\mathbf{grad}\underline{\Phi}\right)\right]=0 \quad (2)$$

The equation in the non-magnetic and non-conducting region is:

$$\mathrm{div}\left[\mu_0\left(-\mathbf{grad}\underline{\Phi}_r+\underline{\boldsymbol{H}}_0\right)\right]=0 \quad (3)$$

where $\underline{\boldsymbol{H}}_0$ is the magnetic field source generated by the inductor coil in the infinite space in the absence of any material region and is computed by the Biot and Savart formula [5-8, 10-13].

(4) $$\underline{\boldsymbol{H}}_0 = \frac{1}{4\pi}\iiint_{v} \frac{\underline{\boldsymbol{J}} \times \boldsymbol{r}}{\boldsymbol{r}^3}\, dv$$

the integration being carried out on the volume V of the coil, where the current density $\underline{\mathbf{J}}$ is a known quantity.

Numerical example

Five turns inductor has been replaced with five single coils with rectangular cross section 12x16mm as in Fig. 1. The geometrical dimensions of the internal inductor are:

- radius 0.0615 m, length 67,5 mm
- height 0.08 m, current 2000 A,
- frequency 9835 kHz.

The geometrical dimensions of cylindrical workpiece are:

- inner radius 0.0815 m, external radius 0.0925 m,
- length 2.0 m.

The computation domain where the magnetic field is computed contains the workpiece to be processed and the surrounding non-conductive and non-magnetic regions, including the inductor.

The volume elements are characterized by number of :

- elements not evaluated 21.13 %
- excellent quality elements 38.6 %
- good quality elements 28.66 %
- average quality elements 9.78 %
- poor quality elements 1.83 %

The computational mesh consists of number of:
nodes: 35675, line elements: 525, surface elements: 4539, volume elements : 21043, mesh order : 2nd order.
For induction heating applications the $\boldsymbol{T\Phi} - \boldsymbol{\Phi} / \boldsymbol{\Phi}_r$ model of the electromagnetic field is used in eddy current problems.

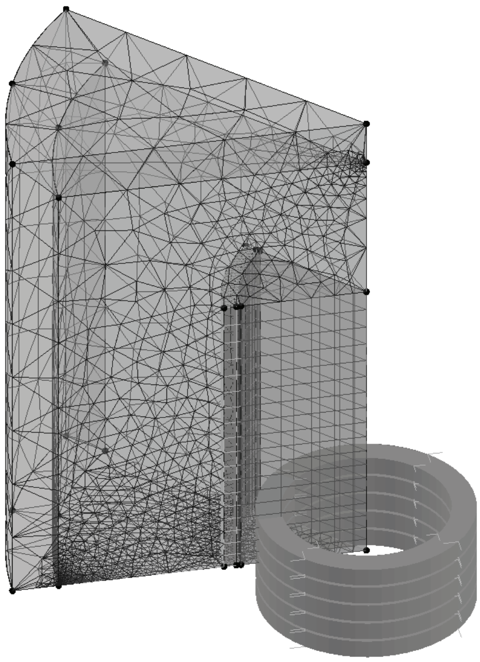


Fig. 2. The meshing of the computation domain.

Presentation of simulation results

Figures 3-5 shows the distributions of magnetic field on presented induction heater. Power source frequency of field current is 9.835 Hz. Figure 3 shows the distribution of magnetic field module for inductor centrally located inside the workpiece.

Isolines of magnetic field on cut planes shows fig. 4a) and 4b). Isolines of magnetic field on volume region inside the pipe shows Fig. 5a) and 5b).

Figure 6 shows the magnetic field distribution in cross-section of presented heater and arrows of the vector magnetic field for selected phasis 0, 90, 180 and 270.

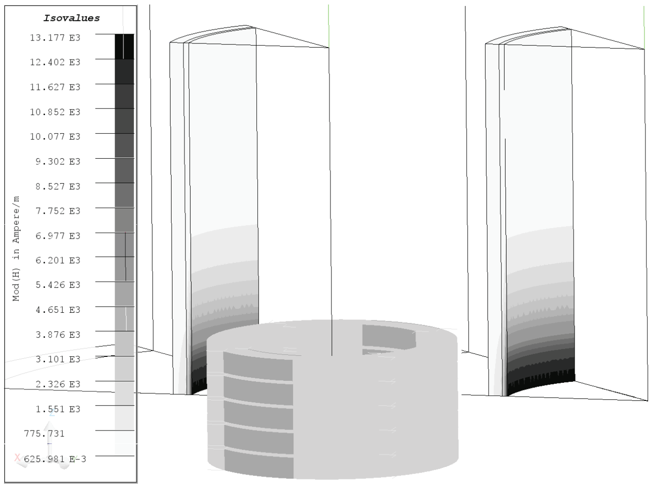
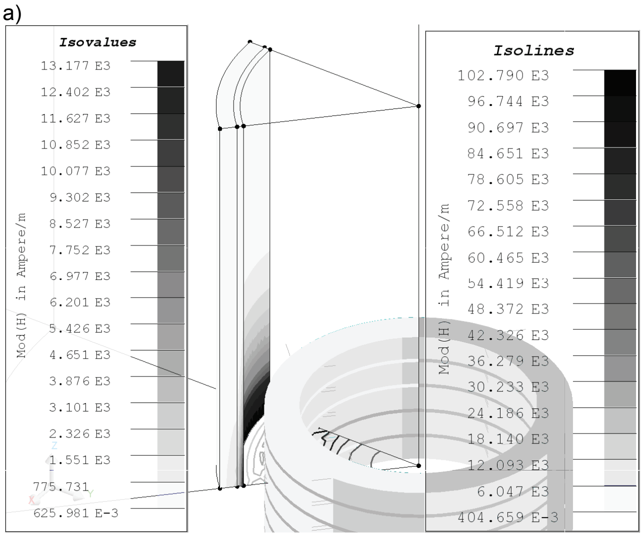


Fig.3. Distribution of magnetic field in cylindrical workpiece

a)



b)

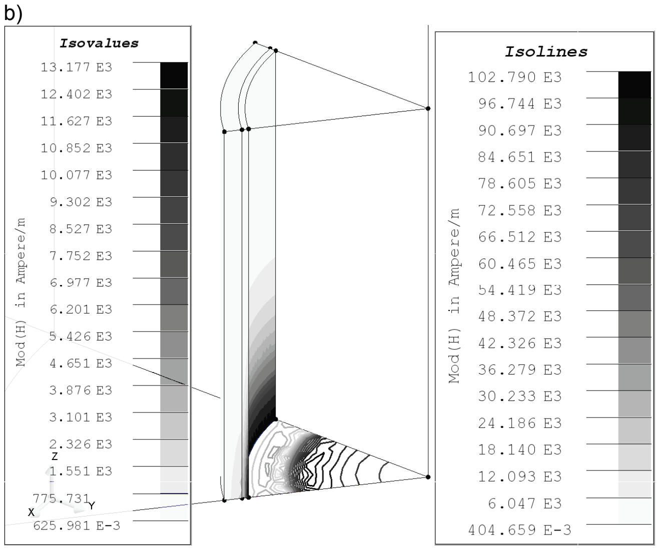


Fig.4. Isolines of magnetic field on cut plane and distribution magnetic field in the workpiece a) with coil b) wiwithout coil

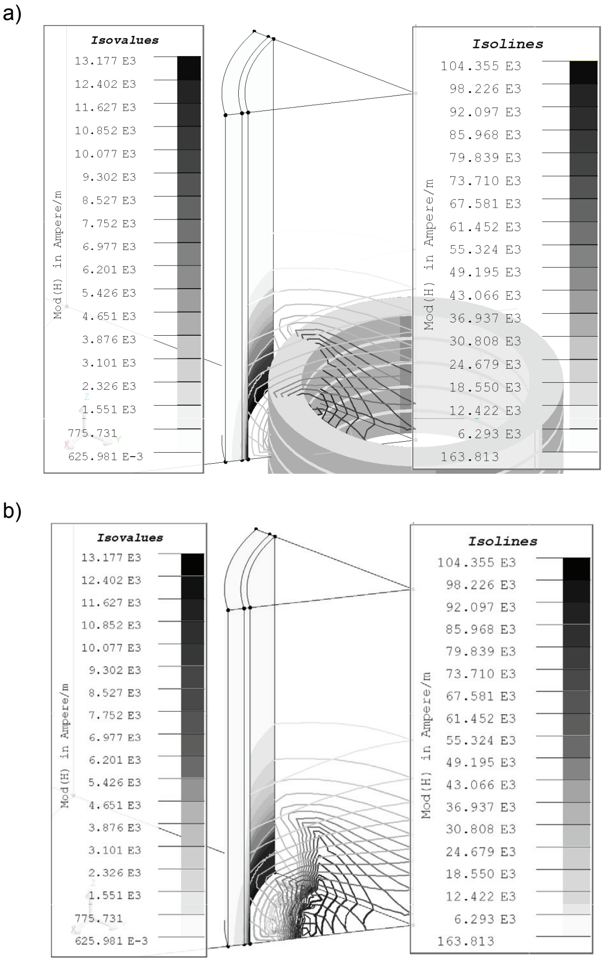


Fig.5. Isolines and distribution of magnetic field on volume region inside the workpiece a) with coil b) wiwithout coil

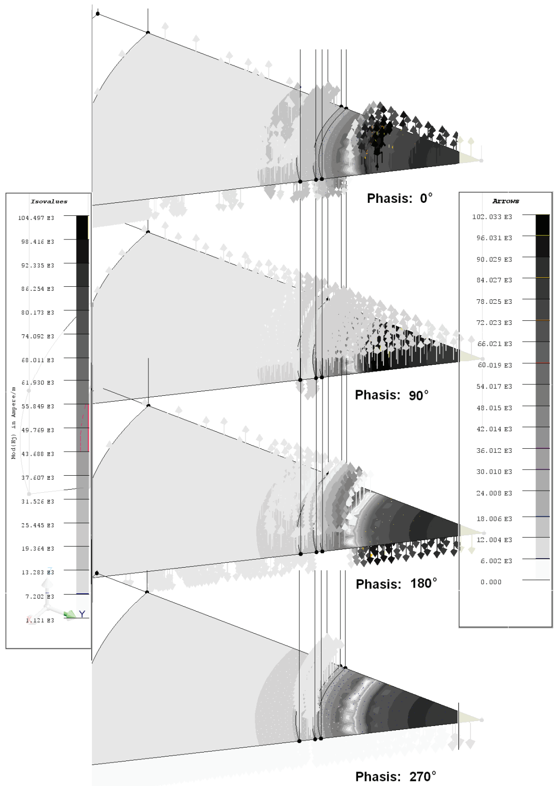


Fig.6. Arrows $\underline{H}$ and distribution of magnetic field $|\underline{H}|$ on cut plane for selected phasis.

Conclusions

Using multi-variant calculations performed FLUX of magnetic field intensity. In this paper we present only the results obtained for the frequency of the power source of 9835 Hz. The highest value of magnetic field strength in the inner layer of the cylindrical workpiece is 13 kA/m. The presented research shows advantages using computer program like FLUX 3D for calculating of distribution of magnetic field in the induction heating device for cylindrical workpieces. This is an remarkable advantage for the designers, because the designer work is realized now using CAD programs, reducing the cost for new developments. The simulation program can give a lot of interesting and important information.

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