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NUMERICAL MODELING OF THE MAGNETIC FIELD DISTRIBUTION IN SINGLE-PHASE SINGLE-CORE TRANSFORMER

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Abstract. An electromagnetic model of single-phase single-core transformer is made and a numerical simulation of the electromagnetic field is performed. The distribution of the magnetic induction in the transformer's core and in the surrounding space is obtained. A comparative analysis of the obtained electromagnetic values with the computed parameters by a chain model is carried out. The investigation enables the determination of the magnetic flux dissipated in the surrounding space outside the transformer that generates the electromagnetic interference.

Keywords: electromagnetic interference, numerical modelling, magnetic induction, transformer.

INTRODUCTION

The purpose of the study is the distribution of the magnetic field of a single-phase single-core transformer.

The low power transformer P = 250VA with primary voltage $U_1 = 220V$ and secondary voltage $U_2 = 72V$ is investigated. The transformer's magnet is made of 0.35 mm thick silicon steel sheets. The primary winding is made of a circular copper conductor of diameter $d_1 = 1.0\,mm$ and with $W_1 = 289$ turns. The secondary winding is made of a circular copper conductor of diameter $d_2 = 1.62\,mm$ and with $W_2 = 104$ turns.

Numerical modeling using the finite element method is performed.
The scheme of the transformer in Figure 1 is shown.

THEORETICAL STATEMENT

The electromagnetic field in the transformer is described with a Poisson‘equation [1]

(1) $$rot\frac{1}{\mu}\nabla\times\left(rot\vec{A}_\mu\right)+\gamma\frac{\partial\vec{A}}{\partial t}=\vec{J}\ ,$$

where: $\vec{A}_\mu$ is the magnetic vector– potential;

$\vec{J}$ is the current density vector;

μ is the magnetic permeability;

γ is the specific electrical conductivity.

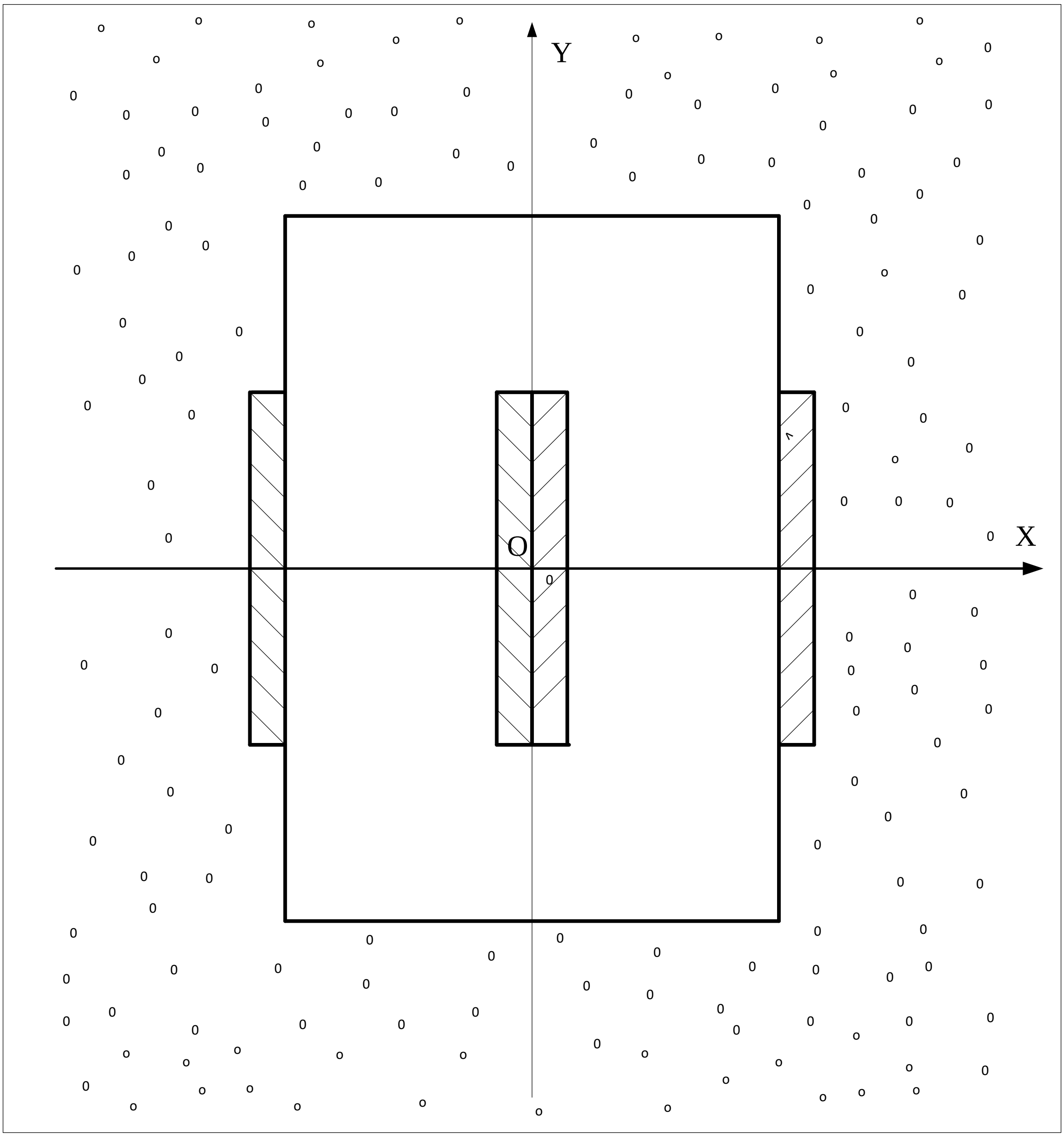

Figure 1. The scheme of the investigated transformer

The current density is non-zero only in the cross-section of the winding.

The current in the primary winding is

(2) $$i_1(t) = i_{1m} \sin \omega t ,$$

where: i_{1m} is the amplitude, and ω is the angular frequency of the current in the primary winding. The primary coil is connected to a sinusoidal voltage source with a frequency f = 50 Hz.

The current density in the primary winding J_1 is

(3) $$J_1 = \frac{N_1}{S_1} i_{1m} \sin \omega t ,$$

where: N_1 is the number of turns of the primary winding;

S_1 is the cross-section of the primary winding.

The current density in the secondary winding is

(4) $$J_2 = \frac{N_2}{S_2} i_2(t),$$

where: N_2 is the number of turns of the secondary winding;

S_2 is the cross-sectional area of the secondary winding;

$i_2(t)$ is the current through the secondary winding.

The magnetic field in the transformer is flat-parallel, magnetostatic in a non-homogeneous environment and therefore the task as a two-dimensional one can be solved.

The all area of the study into two parts is divided - an area of the magnet core and the windings, where the magnetic field is concentrated and an area of the air, where the magnetic field is scattered.

Due to the symmetry of the transformer design, only half of the transformer can be tested.

The magnetic vector-potential has the component only on the z-axis- A_z, since the current density through the windings is in the z-axis direction- J_z.

In this case, the equation describing the distribution of the magnetic field is [2]

(5) $$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial A_\mu}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial A_\mu}{\partial y}\right) = -J_z$$

NUMERICAL MODELING

Numerical modeling using the finite element method FEM is done. The ANSYS software package is used [3, 4].

Poisson equation is solved numerically using the finite element method. The magnetic vector potential is determined by the expression

(6) $$\{A\} = [N_A]^T . \{A_\varepsilon\} ,$$

where N_A is matrix of shape functions of elements and A_ε is magnetic vector potential in the nodes of the finite element.

Magnetic field vectors as derivatives of the magnetic vector potential $\vec{A}$ are defined. The magnetic flux density (magnetic induction) $\vec{B}$ is determined by the expression

(7) $$\{B\} = \nabla \times [N_A]^T . \{A_\varepsilon\}.$$

The magnetic field intensity $\vec{H}$ is

(8) $$\{H\} = \frac{1}{[\mu]}.\{B\},$$

where $[\mu]$ is matrix of magnetic property (magnetic permeability).

The simulations with the following parameters are performed:

- relative magnetic permeability of the magnetic core $\mu_r = 1000$;
- relative magnetic permeability of the air space and cooper winding $\mu_r = 1$;
- current density through the primary winding in the z-axis direction - $J_z = 1000000\ A/m^2$.

The investigations for different cases have been carried out:

- idle mode and normal mode of transformer;
- short circuit in secondary winding;
- shielding of the magnetic field with ferrite sheet.

The distribution of the magnetic induction in the transformer, in case of idle mode and magnetic shielding is shown in Fig. 2 and the magnetic flux lines - in Fig. 3, respectively. Only the upper half of the space is considered due to symmetry.

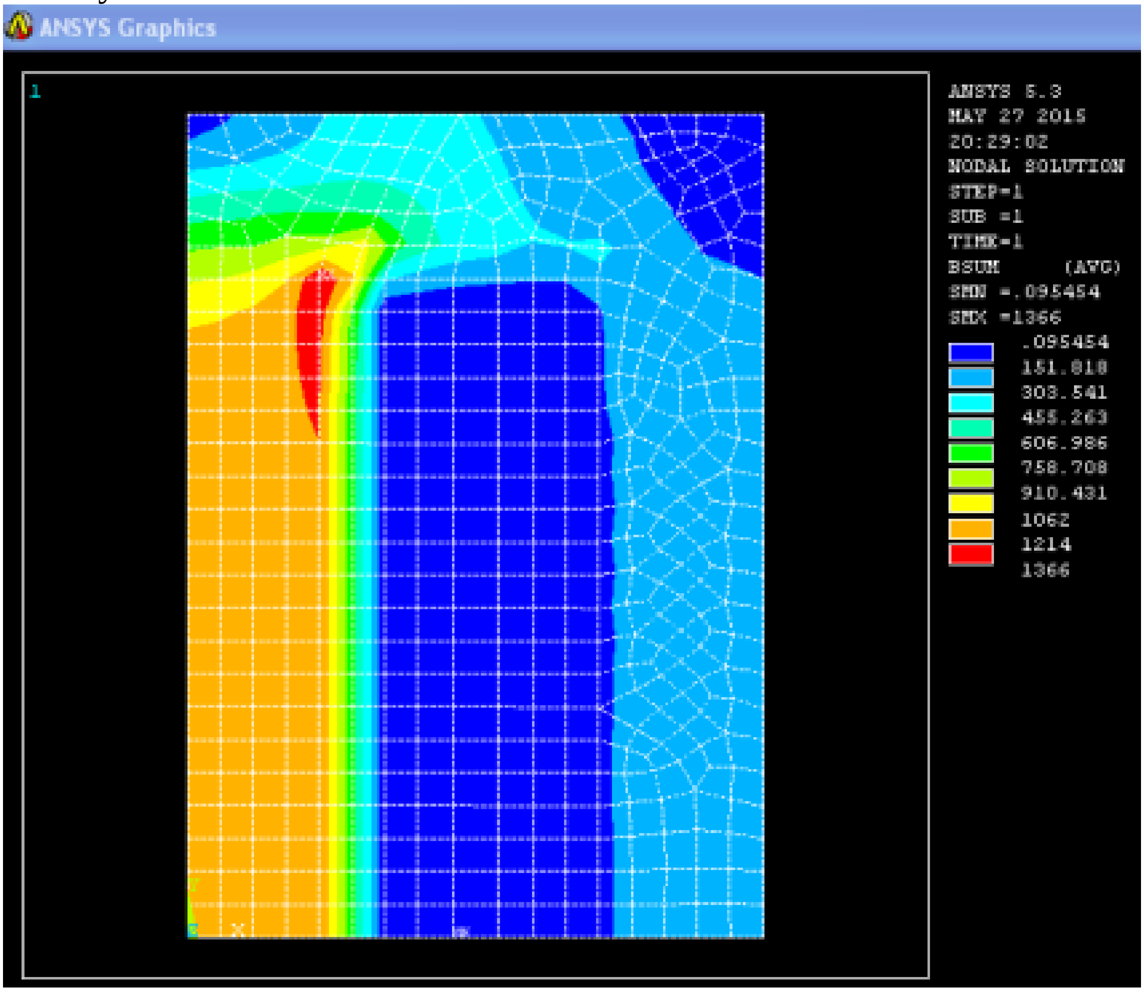

Figure 2. Distribution on magnetic induction in magnetic core in case of magnetic shielding.

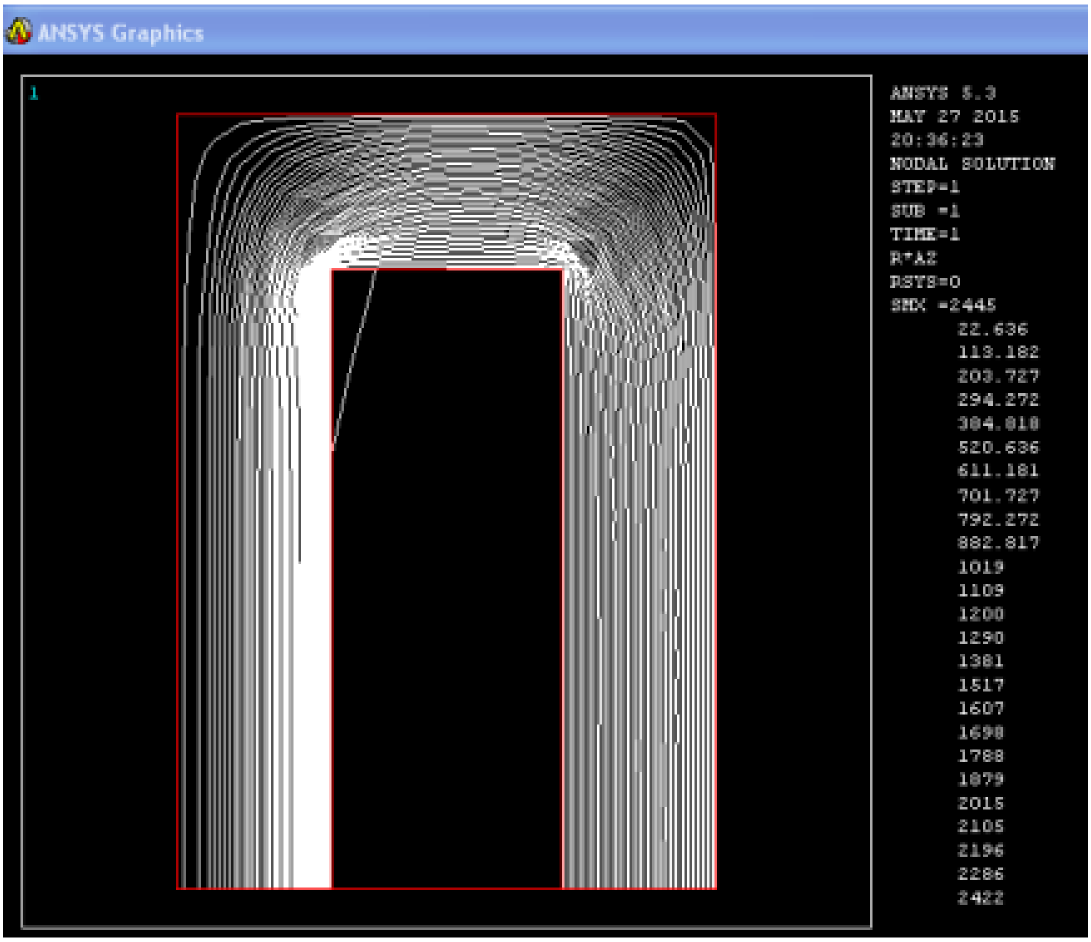

Figure 3. Distribution of magnetic flux lines in magnetic core in case of magnetic shielding.

The shielding of the magnetic field with a ferrite screen ensures satisfactory field uniformity and minimal magnetic flux scattering.

Interesting is the study of the case of a short circuit in the secondary winding. The case of non-magnetic screen is considered.

The distribution of the magnetic flux lines in the transformer in case of short circuit without magnetic shielding in the upper quarter of the investigated area (due to symmetry) is shown in Fig. 4.

The distribution the magnetic induction vector (vector field) in the transformer in case of short circuit without magnetic shielding in the upper quarter of the investigated area is shown in Fig. 5.

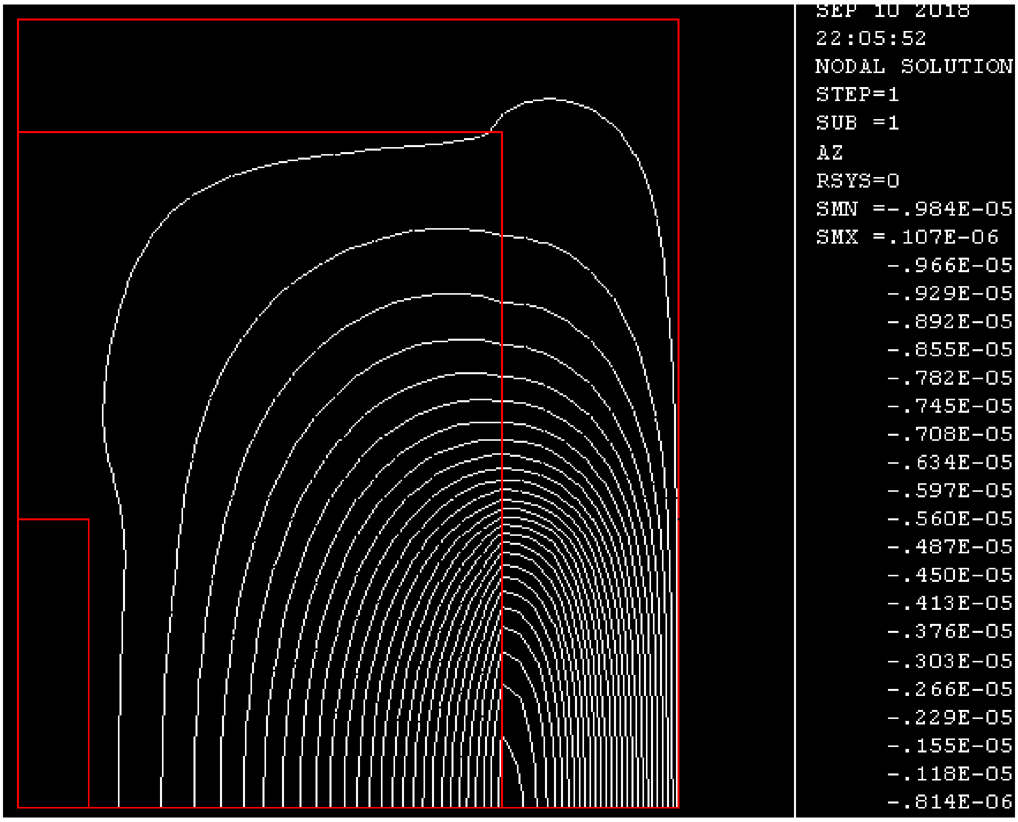

Figure 4. Distribution magnetic flux lines in magnetic core in case of short circuit without magnetic shielding.

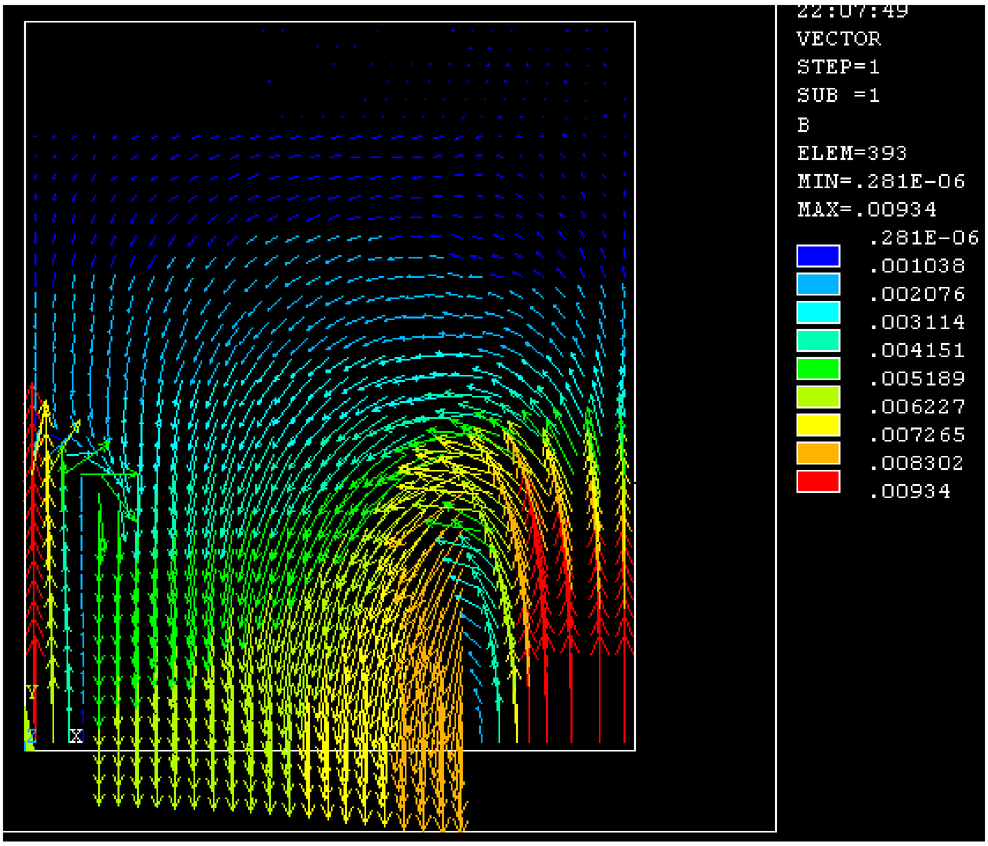

Figure 5. Distribution on magnetic induction in of short circuit without magnetic shielding.

In this case the magnetic field is non-homogeneity in magnetic core and surrounding air area. This leads to the presence of magnetic flux scattering and this is the reason for electromagnetic interference and distortion of the electromagnetic compatibility [6], respectively.

It is necessary to obtain both beavers of H and B to accomplish the loss analysis [5]. This is the reason why simulations to investigate the distribution of magnetic intensity.

The distribution the magnetic intensity on x-axis in the transformer in case of short circuit without magnetic shielding in the upper quarter of the investigated area is shown in Fig. 6.

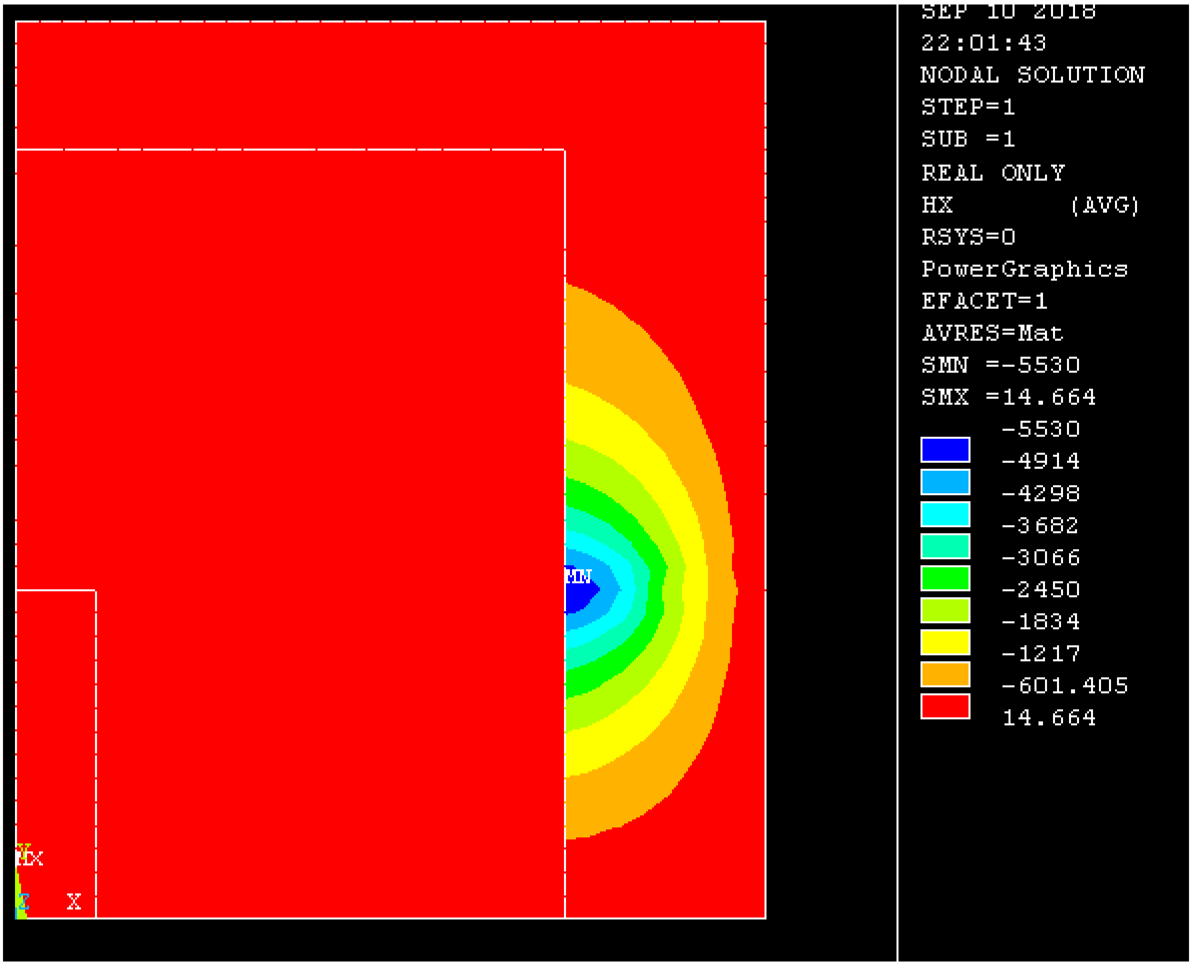

Figure 6. Distribution on magnetic intensity in case of short circuit without magnetic shielding.

The distribution of magnetic intensity in the vicinity indicates the presence of significant distracted magnetic flux, resulting in substantial losses and corresponding electromagnetic disturbances..

CONCLUSIONS

An electromagnetic model of single-phase single-core transformer is made and a numerical simulation of the electromagnetic field is performed.

The distribution of the magnetic induction, magnetic intensity and flux lines in the transformer's core and in the surrounding space in case of idle mode and short circuit is obtained.

The shielding of the magnetic field with a ferrite screen ensures satisfactory field uniformity and minimal magnetic flux scattering.

The investigation enables the determination of the magnetic flux dissipated in the surrounding space outside the transformer in case of short circuit without shielding. This is the reason for electromagnetic interference and distortion of the electromagnetic compatibility.

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