THE CURRENT INDUCED CALCULATION IN CLAW POLE OF AN ALTERNATOR BY FINITE ELEMENT METHOD

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REZUMAT. Calculul câmpului magnetic în alternatorul cu poli gheară permite determinarea performanţelor globale ale alternatorului în orice regim de funcţionare, dar şi o optimizare constructivă în scopul creşterii randamentului şi a reducerii pierderilor. Tensiunea indusă în înfăşurarea statorică, curenţii turbionari induşi în polii gheară cât şi pierderile volumice produse de aceştia, se pot calcula prin MEF, cunoscând distribuţia 3D a câmpului magnetic din alternator.

Cuvinte cheie: câmp magnetic, alternator cu poli gheară, curenți turbionari, MEF.

ABSTRACT. The magnetic field calculation in the claw pole alternator allows us to determine the global performance of the alternator in any operating mode, but also a constructive optimization to increase efficiency and reduce losses . The induced voltage in the stator, the eddy curents induced in the claw poles and the volume displacement caused by these currents can be calculatedby FEM, knowing the distribution of 3D magnetic field in the alternator.

Keywords: magnetic field, claw pole alternator, eddy currents, FEM.

1. INTRODUCTION

Due to the increasing number of electric customers installed on-board the vehicles to increase comfort and safety, it is necessary to design alternators with increased power and with low volume and low weight. 3-Dimensional magneto static field calculation allows geometry optimization in order to design new models of claw pole alternators with high performance, eliminating the classical method of optimization that rely on expensive prototypes and successive tests in the laboratory. Among the numerical methods used in electromagnetism field the most widely used is the finite element method.

In this paper we present a method for calculating the eddy currents induced in the claw pole alternator of a car, with p = 6 pole pairs and Z = 36 notches, with U_n = 14 V şi I_n = 36 A. The complex construction of the rotor, the existence of magnetic fields both radial and axial, require that magnetic field study in the machine to be done by 3-dimensional numerical modeling. In this study, numerical calculation of the field of machine was made with 3D software package FLUX 3D developed by the company CEDRAT.

Besides optimizing the shape of claw pole, another method for increasing the alternator efficiency would be the reduction of losses that occur in the windings, stator and rotor magnetic circuits. In the magnetic cores occur hysteresis losses and eddy current losses due to high frequency magnetic field, characteristic of these machines with large numbers of poles (2p = 12). Because Joule losses can be calculated directly, but dependent on the currents in coils, an analytical description of the core loss is not possible, given the complex geometry of the poles and the magnetic field. In this paper we performed a numerical calculation of these losses.

In the case of claw poles alternator, notch frequency pulsating magnetic field calculated by the formula:

$$f_{teeth} = \frac{Z\,n}{60} \tag{1}$$

where Z is the number of stator slots and has the value Z = 36, and n is the drive speed of the rotor expressed in revolutions per minute. For example, a rotor speed of n = 3000rpm causes a flow pulsation frequency f_{teeth}=1800 Hz .

With increasing rotor speed, frequency currents induced in the claw poles increases according to relation (1), and their penetration depth in core area, consisting of claw poles and ferromagnetic muff is calculated with the equation:

$$\delta = \sqrt{\frac{\rho}{\pi\,\mu_0\mu_r f}} \tag{2}$$

where ρ is magnetic resistivity of the material, magnetic field frequency f is calculated with (1) and μ_r is the relative magnetic permeability of the material.

2. THE 3D NUMERICAL MODEL OF THE CLAW POLE ALTERNATOR

The Volume in which electromagnetic phenomena can be studied only involved the operation of the claw pole alternator is represented by the two magnetic cores and air gap between them.

In this case, the calculation is reduced to a single pair of poles of the six pairs of poles in the alternator and represents one sixth of the physical model, which is limited to the borders of the infinite planes of symmetry and join the two poles of the same polarity (Figure 1).

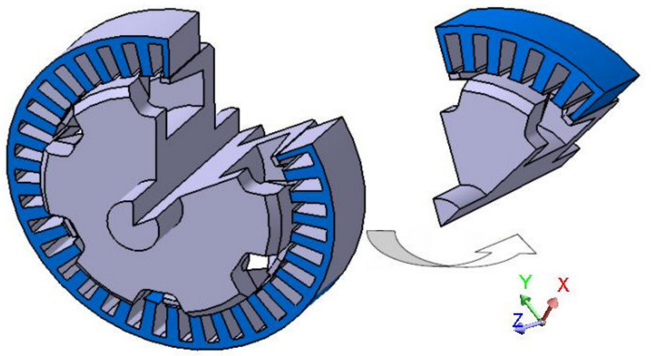

Fig 1. 3D magnetic circuits of the alternator with claw poles and the finite element calculation, the magnetic field.

When operating under load, the excitation coil is supplied from outside by means of rings from a DC source and the stator is covered by the load current.

In this case the sources of the field winding excitation current intensity of the induced currents. Specific magnetic field regime claw pole alternator, rotor speed considering training regime is constant magnetic quasi stationary. This regime is described by the equations:

$$rot\,\mathbf{H} = \mathbf{J} \qquad (3)$$

$$rot\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \qquad (4)$$

$$\mathbf{B} = \mu(\mathbf{H})\mathbf{H} \qquad (5)$$

$$\text{div}\,\mathbf{B} = 0 \qquad (6)$$

$$\mathbf{J} = \sigma\,\mathbf{E} \qquad (7)$$

In the field of computing there are areas of high magnetic permeability (ferromagnetic cores) without current sources, areas with high magnetic permeability (pole claw bush ferromagnetic, polar crowns) with the induced currents sources, areas of low magnetic permeability that is winding induced, with the current source load current and low magnetic permeability areas in which the excitation coil. Therefore, the magnetic field of the alternator sources are: the intensity of the excitation current, the current load and current density induced currents in the pole claw bush ferromagnetic and polar crowns.

Solving the problem of field, described by equations (3) ÷ (7) was made using the formula T-Φ (electric vector potential T) in the region defined by the flanges conductive magnetic poles, and ferromagnetic muff rotor shaft, the total scalar magnetic potential (Φ) In other regions as the magnetic conductive stator core with reduced scalar magnetic potential formulation in (Φr) in computing the remaining non-conducting and non-magnetic field that $J \neq 0$ [1], [2].

In the case of three-dimensional problems is preferable to work with a scalar state variable, the formulation is preferred in terms of numbers, requiring only a single local unknown. Computing field consists of magnetic cores of the alternator is divided into two regions:

- R_1 region in which induce eddy currents and consider the electrical conductivity $\sigma \neq 0$being applied electric vector potential **T**. vector current density **J** is solenoid, which means it can be expressed as:

$$\mathbf{J} = \text{rot}\,\mathbf{T} \qquad (8)$$

- a second region R_2 without power source, where rot **H** = 0, the magnetic field can be written as an expression of scalar magnetic potential Φ.

T-Φ formulation of the law of electromagnetic induction is given by the equation:

$$rot\left[\left(\frac{1}{\sigma}\right)\cdot rot\;T\right] + \frac{\partial[\mu(T - grad\Phi)]}{\partial t} = 0 \qquad (9)$$

A second equation linking **T** and Φ the magnetic flux is obtained from the law, as follows:

$$\text{div}[\mu\,(\,\mathbf{T} - \text{grad}\;\Phi\,)] = 0 \qquad (10)$$

In regions with low relative magnetic permeability and $J \neq 0$ is used in Φr formulation and solve the equation:

$$\text{div}\,(\mu\;\text{grad}\;\Phi_r) = \text{div}\,(\mu\mathbf{H}_s) \qquad (11)$$

$\mathbf{H}_s$ is the magnetic field component produced by the excitation coil, electric current traveled conduction current density **J** is calculated analytically with the Biot-Savart-Laplace formula [3], [4]:

$$\mathbf{H}_S(\mathrm{M}) = \frac{1}{4\pi}\int_V \frac{\mathbf{J}(\mathrm{P})\times\mathbf{r}}{|\mathrm{r}|^3}\mathrm{dV} \qquad (12)$$

where V is the volume conductor region, P is a point current source region, the current point space M and **r** is the vector PM.

To solve the problem field, expressed through the potentials, equations (9), (10) and (11) must be complemented by boundary conditions. Based on electromagnetic phenomena recurrence after a pair of poles, the axes of symmetry appropriate boundaries of poles is placed a condition of periodicity. This may be necessary if the two surfaces is identical mesh is to ensure equal potential and the corresponding points on the border crossing A_1 and A_2, as shown in Figure 2.

Such a point M_1 ($r_{m1}, \theta_{m1}, z_{m1}$) from the border A1 corresponds to a point M_2 ($r_{m2}, \theta_{m2}, z_{m2}$) A_2 on the border, where the cylindrical coordinate system conditions: $r_{m1} = r_{m2}$; $\theta_{m1} = \theta_{m2} + 2\pi/p$; $z_{m1} = z_{m2}$.

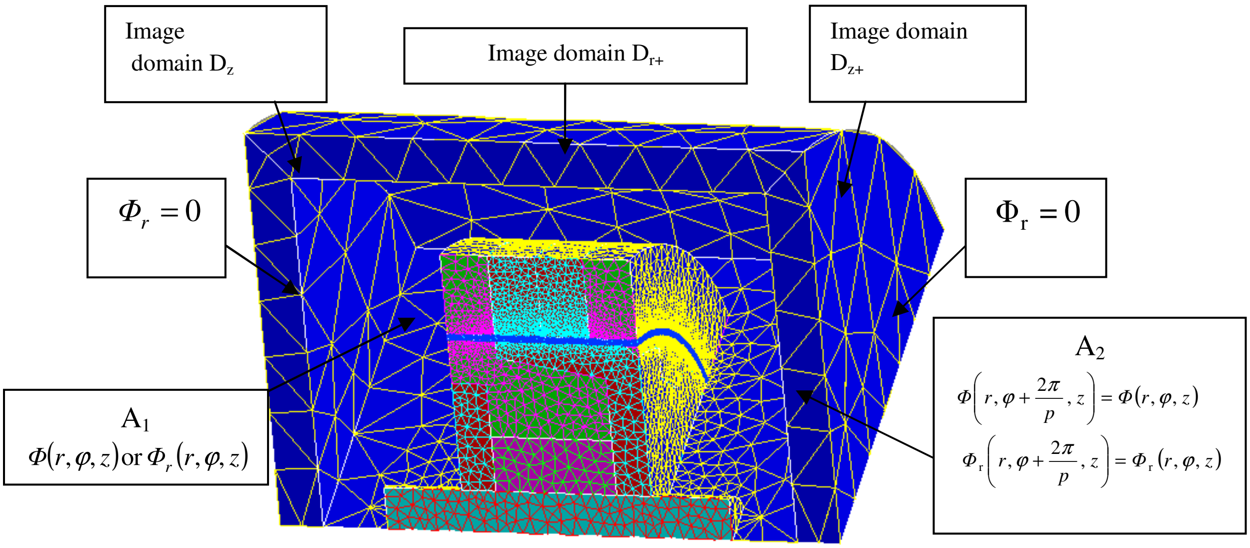

Fig. 2. Finite element network and the boundary conditions of the field calculation, bounded by the infinite region.

The calculation of currents induced by the finite element method involves three-dimensional finite element grid adaptation based on depth of penetration so that the mesh network at high frequencies should be much smoother and be composed of second-order volume elements.

Magnetization characteristics of the stator core sheets and forged steel poles, which express the dependence of magnetic permeability μ, the magnetic field H, according to relation (5) are shown in Figure 3 and Figure 4.

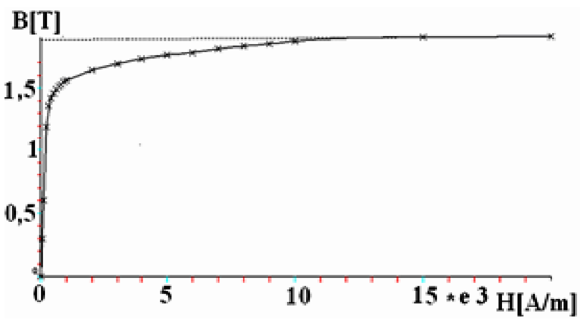

Fig 3. Magnetization characteristic stator core

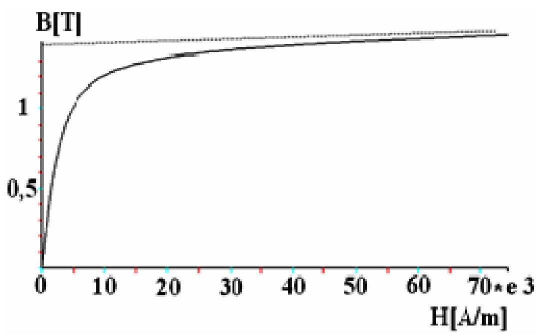

Fig 4. Magnetization characteristic axis rotor

3. THE RESULTS

Eddy currents induced in the ferromagnetic parts of the rotor is determined by solving a 3D magnetic field problem coupled with a circuit problem with a three-phase bridge rectifier and a resistive load R_s = 3.2 Ω.

It solves the problem of field for two different rotor speeds ie n = 400 rpm and n =800 rpm with the excitation coil fed by an excitation current value I_e = 3A. The specific loops in Figure 5 represent the corresponding closure eddy claw poles appearing in volume.

Axial magnetic flux calculated by the surface, b obtained by the intersection of the median of the alternator shaft and bushing is illustrated in Figure 6 and deducted as follows:

$$\Phi = \int_{S_{a,b}} B_{radial} n dA \quad (13)$$

Using second order finite elements in solving the problem of the field, coupled with the problem of electric circuit, with rectified resistive load, considering the currents induced in the claw poles requires a great time working and more than 4 GB RAM.

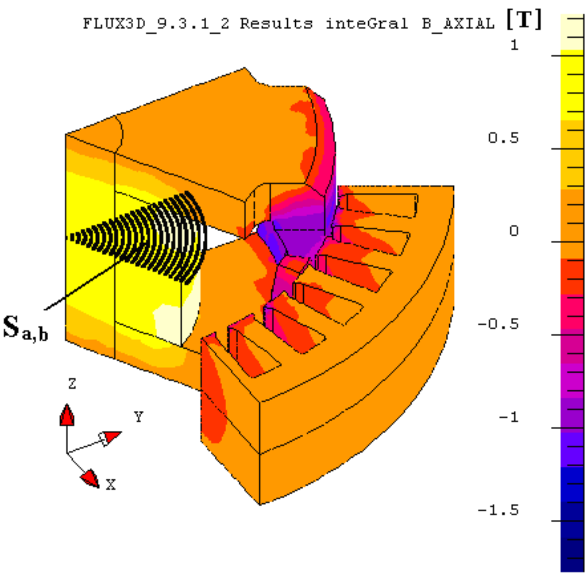

Fig.5. The Surface $S_{a,b}$ in the median plane for axial flow calculations in the tree and muff.

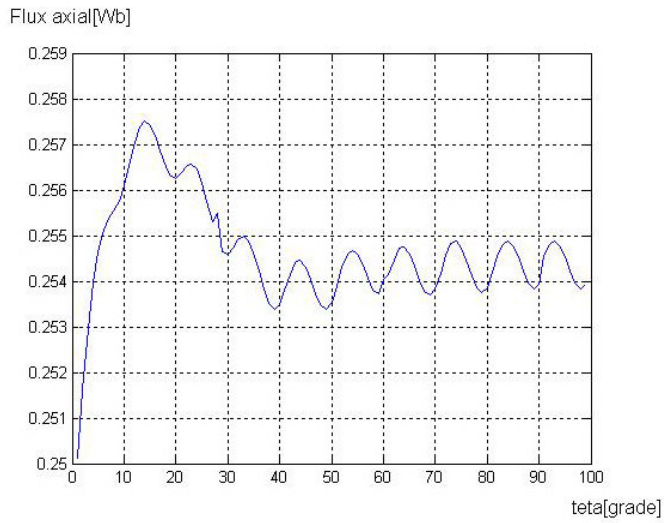

Fig.6. Frequency axial magnetic flux through the shaft and muff according to the rotor position.

Thus, the combined formulation TΦ- Φ_r, the field for the numerical model shown in Figure 2, the mesh network with second order elements containing 122,360 nodes and 967,342elements of volume, compared with the model without induced currents had 73,874nodes and 453,294 elements volume. In this case, the working time necessary to resolve the problem by determining the induced currents for the five discrete steps of the rotor is more than 24 hours on a PIV 2.7 GHz computer with 4 GB of RAM.

In postprocessor program calculates the 3D flow and eddy current losses induced by volume, presented in Table 1, two of revolutions n = 400 rpm and n = 800 rpm.In Figure 7 and Figure 8 shows a map of the density and volume by the eddy current losses, corresponding to two values of speed.

Table 1. Eddy current losses induced by volume

	n = 400 rpm	*n* = 800 rpm
Active losses in ferromagnetic muff	65 W	65,07 W
Active losses in claw pole and crowns	33 W	32,86 W
Depth of penetration into the muff (δ)	1,125 mm	0,795 mm

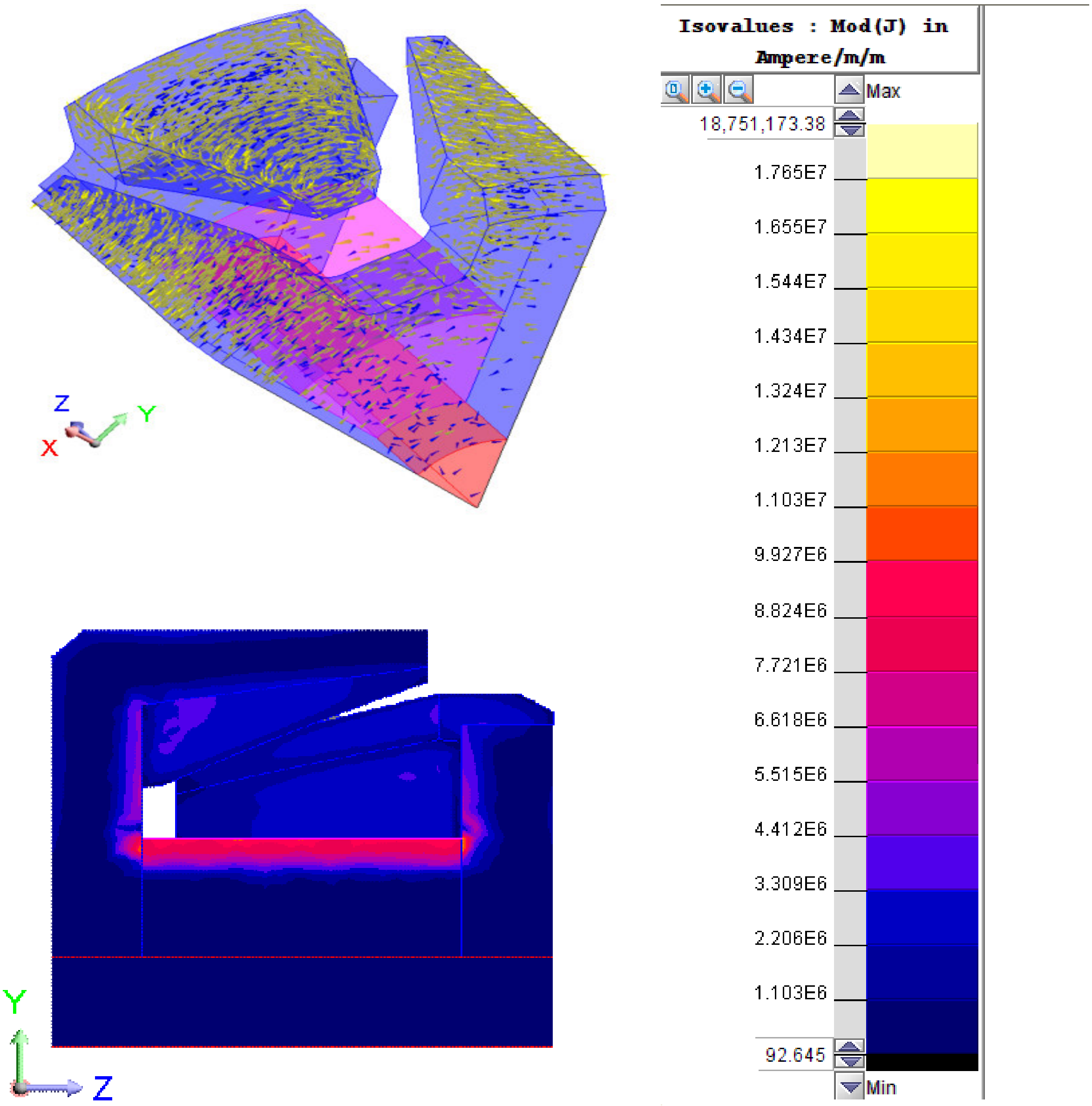

Fig. 7. Eddy currents induced in the ferromagnetic muff and poles at the speed n = 400 rpm

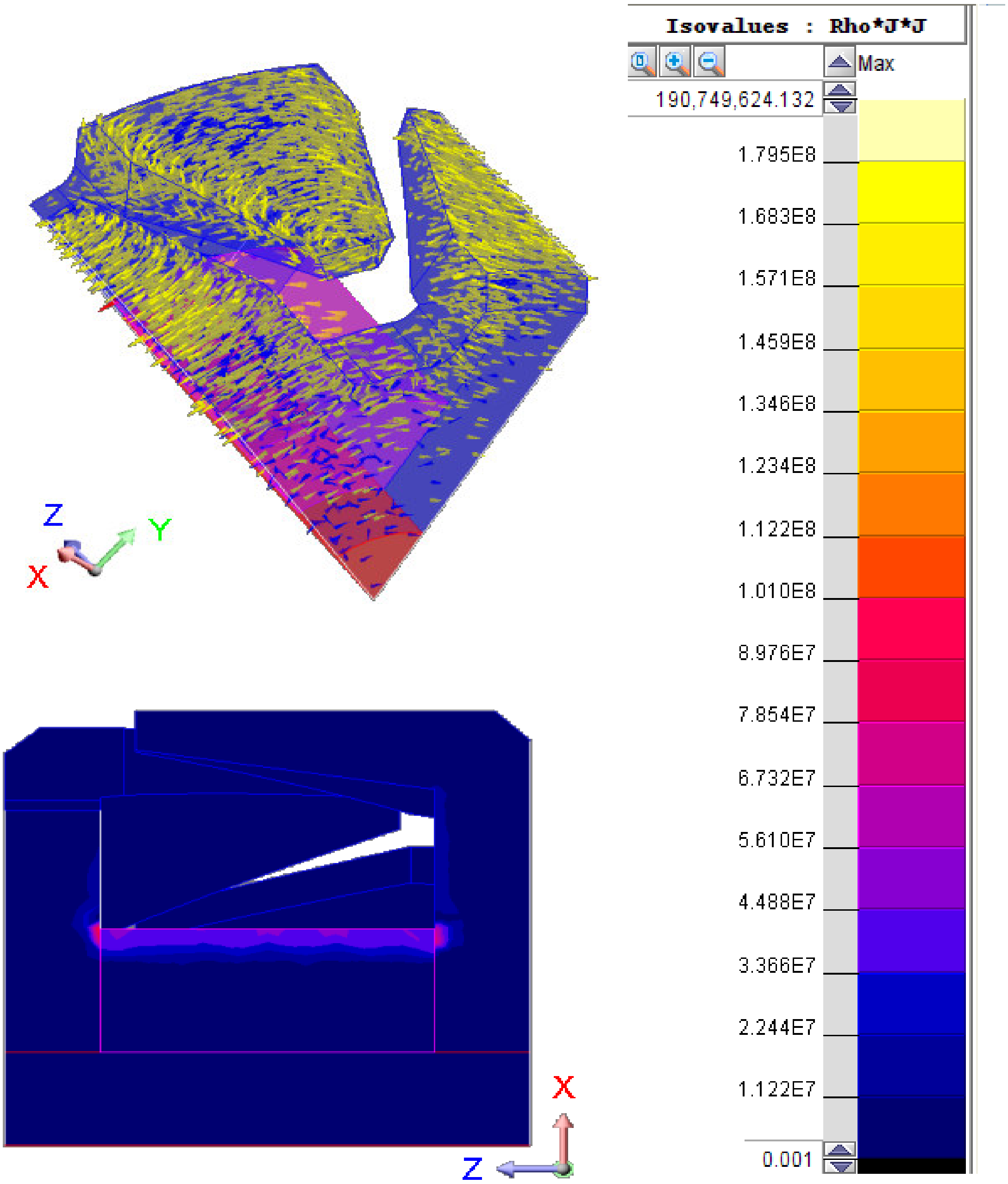

Fig. 8. Eddy currents induced in the ferromagnetic muff and poles at the speed n=800 rpm

5. CONCLUSIONS

This paper determines the eddy currents induced in the claw poles of an electric alternator using the finite element method. The calculation of these currents is to make the field calculation in 3D, built successively as shown in [5].

From the analysis made on the values of eddy currents induced in large parts of the alternator (pole claw ferromagnetic muff and polar crowns) and loss of power produced at these parts can draw some interesting conclusions:

• depth of penetration of eddy currents induced in large parts alternator decreases with increasing speed, as derived from the analysis of Figures 7 and 8;

• axial flux due to pulsation represented in Figure 6, the outer ferromagnetic power losses are greater than the claw pole;

- working arrangements corresponding alternator speeds n ∈ (950 ÷ 6000) rpm, and resolving problems field and calculating the induced currents at these speeds is possible only with very large computational resources and memory to achieve very strong refining large network of finite elements in relation to the depth of penetration;
- calculation of eddy currents induced in the claw poles of the finite element method is useful in determining the core loss occurring in the alternator ferromagnetic cores.

BIBLIOGRAPHY

[1] CEDRAT Recherche: Modélisation des phénomènes électromagnétiques par la méthode des éléments finis, -1995 ;

[2] **Firețeanu V.**, Popa M., Tudorache T., *Modelarea numerică în studiul şi concepția dispozitivelor electrotehnice,* Editura Matrix Rom, Bucureşti, 2004.

[3] **Mocanu C.**, *Bazele Electrotehnicii - Teoria câmpului electromagnetic*, Editura Didactică şi pedagogică Bucureşti, 1991.

[4] **Henneberger, G.**, Block, R., *Numerical Calculation and Simulation of a Claw-Pole Alternator*, Proceedings of the 9th ICEM, Manchester, England,2000

[5] **Stoica C.**, Teză de doctorat, *Cercetări teoretice şi experimentale privind optimizarea funcțional constructivă a generatoarelor sincrone folosite la automobile,* Universitatea POLITEHNICA din Bucureşti, 2009

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