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NUMERICAL MODELING OF EDDY CURRENTS AND HEATING IN NONMAGNETIC STEEL STRUCTURAL ELEMENTS OF POWERFUL TRANSFORMERS AND ELECTRIC REACTORS

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Abstract. The method of computation of eddy currents, losses and heating in structural nonmagnetic steel elements of powerful electric equipment is discussed.

Keywords: powerful electric, transformers, reactors.

1. Introduction

Growth of power of electrical systems and expansion of system interconnection is put by the promoted requirements to reliability and economy of powerful power electric equipment. Creation of powerful unique transformers and reactors limited in their size and weight results in the sharp rise of specific electro-magnetic and, consequently, thermal and electrodynamic load on active and structural elements of this equipment.

In this connection, at planning and making powerful electrical equipment there are some intricate engineering problems, which can be solved by the methods of computation of electromagnetic fields, additional losses and heating in the windings and in the details of constructions, inductive parameters of windings, electrodynamic forces, methods of electromagnetic protection, questions of optimization of structural decisions and a number of others [1, 6, 8, 10, 11].

Knowledge of the electromagnetic field distribution (eddy currents) is the basis for solution of the indicated tasks, with all other electrodynamic sizes being determined.

Both analytical and numerical methods of computation of the electromagnetic fields were developed during the last decades [2 – 6, 8, 11]. A number of algorithms were developed and on their basis the software was created for computation of electromagnetic fields and parameters of powerful engineering and electrical equipment [6 – 8, 11 - 13].

In spite of the fact that the level of computing engineering allows now to solve numerically intricate spatial problems, however there are problems related to geometrical nonlinear tasks. As an example it is possible to present pressing plates on the bars of a magnetic system, yoke beam, insertions in walls and lids and other structural elements the thickness of which is 200 – 300 times less than their length.

In such cases complications consist not only in construction of net when the method of finite elements is used, but also in the necessity to increase computation time.

In the given work the step-by-step approach method of numerical simulation of eddy currents and heating in structural elements made of nonmagnetic steel of powerful transformers and reactors is offered, which allows a three-dimensional task to convert into a two-dimensional task.

2. Problem formulation

It is assumed that the element of construction of a transformer or reactor (pressing plate on the bar of a magnetic system, involute of yoke beam, insertions in walls and lids of tanks) is the conducting body of thickness of h and limited by the flat surface S. The stream of induction $B_z(t)$ falls on the S surface athwart [4, 5].

Thus

$$B_z(t) = B_0 e^{i\omega t}, \qquad (1)$$

where B_0 is magnetic induction at $t = 0$, and ω is angular frequency.

Passing a magnetic stream through the S surface induce eddy currents in the conducting body.

It is accepted that the surface of the S conducting body is located in plane XOY, and the magnetic stream is parallel to the axis OZ. Therefore, in future we drop the index of z.

At such approach, structural elements made of nonmagnetic steel will be the sheets of arbitrary geometrical form with the cuts of arbitrary form or without them, thus their thickness of h will be less than depth of penetration $\delta \approx (2/\sigma\omega\mu)^{0.5}$.

3. Numerical solution and results

Taking into account the accepted assumptions, the task of computation of eddy currents and losses in a three-dimensional construction is converted into the task for the sheet of complicated form at the given induction of the magnetic field.

Using the second Maxwell's equation [6]

$$\vec{\nabla} \times \vec{E} = -\partial B / \partial t \qquad (2)$$

and also taking into account that

$$\vec{E} = \vec{j} / \sigma \qquad (3)$$

we will get

$$\vec{\nabla} \times \vec{j} = -\sigma \frac{\partial \vec{B}}{\partial t} . \qquad (4)$$

Because $div\vec{j} = 0$, using electric vector potential $\vec{T}$, in accordance with determination [6, 11]

$$\vec{j} = \vec{\nabla} \times \vec{T} \qquad (5)$$

and taking into account (4), we get

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = \sigma \frac{\partial B}{\partial t} . \qquad (6)$$

In the equation (6) T – normal component of vector $\vec{T}$.

At the given normal stream of induction (1) determination of the T potential and, consequently, the vector of current density $\vec{j}$ is converted with consideration of (5) and (6) into the boundary problem for the Poisson equation at the zero Dirichlet conditions:

$$\nabla^2 T = -j\omega\sigma B_0 ,$$

$$T_\Gamma = 0 . \qquad (7)$$

The values of the components of eddy current are determined in accordance with (5)

$$J_x = \frac{\partial T}{\partial y} ; \quad J_y = -\frac{\partial T}{\partial x} . \qquad (8)$$

The boundary problem (7) can be solved by means of the ANSYS software [7, 12, 13].

At the second stage it is possible to solve the task of estimation of heating, as three-dimensional task for determination of exceeding of temperature of body.

The task is converted into the boundary problem for the Poisson equation with the boundary condition of convective heat exchange on the border of the Γ by a volume region Ω with permanent heat conductivity λ and permanent coefficient of heat emission α [9]

$$div(\lambda grad \theta) = -Q , \qquad (9)$$

$$-\lambda \frac{\partial \theta}{\partial n} = \alpha(\theta - \theta_0) . \qquad (10)$$

In (9) the Q is equal to the losses from eddy currents J_x and J_y.

In accordance with these considerations the computation of eddy currents and losses has been conducted in the nonmagnetic yoke beam of the three-phase power transformer АТДТН – 250000/345. Frequency of current – 50 Hz, electric conductivity of beam of $0{,}11 \cdot 10^7$ s/m, length of beam - 7150 mm, width of the area – 1312 mm, thickness of the area – 12 mm.

In Fig.1 and Fig.2 the three-dimensional construction of the yoke beam and its involute is presented.

Magnetic induction has been determined by the program in the computation plane that coincides with the central plane of the yoke beam [8]. As a result, for the three-phase system two tables of values of induction in a computation net covering the projections of involute of central plane of beam on a plane have been determined. One table contains the values of projection of vector of normal constituent of induction on the real temporal axis $\operatorname{Re} B_n(x, y)$ (Fig.3), the second table contains values of projection of normal constituent of induction on the imaginary axis $\operatorname{Im} B_n(x, y)$ (Fig.4). Values of vectors of eddy current density induced by $\operatorname{Re} B_n(x, y)$ and $\operatorname{Im} B_n(x, y)$ are depicted in Fig.5 and Fig.6.

The distribution of total losses from eddy currents is shown on Fig. 7, and the distribution of temperature of the proper to the calculated values of total losses is shown on the Fig. 8.

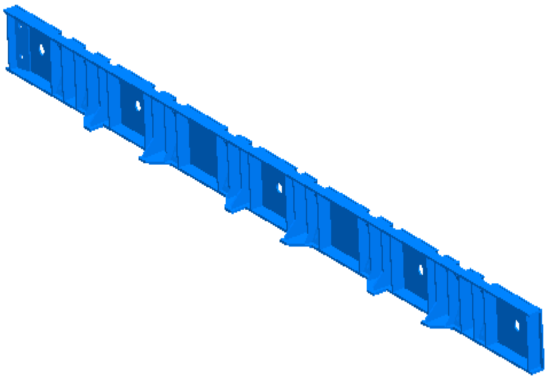

Fig. 1. Three-dimensional construction of the yoke beam

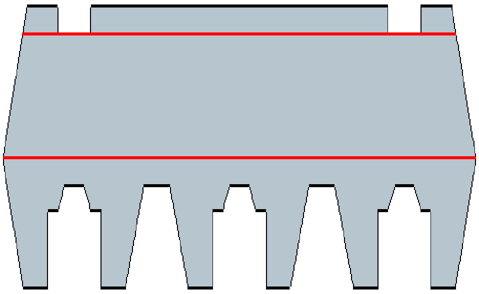

Fig. 2. Involute of yoke beam

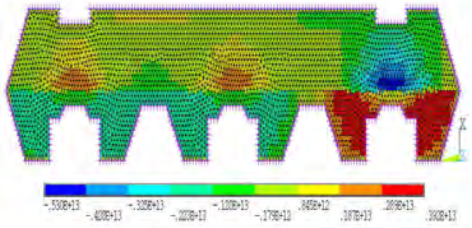

Fig. 3. Distribution of induction of the actual making ReBn

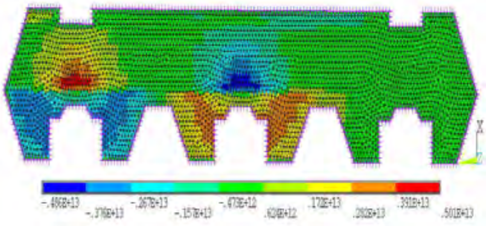

Fig. 4. Distribution of induction of the imaginary making ImBn

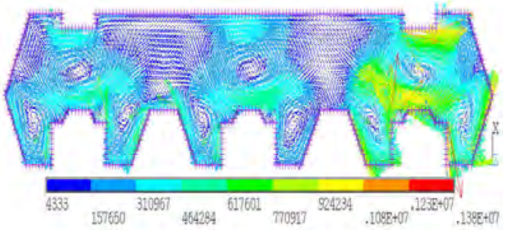

Fig. 5. Distribution of vectors of eddy current density for ReBn

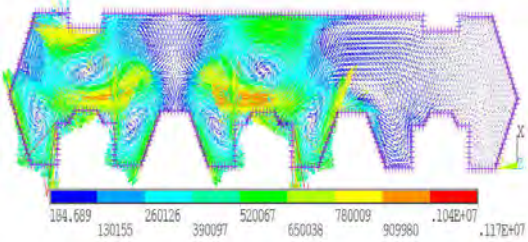

Fig. 6. Distribution of vectors of eddy current density for ImBn.

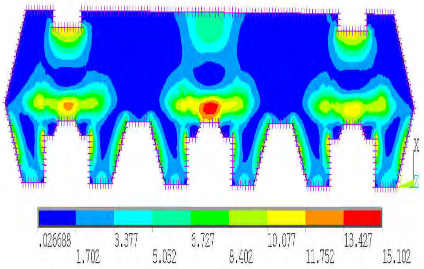

Fig. 7. Distribution of local losses

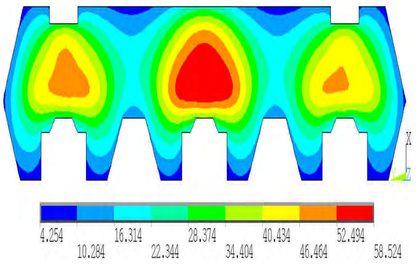

Fig. 8. Distribution of temperature

4. Conclusions

The proposed method of computation of eddy currents, losses and heating in structural elements made of nonmagnetic steel can be recommended at the stage of planning powerful electric equipment.

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ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ВИХРОВИХ СТРУМІВ ТА НАГРІВАННЯ У НЕМАГНІТНИХ СТАЛЕВИХ СТРУКТУРНИХ ЕЛЕМЕНТАХ СИЛОВИХ ТРАНСФОРМАТОРІВ ТА РЕАКТОРІВ

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М. Мислович

Запропоновано метод обчислення вихрових струмів та нагрівання у структурних елементах силового електротехнічного обладнання, виготовлених з немагнітної сталі.