Magneto-Thermal Modeling of the Structural Components in a Single Phase Transformer

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Abstract—The paper presents some particular aspects regarding numerical modeling of the structural components in a single phase transformer. The problem is treated as a coupled magneto-thermal application. The conditions for an accurate finite element method analysis of this device are determined. Some models for material properties and solutions for the thermal problem of the single phase transformer are proposed. A complex concrete application emphasizes theses considerations.

Index Terms—Single phase transformer, magneto-thermal modeling, finite element method, structural components.

I. INTRODUCTION

Power transformers are one of the most vital and costliest equipments of the power systems. The steady increase in the rating and size of transformers over the last few decades poses real challenge to transformer designers in today's competitive market conditions. The methods for design of active parts (core and windings) are well established. However, the design of inactive components (structural parts) is still not straightforward and requires careful treatment. The excessive losses in these components and the resulting overheating hazards could be dangerous, particularly at overloading which is not uncommon these days [1].

Even if the single phase transformer is not a recent magneto-thermal application, the continuous development of numerical techniques and increasing of the computers performances give the possibility of an advance analysis of this device. The purpose is to elaborate the numerical model of the transformer. Having the model, an optimal synthesis is allowed in order to improve their operating parameters (e.g. efficiency, losses and temperature in structural components) by the means of correlation between geometric parameters and materials properties. In this paper the finite element method analysis of electromagnetic and thermal process within a single phase transformer is performed.

The methodology used is based on the weak and the strong coupling. In the weak coupling the two systems of equations are solved independently. Firstly the losses are calculated using a harmonic magnetodynamic formulation, with a magnetic vector potential *a* and an electric scalar potential *v*, solved by finite element method. Next, the transient thermal modeling is applied.

In the strong coupling the problem is solved step by step. So, at the beginning of the process ($t = 0$) in a 3D system it is determined the distribution of the harmonic electromagnetic field. Based upon this and knowing the values of the electromagnetic properties of the materials, corresponding to the initial temperature, it is determined the volumic density of the eddy current losses. Having the distribution of the thermal sources we can make a first determination of the distribution of thermal field at the first time step. Corresponding to these temperature values we can update the physical properties of the problem (material properties and thermal transfer characteristics). Then, we go through an iterative scheme "calculus of electromagnetic field – calculus of thermal field – updating properties" finally resulting the solution of coupling between electromagnetic and thermal fields at first time step. Next, there is a sequence of time steps in the same way, the process being stopped by the condition of reaching a value of stabilized temperature.

Iron cores in electrical devices are usually made of lamination stacks in order to reduce the eddy-current losses due to time-varying flux excitations. When simulating such devices using the finite-element method, it is usually impossible to model the eddy currents in each separate lamination. Commonly these currents are first completely ignored, whereupon the Joule losses may be estimated from the results of the eddy-current free model.

So, in the finite element analysis of the magnetic field in transformers, the laminated cores are normally modeled by using a solid core and the eddy currents in the steel plates are neglected.

Some devices such as frames, bus bars of transformers, windings, shielding, etc. are mainly made up of sheet or line type parts of thin air-gaps or cracks. Modeling these parts using traditional finite volume elements used in 3D software is tiresome, and even impossible. Moreover, the skin effect in ferromagnetic materials increases the difficulties of meshing eddy current problems in under sinusoidal conditions. An alternative to this difficulty of meshing the thin regions is the use special "shell elements" for the modeling of magnetic or thin conducting regions, and "surface impedance" elements for the modeling of conducting regions having a strong skin depth [2, 3]. In this paper the frames are modeled by a surface impedance method [1].

II. APPLICATION

The example considered for validation of the proposed approach is a single phase transformer. The calculation domain for the harmonic magnetic field is constituted by a core, windings carrying a sinusoidal current, frames and the oil (Fig. 1, where the region with oil is omitted). The calculation domain for the transient thermal field is composed

by the frames, the wooden supports, the pressing table and the oil (Fig. 2, where the region with oil is omitted).
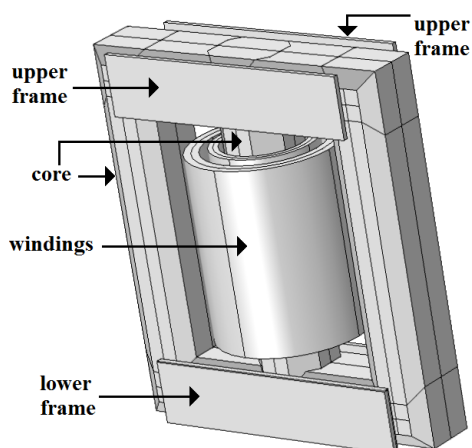

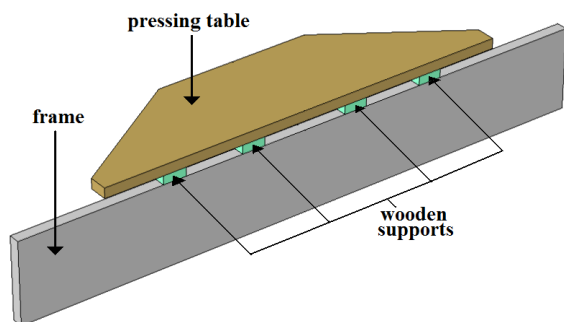Fig. 1. Magnetic calculation domain.

Fig. 2. Thermal calculation domain.

Fig. 3 shows the magnetic flux density distribution in the frames and in the cut planes of the axis x, y and z crossing the center of the core.
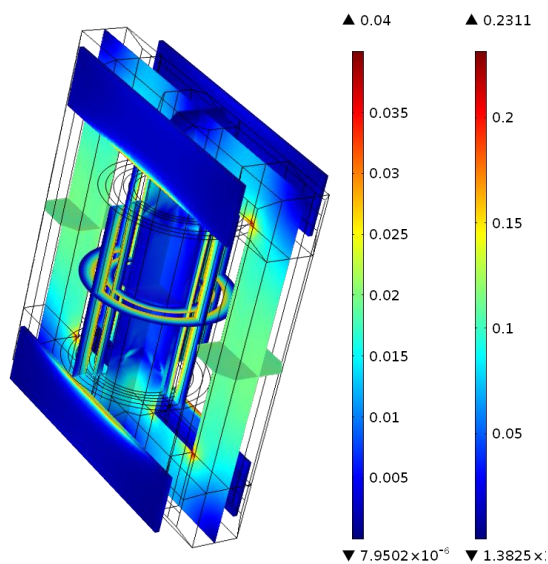

Fig. 3. Magnetic flux density: in the frames and in the cut planes of the axis x, y and z crossing the center of the core.

Fig 4 shows the eddy current losses on the single phase transformer frames. The left frames has a cooper shielding fixed on it. Because of this the losses in the left frames are smaller than the losses in the right frames. The temperature

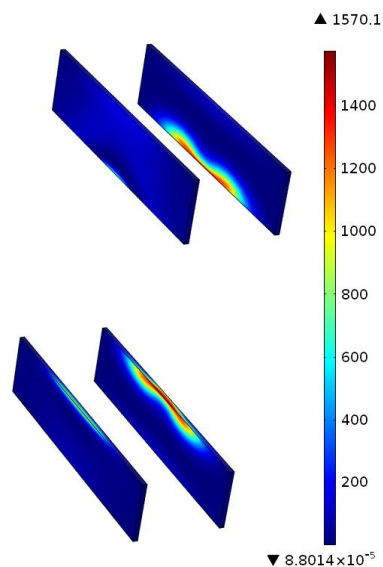distribution in the thermal calculation domain is presented in Fig. 5.

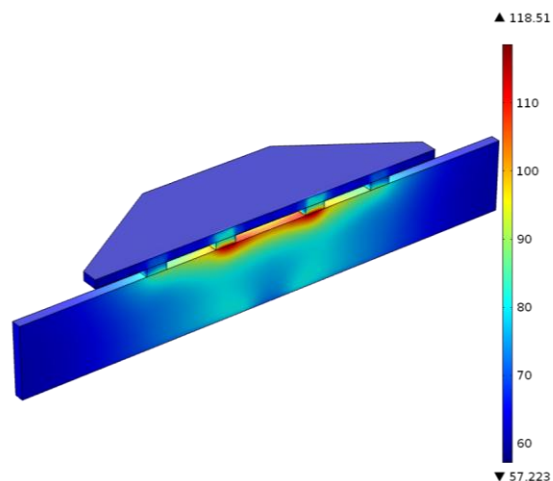Fig. 4. Eddy current losses [W/m^2] on the single phase transformer frames.

Fig. 5. Temperature distribution [^{o}C] in the thermal calculation domain.

The main contributions of this paper are (i) the comparison between the results obtained by the weak with the strong coupling between electromagnetic and thermal equations; and (ii) the application of the methodology in a complex concrete application.

The equations of the coupling between the harmonic electromagnetic field and the transient thermal field; the boundary conditions applied; the electromagnetic and mechanical results will be detailed and presented in the extended paper.

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