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Evaluation of Eddy Losses Due to High Current Leads in Transformers Using a Subproblem Method

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***Abstract** - A subproblem finite element method is developed for evaluating the eddy losses due to high current leads in transformers. The structural component of the transformer is modeled with classical volumetric elements or more efficiently with a thin shell model (surface impedance technique). Tools are then developed to correct the inaccuracies near edges and corners inherent to thin shell models for magnetodynamic problems. Improvements of local fields make possible accurate calculations of eddy losses and of temperature rise.*

Introduction

In large transformers, the eddy losses in structural components in the vicinity of high current leads can become substantial. It could lead to hot spots if adequate magnetic clearances are not provided or shielding measures are not taken [1]. When a high current bar runs parallel to a structural plate (e.g., tank), there are two possible configurations as shown in Figs. 1(a) and (b). The configuration in which the edge (thickness) of the bar faces the plate (case b: edge-wise) is better than the other one in which the width of the bar (w) faces the plate (case a: width-wise) [1]. For two bars carrying currents in opposite directions (go and return), there are three possible configurations as shown in Figs. 1(c), (d) and (e). In all of the three cases, the loss increases with the raise in the distance of separation (s) between the two bars. Hence, the distance of separation should be minimum as permitted by mechanical, thermal and electrical considerations [1].

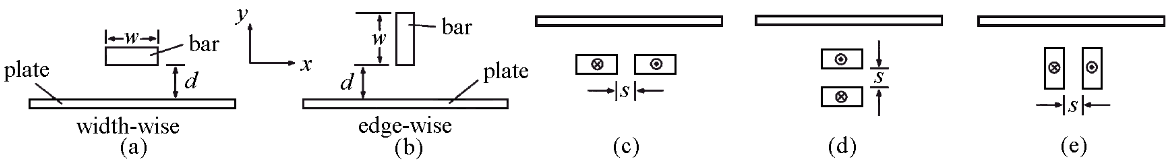

Fig. 1 - High current carrying bar parallel to structural plate (a) and (b); and different configurations of bars carrying go and return currents (c), (d) and (e).

Some structural components of the transformer are made up of sheet. Modeling these parts using traditional volumetric elements used in 3D software requires considerable amount of time and computational efforts. Moreover, the skin effect in ferromagnetic materials increases the difficulties of meshing eddy current problems under sinusoidal conditions. To cope with these difficulties, it is possible to use special shell elements for the modeling of magnetic or conducting thin regions, surface impedance elements for the modeling of conducting regions having a low skin depth. In this paper, a subproblem finite element method is developed for evaluating the eddy losses due to high current leads in transformers. The structural component of the transformer is modeled with volumetric elements and with surface impedance technique (thin shell model). This paper shows that the application of surface impedance on the plate reduces the computational efforts. The interior of the plate is not meshed and is rather extracted from the studied domain, being reduced to a zero-thickness double layer with interface conditions linked to the inner analytical distribution [2]. However, the thin shell models suffer from inaccuracies in the vicinity of geometrical discontinuities, edges and corners, increasing with the thickness, which limits their range of validity. The contribution of this paper consists in developing and validating tools to correct the inaccuracies near edges and corners inherent to thin shell models for magnetodynamic problems. Improvements of local fields make possible accurate calculation of eddy losses. The structural component, wherein eddy current losses need to be calculated, is allowed to reach a steady-state temperature rise. The temperature rise in the plate is given by $\Delta T = P/h\ A$, where P is the eddy losses in the plate (W), A is the area of the convection surface (m^2), h is the heat transfer coefficient (W m^{-2} $^oC^{-1}$), and ΔT is the temperature difference between plate and oil (^{o}C) [3].

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Application

The example of Fig. 1(c) is considered for validation of the proposed approach. The magnetic flux lines: reference, perturbation and corrected solutions shown in Figs. 2. 2(a), 2(b) and 2(c) are examples of preliminary results considering the plate modeled with volumetric elements. The reference problem (Fig. 2(a)) is constituted by the windings carrying a sinusoidal current. The subproblem 1 (Fig. 2(b)) considers the insertion of the plate in the calculation domain. The sum of both these solutions gives the total solution (Fig. 2(c)). Figs. 2(d) to 2(g) are other examples of preliminary results considering the plate modeled with surface impedance. The reference problem (Fig. 2(d)) is constituted by the windings carrying a sinusoidal current. The subproblem 1 (Fig. 2(e)) considers the insertion of the plate modeled by surface impedance (one dimensional approximation). The subproblem 2 (Fig. 2(f)) considers the correction using the actual volumetric geometry of the plate in the calculation domain, thus an accurate consideration of end effects. Fig. 2(g) shows the resulting corrected solution, validated as being the same as in Fig. 2(c) but obtained in a more efficient way.

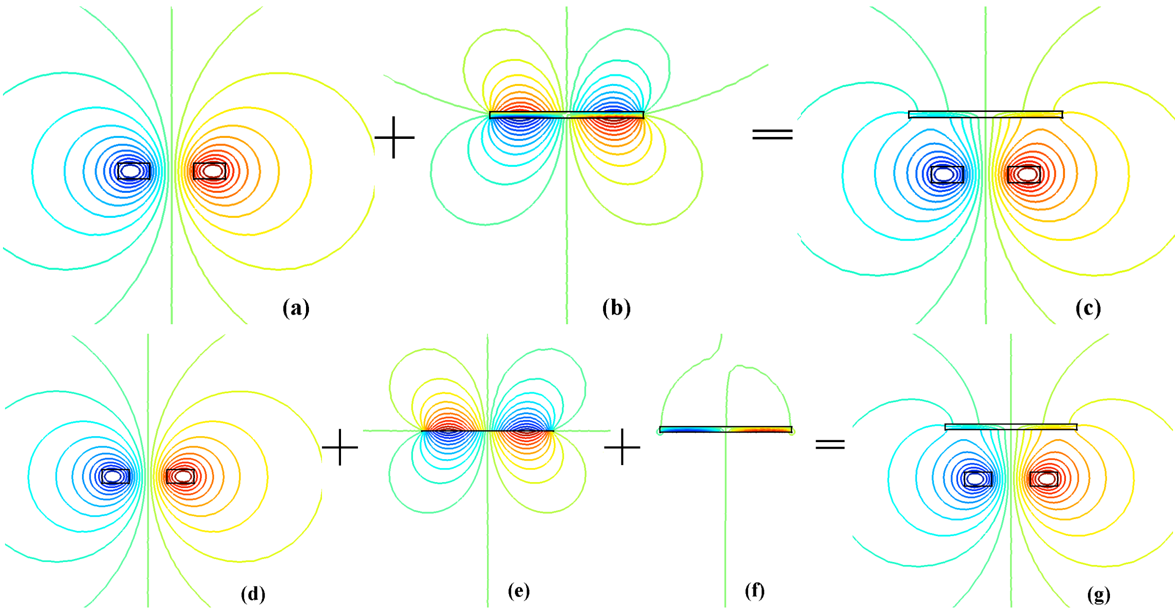

Fig. 2 - Magnetic flux lines considering the plate with volumetric elements (top) and with the corrected surface impedance (bottom).

The application of the tools developed for all the cases showed in Fig. 1, the eddy losses and the steady-state temperature rise in the plate will be detailed and presented in the extended paper. As example of a practical case, the proposed approach will be applied to model the tank of a transformer. The temperature rise in the tank will be validated comparing the results with measured ones by using thermocouples.

References

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