Study on Eddy-Current Loss inside Copper Shielding of Transformers under DC biasing Condition

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Abstract— DC bias excitation is an undesired working condition of AC transformers, the asymmetrical saturation of the core, the heavy noise, the serious vibration, and the local loss concentration can all potentially occurred in biased transformers. The effect of the exciting current under different dc-biased magnetization on eddy-current loss in copper plate based on a reduced engineering-oriented benchmark model (TEAM Problem 21) is investigated. Experiment scheme for dc biasing is presented and the distribution of the eddy current loss under different dc-biased excitation conditions was studied in detail. The engineering applicability of three dimensional eddy current analysis methods for dc-biased magnetization field computation and the practical loss modeling are examined, which has been demonstrated via the numerical modeling results and the measured data.

I. INTRODUCTION

With the development of High Voltage Direct Current Transmission (HVDC), the effect of DC biasing magnetization on AC power transformers becomes a serious problem. The AC power transformers working near a HVDC system are often affected by the DC biasing. The direct currents will deeply saturate the transformer core during half an alternating cycle, increase the magnetizing currents, and produce rich harmonics [1].

The eddy-current loss is generated in the electromagnetic shields of power transformers due to the leakage flux of the iron core. In the electromagnetic design of larger power transformer, the stray-field loss should be controlled within an acceptable level for saving the energy, as well as avoiding the un-allowed overheating. It is well-known that, under dc-biased condition, the leakage flux waveform of the iron core is different from than under standard sinusoidal excitation [2-3], so what is the eddy-current loss distribution in the electrical materials becomes a certainly important problem for electromagnetic design of larger power transformers.

The purpose of this paper is to analyze the eddy current distribution and eddy current loss and highlights the effect of dc-biased magnetization on eddy current loss in the copper shielding.

II. TEST MODEL

In order to detail the electromagnetic behavior of the copper shielding excited by dc-biased fields, a simplified model is proposed based on the benchmark model of Problem 21^c-EM1 [4-6], in which the solid magnetic steel plate of 10 mm thick is removed, only the copper plate is used in the model, called test model, as shown in Fig.1.The detailed exciting source and material parameters of the test model are as follows:

1) Exciting Source

There are two exciting coils with the same dimension, in which the exciting currents flowing in two coils are in opposite directions. The number of turns of each coil is 300.

2) Conductors

Copper plate (used in $P21^c$-EM1)

a) The dimension: 458×270×6 mm;
b) The conductivity: $\sigma=5.7143\times10^7$ S/m;
c) The relative permeability is equal to 1;
d) The assumed density: 8.9×10^3kg/m^3.

Fig. 1. Test model (photo).

The structure dimensions of the Problem 21^c-EM1 model are shown in Fig.2.

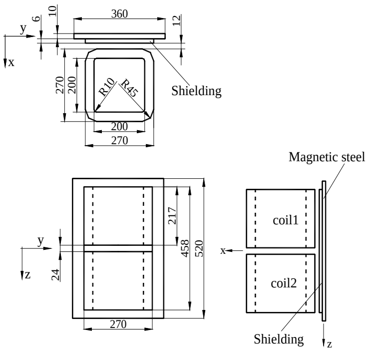

Fig. 2. Structure dimensions of Problem 21^c-EM1 (mm)

III. MEASUREMENT AND SIMULATION

Different dc and ac currents are applied to the coils simultaneously, the waveform of the exciting source is unsymmetrical which is various from the standard sinusoidal one, as shown in Fig.3.

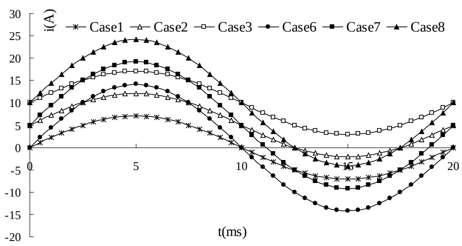

Fig. 3. Waveform of exciting current

The experimental scheme based on the model is designed, in which the model is driven by both AC and DC currents simultaneously as shown in Fig.4, where *I* is the exciting current of the model which flows through the exciting coil *U1* is the exciting voltage; *U2* is the induced voltage.

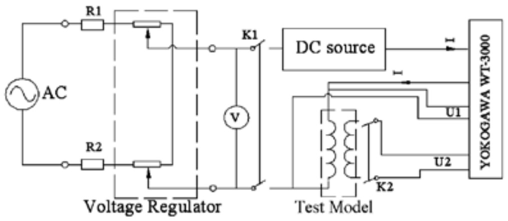

Fig. 4. Experiment scheme

The experiments on the test model have been performed, and the eddy current loss in the copper plate under all the exciting cases (see Fig.3) was obtained by using the Precision Power Analyzer, WT-3000, Yokogawa, Japan, as shown in Table I.

TABLE I
THE MEASURED LOSS OF THE MODEL

Exciting Condition	Loss(W)	Exciting Condition	Loss(W)
Case 1	2.33	Case 6	9.93
Case 2	2.37	Case 7	9.90
Case 3	2.40	Case 8	9.96
Case 4	2.39	Case 9	9.95
Case 5	2.42	Case 10	9.98

The well established *T-Ω* method is used to solve for the magnetic field, in the ***T-Ω*** transient solver the eddy current region with the electric isotropy can be basically formulated by (1), the insulating medium can be formulated by (2), (3).

$$\nabla\times\left(\frac{1}{\sigma}\nabla\times\boldsymbol{H}\right)+\boldsymbol{\mu}\frac{\partial\boldsymbol{H}}{\partial t}=0 \quad (1)$$

$$\nabla\cdot\left[\mu\left(-\nabla\psi+\boldsymbol{H}_s\right)\right]=0 \quad (2)$$

$$\boldsymbol{H}=-\nabla\psi+\boldsymbol{H}_s \quad (3)$$

The 3-D eddy current simulation model is shown in Fig.5, B_x, B_y and B_z have an orthogonal magnetic property.

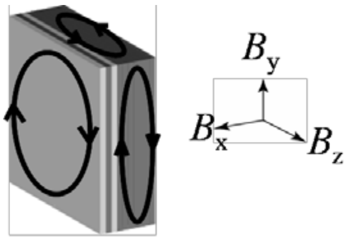

Fig.5. 3-D eddy current simulation model

Calculated results of the eddy current loss of the copper plate is shown in TABLE II.

TABLE II
THE CALCULATED LOSS OF THE MODEL

Exciting Condition	Loss(W)	Exciting Condition	Loss(W)
Case 1	2.38	Case 6	9.48
Case 2	2.41	Case 7	9.51
Case 3	2.43	Case 8	9.69
Case 4	2.48	Case 9	9.71
Case 5	2.51	Case 10	9.78

Comparison between measured loss results and the computation ones is shown in Fig.6; it is observed that there is a good agreement between the two results, which proves the effectiveness of the proposed finite element method in solving the DC biased problem in transformers. Take Case 3 for example, the eddy current distribution in down surface of the copper plate is shown in Fig.7. All the advance experiment and field analysis are really helpful to build a reasonable computation model of a practical engineering problem.

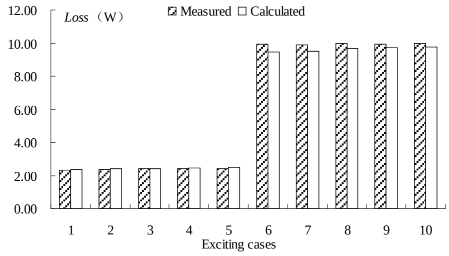

Fig. 6. Measured and calculated loss of the model

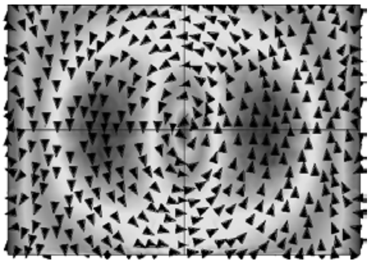
Fig.7 . The eddy current distribution in the down surface of copper plate under Case 3

IV. CONCLUSION AND DISCUSSION

Detailed measurement and computation have been carried out based on a reduced benchmarking model to examine the effect of dc biased magnetization on eddy current loss inside copper plate. A numerical model for electromagnetic field computation under DC biasing is presented. 2-D and 3-D numerical simulation model are established, the modeling results indicate that the proposed engineering-oriented method is effective in solving the dc biasing eddy current problem.

ACKNOWLEDGMENT

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