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STRAY LOSSES IN TRANSFORMER TANK

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Abstract: *This paper presents the application of 3D finite-element approaches to calculate losses in the tank and frame of the transformer. The equations, boundary conditions and excitations of models are explained with some detail in this work. For calculation was used program OPERA 9.0. 40MVA transformer was modeled.*

Key words: *Stray losses, transformer, FEM, transformer frame.*

INTRODUCTION

Stray losses include eddy and circulating current loss, loss due to high current field, and frame and tank losses. [1].

Frame Loss

Frames (yoke beams), serving to clamp the yoke and support the windings, are in a vicinity of stray magnetic field of windings. Due to large surface area and efficient cooling, hot-spots seldom develop. Losses in frames have been calculated by Finite Difference Method (FDM) and analytically. Loss in frames can also be calculated efficiently by 3-D Reluctance Network Method, but may not be as accurately as that by FEM. The loss in frames can be reduced by either aluminium shielding or by use of non-metalic platforms for supporting the windings.

Tank Loss

Tank and clamp losses are very difficult to calculate accurately [1]. Here we are referring to the tank and clamp losses produced by the leakage flux from the coils. The eddy current losses can be obtained from the finite element calculation, however the axisymetric geometry is somewhat simplistic if we really want to model a 3 phase transformer in a rectangular tank. Modern 3D finite element and boundary element methods are being developed to solve eddy current problems.

This paper shows the application of three-dimensional (3D) finite element approaches to estimate stray losses on tank walls of distribution transformers. Details of the equations, excitations and boundary conditions that were used to solve the problem are given in the paper. The numerical approach taken in this work assumes that the stray magnetic field has linear behavior.

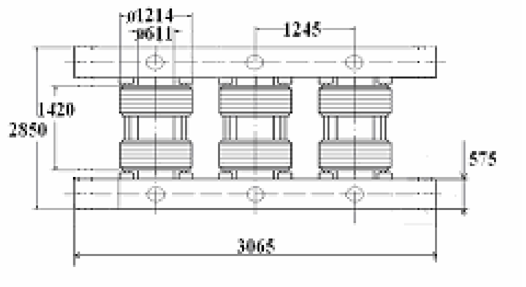

Fig.1. Geometrical sizes of transformer

The finite element approaches used in this work also assume that transformer currents are perfectly sinusoidal, thus the electromagnetic equations can be solved in the frequency domain. Parameters of the transformer are given in Table 1.

Parameter	Value + Unit
Output	40 MVA
Voltage	110+(-) 2x8% /23 kV
Connection	Yd1

Tab. 1: Parameters of transformer

	Armature and plates	Tank
height [mm]	575	2890
width [mm]	3065	4015
thickness [mm]	20	20

Tab. 2. Sizes of calculation parts

1 3D ELECTROMAGNETIC FORMULATION

The calculation of losses in the tank wall of a pad mounted transformer is also formulated using a 3D finite-element model. A brief discussion of the equations, excitations and boundary conditions that were used to set up the problem are given here [2], [3].

The 3D boundary value problem is formulated using the potential formulation. The magnetic vector potential *A* is used for any kind of material region (such as air, source current regions and non-conducting permeable regions). It is not difficult to show that the fallowing equations define the 3D eddy current problem:

$$\nabla\times\frac{1}{\mu}\nabla\times\mathbf{A}+j\omega\sigma\mathbf{A}+\sigma\nabla\mathrm{V}=0 \tag{1}$$

where V is the electric scalar potential – used only for eddy current regions. Whereas

$$\nabla\times\frac{1}{\mu}\nabla\times\mathbf{A}=\mathbf{J}_{\mathbf{S}} \tag{2}$$

applies for other regions. Here, μ is the permeability and σ is the electric conductivity. $\mathbf{J}_\mathbf{S}$ denotes a source current density, which is known. The boundary conditions can be formulated as:

$$\frac{1}{\mu}\nabla\times\mathbf{A}\times\mathbf{n}=\mathbf{J}_{\mathbf{S}} \tag{3}$$

and

$$\mathbf{A}\times\mathbf{n}=0 \tag{4}$$

where the tangential component of the magnetic field intensity and the normal component of the magnetic flux density are zero for (3) and (4), respectively. Equations (1) to (4) define the magnetic field uniquely.

2 ELECTROMAGNETIC PARAMETERS

For modeling were used follows parameters:

- Electrical conductivity of tank and frame 5[MS/m]
- Electrical conductivity of core 2[MS/m]
- Current density of 23kV winding 2,073 [A/mm^2]
- Current density of 110kV winding 2,2477 [A/mm^2]
- Frequency 50Hz

Boundary condition :

Tank wall : A=0, Dirichlet´s condition.

3 EXAMPLES OF CALCULATIONS

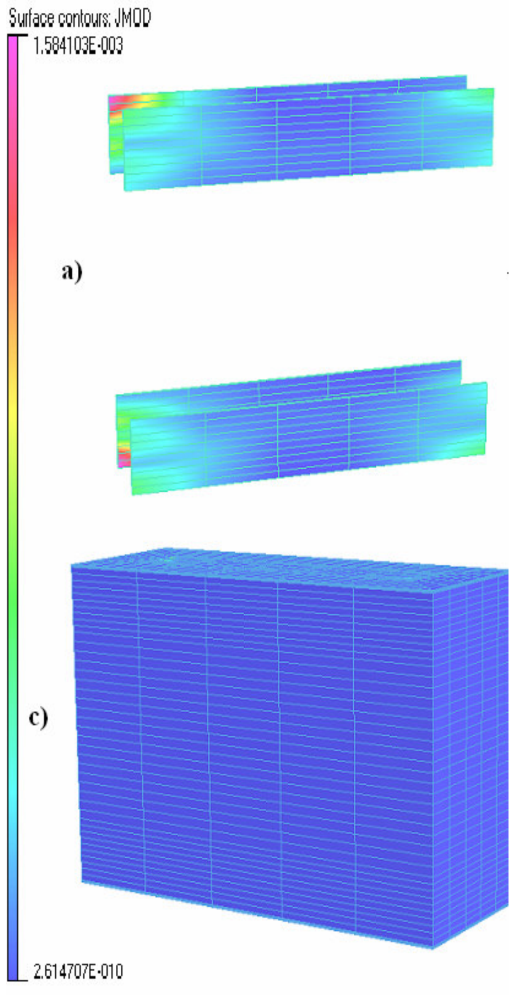

Fig. 2 Distribution of current density a) frame b) tank

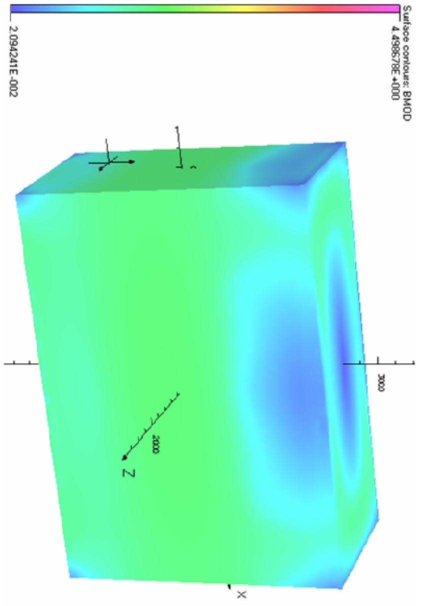

Fig. 3. Distribution of magnetic field

Fig. 4. Magnetic circuit of transformer and frame construction

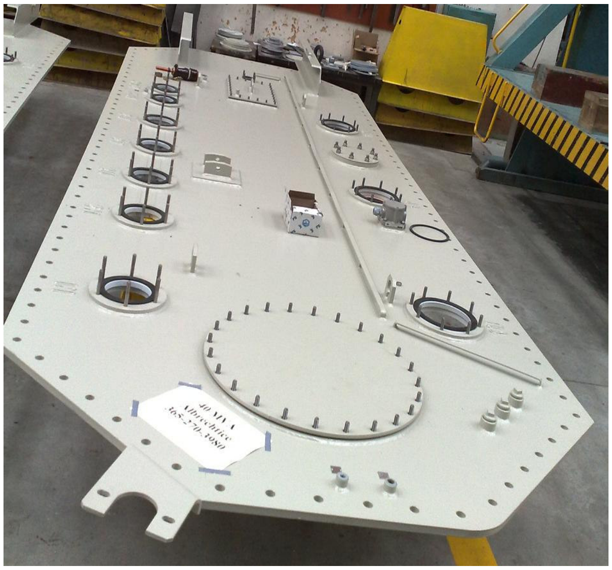

Fig. 5. Cover plate of transformer

Fig. 6. Transformer tank

Fig. 2. shows the map of the magnetic field – 3D program OPERA 9.0, FEM. Fig. 3. shows the tank of the 40MVA transformer – ETD Transformatory a.s.[4].

4 CONCLUSION

The losses effects of induced eddy current in the transformer tank and frame have been computed – Tab. 3.

No.	A	B	C	D	E	F
1	3240	4123	5034	2662	7697	4,73
2	7290	8804	4822	2588	7411	4,55
3	12960	15159	6085	2524	8610	5,29
4	15210	17298	5893	2454	8347	5,13
5	20250	23188	6351	2504	8856	5,44

Tab. 3. Results of calculations

A – No. of mesh elements
B – No. of mesh nodes
C - ΔP_d – losses in tank [W]
D - ΔP_d - losses in armature and plates [W]
E – total losses, C+D, [W]
F - % ΔP_d , %losses – no-load + short-circuit [%]

The stray loss in a structural component is reduced by a number of ways [5]:

- use of laminated material
- use of resistivity material
- reduction of flux density in the component by use of material with lower permeability
- reduction of flux density in the component by provision of a parallel magnetic path having low reluctance and loss
- reduction of flux density in the component by diverting / repelling the incident flux by use of a shielding plate – shunt - having high conductivity.

The magnetic shunts are more effective in controlling stray losses as compared to the non-magnetic (eddy current) shields. There are basically two types of magnetic shunts, viz. width-wise and edge-wise shunts, fig. 7.

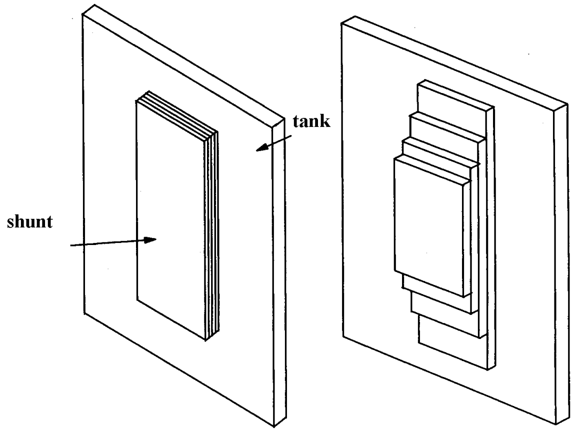

Fig. 7. Width-wise and optimum width-wise shunt

The width of shunts should be as small as possible to reduce entry losses at their top and bottom portions were the leakage field impinges on them radially. As the shunt width reduces, the number of shunts increases leading to a higher manufacturing time.

The saving of shunt material (laminations) obtained has to be compared with extra manufacturing time required. An optimum design of a similar tank shield arrangement is reported in [8] by using the orthogonal array design of experiments technique in conjunction with 3D, which could be serial of this work.

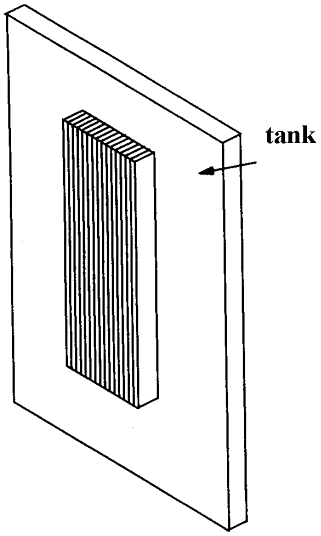

Fig. 8. Edge-wise shunt

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