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IMPACT OF ELECTROMAGNETIC SHIELDS ON LOCAL OVERHEATING IN TRANSFORMER TANK

SUMMARY

The paper describes different influences of magnetic and electromagnetic shielding on stray flux distribution in power transformers. The application of electromagnetic shields on the reduction of high temperature spots in transformer tank is studied in detail by using a 3D model for a coupled electromagnetic-thermal calculation.

The analysis of transformer models with various shapes and dimensions of electromagnetic shields show which factors are the most important for reduction of temperature hot spots in the tank. Proposed shielding solution should reduce the total stray loss and maximum temperature value. It is shown that the reduction of these values is not always achieved by shielding most of the area endangered by the stray flux from the high current leads. The choice of the shield must take into account the surrounding component material properties and transformer lead arrangement.

Keywords: coupled calculation, electromagnetic shielding, high current leads, stray flux, transformer

1. INTRODUCTION

Reduction of stray losses in transformer tanks can be realized with various methods. The goal of every method is to reduce magnetic flux in steel parts. The most common solution is to insert magnetic or electromagnetic shields.

Magnetic shields divert the flux from the transformer tank. By shunting the tank they reduce the amount of flux that goes in the tank, leading to reduction of tank losses. On the other hand, electromagnetic shields use the reacting effect of eddy currents and prevent the stray flux from going into the tank [1]. In both cases, losses arise in the shields. The shielding is considered satisfactory if the total losses in the tank and shields are less then losses in the unshielded tank.

Nevertheless, reduction of losses does not always include reduction of high loss density spots in the tank. If these spots are not appropriately cooled, high temperature rise can occur.

This paper will show how electromagnetic shields can be used for shielding of metal parts endangered by the stray flux from LV leads. The possibility of shaping electromagnetic shields in many ways makes it easy to shield these parts.

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2. REDUCTION OF TOTAL STRAY LOSSES

In order to demonstrate the efficiency of various shielding methods, a simple 2D model is chosen for the estimation of stray losses in a transformer. This model will be used for the comparison of transformer stray losses when using electromagnetic and magnetic shielding. Program used for the calculation is MagNet (Infolytica software package for electromagnetic calculation). The calculation is performed using finite element method (FEM). Model is shown in figure 1.

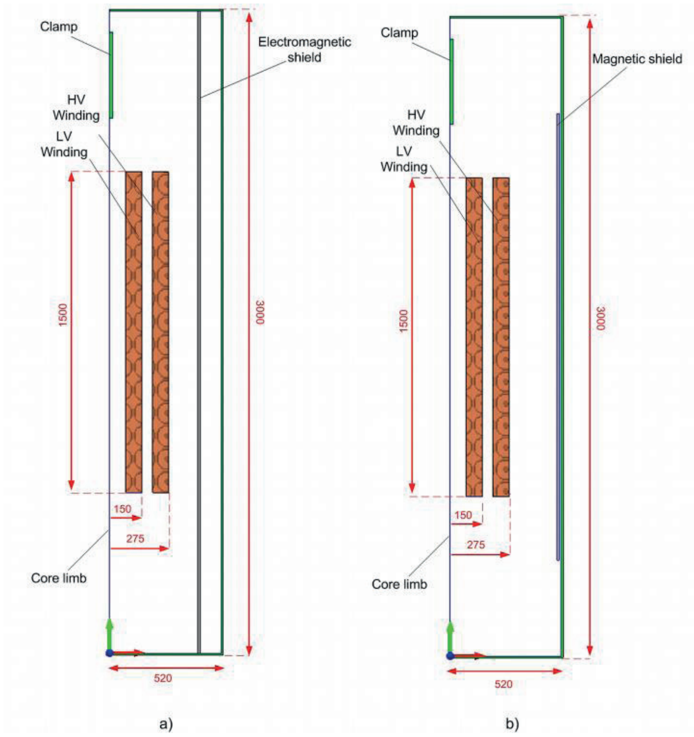


Figure 1 - Model for analysis of winding stray flux losses with a) electromagnetic and b) magnetic shields on the tank

In order to design a simple model for investigation of stray losses in a transformer, some simplifications have been chosen to achieve faster and practical analysis of the problem:

- 2D model is planar
- only one phase is accounted in the analysis while neglecting the effect of other phases
- currents in the windings are equally distributed, while their values are sinusoidal functions of time
- eddy currents in the windings are neglected
- geometry is simplified, various constructional parts are excluded from the model
- material parameters are linear (Table I), transformer core limb is modeled with a normal field boundary condition

Table I - Material properties

Material	Electrical conductivity [MS/m]	Relative magnetic permeability	Thermal conductivity [W/Km]
Magnetic steel	5,6	250	40
Nonmagnetic steel	1,5	1,5	20
Aluminium	37,7	1	200
Electrical steel	0	20000	-

Different stray flux distribution can be observed from the comparison of results for models with electromagnetic (aluminium) shields and magnetic (electrical steel) shields. Results are shown in figure 2.

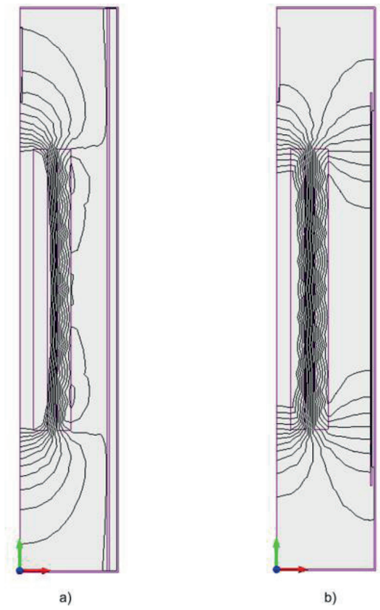


Figure 2 - Winding stray flux distribution with a) electromagnetic and b) magnetic shielding of the tank

When using electromagnetic shielding, flux is diverted from the tank and more flux is present in the winding and other constructional parts of the transformer (for example transformer clamps). On the other hand, when using magnetic shield, most of the winding stray flux goes into the shields. For this reason stray flux does not have to be closed through the other parts of the transformer. Influence of various paths of the stray flux on the losses in the transformer parts are analyzed in [2]. The dependence of stray losses on the thickness of electromagnetic shields is discussed in [3]. It is concluded that the best way to use the electromagnetic shields is to weld them on the tank. When choosing the thickness of the electromagnetic shields, one has to consider the thermal effects of the shields and the effect on the total cost of the transformer.

Taking in consideration the stray losses in the tank, shields, windings and other constructional parts of the transformer, magnetic shields are more efficient in total reduction of winding stray losses [2].

3. REDUCTION OF LOCAL OVERHEATING

3.1. Model definition

Reduction of total stray losses does not always lead to the reduction of local temperature rises in the constructional parts. When defining a numerical model, one has to consider the geometry of the transformer in detail. Local overheating can occur in parts that are usually neglected in simplified 2D models used for numerical calculations. So, in this case, all transformer stray flux sources have to be considered. For now, only winding stray flux was taken into account. If a transformer has high LV current value, due to the small clearances between leads and metal parts, high loss density spots can be generated. If these spots are not cooled appropriately, high temperature rise in these spots can occur.

For the purpose of the analysis of generation of hot spots, a 3D transformer model has to be defined. Also, in order to analyze temperature rise in the metal parts, model has to be adapted for the thermal calculation.

The goal of the model is to investigate impact of electromagnetic aluminium shields on local overheating in metal constructional parts. Since magnetic shields are chosen for the shielding from the winding stray flux, only parameters of the model will be dimensions and positions of electromagnetic shields.

For the calculation of losses and temperatures MagNet and ThermNet software packages are used [4]. When making a thermal calculation, heat sources are represented by the losses that are already calculated in MagNet. Although a strong coupling exists between electromagnetic and thermal phenomena, in this paper, weak coupling method is employed. This means that all material parameters are independent of temperature [5]. Also, values of heat transfer coefficient do not depend on the value of the temperature rise of the component. The basic characteristics of the 3D model are:

- all three phases are accounted in the model
- low voltage leads are modeled in detail
- windings are modeled as cylinders, where the currents are equally distributed while the effect of eddy current is neglected
- metal parts that are included in the model are transformer tank and the clamping system
- core has zero electrical conductivity with linear isotropic relative permeability
- steel parts are linear and are given in Table I

Transformer core, windings and LV leads from the 3D model are shown in figure 3.

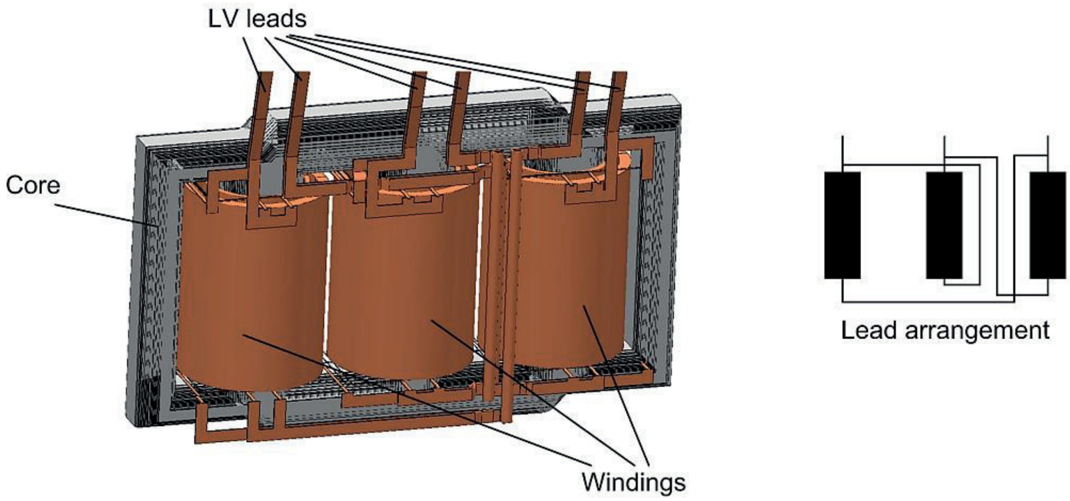


Figure 3 - Transformer with modeled lead arrangement

The main aspect of this paper is local overheating of the tank. Transformer tank is shown in figure 4. Since the current in LV winding is 10 kA, nonmagnetic steel is used for the construction of the part of the tank cover (metal enclosure). Electrical steel is used for the magnetic shielding of vertical tank parts from the winding stray flux. Temperature distribution for the transformer is shown in figure 5.

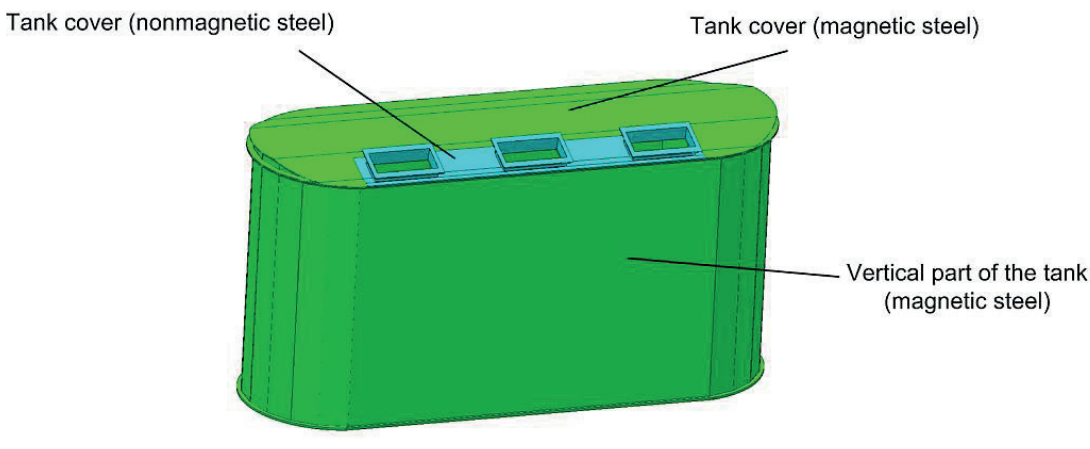


Figure 4 - Transformer tank

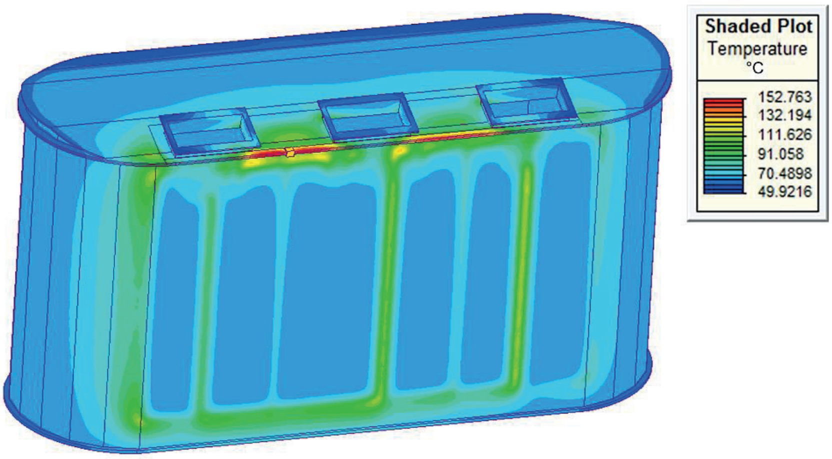


Figure 5 - Temperature distribution on the tank

Because magnetic shields are not designed for the shielding from the flux induced by high current leads, another shielding has to be added. Electromagnetic shields are a better choice than the magnetic shields because they are easier to shape and mount at various positions inside a transformer. Also they are used to direct the flux away from the surfaces that they cover. First type of aluminium shield ("L" shaped) that will be used in the calculation is shown in figure 6. Positions and thicknesses of the shield can be varied in accordance with space left between the leads and the top cover of the transformer (figure 7). By this way the dependence of stray losses and temperature rise on the shielding position and thickness can be shown.

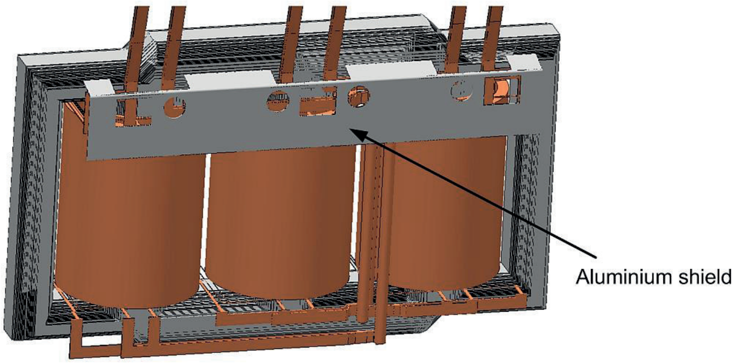


Figure 6 - Aluminium shield used for electromagnetic shielding of the tank of the transformer

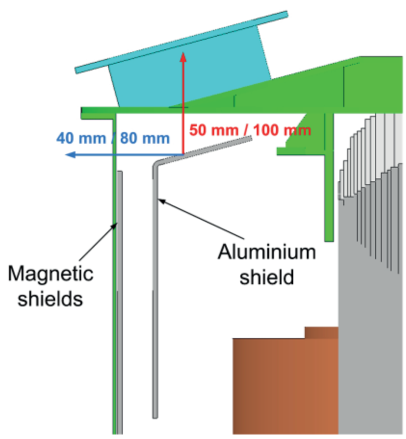


Figure 7 - Positioning of the aluminium shield inside the tank

3.2. Local overheating and stray losses with the "L" shaped electromagnetic shield

Temperature distribution on the transformer tank for the thickness of the shield 15 mm is shown in figure 8. From the start, the aluminium shield is positioned 160 mm from the tank cover and 125 mm from the vertical part of the tank. Aluminium shield is also moved in another two positions (table II) with three different thicknesses (table III). First position makes the shield 50 mm closer to the tank cover and 40 mm closer to the vertical part of the tank, while the second position makes the shield 100 mm closer to the tank cover and 80 mm closer to the vertical part of the tank.

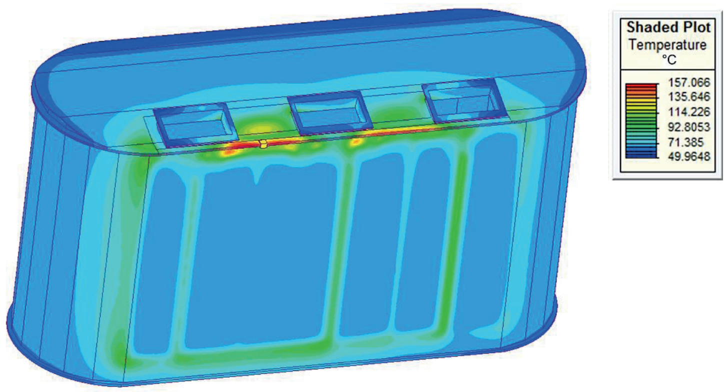


Figure 8 - Temperature distribution with the "L" shaped aluminium shield in the position 1

Table II - Position of the "L" shaped aluminium shield

Position	Distance from the vertical part of the tank	Distance from the tank cover
1	125	160
2	85	110
3	45	60

For a more detailed analysis, change of losses in transformer tank is shown in table III. It can be concluded that all the losses in magnetic steel parts are reduced, while losses in the tank cover part made of nonmagnetic steel have risen.

Table III - Losses and maximum temperatures

	no Al shield	5 mm			15 mm			25 mm		
		1	2	3	1	2	3	1	2	3
Tank cover - nonmagnetic part [kW]	6,9	7,8	8,2	9,0	7,9	8,4	9,2	7,9	8,4	9,4
Tank cover - magnetic part [kW]	5,9	5,8	5,7	5,7	5,8	5,7	5,7	5,8	5,7	5,7
Vertical part of the tank [kW]	31,7	27,5	27,8	28,1	27,7	28,1	28,3	27,5	27,9	28,1
Aluminium shield [kW]	0	14,5	13,1	11,8	6,9	6,1	5,5	6,3	5,5	5,0
Total losses [kW]	44,5	55,6	54,8	54,6	48,3	48,3	48,7	47,5	47,5	48,2
Maximum temperature [°C]	152,7	156,3	160,1	166,6	157,1	161,4	169,1	157,1	161,6	169,5

In order to reduce the local overheating in nonmagnetic steel, main cause of this temperature and loss rise has to be investigated. Further investigation will have to include the analysis of distribution of stray flux induced by high current leads. This will simply be done by introducing 2D models in the analysis.

3.3. Research of high current leads stray flux

Aluminium shields can have influence on loss value and temperature rise when the horizontal leads are present close to the top cover of the transformer [6]. For this purpose, a simple 2D model corresponding to the dimensions of the transformer in figure 5 is made. Figure 9 shows the model and figure 10 the resulting flux for various positions and shapes of the aluminium shields.

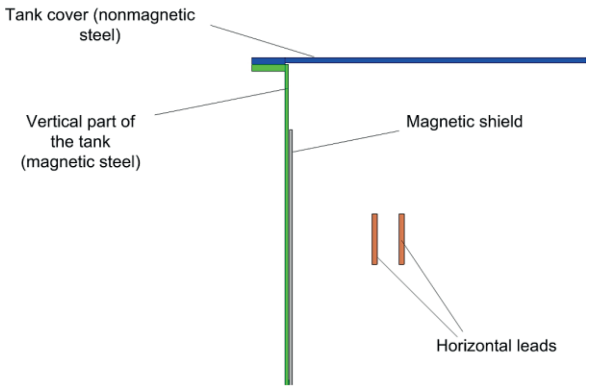


Figure 9 - 2D model

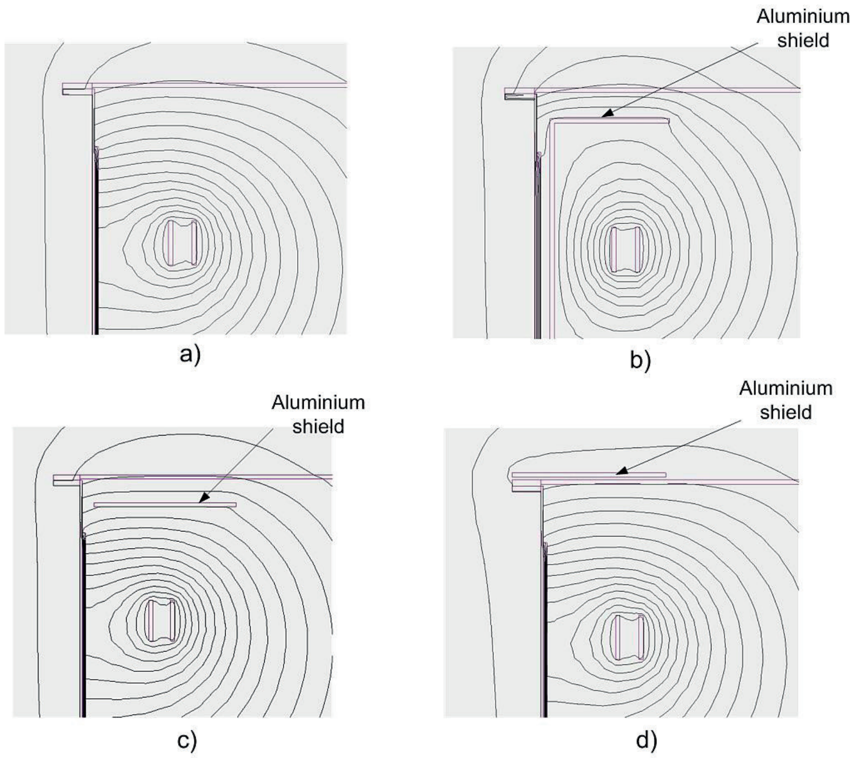


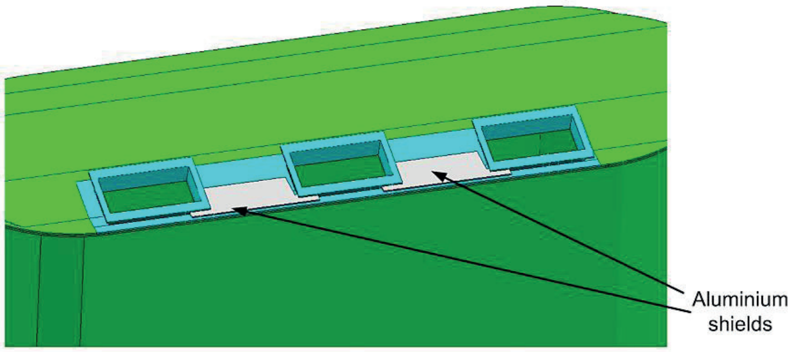
Figure 10 - Flux distribution for 2D model for a) no aluminium shield, b) "L"shaped aluminium shield, c) horizontal aluminium shield below the top cover, d) horizontal aluminium shield above the top cover

From table IV it can be concluded that although “L” shaped aluminium shields cover the biggest surface of the tank and top cover, they result with loss rise in the tank and the cover.

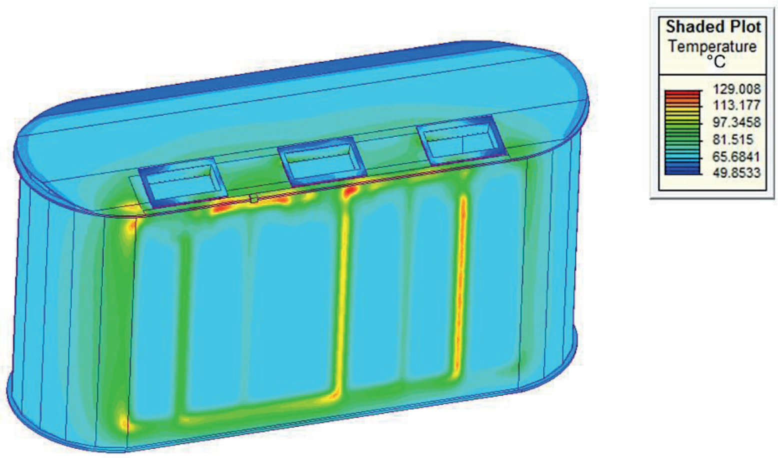
Table IV - Calculated losses and temperatures for the 2D model

	no shield	"L" shaped Al shield			horizontal Al shield inside			horizontal Al shield outside
		Position 1	Position 2	Position 3	Position 1	Position 2	Position 3	
Losses in vertical part of the tank [W/m]	431,9	452,4	506,2	553,1	393,4	408,9	425,3	395,8
Losses in tank cover [W/m]	380,2	495,5	576,9	669,4	344,7	355,9	359,3	219,9
Al shield losses [W/m]	0	269,2	212,6	172,2	73,4	54,3	40,8	37,6

For this reason, another shapes and positions of the shields have to be proposed. Results from the 2D model show that the best way to reduce losses in metal parts is to place aluminium outside the transformer, just over the top cover. This conclusion is adapted to the transformer 3D model (figure 11). Losses and temperatures for the transformer with the aluminium shield above the tank cover are shown in table V.



a)



b)

Figure 11 - a) Model with aluminium shields above the tank cover and b) results of the thermal calculation

Table V - Calculated losses and temperatures for the 3D model with and without aluminium shield above the tank cover

	No Al shield	Al shield outside
Tank cover - nonmagnetic part [kW]	6,9	5,1
Tank cover - magnetic part [kW]	5,9	5,9
Vertical part of the tank [kW]	31,7	31,1
Aluminium shield [kW]	0	0,6
Total losses [kW]	44,5	42,7
Maximum temperature [°C]	152,7	129,0

The use of aluminium shields above the top cover reduces the temperature hot spot value and total losses in the tank. This proves that horizontal leads are the main source of high loss density spots in the tank. The comparison of results in table V with results of the transformer model with the optimal position of the "L" shaped aluminium shield is shown in figure 12.

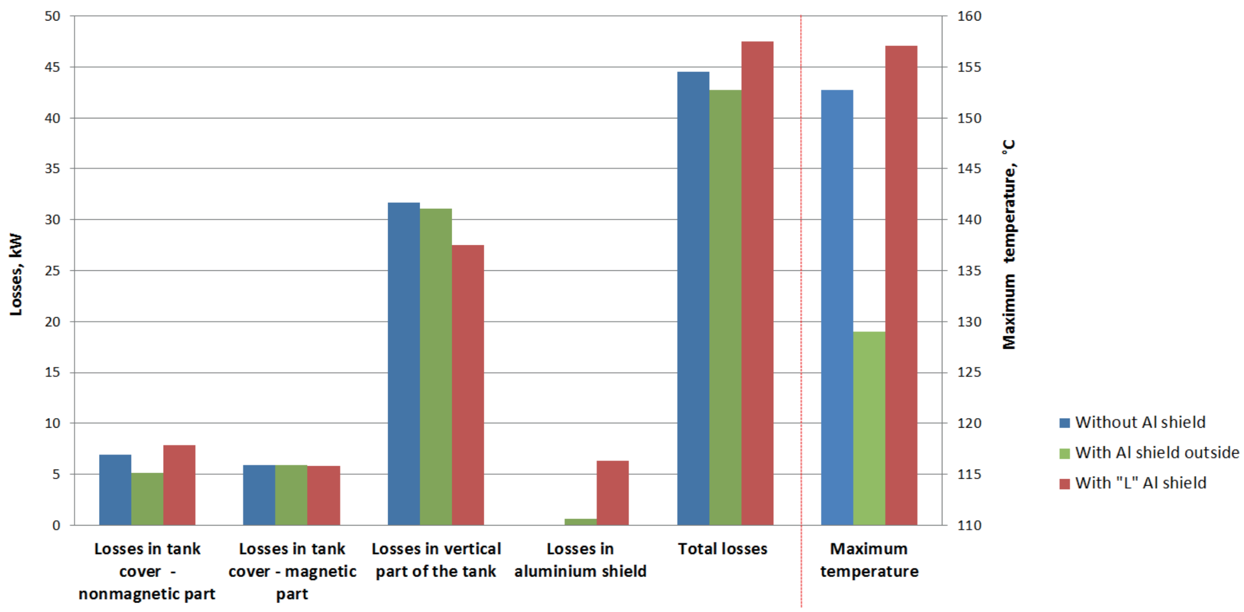


Figure 12 - Losses and maximum temperature in the tank for the 3D transformer model

4. CONCLUSION

When using aluminium shields for reduction of high loss density values in metal parts it is important to analyze the shielding effect on the stray flux redistribution. Using modern FEM tools for coupled electromagnetic - thermal calculation it is possible to quickly study the best position and shape that could be used in practice.

As it is shown in the paper, the best shielding effect is not always achieved by shielding most of the endangered areas. When studying the flux induced by high current leads, it is important to determine which leads have the biggest influence on the temperature hot spots. Usually, this could be the horizontal leads which are common for the delta connected LV leads. Also, nonmagnetic and magnetic steel used in the tank construction can have an important impact on the position of the hot-spot. In the paper it is shown that for the studied lead arrangement the highest loss density values are generated in the nonmagnetic part of the top cover. The way to be sure that the flux will not go through the nonmagnetic steel is to place aluminium plates above the top cover. Reactions of eddy currents in electromagnetic shields force the flux out of the top cover which reduces its losses and temperature hot-spot value. So, when making a shielding selection, one should always consider the effect of various materials of shields and surrounding constructional components.

The possibility of placing the shields outside the tank has already been mentioned in [7]. Although the suggested position of the aluminium shield is not usually seen in practice, the desired effect of temperature hot-spot value reduction is achieved.

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