NUMERICAL FIELD ANALYSIS FOR AN AIR CORED SPIRAL STRIP TYPE PULSE TRANSFORMER

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Abstract

The structure of an air cored high voltage pulse transformer is relatively simple, but considerable attention is needed to prevent breakdown between transformer windings. Since the thickness of the windings in spiral strip type is on the order of sub-millimeter, field enhancement at the edge of the windings is very high. It is, therefore, important to find proper electrical insulation parameter to make the system compact. Several shapes of the winding are considered and are analyzed by numerical field simulations to find an optimum transformer design parameter. Two design parameters are considered in the numerical simulation. Those are radius of the tip and radius of the edge in the transformer. The several dielectric insulation materials also are analyzed numerically to find out the field grading in the windings.

I. INTRODUCTION

The gap between spiral strip windings in air cored high power pulse transformer must be very close to achieve good flux linkage between the primary and secondary windings. Thin copper foil has been widely used for the windings. The main advantage of this types of the transformers is that the frequency limitations imposed on a transformer by its magnetic core are now removed and hence these transformers can be used at very high frequency.[1] Since the copper foil is very thin, very large field enhancement occurs at the edges of the windings. Two kind of the method have been adopted to reduce the field enhancement at the edge of the windings. The one is roundness treatment of the edge of the windings and the other is insulation material property control around windings. [2]

In this paper, the field enhancement at the edge of the winding is calculated by finite element method to find an optimum design parameter. Radiuses of the tip and edge of winding electrode and dielectric constant of insulation materials have been used as control parameter in the calculation.

II. NUMERICAL CALCULATION

The system for the calculation is single sided air cored pulse transformer constructed at PAL.[3] Since gap between the electrodes (0.01 cm) in the transformer is very narrow compared to the size of the system (45cm x 26 cm), the system can be simplified for the calculation as shown in Figure 1. Here only two adjacent layers of the electrodes are considered for simplicity. This simplification may be valid when the field near the tip of electrode D is considered. The coordinates used in the figure are in centimeter. The coordinate of center position in the figure is (x, y) = (0,0). Horizontal direction is used as x axis and vertical direction is used as y axis. Here A and D shown in the figure are the film electrodes. B, C and E are dielectric materials for insulation. The film electrode thickness is 0.01cm.

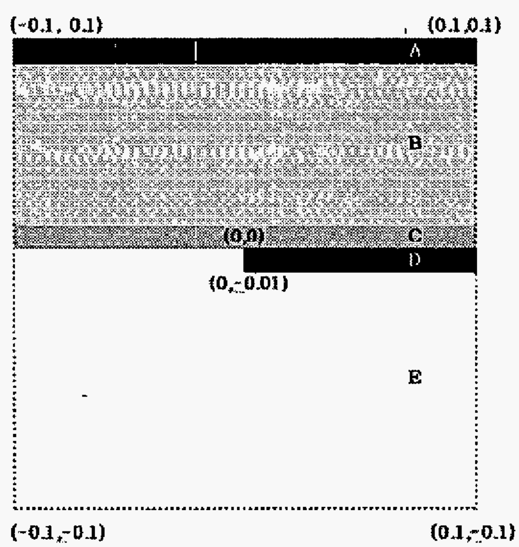

Figure 1. The system used in the calculation

Two electrode edge types are considered in the analysis and the shapes are as shown in figure 2 and figure 3. Here R1 and R2 are radius of the circle and D is the thickness of the film electrode. The location coordinate

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for the point A (shown in figure 2) and for the point C(shown in figure 3) is (0,0) in the figure 1.

Different center positions and lengths of the circle have been used in the simulation to make different edge shape as shown in table 1 and 2. The electrode type 1a is same as type 2a. It has been listed separately for comparison of two edge types.

The electric field calculation is based on the generalized Poisson equation. [4]

$$\nabla \cdot (\varepsilon_r \nabla \phi) = -\frac{\rho}{\varepsilon_o} \qquad (1)$$

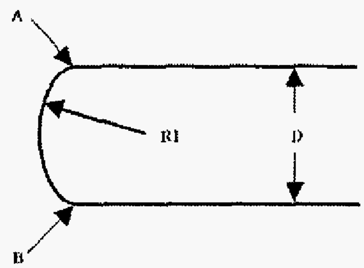

Figure 2. The electrode edge (type 1)

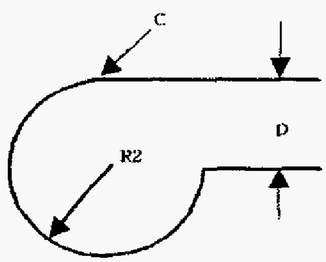

Figure 3. The electrode edge (type 2)

Table 1. Parameters for electrode edge (type1)

Type	Center position (x,y)	R1
1a	(0.0, -0.005)	0.005
1b	(0.002, -0.005)	0.007
1c	(0.004, -0.005)	0.009
1d	(0.006, -0.005)	0.011
1e	(0.008, -0.005)	0.013
1f	(0.010, -0.005)	0.015
1g	(�, -0.005)	�

Table 2. Parameters for electrode edge (type2)

Type	Center position (x,y)	R2
2a	(0.0, -0.005)	0.005
2b	(0.0, -0.010)	0.010
2c	(0.0, -0.015)	0.015
2d	(0.0, -0.020)	0.020
2e	(0.0, -0.025)	0.025
2f	(0.0, -0.030)	0.030

The field calculations for the several electrode shapes and insulation layouts are carried out by using commercially available software "Tricomp 2D". [5]

III. RESULT AND ANALYSIS

The potential of electrode A shown in figure 1 is set at the ground potential and electrode D at 100 kV for the numerical calculation. Six cases of the insulation layout have been used and marked as case 1 to 6 as shown in table 3. The dielectric constants for the insulation layers are Mylar(ε_r = 3.0), Mica(ε_r = 8.0), air(ε_r = 1.0) and transformer oil (ε_r = 4.5). Case 1 and 2 are for the single layer insulation and case 3 to 6 for the multi-layer insulation.

Table 3. Relative dielectric constants for the insulation layers

Case	Relative Dielectric Constant		
	Dielectric Layer B	Dielectric Layer C	Dielectric Layer E
1	3.0	3.0	1.0
2	3.0	3.0	4.5
3	3.0	4.5	1.0
4	3.0	4.5	4.5
5	3.0	8.0	1.0
6	3.0	8.0	4.5

Some of the field calculation results for the insulation layer case 6 are shown in figure 4(a) to 4(d). The figures show that the field enhancement around the tip of the electrode D is very high compare to other places.

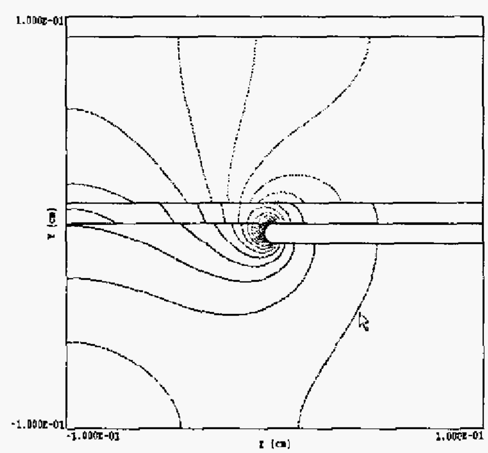

Figure 4(a). The contour plot of electric field for electrode edge (type 1a same condition as type 2a)

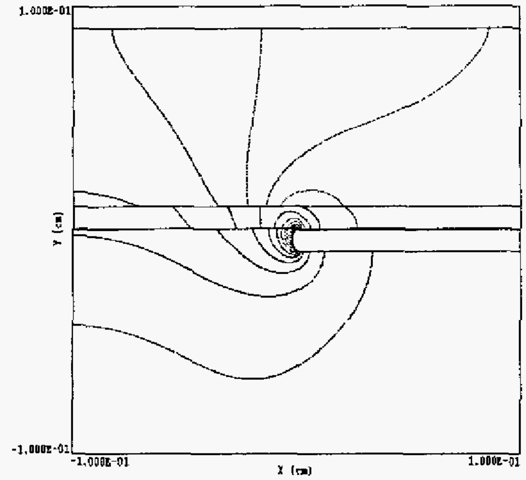

Figure 4(b). The contour plot of electric field for electrode edge (type 1e)

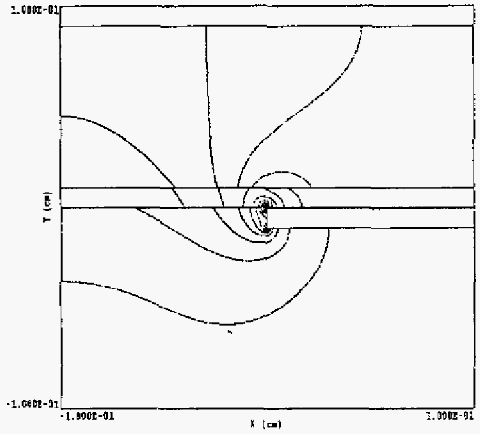

Figure 4(c). The contour plot of electric field for electrode edge (type 1g)

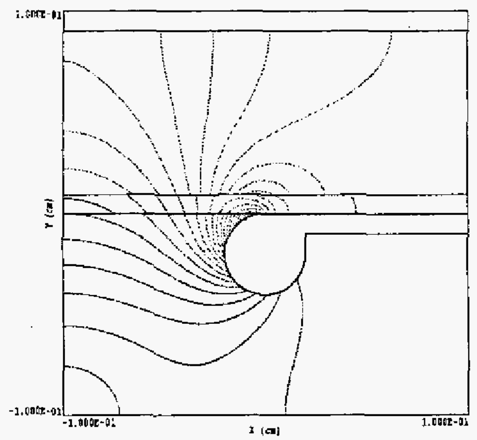

Figure 4(d). The contour plot of electric field for electrode edge (type 2d)

The electric field distribution near the electrode for the case 6 is shown in figure 5. Since the electric field at the interface between electrode and insulator is not defined, the electric field is calculated at $y = 1.0 \times 10^{-5}$ cm.

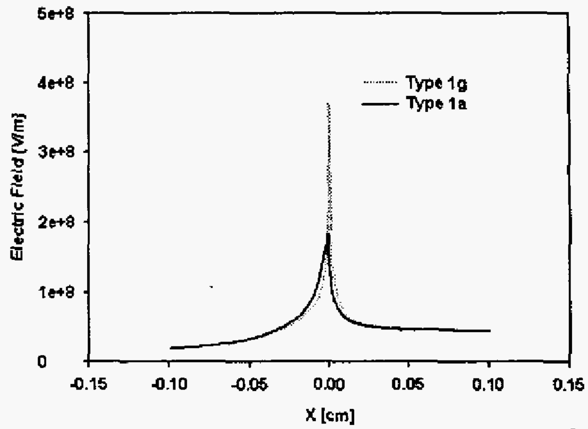

Figure 5. The electric field distribution at $y = 1.0 \times 10^{-5}$ cm (type 1a, case 6).

The figure 5 indicates that the electric field increase sharply near the electrode edge. The maximum electric field for the type 1g electrode is much greater than that for the type 1a electrode. To compare the field enhancement between the electrode types, the maximum electric field at the insulation layer C has been calculated and shown in figure 6. Field enhancement factor, F_E , shown in the figure 6(a) and 6(b) is a normalized field value as follows.

$$F_E = E_m / E_a \qquad (2)$$

E_m is the maximum electric field at the insulation layer C and E_a is average electric field between two electrodes which is same as the electric field between two infinite parallel electrodes where the potential is set at same potential as the potentials at the electrode A and D.

Figure 6(a) and 6(b) show that the field enhancement increases with respect to R1 for the type 1 electrodes and decrease with respect to R2 for the type 2 electrodes. The figures also show that field enhancement factors for Case 1, 3 and 5 are about two times greater than the case 2, 4 and 6. This means that the field enhancement in air environment is lowered about two times by filling with transformer oil. The figure 6(b) also reveals that the field enhancement near the electrode edge is further reduced by insulating the electrode edge with high dielectric material.

IV. SUMMARY

The electric field of an air cored high voltage pulse transformer has been numerically calculated and analyzed. The field enhancement near the electrode edge can be reduced by increasing radius of the electrode edge(type 2) and by increasing dielectric constant of the insulating material near the electrode.

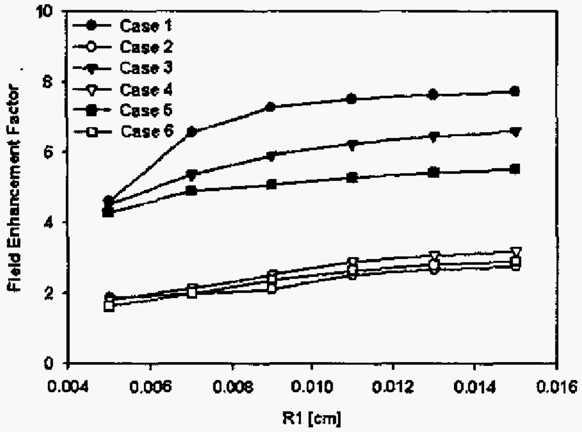

Figure 6(a). Field enhancement factor plot as a function of radius R1 for edge type 1.

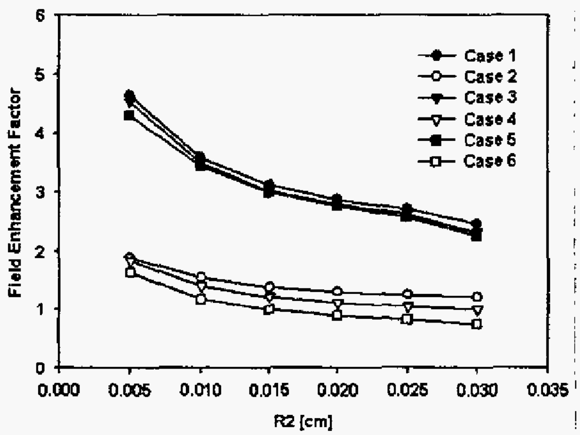

Figure 6(b). Field enhancement factor plot as a function of radius R2 for edge type 2.

V. REFERENCES

[1] Paul W. Smith, Transient Electronics, Wiley, 2002, pp. 137-160.

[2] T. H. Martin, A. H. Guenther and M Kristiansen, "Nanosecond Pulse Techniques", in Advances in Pulsed Power Technology, Vol. 3, Plenum, 1996, pp.35-74.

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[4] S. Humphries, Jr., Field Solutions on Computers, CRC Press, 1998.

[5] Field Precision, PO Box 13595, Albuquerque, New Mexico 87192 , Home page: http://www.fieldp.com