유효면적비교를 통한 COIL TYPE 진공인터럽터 전극의 축자계 분석

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Analysis of axial magnetic field of coil type vacuum interrupter electrodes by comparing effective area at mid-gap plane

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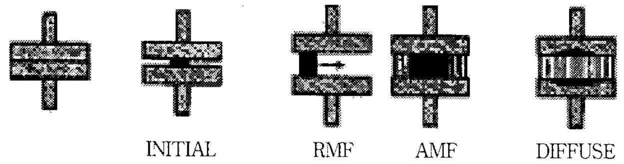
Abstract - In this paper, we calculated the axial magnetic field at mid-gap plane between upper and lower electrode in vacuum interrupter by means of commercial finite element method Maxwell 3D and compared on the basis of "effective area" criterion. The models used in this paper are coil type(axial magnetic field) vacuum interrupter electrodes which have different numbers of coil segment. We used Dr. Schulmann's experimental equation which indicates minimum critical value of axial magnetic field to diffuse arc.

1. INTRODUCTION

Vacuum circuit breaker(VCB) is now emerging as an alternative of gas circuit breaker(GCB) which uses SF6 gas as an insulator whose dielectric strength is outstanding. But we have to reduce SF6 gas because SF6 gas is one of greenhouse gas and efforts to reduce greenhouse gas are now trend of the world. Therefore, we can say VCB is the optimal alternative of GCB because vacuum is environmentally friendly. The vacuum interrupter is the core part of VCB to interrupt arcing current. There are mainly two methods to extinguish arc. They are radial magnetic field (RMF) method and axial magnetic field (AMF) method. We deals with AMF method in this paper.

Compared with RMF, AMF arc quenching method has different principle to extinguish arc. Figure 1 shows features of the interruption process and shape of arc in cases of RMF and AMF respectively.

In case of AMF arc quenching method, effective area of mid-gap plane is important because wider effective area means that the electrode can be prevented from severe damage by means of pinch effect in AMF which is parallel to current flowing through electrodes. This results in multiple slightly damaged spots. Therefore the more mid-gap plane has effective area, the better surface can be protected from being melted.



<Figure 1> Features of the interruption process

2. ANALYSIS AND DISCUSSION

2.1 Numerical approach

1. Magnetic vector potential

$$\nabla\times H = J_0, \qquad \nabla\times(\nu\nabla\times A) = J_0 \tag{1}$$

$$\nabla\times(\nu\nabla\times A) = J_0 + J_e \tag{2}$$

$$\nabla\times E_e = -\frac{\partial}{\partial t}(\nabla\times A) \tag{3}$$

because equation(4) is a case of conservative field, the solution can be expressed as following equation(4) as function of electric scalar potential.

$$E_e = -\frac{\partial A}{\partial t} - \nabla\Phi \tag{4}$$

$$J_e = -\sigma\left(\frac{\partial A}{\partial t} + \nabla\Phi\right) \tag{5}$$

2. Current vector potential

The external input current has to be continuous in calculation region.

$$\nabla\cdot J_0 = 0 \text{ or } J_0 = \nabla\times T \tag{6}$$

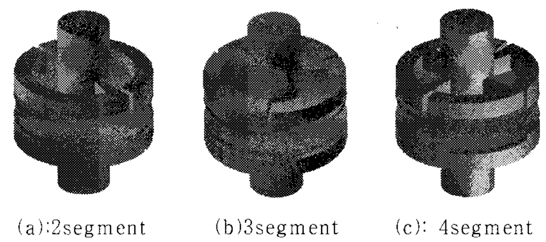
$$\nabla\times E = 0 \text{ and, } J_0 = \sigma E \text{ (in case of static electric field)}$$

$$\nabla\times E = \nabla\times\left(\frac{J_0}{\sigma}\right) = 0 \tag{7}$$

$$\nabla\times\left(\frac{1}{\sigma}\nabla\times T\right) = 0 \tag{8}$$

ν : reluctivity, σ : conductivity, Φ : electric scalar potential
J_0 : external input current density , J_e : eddy current density,
T : current vector potential

2.2. Analyzed model



<Figure 2> AMF contact arrangement

The vapor shields and the ceramic envelope are not taken into account in the calculations to consider only axial magnetic field by structure of electrode. And diameter of contact electrode and gap distance between upper and lower electrode is 80mm and 10mm respectively. We suppose that the arc is cylindrical and has the same diameter with contact electrode. All of the contact electrodes of these 3 models have no slots on them.

<Table 1> Material property

	Material	Conductivity	μ_r
Coil electrode	copper	5.8×10^{7}	1
Conducting rod	copper	5.8×10^{7}	1
Arc cylinder	arc	2800	1
Contact electrode	CuCr50	5.8×10^{6}	1
Vacuum	vacuum	0	1

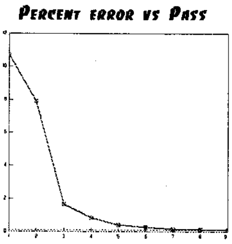
2.1. Method of simulation

The numerical simulations were carried out with the 3-dimensional Finite Element Method commercial software Maxwell 3D. We have solved magneto-dynamic problems to take into account eddy currents effects(eddy effect). We input sin wave external input current as a matter of convenience and its frequency was 60Hz.

We have already known the experimental equation by schulmann which correlates default current and minimum critical magnetic flux density to diffuse arc. We use 50kA as default current

$$B_{critical} = 3.2(I-9)[mT] \tag{9}$$

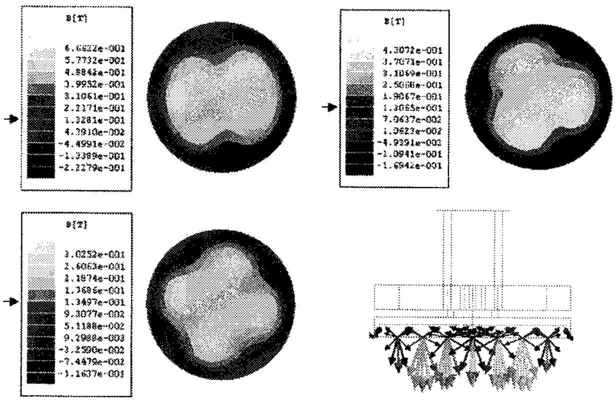
We could find critical magnetic field $B_{critical}$ by inserting the current of 50kA into the equation(9). The value $B_{critical}$ was 0.131[mT].



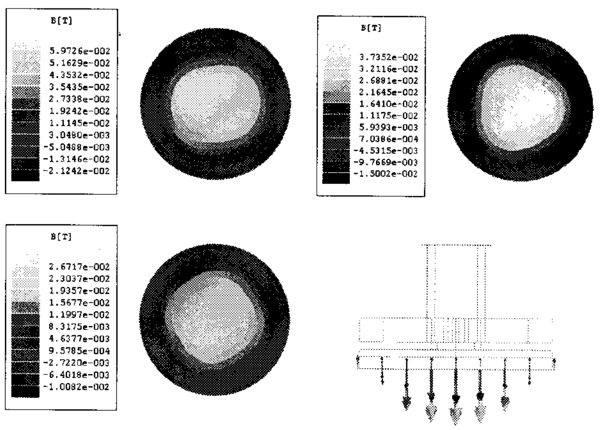
Pass	Type	Frequency	Tetrahedra	Energy Error(%)
1	A	60	5357	10.7275
2	A	60	6996	7.8934
3	A	60	9198	1.6360
4	A	60	12068	0.8313
5	A	60	15639	0.4855
6	A	60	20323	0.2617
7	A	60	26453	0.1856
8	A	60	34540	0.1234
9	A	60	45128	0.0848

<Figure 3> An example of calculation process

2.3. Result and discussion



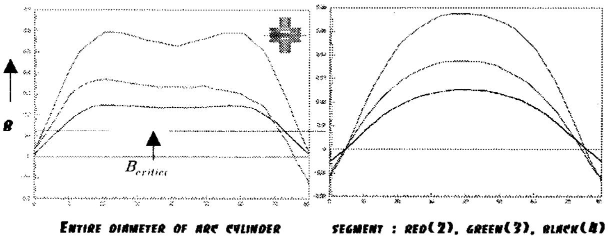
(a) at current peak



(b) at current zero

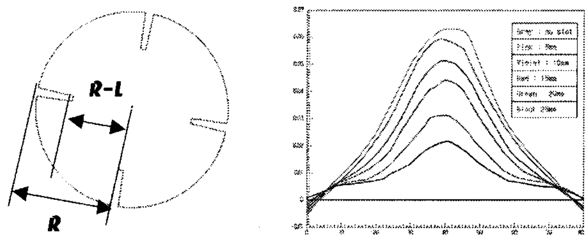
<Figure 4> Distribution of AMF at mid-gap plane (a) at current peak, (b) at current zero

Figure 4 shows the distribution of AMF at mid-gap plane at current peak and current zero. And Figure 5 is 2D plot of AMF from Figure 4. In Figure 4(a) the calculated critical magnetic flux density was marked by arrows just beside color index to easily identify the affective area. The shape of effective area on contact electrode was influenced by the number of coil segments both at current peak and current zero. And magnitude of AMF has reverse proportion relation to the number of coil segments. Figure 4(b) shows magnetic flux density at current zero. We call it "residual magnetic field". This occurs due to the phase shift between source current and magnetic field caused by source current. This causes a decrease in axial magnetic field generated by current flowing through coil electrode. but if there are slots on contact electrode it is possible to increase the amplitude of axial magnetic field by reducing the influence of eddy current. There is an example of influence of the length of slot L on contact electrode in Figure 6.



(a) at current peak (b) at current zero

<Figure 3> 2D plot of AMF



<Figure 6> An example of influence of the length of slot (4 segment coil type electrode)

3. CONCLUSION

In this paper, 3 kinds of axial magnetic field type vacuum electrode were analyzed and compared by means of 3D finite element method simulations. Especially, we used 'schulmann's experimental equation' and 'effective area' as comparison criteria.

As a result, The shape of effective area on contact electrode was influenced by the number of coil segments both at current peak and current zero and the magnitude of AMF has reverse proportion relation to the number of coil segments. This is related to the length of current path. The longer the path is, the more magnetic flux density generated by the current, which flows through the coil path, can be concentrated to a local spot on contact electrode. In the foreseeable future, we plan to calculate and analyze phase shift between source current and magnetic field caused by the current.

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