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The Numeric Calculation of the Magnetic Stationary Field in the Current – Limiting Circuit Breaker's Arcing Chamber of 1250A, 800V

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Abstract

The direct current is mainly obtained by rectifying the alternating current with power diodes and thyristors, so with semiconductor devices, which have a small thermal capacity. Therefore, it's necessary that direct current installations to be protected by very fast fuse or power switches, fast, capable of limiting the amplitude and duration of the shortcircuit current. For this the current limiting circuit breakers are conceived as elaborated solutions especially for the arc quenching system, meaning the path of current and the arcing chamber.
In this paper the authors present few optimization solutions of some quenching systems which will lead to more performant constructive choices.

Key words: *arcing chamber, optimization, numeric calculation.*

Introduction

Modern designs employ current limiting technology where the arc is forced rapidly away from the contacts through an arc chamber and into a set of splitter plates. The motion of the arc is dependent on a complex interaction of the anode and cathode root and the arc plasma motion [5]. The arcing chamber for this current limiting circuit breaker uses the magnetic blow – out effect constructed ferromagnetic plates for the arc's extension and the niche effect associated with the electrode effect for arc quenching [1].

The Physical Model of the Current Limiting Circuit Breaker's Quenching System of 1250A, 800V

By niche effect, the electric arc, issued between the contact pieces is being pushed inside the arcing chamber and then is divided into a number of sections equal to the number of the distances between the ferromagnetic plates having the shape of "V" letter. In this way the electrode effect appears, which means the occurrence of the drop voltage at the anode and cathode. The conditioning of arc quenching based on the electrode effect principle associated with niche effect, comes off from the Ayrton’s relation, where the voltage necessary for the electric arc is [1]:

$$u = a + \frac{b}{i}\text{, where} \tag{1}$$

$a = \alpha + \gamma l$, $b = \beta + \delta l$, where $\alpha, \beta, \gamma, \delta$ are material constants, l is arc’s length and i is intensity of current.

In case of dividing the electric arc in sections, the condition for its quenching becomes:

$$n\alpha + \gamma l > u_s \tag{2}$$

or if we see it from an energetically point of view:

$$\int_0^{t_a} (n\alpha + \gamma l) i dt > \int_0^{t_a} (U - Ri) i dt + \frac{1}{2} L i_0^2, \tag{3}$$

in direct current, or more accurate, [4]

$$\underbrace{\int_0^{t_a} \underbrace{(n\alpha + \gamma l) i dt}_{\text{the energy in arc channel}} + \underbrace{2n\frac{2}{\sqrt{\pi}}\theta^* A\sqrt{\lambda c_1 t}}_{\text{the heat drawn through the arc's base}}}_{\text{the necessarry energy for the electric arc's burning}} > \underbrace{\int_0^{t_a} (U - Ri) i dt + \frac{1}{2} L i_0^2}_{\text{the energy beated into the electric arc}} \tag{4}$$

where: n- number of plates,
i_0- interrupted current,
θ*- heating at the electric arc base,
A - contact’s area,
c_1- the specific heat,
t - arc’s burning time,
u_s – source’s voltage,
R – resistance of circuit when stands the limiting circuit breaker,
L- inductance of circuit when stands the limiting circuit breaker.

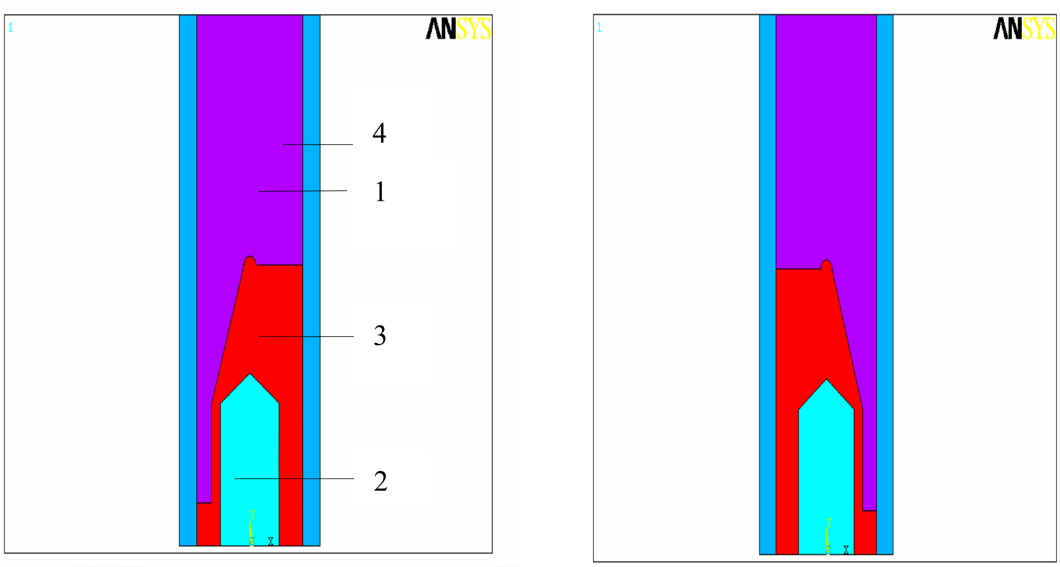

Fig. 1. Interest area, ferromagnetic plate – ramp *1* - ferromagnetic plate, *2* - ramp , *3* - air , *4* - insulated wall.

Therefore it's aimed an augmentation of the burning voltage for obtaining a short lifetime for the electric arc. Augmentation of the burning voltage is achieved by increasing the arc's length and by its intensive cooling. The plates are placed alternately so that the next is symmetrical to the first one. So, the electric arc has a plied form, which leads to an extension of its length. In Fig. 1 there are represented the ferromagnetic plate 1, the ramp 2, the air 3 and the insulated wall 4.

Obtained Results

Numerical simulation was realized by using a finite element package ANSYS - Electromagnetic. This program is based on the finite element method for solving Maxwell equations and can be used for electromagnetic field modelling where the field is time-invariant or time-harmonic, in electrostatics, eddy currents and permanent magnets.

ANSYS analyze assumes three stages: pre-processor, solver and postprocessor.

The pre-processor is used for drawing the problems geometry, defining materials, defining boundary conditions, also the mesh is generated and the loads are applied on the elements.

ANSYS includes a variety of elements which can be used in modelling the electromagnetic phenomenon [7].

In present application, for the modelling of the static magnetic field we choose PLANE53 element, which permits two dimensional magnetic field modelling in planar and unsymmetrical problems. This element is based on the vector magnetic potential formulation with the gauge Coulomb and is suitable for the non-linear static magnetic field.

Also in this phase we choose and define the materials. For the path of current and the ramps copper has been chosen. For the two ferromagnetic plates, has been chosen the steel M3. The arcing chamber along with the path of current is together in a box and inside of it air has been defined as material property.

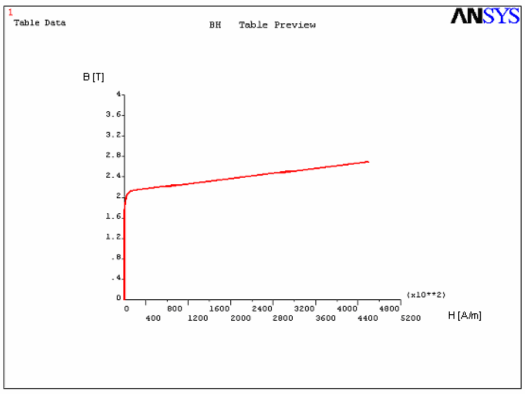

Fig. 2. B-H curve for the ferromagnetic material used for the ramps

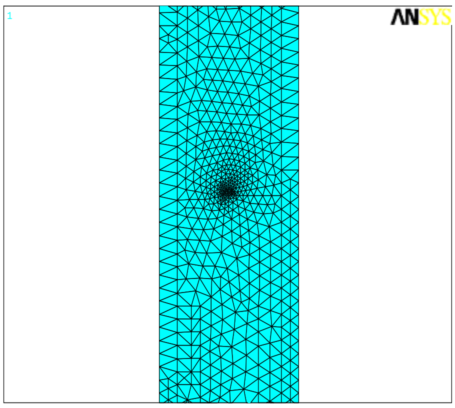

Fig. 3. Domain mesh generation ferromagnetic plate – ramp

The nonlinear B-H curve of the ferromagnetic material used for the ferromagnetic plates is presented in Fig. 2. ANSYS offers the possibility of constructing the geometric model as well as importing it from a CAD program [10]. Next step in pre-processor phase is mesh generation

(Fig.3) and load applying on the elements. We used a mesh with 3335 nodes and 1606 triangular elements.

Current density applies directly on the finite elements which form the conductors (the ramp). The current density is given in SI units (A/m^2). The applied boundary conditions are Dirichlet condition A=0, when A is vector magnetic potential. The solver takes a set of data files that describe problem and solves the relevant Maxwell's equations to obtain values for the magnetic field through the solution domain [10]. The primary unknowns are nodal values of the magnetic vector potential and their derivatives are the secondary unknowns (flux density). There are available some solvers like Incomplete Cholesky Conjugate Gradient Solver, Jacobi Conjugate Gradient Solver, Sparse Direct Solver. For solving the nonlinear equations, this program uses the Newton-Raphson Method [10]. This is a graphical program that displays the resulting fields in the form of contour and density plots. The program also allows the user to inspect the field at arbitrary points, as well as evaluate a number of different integrals and plot various quantities of interest along user-defined contours. It's also possible to save the plotted results in EMF format (Extended Metafile). The Fig. 4 shows the magnetic field lines which cross the ferromagnetic plate and the ramp and Fig. 5 shows the map of values of flux density. We can observe a build-up of field lines in the lower part of the ferromagnetic plates. In this area the flux density has 0,5303 T and 0,5310 T values for the two alternately disposed ferromagnetic plates. These values have been obtained in the case of which the ramp is crossed by a current with a density of 8,33 . 10^6 A/m^2. The force that applies over the ferromagnetic plates is obtained via stress tensor methods [11].

$$\vec{F} = \oint_{\Sigma} \left[\left(\vec{B} \cdot \vec{n} \right) \cdot \vec{H} - \frac{1}{2} \mu_0 H^2 \vec{n} \right] d\Sigma \tag{5}$$

where denotes the direction normal to the surface $\vec{n}$ at the point of interest. While an integration of (5) theoretically gives the magnetic force on an object, numerical problems arise when trying to evaluate this integral on a finite element mesh made of first-order triangles. Though the solution for vector potential A is relatively accurate, the distributions of B and H are an order less accurate, since these quantities are obtained by differentiating the trial functions for A.

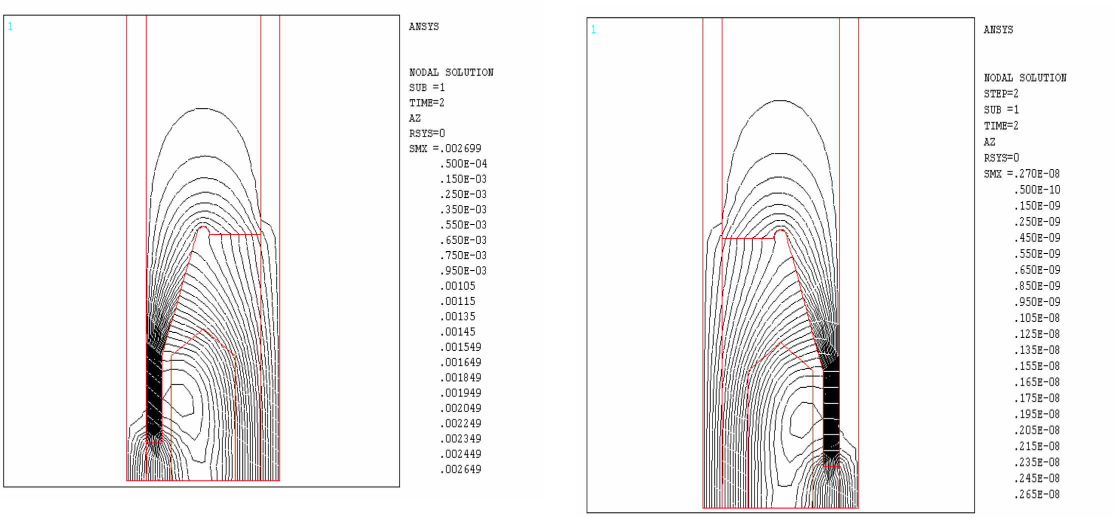

Fig. 4. Magnetic field lines in the interest area
ramp – ferromagnetic plates

That is, A is described by a linear function over each element, but B and H are piece-wise constant over each element. Errors in B and H can be particularly large in elements in which the exact solution for B and H changes rapidly–these areas are just not well approximated by a piece-wise approximation. Specifically, large errors can arise in the tangential components of B and H in elements adjacent to boundaries between materials of different permeability. The worst errors arise on this sort of interface at corners, where the exact solution for B is nearly a singularity [11].

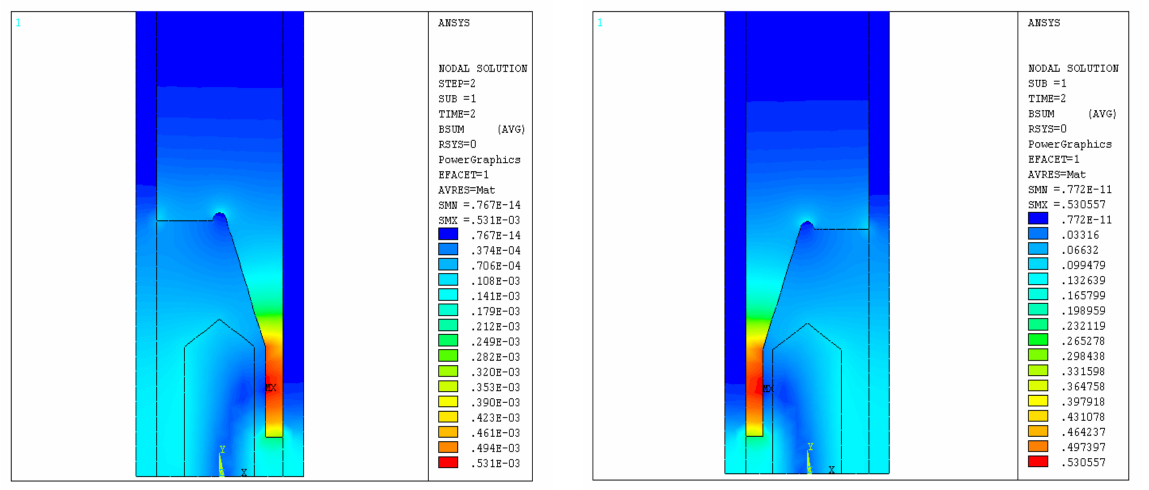

Fig. 5. The flux density spectrum in the interest area
ramp – ferromagnetic plate

Always we define the contour in a clockwise direction to get the correct sign. Hence we have obtained the following results: Ft – the tangential component of magnetic force has the value of $5,71*^{-2}$ N, F_n – the normal component has the absolute value $1,83 *^{-1}$ N. The total value of the magnetic force is $1,91*^{-2}$ N.

Conclusions

The results obtained by computer modelling using ANSYS/Emag confirms that the numerical simulation of the magnetic field in the arcing chamber of the current-limiting circuit breaker can be successfully realized.

For increasing the efficiency of the quenching system we can use cumulatively more arc quenching principles: the principle based on the electrode effect associated with niche effect, the principle of the magnetic blow-out system, the principle of electric contact with cold walls and the loop effect of the path of current.

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Calculul numeric al câmpului magnetic staţionar în camera de stingere a întreruptorului limitator de 1250 A, 800 V

Rezumat

Energia electrică în curent continuu se obţine in principal prin redresarea cu diode şi tiristoare de putere, deci cu dispozitive semiconductoare care poseda o capacitate termică redusă. Ca urmare, este necesar ca instalaţiile de curent continuu să fie protejate cu sigurante de putere ultrarapide (SUR) sau întreruptoare de putere, rapide, capabile să limiteze curentul de scurtcircuit ca amplitudine şi durată. Pentru aceasta intreruptoarele limitatoare sunt concepute ca soluţii elaborate în special în ceea ce priveşte sistemul de stingere, adică calea de curent si camera de stingere.

În lucrarea de faţa autorii prezintă cateva soluţii de optimizare a unor sisteme de stingere care sa conducă la variante constructive mai performante.