Electro-Thermal Numerical Model for Optimization of High Currents Dismountable Contacts

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Abstract: - The paper presents a electro-thermal numerical model which can be used for the optimization of dismountable contacts of high currents by neglecting the skin effect. The numerical model is obtained by the coupling of the electrokinetic field problem with the thermal field problem. For an imposed limiting value of the temperature, using the model, one can determine the optimal geometry of dismountable contact.

Key-Words: - Numerical Modeling, Dismountable Contacts, Coupled Problems, Finite Volumes, Optimization

1 Introduction

The optimization of the dismountable contacts (figure 1) for high currents (1250 – 4000 A), used in the design of electrical equipment in metal envelope, is possible by solution of a coupled problem, electrical and thermal. The dismountable contact of a system of bus bars has a non-uniform distribution of current density (figure 2) on the cross-section of the current leads. The non-uniform distribution of the current density implies a non-uniform distribution of source term in the thermal conduction equation.

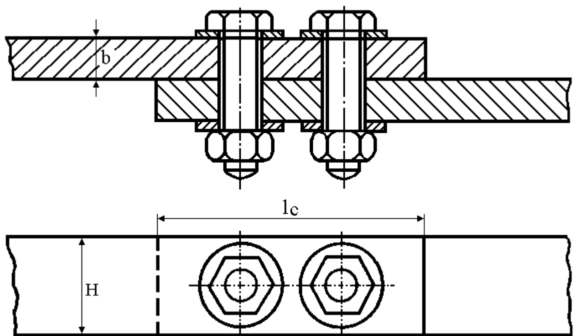

Fig. 1 Dismountable contacts

The distribution of the electric quantities can be obtained by solving of Laplace equation for electric potential. The solution of this equation depends on the temperature by electric conductivity. In its turn the electric conductivity influences the source term in the thermal conduction equation and thus the value and the distribution of the temperature of electrical contact.

Obtaining the correct distributions for the electric quantities (potential, intensity of the electric field, current density and losses by Joule effect) and thermic (the temperature, the gradient of temperature, density of the heat flow, the convection flow on the contact surface, etc) is possible by the coupling of the two problems, electric and thermal.

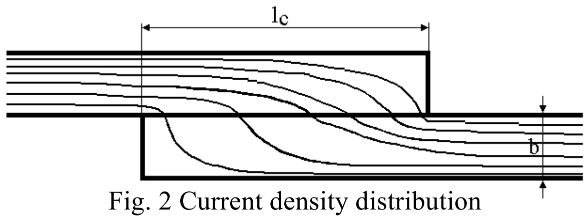

Fig. 2 Current density distribution

The numerical model allows the calculation of the constriction resistance (caused by the variation of the cross section of the current lead).

2 Mathematical Model

The mathematical model used for obtaining the numerical model has two components coupled by the electric conductivity, which varies according to the temperature, $\sigma(T)$ and the source term $S(T) = \sigma(T)E^2 = \rho(T)J^2$

- the electrical model ;
- the thermal model.

2.1 Electrical Model

The electrical field is studied using a 2D model describes by the Laplace equation for the electric potential.

$$\frac{\partial}{\partial x}\left(\sigma(T)\frac{\partial V}{\partial x}\right) + \frac{\partial}{\partial y}\left(\sigma(T)\frac{\partial V}{\partial y}\right) = 0, \quad (1)$$

where electric conductivity and thus the electrical resistance vary according to the temperature as

$$\rho(T) = \rho_{20}\left(1 + \alpha_R (T - 20)\right) \quad (2)$$

By knowing the electric potential, one can obtain the intensity of the electric field $\vec{E} = -\overrightarrow{grad}(V)$ and the current density $\vec{J} = \sigma\vec{E}$ (law of electric conduction). The Joule losses (by the unit of volume) which represents the source term in the thermal conduction equation are calculated by the following relation

$$S(T) = \vec{J}\cdot\vec{E} = \rho(T)J^2 = \sigma(T)E^2 \quad (3)$$

2.2 Thermal Model

The temperature distribution in the domain of analysis is given by the thermal conduction equation in steady state

$$\frac{\partial}{\partial x}\left(\lambda(T)\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda(T)\frac{\partial T}{\partial y}\right) + S = 0 \quad (4)$$

where λ is the thermal conductivity which one considers constant in the temperature range of the current lead (bellow $200\ ^{\circ}\mathrm{C}$).

3 Domain of Analysis and Boundary Condition

One considers a simplified analysis domain which is presented in figures 3 and 4 where one neglects the existence of the fastening bolts.

3.1 Electrical Model

The boundary conditions of the electrical model are presented in figure 3. In the general case, one knows the current I carrying the current lead and which determines a voltage drop $V_1 - V_2$. In this model, one initializes a voltage drop for which one calculates the current which corresponds to it (at each iteration) and then in a iteration loop one modifies the voltage drop to obtain the desired value of the current.

The current which passes any section of the current lead is calculated by the following relation

$$I = \int_S (\vec{J}\cdot\vec{n})dS , \quad (5)$$

where S is the cross-section of the current lead.

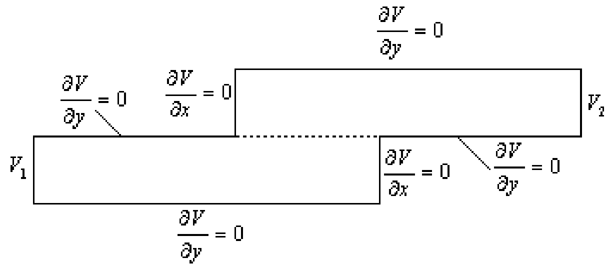

Fig. 3 Analysis domain and boundary conditions for electrical model

3.2 Thermal Model

The two assembled bars are considered sufficiently long to be able to set, on the boundaries AB and CD (figure 4) the boundary conditions of Neumann homogeneous type.

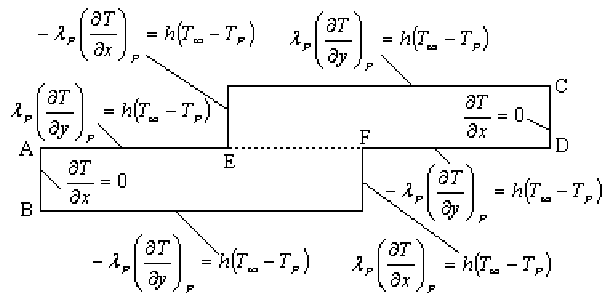

Fig. 4 Analysis domain and boundary conditions for thermal model

On the other borders, one sets boundary conditions of the convection type, with a heat exchange coefficient h to the environment having the temperature T_∞.

4 Numerical Algorithm

The numerical model is obtained by the discretization of the differential equations (1) and (4) by using the finite volumes method [1].

The coupled model is of alternate type [2] where the equations are solved separately and coupling is realized by the transfer of the data of one problem to the other. The two problems (electric and thermal) are integrated in the same source code and thus use the same mesh.

The numerical algorithm is the following :

1. Initialise the boundary conditions ;
2. Solve the electrical model ($V(x,y)$, $E(x,y)$, $J(x,y)$, $S(x,y)$, I) ;
3. Solve the thermal model ($T(x,y)$, $G(x,y)$, P_J) ;

4. If not convergence then update $\sigma(x, y)$ and goto 2.

5 Output the results ($V(x, y)$, $E(x, y)$, $J(x, y)$, $S(x, y)$, I, $T(x, y)$, $G(x, y)$, P_J, etc.).

The criterion of convergence of the coupled model was selected the value of the current, through the current lead, calculated using the relation (5).

5 Numerical Results

Figures 5, 6 and 7 present some numerical results. The dimensions of the analysis domain are those of figure 5.

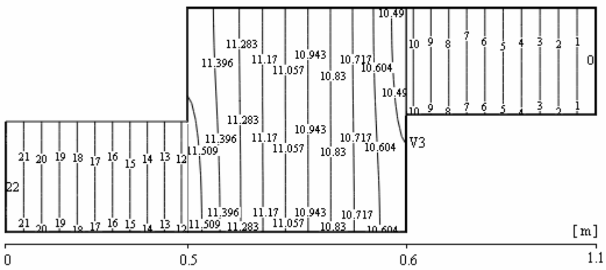

Fig. 5 Potentiel distribution (in mV)

The principal difficulty, in modelling and simulation the temperature distribution of a dismountable contact, is to take into account the resistance of contact (especially disturbance resistance because the resistance of constriction can be calculated by the model). In a first stage, one simulated the resistance of contact by the injection of an additional source term S_c, distributed in a uniform way, (equal to $1010\,\mathrm{W}$ in our example) on the contact line l_c (see figure 1).

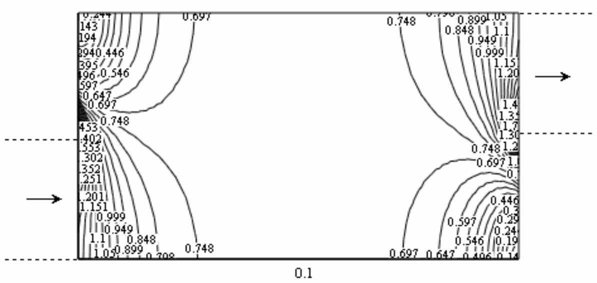

Fig. 6 Current density distribution in the contact region (in A/mm^2)

The optimization of the contact design supposes to determine the value of dimension T such that the maximum temperature, in the contact region, remains lower than the acceptable limiting value allowed by standards.

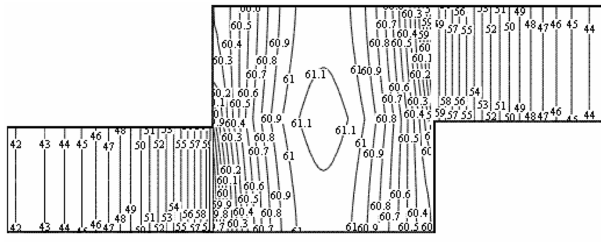

Fig. 7 Temperature distribution (in $^{o}\mathrm{C}$)

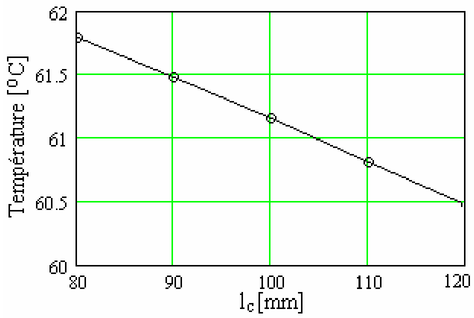

Fig. 8 Maximum temperature of contact versus length of contact ($S_c = 1.01\,\mathrm{kW}$).

6 Model Validation

The numerical validation of the model was made using a simplified analysis domain, by using a current lead with variable cross section. The analysis domain and the boundary conditions are presented at figures 9 and 10, [3].

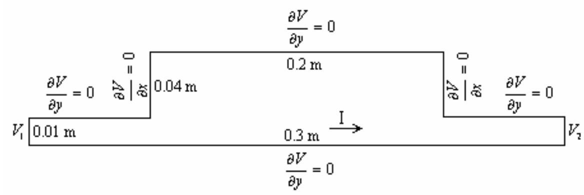

Fig. 9 Electrical model for numerical validation

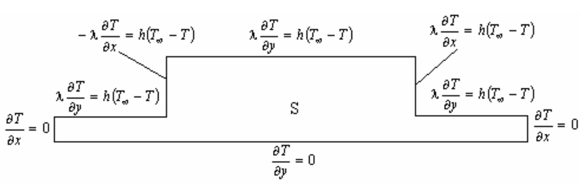

Fig. 10 Thermal model for numerical validation

The numerical results obtained in this case are presented in figures 11, 12 and 13.

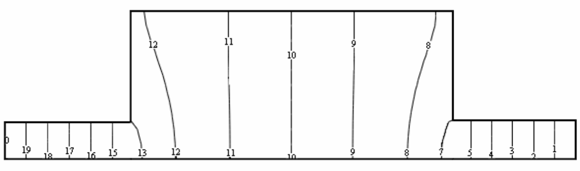

Fig. 11 Electric potential distribution

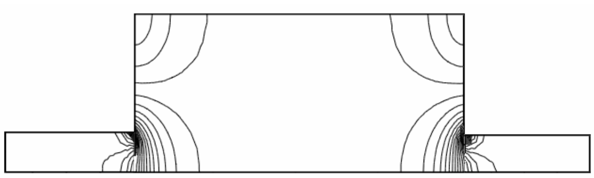

Fig. 12 Current density distribution

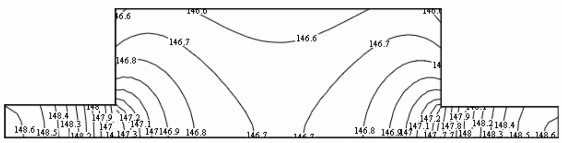

Fig. 13 Temperature distribution

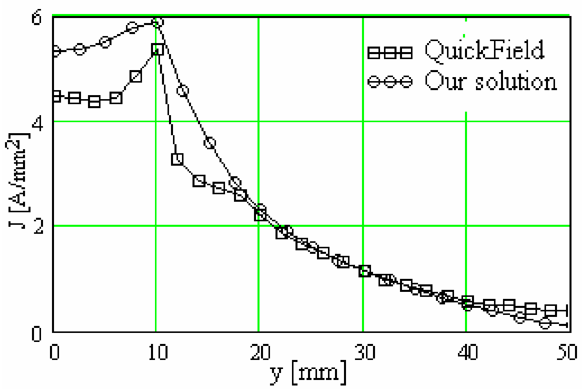

Fig. 14 Current density distribution ($x = 55\,\mathrm{mm}$)

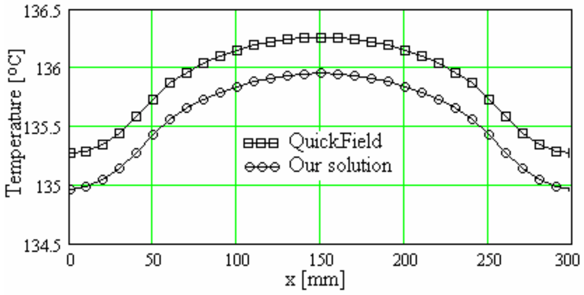

Fig. 15 Temperature distribution ($y = 0$)

The results presented in figures 11 - 13 were obtained for a current $I = 965.22\,\mathrm{A}$ what corresponds to a voltage drop $V_1 - V_2 = 0.02\,\mathrm{V}$ (the thickness of the current lead was considered $0.01\,\mathrm{m}$).

The numerical validation of the results of this model was made by using the software QuickField (version student) for the electrical model and the software Mirage (FEMM) for the thermal model. In figure 14, one presents the current density distribution in the proximity of the variation of the cross section of the current lead. The larger errors around the value of $y = 10\,\mathrm{mm}$ can be justified by the fact that the maximum number of nodes used in QuickField is too small in an area where the gradient of the electric quantities is very large.

In figure 15, one presents the temperature distribution on the symmetry axis of the current lead. One notes a very good agreement between our results and the results obtained using the Mirage software.

7 Conclusions

The elaborated model can be used for the optimization of the current leads of high currents with variable cross-section, such as the dismountable contacts. The model allows the calculation of the constriction resistance, as a component of the contact resistance but one cannot take into account the disturbance resistance which is an important component of the contact resistance.

The results presented in figure 8 shows that it is possible to optimize the geometry and to reduce the mass of the contact. However an experimental validation of the numerical results is absolutely necessary.

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