Temperature and Electromagnetic Force Analysis of GIB Plug-in Connector with Different Insert Depth under Short Circuit Fault

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Electrical dynamic stability and thermal stability are essential for plug-in connector used in gas insulated bus(GIB). However the insert depth of connector can be changed under the effect of daily cycling loads such as the operating current and the environment temperature, which may cause contact degeneration. In order to provide an effective condition monitoring of plug-in connector, A multi-physics coupling FEM model has been developed. The spring preloading contact force and the contact bridge radius can be obtained by mechanical analysis with different insert depth. Power loss and electromagnetic force obtained from electromagnetic field analysis are used as load inputs in thermal-mechanical coupling analysis. Temperature and force characteristics of plug-in connector with different insert depth under short circuit fault are calculated. The results show that the temperature rise of connector becomes larger with the decrease of connector insert depth. The electromagnetic repulsion force of contact finger increase whereas the preloading contact force is decrease, and the serious contact failure can be induced with small contact force.

***Index Terms*—Coupled field, FEM, Insert depth, Plug-in connector, Short circuit**

I. INTRODUCTION

THE plug-in connector used in the main electrical connection of gas insulated bus (GIB) belongs to static contact without switch operation(Fig.1). However small relative sliding can be induced between contact elements and the connector insert depth (D1) can be changed due to daily cycling loads such as operation current and environment temperature, then leading contact degradation. Electrical dynamic and thermal stability of plug-in connector with different insert depth under short current impact will directly affect the equipment safety.

Temperature rise and electromagnetic force of electric connector are analyzed by analytical and numerical methods[1-4]. However few research pay attention to the influence of insert depth on electrical stability and thermal stability of plug-in connector under short circuit fault impact through some design characteristics including temperature rise and electromagnetic force have calculated by closed formulas[5].

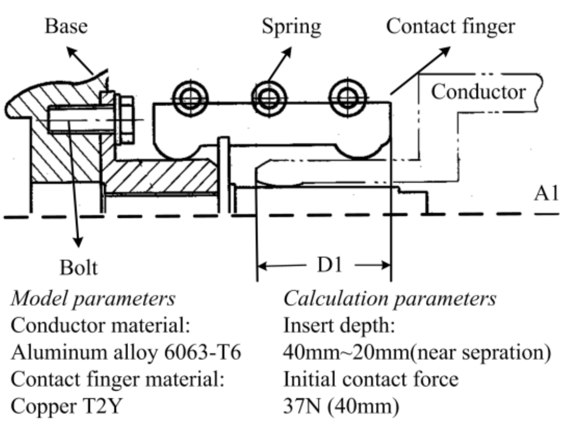

Fig.1. Physical model of GIB connector.

In this paper, the contact resistance, temperature rise and the electromagnetic force of plug-in connector with different insert depth under short circuit fault are calculated using 3-D FEM method. Physics model is shown in Fig.1 and assumptions of numerical model are as follows

16 pieces contact finger arranged clockwise around center conductor axis(A1). So the connector belongs to axisymmetric structure and only one contact finger is considered for simple.

Only mechanical contact area is considered for the chemical stability of SF_6 gas.

II. NUMERICAL CALCULATION METHOD

A transient coupling method is used to calculate the temperature and the electromagnetic force of plug-in connector under short circuit fault. First, initial conditions such as contact force and contact bridge radius are obtained from mechanical analysis of connector with different insert depths (Table.1). Second, current, electromagnetic force and power losses of connector obtained from electromagnetic field analysis using contact bridge model. Third, thermal-mechanical filed analysis of plug-in connector is conducted using the power loss and electromagnetic force densities as load inputs.

TABLE 1
CONTACT PARAMETERS UNDER DIFFERENT INSERT DEPTH

Insert depth(mm)	40	35	30	25	22	21	20
Contact force(N)	37	36.6	36.3	35.6	31.9	26.3	17.4
Radius($10^{\wedge-1}$mm)	1.8	1.79	1.78	1.77	1.71	1.60	1.39

A. Contact Bridge Model

Current constriction effect and the role of contact resistance between contact interfaces can be simulated by contact bridge model. The height of contact bridge is 0.2mm and the radius of contact bridge can be calculated by Hertz formula[6]

$$a = (3F_j R / 4E^*)^{1/3} , \quad (1)$$

where a is the radius of contact bridge, F_j is the contact force, R is the equivalent radius of contact finger and conductor plug, E^* is the equivalent Young's modulus of connector.

B. Field mathematical models

The governing equation of quasi-static electromagnetic field can be described as follows with magnetic vector potential $\mathbf{A}$.

$$\begin{cases} \nabla^2 \mathbf{A} = -\mu(\mathbf{J_s} + \mathbf{J_e}) \\ \mathbf{A}|_{C1} = 0 \end{cases}, \quad (2)$$

where μ is magnetic permittivity, $\mathbf{J_s}$ is source current and $\mathbf{J_e}$ is eddy current, *C1* is the boundary of solution region.

Electromagnetic force induced by the interaction between current density and magnetic field can express as

$$\mathbf{F} = \int_V \mathbf{J} \times \mathbf{B} dV. \quad (3)$$

Joule heat is produced since source and eddy currents flow through the plug-in connector. Mathematical model of thermal coupling field with current can be shown as

$$\begin{cases} \rho c\left(\partial T / \partial t\right) - \lambda(\mathrm{T}) \cdot \nabla^2 T = \rho_e \left|\mathbf{J_s} + \mathbf{J_e}\right|^2 \\ -\lambda(T)\dfrac{\partial T}{\partial n} = q_s \text{ on connector terminal} \\ -\lambda(T)\dfrac{\partial T}{\partial n} = K_T(T - T_0) \text{ on conductor surface} \end{cases}, \quad (4)$$

where $\lambda(T)$ is thermal conductivity, ρ is material density, c is material specific heat capacity, ρ_e is electrical resistivity and T_0 is environment temperature.

Contact status of plug-in connector is influenced by spring preloading force, conductor gravity and electromagnetic force. Mathematical model of mechanical field are summarized

$$[M][\ddot{\mathbf{u}}] + [K(T)][\mathbf{u}] = [\mathbf{F}_e] \quad (5)$$

where M is mass matrix, $K(T)$ is stiffness matrix, $\mathbf{u}$ is nodal displacement and $\ddot{\mathbf{u}}$ is nodal acceleration. **Fe** is nodal force including electromagnetic force and conductor gravity.

III. DYNAMIC BEHAVIORS OF PLUG-IN CONNECTOR

Dynamic behaviors of temperature rise and electromagnetic force under short circuit fault are analyzed by numerical calculation model. Initial current before short circuit fault is 900A and environment temperature is 25℃. Fault during time is 0.06s and instantaneous value of short current is shown as

$$i(t) = \sqrt{2} I \left(e^{-\alpha t} - \cos(\omega t)\right) \quad (6)$$

where $I=10kA$, $\omega = 100\pi$, decaying constant $\alpha = 22.311 s^{-1}$.

A. Temperature rise

Temperature field distribution of plug-in connector before and after short circuit fault(insert depth:40mm) are shown in Fig.2(a)-Fig.2(b). Temperature rise of contact spot are much higher than other parts of connector for the limited short fault time(0.6ms). Max temperature of plug-in connector at peak short current value(t=6.7ms) with different depth is described

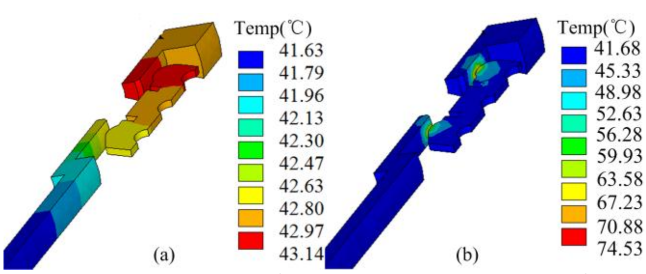

Fig.2. Thermal characteristics of GIB connector under short circuit fault.

in Table2. As a result, temperature increasing slowly when the insert depth greater than 22mm. However contact temperature rising sharply since the insert depth less than 22mm which leading connector material collapse and overheating fault.

TABLE 2
DIFFERENT CONNECTOR TEMPERATURE UNDER SHORT FAULT

Insert depth(mm)	40	35	30	25	22	21	20
Temperature(℃)	74.5	76.8	78.1	81.3	96.5	136.4	435.2

B. Electromagnetic force

Glancing at the distribution of current and electromagnetic force in plug-in connector under peak value of short current fault(Fig.3(a)-Fig3(b)), electromagnetic force of contact finger has opposite direction with spring preloading force which mean that contact force can be reduced by the action of electromagnetic force. Amplitudes of electromagnetic force are increasing with decreasing of insert depth and the contact force, and the preloading contact force nearly offset by the electromagnetic force at 20mm insert depth which cause contact loss, leading connector failure and unplanned outage.

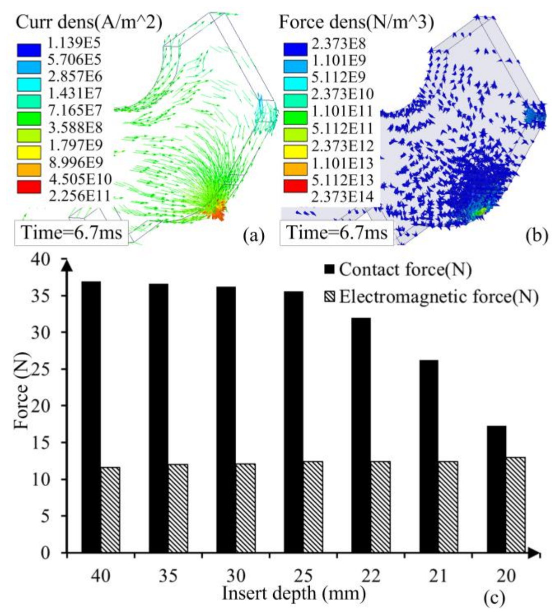

Fig.3. Force characteristics of GIB connector under short circuit fault.

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