Multi-physics Calculation and Contact Degradation Mechanism Evolution of GIB Connector Under Daily Cyclic Loading

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A 3D electromagnetic-thermal-mechanical coupling FEM model of gas insulated bus(GIB) connector is proposed in this paper, with special attention on the contact degradation mechanism under normal operation conditions which is important in the condition monitoring of the equipment. The current constriction effect and contact resistance are taken into account through modeling an equivalent contact bridge between the contact interfaces, and varying of friction coefficient is also considered. Power loss derived from electromagnetic field is applied to be load inputs in thermal-mechanical field analysis. The validity of calculation model has been demonstrated by temperature rise experiments, and the influence of daily changing current and environmental temperature on thermal and mechanical characteristics of plug-in connector has been analyzed using the calculation model. Analysis results show that daily change of current and environmental temperature can make relative motion between the conductor and the plug-in connector, and the insert depth of connector can be changed under the action of alternating thermal loading induced by daily change of current and environmental temperature, leading contact degradation and overheating fault of plug-in connector.

***Index Terms*—Condition monitoring, Degradation, Finite element analysis, Friction, Plug-in connector**

I. INTRODUCTION

THE plug-in connector of gas insulated bus(GIB) is essential for the equipment installation and maintenance. Connector overheating fault which induced by serious contact degradation has been researched [1]. Whereas the contact degradation mechanism was not clear, this hindered the development of GIB contact designing and monitoring technology.

The GIB connector is often subjected to daily changing of load current and environmental temperature, and research has found that relative motion between contact interface may happened under external temperature or vibration[2]. Very little work paid attention to contact degradation of GIB connector through some numerical models have been introduced[3-5].

A 3-D multi-physics coupling FEM model is developed in this paper (Fig.1), plug-in connector contain 16 contact fingers arranged clockwise around center conductor axis can eliminate the influence of thermal stress on insulators. K-type thermal couple (T1) placed on the vicinity of conductor is used to measure temperature rise of connector. Relative displacement is represented by changing of conductor insert depth (D1).

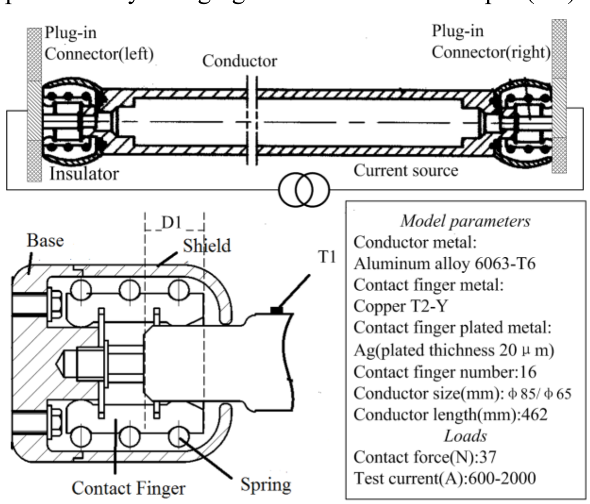

Fig. 1. Schematic structure of GIB connector.

Assumptions about calculation model are given as follows:

The quasi-static approximation can be used since steady state ac flows in the bus conductor.

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

II. NUMERICAL CALCULATION METHOD

Electromagnetic-thermal-mechanical coupled FEM model of plug-in connector is developed with the Ansys Parametric Design Language (APDL). Firstly, current distributions of plug-in connector can be obtained from electromagnetic field analysis using contact bridge model. Secondly, the electro-thermal-mechanical filed analysis of plug-in connector is conducted using current densities as load inputs.

A. Contact Bridge Model

A contact bridge model has been introduced to simulate the current constriction effect and contact resistance between contact interfaces. The height of contact bridge is 0.2mm and the radius of contact bridge can be calculated by Hertz formula[5]

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

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. Friction model

The daily cycle changing of temperature and load current in plug-in connector can be conclude as low velocity loading for rather long cycle time. The friction coefficient is not constant but varies with slip rate, leading discontinuous sliding motion and unrecoverable relative displacement, and then changing the insert depth of connectors. Relationship between friction coefficient and relative motion velocity can show as[6]

$$\mu(\mathrm{v}) = \mu_d + (\mu_s - \mu_d)\,\mathrm{e}^{-c|v|}, \tag{2}$$

where v is the slip rate, μ_s and μ_d are the static and dynamic friction coefficient, c is the decay coefficient.

III. CALCULATION RESULTS AND DISCUSSIONS

A. Field distributions and temperature rise

Distributions of current density, displacement, von-mises stress and the temperature in plug-in connector (load current 2000 A, environment temperature 25℃) are shown in Fig.2. The current density in contact bridge is much larger than other parts of connector for the current constriction effect(Fig.2(a)); Non uniform displacement between contact interfaces yielded due to the conductor gravity (Fig.2(b)). The maximum von-mises stress conduct on the contact spot is shown in(Fig.2(c)) where plastic deformation induced; Temperature in contact spot are highest for the existence of constriction joule heating source, and the temperature rises of different contact fingers are not same with different contact bridge radius (Fig.2(d));

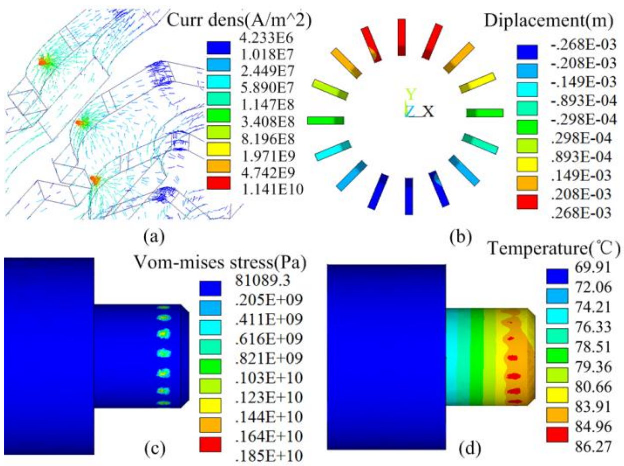

Fig. 2. Field distributions of GIB connector

Tested plug-in connector temperature changing with the same trend as the calculated results under different test currents (Table 1) and calculated values are larger than those from test for the surface heat transfer coefficient obtained by approximation. It can be seen that the temperature in the vicinity of conductor, where thermal couple placed (Fig.1) is about 16℃ lower than contact zone under 2000A (Fig.2(c)) for the experiment temperature test can only approach the temperature at measurement point and it is hard to locate temperature sensors on the contact zone.

TABLE 1
CONNECTOR TEMPERATURE UNDER DIFFERENT CURRENTS

Current（A）	600	900	1000	1500	2000
Test(℃)	39.21	41.66	50.82	62.55	67.12
Calculated(℃)	39.98	42.45	49.08	62.60	69.91

B. Daily contact evolution

Transient characteristics of temperature and relative position of GIB plug-in connector which subject to cyclic daily loading are shown in Fig.3. Daily changes of current obtain from one 220kV gas insulated substation in China Southern Power Grid Company and the daily changes of environment temperature is taken as approximation of the local meteorological temperature by a sine function. Results show that the connector temperature cycle varying, and the relative displacement between contact elements occurs under daily cyclic of load current and environment temperature.

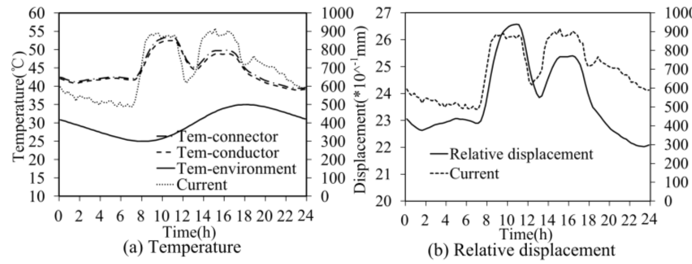

Fig.3. Transient characteristics of GIB connectors during one day

C. Relative motion characteristics

Friction force of two end plug-in connectors within one cycle and the movement of conductor can be seen in Fig.4. It can be seen that the unrecoverable relative displacement under cyclic loading (Fig.4(d)) can be conducted due to nonlinear changes of friction force and velocity(Fig.4(a)-Fig.4(c)), Poor contact and overheating fault can be induced with insufficient insert depth. Relevant experiment will be carried out.

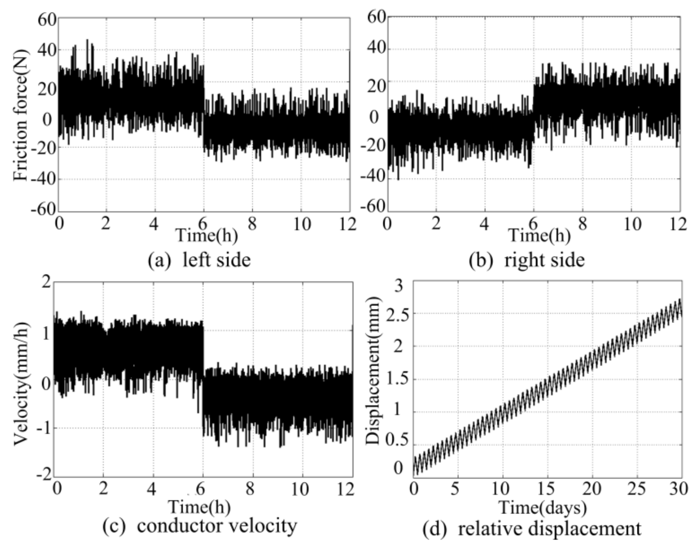

Fig.4. Relative displacement of GIB connectors

IV. REFERENCES

[1] Y. Mukaiyama, I. Takagi, K. Izumi, T. Sekiguch, A. Kobayashi, T, Sumikawa. "Investigation on abnormal phenomena of contacts using disconnecting switch and detachable bus in 300kV GIS," *IEEE Trans. Power Delivery.,* vol.5, no.1, pp. 189-195, 1990.

[2] Yu-Zhi (Liza) Lam, John W. McBride, Christian Maul, and John K. Atkinson, "Displacement measurements at a connector contact interface employing a novel thick film sensor," *IEEE Trans. Components and Packing Technologies.,* vol. 31, no.3, pp. 566-573, 2008.

[3] R. Gollee and G. Gerlach, "An FEM-based method for analysis of the dynamic behavior of ac contactors," *IEEE Trans. Magnetics.,* vol.36, no.4, pp. 1337-1340, 2000.

[4] Arnaud Monnier，B Froidurot，C Jarrige，etc. "A mechanical, electrical, thermal coupled-field simulation of a sphere-plane electrical contact," *IEEE Trans. Components and Packing Technologies.,* vol.30, no.4, pp. 787-795,2007.

[5] R.Holm, *Electric Contacts, Theory and Applications*, 4th ed., vol. 2. Springer: New York, 1979, pp. 9-10.

[6] David J. Benson and John O. Hallquist. "A single surface contact algorithm for the post-buckling analysis of shell structures". *Computer Methods in Applied Mechanics and Engineering*.,vol.78, no.2. 1990.