Mapping Method between Variable Finite-Element Meshs in Magnetic-Thermal Simulations

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In the coupled electromagnetic fluid-dynamical and thermal simulations which are done by weak coupling FEM for the electromagnetic devices, as thermal loads energy losses obtained from electromagnetic calculations are transferred between meshes to calculate the temperature distributions by considering the influence of fluid flow. Because the requirements of meshes discretization scheme are quite different between electromagnetic and fluid-thermal fields, the same finite element model is applied to analyze as possible as to meet the both requirements. It will lead to increase the number of meshes and the time of calculation. However, if the different finite element models are used, the data cannot be directly transferred between corresponding meshes. In this paper, a variable mesh mapping method is proposed. The energy losses can be transferred between the different meshes by Gauss integral and coordinate transformation. Moreover, the strategy of precision control and error correction coefficient is proposed to ensure calculation accuracy. This method is applied to an air insulation bus duct system in a literature, the calculation results are compared with the normal same meshes mapping method and experiment results. It provides the validity of the variable meshes mapping method.

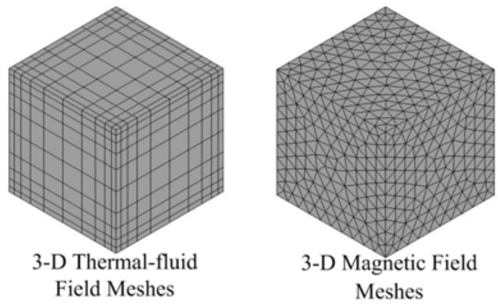
***Index Terms*—Electromagnetic fields, Finite element analysis, Fluid dynamics, Numerical analysis, Temperature**

I. INTRODUCTION

IN WEAK coupled multiphysics simulations, the diverse fields are computed sequentially, the calculation results of one field are imposed to another field as the excitation. For example, the losses calculated by magnetic field analysis are used as the input for the thermal field analysis, which is deeply dependent on accurate air fluid field analysis. S. L. Ho and W. N. Fu, *et al.* analyzed an air insulated bus duct system and a novel traveling wave induction heating system based on weak coupled magnetic-thermal fields approach [1][2]. Weili Li, *et al*., deduced the weak coupled calculation of magnetic-thermal field and the determination of heat transfer coefficient for large generators [3][4].

In these cases, the data should be transferred from meshes in one field to those of another meshes the weak coupling multi-physical simulation, as shown in Fig. 1. Such meshes are matching, meaning that both the geometrical model and finite element model must conform in different fields. However, the requirement of mesh density and shape may differ due to different process of solving magnetic field equations and fluid-thermal field equations. Thus, the data transfer method in high precision and efficiency between variable meshes of different fields must be paid more attention to.

In this paper, a variable meshes mapping method, which can be applied to multi-physics simulations, is proposed. Gauss-Legendre integration and isoparametric element transfer are employed to realize the data transfer between meshes with different density and shape. The temperature rise of an air insulated bus duct system (AIBDS) was studied in [5]. A 2-dimentional magnetic and fluid-thermal model was built, taking the same meshes in different fields into account. In the process of coupling, losses were mapping from magnetic meshes to the thermal meshes. Applied to the multi-physical simulation of AIBDS model, the proposed method can provide approximate results on the values of temperature.



(a) Hexahedral regular meshes (b) Tetrahedral irregular meshes

Fig. 1 Different 3-D meshes in different fields

II. PRINCIPLE OF VARIABLE MESHES MAPPING METHOD

In multiphysics simulations which are done by weak coupling method, there are different appropriate discretization schemes for electromagnetic and fluid-dynamical computation domain. For example, because of skin effect, refined triangular meshes are adopted in the conductor domain. However, refined quadrilateral meshes are adopted in fluid-solid interface. If data transfer can be achieved between matching meshes with a unified computational model, the discretization schemes should be considered to simultaneously satisfy the precision and efficiency requirements of different physical fields. Then a huge amount of computation will be caused. Thus, in this paper, a novel data transfer method based on Gauss-Legendre integration and isoparametric element is presented for weak coupled magnetic-fluid-thermal field analysis.

III. Strategy of Accuracy Control

A. Variable meshes discretization strategy

In electromagnetic field calculations, whatever the shape of mesh, the size and distribution of meshes should match with the rate of change of current density distribution.

In thermal and fluid field calculations, fluid-solid interface is the boundary between the two different media. The mesh quality in domain near interface will have influence on calculation accuracy and convergence.

B. Proprtion of Number of integration points and Mesh Size

The control strategy is that the number of integration points is not less than the number of meshes. Considering the non-uniformity of size of electromagnetic meshes, the number of integration points is not recommended less than 1.5 times the number of meshes in the electromagnetic field.

C. Correction Method of Total Error

Comparing the sum of mapping energy loss in each mesh with the total energy loss of the model in electromagnetic field, the correction coefficient λ can be obtained. Then the heat load of each mesh obtained by mapping method should divide by the correction coefficient to obtain the more accurate value.

IV. Application in an Air Insulation Bus Duct System

Three-phase bus duct system plays an important role in power distribution system. The performance of the bus air system is influenced by the temperature distribution. The eddy currents are induced in both busbars and steel outer enclosure. The natural convection is main heat transfer way in the air insulation bus duct system.

The governing equations of both eddy current field and fluid-thermal field may be quoted in [5].

The thermal conductivity of steel outer enclosure is 49.3 W/(m·K). The variable meshes are used for magnetic and fluid-thermal field analysis, respectively. The variable meshes mapping is applied to analyzed the thermal characteristics of AIBDS. The computational results are compared with those by using matching mesh. The root mean square (RMS) of excited current is 1000A and the frequency is 50Hz. The ambient temperature is 28℃. The coefficients of convection heat transfer of the top, bottom and sides of outer enclosure are 3.082, 6.164 and 5.436 (W·m-2/℃), respectively.

The temperature distributions in AIBDS are shown in Fig. 2. Due to the non-uniformity distribution of current and the heat transfer characteristics, the temperature closed to buses and the top side is higher than other parts in AIBDS. The air flows upward through the interval of buses and then flows downward along with the sides. The air pressure of the top is greater than that of bottom because of the air flowing.

Table I illustrates the temperature distribution computed by using conforming meshes. It lists the error analysis of temperature calculation in AIBDS comparing with experiment results.

Due to natural convection, the interaction between temperature and air flow velocity may lead the error increasing of temperature calculation by using variable meshes mapping.

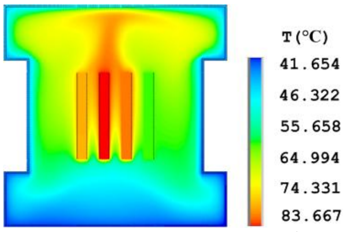


Fig. 2. Temperature distributions of AIBDS (Unit: ℃).

TABLE I
Comparison of Calculation and Experiment Temperature

Phase	Variable meshes	Matching mesh	Experiment measure	Error1	Error2
A	78.4℃	78.6℃	83.2℃	5.7%	5.5%
B	83.6℃	83.8℃	85.3℃	2.0%	1.7%
C	81.3℃	81.4℃	81.2℃	0.12%	0.2%

Error1 and Error2 are the relative errors between the temperature calculated by variable meshes and temperature achieved by matching mesh at measuring probe with that of experiment, respectively.

V. Conclusion

In this paper, the variable meshes mapping method is proposed for the data transfer between the different meshes in different fields in weak coupled magnetic-thermal simulations. The calculation accuracy of this method is mainly influenced by four factors, such as the rate of change of the current density, the numeber of integration points, the numeber of one mesh in thermal-fluid field containing the meshes in electromagnetic field, and the order of shape function of meshes in electromagnetic field.

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