A Three-Dimensional Multispecies Fluid Model of Coupled Multi-physics Simulations in Electromagnetic Devices with Moving Parts

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***Abstract*—For coupled electromagnetic, fluid-dynamical and thermal simulation of electromagnetic devices with moving parts, if the computational domains of fluid and solid are both established, the velocity of moving parts cannot directly be applied on the interface due to no-slip boundary condition in fluid dynamic theory. In this paper, a three-dimensional multispecies fluid model is described. According to their own properties, moving parts are regarded as different fluid species so that the velocity can be applied as load. A comparison of the results obtained by traditional and novel methods indicates that the multispecies fluid model is available for the fluid-dynamical simulation of devices with moving parts. The rotating and sliding problems can be solved by this multispecies fluid model.**

***Index Terms*—Electromagnetic analysis, Electromagnetic devices, Fluid dynamics, Numerical simulation, Thermal analysis.**

I. Introduction

The design of electromagnetic devices requires coupling electromagnetic field with the other disciplines, such as Thermal, Structural and Fluid flow [1]. For many devices including motor [2]-[4], bus duct system [5], reactor [6], GIS bus bar [7] and transformer [8], etc., as their temperature is greatly influenced by cooling system used, the thermal source obtained from a electromagnetic model is coupled to a thermal and fluid-dynamical model to achieve temperature calculation [3].

The power loss activates three heat transfer mechanisms, i.e., conduction, radiation, and convection. It is widely accepted that convection is the most important mechanism and the most complex to model [3], [9]. For some electromagnetic devices, such as motor, there are some moving parts which will influence the fluid flow. Therefore, the influence of the moving parts must be considered. However, according to no-slip boundary condition in fluid dynamic theory, the flow velocity on interface between fluid and solid is zero. Namely, the velocity of solid cannot be applied directly when there are moving solid in fluid computing domain.

To achieve the fluid-dynamical simulations in the domain with moving structural parts, three typical methods have been applied previously. In the computational domain, only fluid model is established without solid model. Slip boundary condition, thus, is defined, and the velocity of moving parts can be applied on the interface between fluid domain and solid domain. Then, the flow velocity of fluid can be calculated [10]. However, for this method, some moving parts of electromagnetic devices usually are heating elements, such as rotor of induction motor, so their models cannot be neglected. By equivalent thermal circuit method, the rotor rotation-effects on air convection have been considered [4]. This method of equivalent lumped parameters is insufficient to achieve more accurate results. Moreover, the solid model is established in computational domain. Through using the dynamic mesh model, when the solid steps every movement, the calculation model must be remeshed [11]. The excessive computation by remeshing will influence the calculation speed of Navier-Stokes equations.

In this paper, the moving parts of devices were regarded as some fluid models, which are different from the cooling fluid medium. With these various fluid components, a 3-D multi-species fluid model was used to simulate the coupling process of electromagnetic devices with moving parts. Multispecies fluid model is used to describe the fluid mixture, which consists of several species fluids with different properties. The flow velocity on the interface between the two domains of different fluids can be easily applied in whole computational domain. For coupled multi-physics simulations of devices with moving parts, according to different properties, moving parts were considered as different species fluids. Thus, the multi-species fluid models are applicable for treatment of rotating and sliding problems.

II. Three-Dimensional Multispecies Fluid Model

For fluid medium, some physical quantities, i.e., flow velocity, temperature and species, are non-uniform so that there is transport process. However, in this paper, moving parts were defined as different fluids, among which a chemical reaction will never take place. Therefore, without this material transformation, each species of fluid has the independent governing equations. Two kinds of problems solved by multispecies fluid model are as follows.

A. *Rotating Problem*

For this kind of problem, the typical model is rotary motor. The stationary parts of devices are defined as solid model in the analysis of coupled multi-physics simulations. However, the rotary parts, such as the rotor and shaft, can be defined as different species fluids from the cooling medium, as shown in Fig. 1.

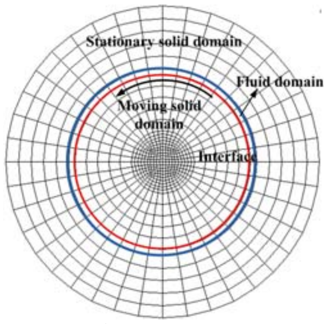


Fig. 1. Computational model of rotating problem.

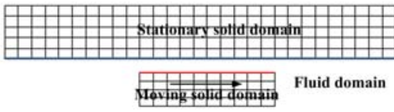


Fig. 2. Computational model of sliding problem.

TABLE I
AIR VOLUME UNDER THREE SITUATIONS (m^3/s)

Domain	Only air domain without solid	Multispecies fluid model	Non-rotation
Vents	9.42e-3	9.39e-3	8.06e-3
Air gap	5.58e-3	5.61e-3	6.94e-3

B. Sliding Problem

For this kind of problem, the typical model is linear motor, and the trajectory of moving parts is linear and runs parallel to the interface, as shown in Fig. 2. After defined as fluid domains, the velocity can be applied on all nodes in the model of moving parts. Thus, for these domains, the Navier-Stokes equations needn't be solved.

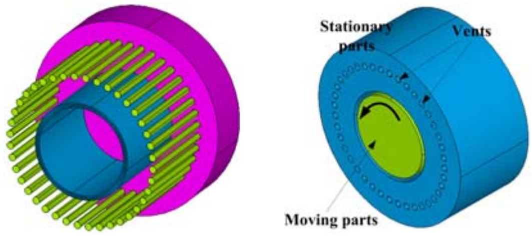
III. METHOD VALIDATION

To validate the effectiveness of multispecies fluid model, two three-dimensional calculation models for rotating problem were established. One only consists of cooling fluid domain with slip boundary condition [10], as shown in Fig. 3(a), and the other consists of stationary solid domain and multispecies fluid domains, including moving parts, as shown in Fig. 3(b). Then, the calculation results of the latter were compared with that of the former.

To investigate the impact of rotation on fluid flow, it is assumed that the moving part is stationary. Under the three situations, with the same total air volume on the inlet, the air volume on the outlet of all vents and air gap can be calculated by using Gauss-Legendre Integral Formula, as shown in Table I. Furthermore, the same heat value per element is respectively applied to achieve the coupled fluid-dynamical and thermal simulations under the condition of rotation and non-rotation. Fig. 4(a) and Fig. 4(b) show the temperature distributions with regard to the two models.

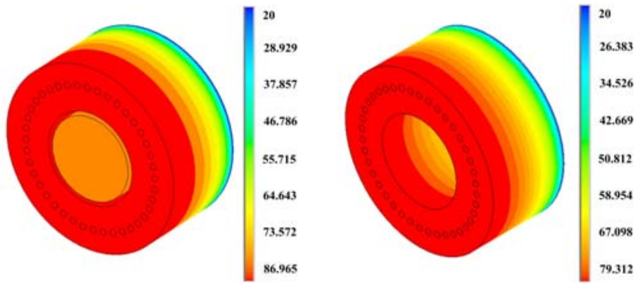
IV. CONCLUSION

For a three-dimensional model with a rotating part, fluid-dynamical simulation was achieved by using traditional and multispecies fluid methods, respectively. A comparison of the results obtained by these two methods indicates that the multispecies fluid model is available for the fluid-dynamical simulation of devices with moving parts. In addition, the impact of the rotation for axial fluid flow cannot be ignored, so moving parts must be considered in coupled simulations.



(a) (b)

Fig. 3. Two calculation models. (a) Only air domain without solid. (b) Multispecies fluid model.



(a) (b)

Fig. 4. Results of temperature distributions (°C). (a) Non-rotation. (b) Rotation.

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