Thermal Design of Natural Cooled Axial Flux Permanent Magnet Synchronous Generator Using Electromagnetic and Fluid-Dynamical Finite-Element Analysis

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***Abstract*—Axial flux permanent magnet synchronous generators are of interest in power generation and traction application for its compactness and high power density these days. The high power density may cause thermal problem in this kind machine and, thus thermal design of a natural cooled machine was studied in this paper. The electromagnetic analysis was carried out by three dimensional finite element analysis and the computation of thermal field is performed via a coupled thermal and fluid-dynamical model based on FEA, where heat source was obtained from electromagnetic analysis. In order to enhance ventilation, blade was added to rotor due to its normal structure and models with blades at inner and outer radius was compared by simulation.**

I. Introduction

This paper studies the thermal behavior of an axial flux permanent magnet synchronous generator (AFPMSG) used for low power wind turbine system. As this 3kW generator is stalled in nacelle, natural cooling was utilized due to space and cost limit. However, axial flux machine have advantages over radial flux machine in power density, the thermal problem should be carefully studied to insure a 20 years life for this kind of application.

There are principally two methods for conducting the thermal analysis of electrical machines, lumped-parameter method and numerical method. Lumped parameter models for air cooled AFPM have been previously studied [1, 2].
Although the kind method has a high solution speed, the flow field and convection coefficients have to be evaluated by empirical equation, experimental test or computational fluid dynamics in order to create an accurate model. The main strength of numerical analysis is that any device geometry can be modeled. However, it is very demanding in terms of model setup and computational time. There are two types of numerical analysis: finite-element analysis (FEA) and computational fluid dynamics (CFD). CFD has the advantage that it can be used to predict flow in complex regions, such as around the motor end windings [3]. FEA can only be used to model conduction heat transfer in solid components.

Study on CFD analysis of axial flux machines with SMC core have been reported in [4, 5] , the simulation results agrees well with infrared image under test. The heat transfer coefficients ware calculate by CFD for a torus AFPM [6].

II. Thermal and Fluid-Dynamical Analysis

In this paper, the thermal design of a natural cooled AFPMSG was described by CFD. The designed generator has 3kW and 240rpm. A three-dimensional model was shown in Fig. 1. In order to get effective ventilation, blades are added to rotor yoke. As shown in Fig. 2,the computational model in CFD has blades added at inner radius. Air velocity is illustrated in Fig. 3 and the temperature distribution of models with blades at inner and outer radius were compared in Fig. 4 and Fig. 5. A prototype machine was manufactured and the thermal test was carried out as shown in Fig. 6. The results will be given in full paper.

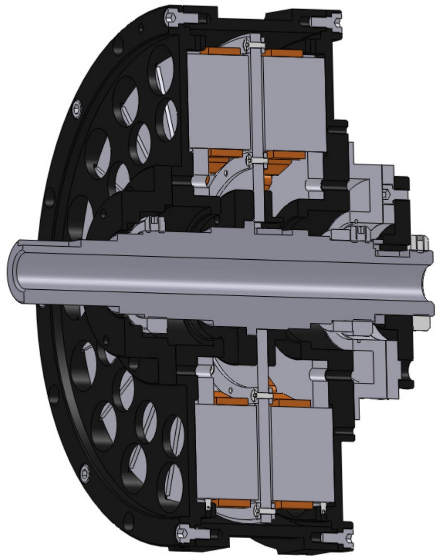

Fig. 1 3D model of proposed structure for AFPMSG.

A. *Thermal Analysis Using CFD*

The fluid-dynamical behavior of nonturbulent incompressible fluids can be modeled by Navier-Stokes equations.

$$\begin{cases} \rho \dfrac{\partial \vec{u}}{\partial t} - \nabla\left[\eta\left(\nabla \vec{u} + \left(\nabla \vec{u}\right)^T\right)\right] + \rho\left(\vec{u}\cdot\nabla\right)\vec{u} + \nabla p = \vec{F} \\ \nabla \cdot \vec{u} = 0 \end{cases} \quad (1)$$

where the symbols used are explained in the nomenclature.
For a fluid, the resulting heat equation is

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot \left(-k\nabla T + \rho C_p T \vec{u} \right) = Q \quad (2)$$

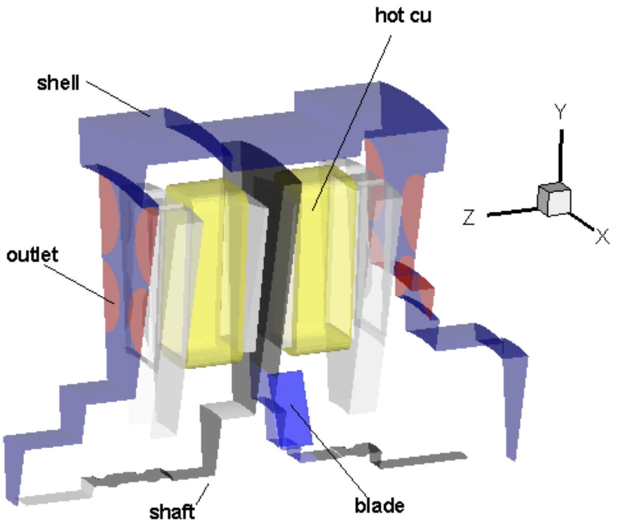

Fig. 2 Compuational model in CFD.

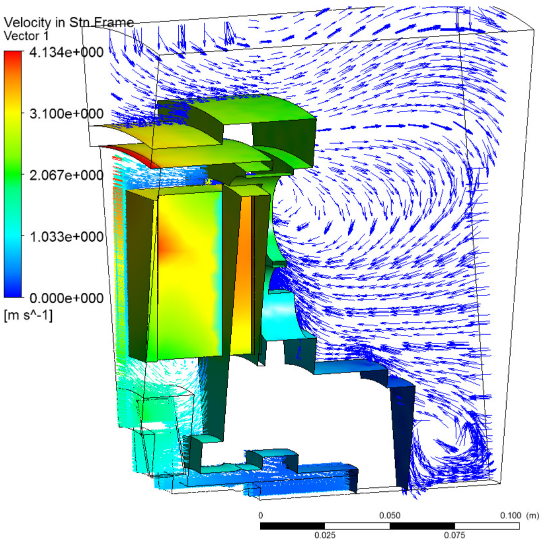

Fig. 3 Air Velocity around the machine.

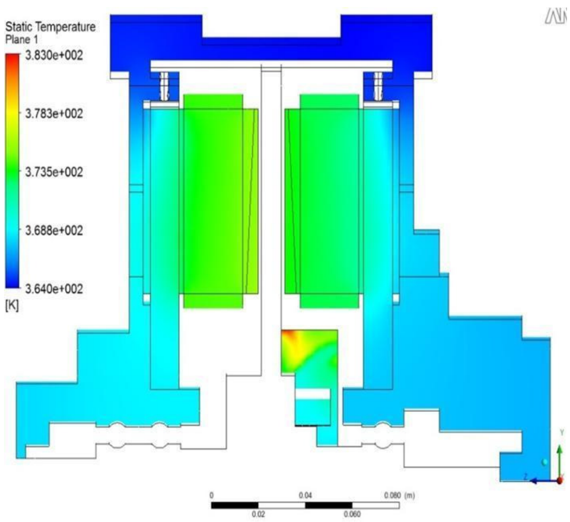

Fig. 4 Temperature distribution of AFPMSG with blade at inner radius.

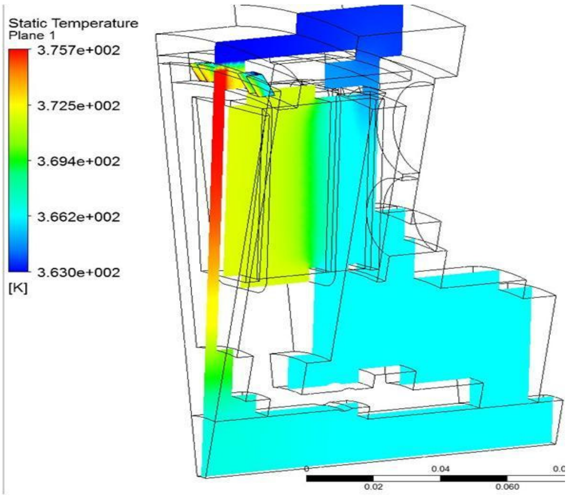

Fig. 5 Temperature distribution of AFPMSG with blade at outer radius.

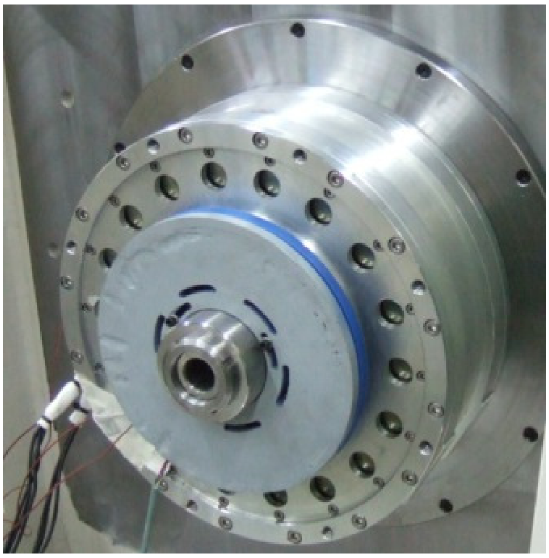

Fig. 6 Prototype machine under thermal test.

III. References

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