Development of Lumped-Parameter Thermal Model for Axial Flux Permanent Magnet Synchronous Machine

Jian Li, Da-Woon Choi and Yunhyun Cho
Dept. of Electrical Engineering
Hadan 2 Dong, #840, Saha-gu, 604714, South Korea
lijian613@gmail.com

Abstract— This paper investigated the thermal analysis of axial flux permanent magnet synchronous machine (AFPM) through lumped parameter model. Using the loss from electromagnetic analysis as heat generating source, thermal behavior was studied by constructing a thermal equivalent circuit in both axial and radial direction. The results show good agreement with CFD result and experiment data, which indicates that this method has good accuracy and reliability for dealing with thermal behavior of AFPMs.

I. INTRODUCTION

Axial flux permanent magnet machines are of interest in power generation and traction application for its compactness and high power density these days. However, the thermal problem comes out while the volume of machine could be reduced by 30% or 50% compared with conventional radial flux machines. Thus AFPM machines are easy subject to cooling problems. The heat generated in machine must be removed so that the temperature limitations established for the machine materials such as insulating materials, lubricants, and permanent magnets are complied with. Besides, lower operating temperature reduces extra copper losses introduced by the temperature coefficient of the winding resistance.

There are principally three methods for conducting the thermal analysis of electrical machines. The first is lumped-parameter method, the second the computational fluid dynamic (CFD) method. Commercial CFD codes such as FLUENT and CFX packages have extended capabilities to analyze heat transfer process within arbitrary geometry. However, CFD modeling is time consuming for thermal analysis at preliminary design stage. In case of optimization, it is impractical to use CFD method since this process will require excessive time to conduct modeling, meshing and solving of each candidate machine design.

Thermal analysis using lumped parameter model for radial flux electrical machines (induction machine, permanent magnet machines and switched reluctance machines) were widely studied in literature [1-4]. Calculation of parameters in general electrical machines was reported in [5, 6]. Thermal analysis of AFPMs through lumped parameter model was developed based for rolling core structure with general winding or toroidal winding [7, 8].

II. EQUIVALENT CIRCUIT OF CANNED INDUCTION MOTOR CONSIDERING CAN LOSS

The AFPM studied in this paper was designed for lower power wind turbine. It is composed of segmented coil-wound teeth, stator yoke, PMs and rotor yoke. The frame and end covers were made by aluminum in order to reduce weight. The 1/8 model of prototype machine is shown in Fig. 1. The stator yoke core was laminated in axial direction, and segmented teeth in radial direction were then inserted to stator yoke. The corresponding thermal network was shown in Fig. 2. The proposed model is intended to compute the motor over temperature in steady-state condition. For this reason, thermal capacitance has been neglected.

The choice of nodes and their assignments in the thermal network was based on temperature distribution, mechanical complexity and material properties. The nodes of end core, stator yoke, stator teeth, coil, air gap, PM and rotor yoke were chosen at middle radius, theses nodes construct axial path, shown in black color. And the nodes of housing, bearing, shaft, end coil, air at inner and outer radius are elements of radial paths, which are shown in blue color. Conduction and convection between various parts was modeled by thermal resistance.

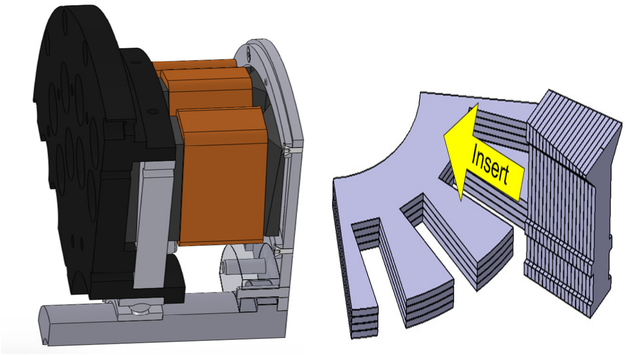


Fig. 1. 1/8 model of prototype machine.

As shown in Fig. 3, the basic conductive thermal equivalent circuit for stator yoke and teeth are derived from heat conduction equations [9] with the following assuming:

The radial and axial heat flows are independent of each other; there is no heat flow in the circumferential direction only. Due to its novel structure, the thermal conductivities λ_a and λ_r are given for radial and axial direction. The thermal network will be simplified and then solved. The results comparison with experiment data will be reported in full paper.

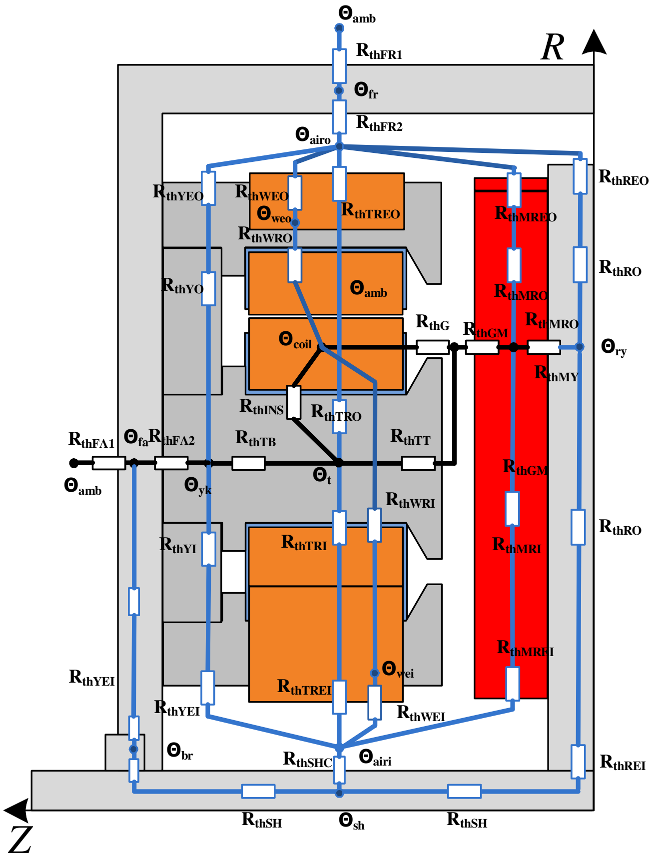
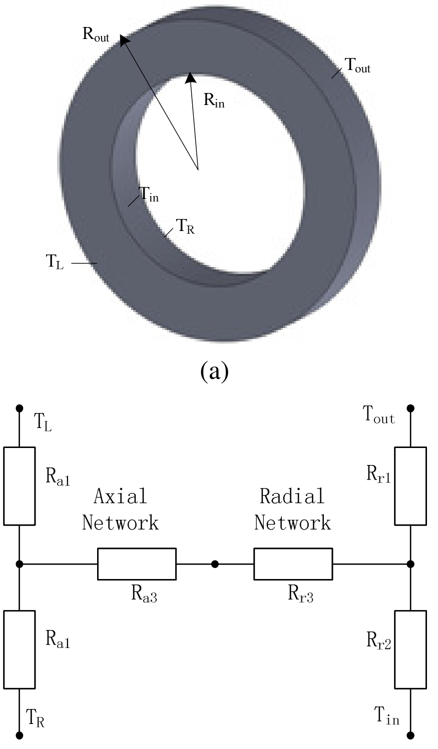


Fig. 2. Thermal equivalent circuit model for AFPM.



(a)

(b)

Fig. 3. Basic axial and radial conductive thermal circuit.

$$R_{a1} = \frac{L}{2\pi\lambda_a (R_{out}{}^2 - R_{in}{}^2)} \tag{1}$$

$$R_{a2} = \frac{L}{2\pi\lambda_a (R_{out}{}^2 - R_{in}{}^2)} \tag{2}$$

$$\mathrm{R}_{a3} = \frac{-\mathrm{L}}{6\pi\lambda_a (\mathrm{R}_{out}{}^2 - \mathrm{R}_{in}{}^2)} \tag{3}$$

$$R_{r1} = \frac{1}{4\pi\lambda_r L}\left[1 - \frac{2R_{in}{}^2 \ln\left(\frac{R_{out}}{R_{in}}\right)}{\left(R_{out}{}^2 - R_{in}{}^2\right)}\right] \tag{4}$$

$$R_{r2} = \frac{1}{4\pi k_r L}\left[\frac{2R_{out}{}^2 \ln\left(\frac{R_{out}}{R_{in}}\right)}{\left(R_{out}{}^2 - R_{in}{}^2\right)} - 1\right] \tag{5}$$

$$R_{r3} = \frac{-1}{8\pi\left(R_{out}{}^2 - R_{in}{}^2\right)\lambda_r L}\left[\begin{array}{c}\left(R_{out}{}^2 + R_{in}{}^2\right) - \\ \dfrac{4R_{out}{}^2 R_{in}{}^2 \ln\left(\frac{R_{out}}{R_{in}}\right)}{\left(R_{out}{}^2 - R_{in}{}^2\right)}\end{array}\right] \tag{6}$$

III. REFERENCES

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