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3D thermal analysis of a permanent magnet motor with cooling fans

Key words: Axial flux permanent magnet (AFPM) machine, Computational fluid dynamics (CFD), Cooling fan, Motor drives, Thermal analysis

Introduction

Fig. 1 Photo of the AFPM

It is widely known that the performance of PM machines in many applications, including high speed trains, is affected by overheating, which can easily cause magnet demagnetization, and degradation of the isolation materials and of motor efficiency. Therefore, it is very important to develop an effective heat dissipation technique for PM machines. In this paper, a novel and special cooling system design for an axial flux permanent magnet (AFPM) machine is carried out as a case study. In the literature there has been much research on the electromagnetic aspects of AFPM machines, but their thermal performance has not been fully investigated

CFD modelling

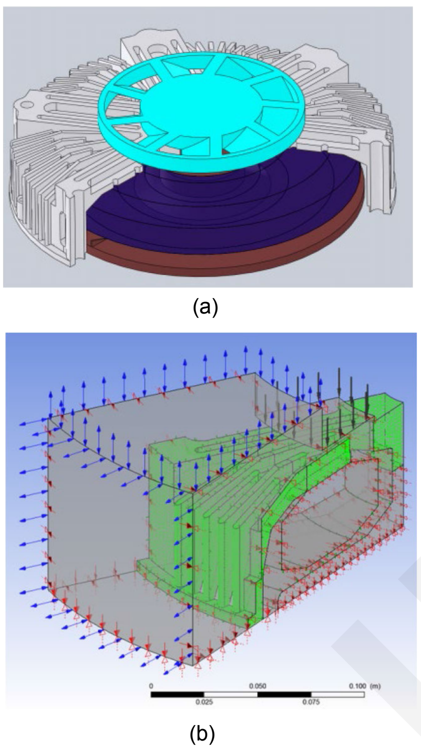

Fig. 2 Numerical model of the AFPM

$$\frac{\partial(\rho u_i)}{\partial x_i}=0,$$

$$\frac{\partial(\rho u_i u_j)}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}-\frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}\right)\right]+\frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right),$$

$$\frac{\partial(u_i(\rho E+p))}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\lambda_{\mathrm{eff}}\frac{\partial T}{\partial x_j}+u_i(\tau_{ij})_{\mathrm{eff}}\right]+S_E,$$

Table 1 Heat generated in the 1/24 model

Component	Volume (m^3)	Heat (W)	Source (W/m^3)
Stator	3.74×10^{-5}	16.25	4.34×10^{5}
Rotor	1.29×10^{-4}	16.25	1.26×10^{5}

Analysis of CFD results

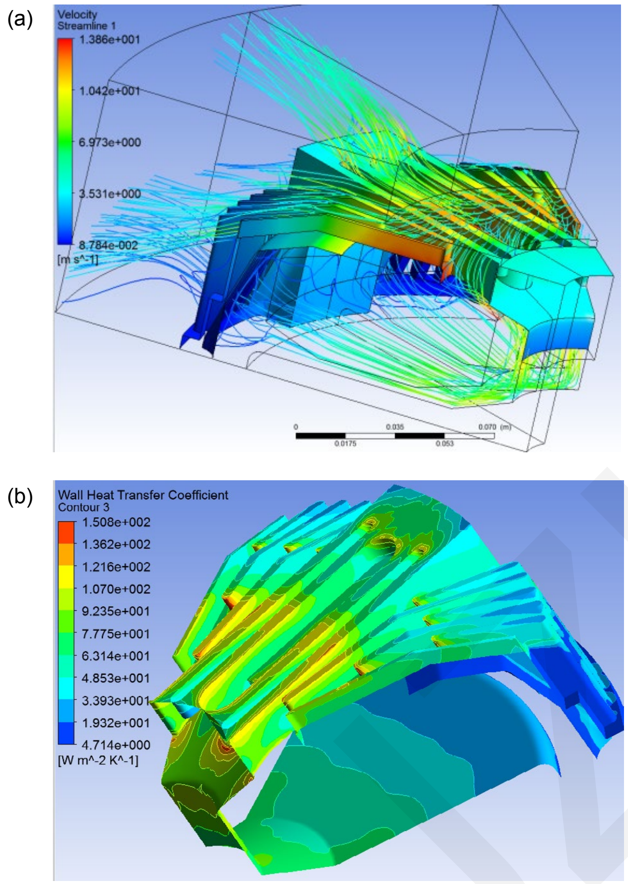

Fig. 4 Air streamline and wall heat transfer coefficient around the AFPM with fan #1

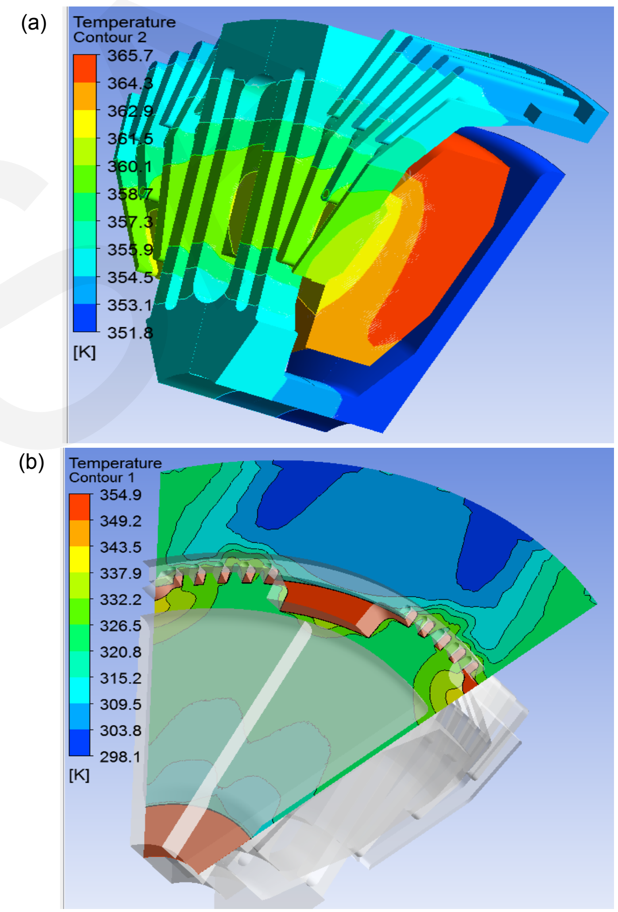

Fig. 5 Temperature distribution of the machine (a) and the middle plane at the air gap (b)

Conclusions

The CFD method has been used to investigate heat transfer in an axial flux permanent magnet machine and to optimize a cooling fan design. Some simplifications and assumptions are made to facilitate a numerical analysis, based on the steady CFD method, to predict the coolant air mass flow, velocity, and pressures outside and inside of the machine and the temperature distribution of the machine. The comparison results of the AFPM machine without a cooling fan and with two designs of cooling fans reveal that cooling fans are helpful in enhancing heat transfer and reducing the temperature of the machine, and a good design of cooling fans based on aerodynamics is efficient and essential to avoid overheating problems. Further work will be set out to conduct extensive experimental tests on these prototypes.