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Experimental validation of CFD modelling for heat transfer coefficient predictions in axial flux permanent magnet generators

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ABSTRACT

This paper describes the experimental validation of CFD modelling for heat transfer coefficients in an axial flux permanent magnet (AFPM) generator. A large scale low speed test rig was designed and constructed. The geometric parameters and the rotational speed of the test rig were determined by dimensional analysis, to ensure the flow characteristic remains unchanged as compared with commercial AFPM generators. The heat transfer coefficients in the test rig were measured at rotational Reynolds number, Re_ω from 0 to 2×10^6, non-dimensional flow rate, C_w up to 11,000 and gap ratio, $G = 0.016$, by using the combination of heat flux sensors and thermocouples. Due to the large size of the scaled-up rig, natural convection played a significant part in the heat transfer and this had to be compensated for in the forced convection heat transfer coefficient calculations. Extra experiments were designed and conducted to identify the effect of natural convection on the machine's cooling. The experimentally determined results were compared to heat transfer coefficients predicted by CFD models and good agreement was obtained.

1. Introduction

In the development of a rapid thermal modelling tool for axial flux permanent magnet (AFPM) machines, it is important to acquire reliable local surface heat transfer coefficients (HTC) inside the machines. The accuracy of thermal modelling is heavily dependent on the surface HTCs, especially for air-cooled machines. Thus, it is necessary to construct reliable empirical relationships between the local HTC and the size and topology of different AFPM machines by empirical parametric studies.

HTC parametric studies can be achieved either by conducting a series of experiments with different control parameters, or by using experimentally validated CFD modelling methods. The construction of a flexible test rig which is capable of evaluating a range of different sizes and topologies of axial flux machines is uneconomical and time consuming. Therefore, CFD modelling is used as an alternative. In the past decade, many CFD solvers have been developed commercially for different industrial applications but if they are to be used with confidence, it is necessary to carry out experimental validation.

The design of a large scale, through flow air ventilated AFPM machine test rig for accurate heat transfer coefficient measurement is discussed in this paper. Dimensional analysis was performed to ensure that the flow characteristic inside the large scale generator is similar to the real machine, in this case the Durham University 1.5 kW, 1500 rpm, 300 mm diameter AFPM generator (see Fig. 1). Several sets of experiments were designed and conducted on a large scale test rig. The heat transfer coefficients and temperatures obtained from these experiments are compared with CFD.

2. Review of convection heat transfer coefficient measurement techniques

Heat transfer/heat flux measurements are required in order to acquire the local surface heat transfer coefficients in AFPM machines, see Equation (1). In most literature, ambient temperature is used as the reference temperature for heat transfer coefficient calculation. For convenient, the ambient air temperature is used as the reference temperature in the entire heat transfer coefficient calculations discussed in this paper.

$$h = \frac{q}{A\left(T_{surf} - T_{ref}\right)} \tag{1}$$

where q = Heat transfer, W, A = Heat transfer surface area, m^2, T_{surf} = Surface temperature, K, T_{ref} = Reference temperature, K.

All of the heat flux experiments conducted by previous researchers [1–15] involved measuring either the effect of heat

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