Research Paper

Wafters design for totally enclosed electric machines

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HIGHLIGHTS

- Design criteria of wafters for totally enclosed electric machines.
- An experimentally validated CFD model for the modelling of electrical machines.
- Statistical models to predict the convective heat transfer in the end windings.
- The influence of wafters in the working temperatures of a particular machine.

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ABSTRACT

A computational fluid dynamics (CFD) model representing the effect of wafters in a totally enclosed electric machine is presented, introducing the most relevant theoretical assumptions and simplifications. The validation of the model is conducted through experimental measurements. From the CFD simulation data, a second-order response surface is developed using statistical tools, from which the wafters’ influence on the convective heat transfer from the stator end windings is predicted. Wafters design criteria are obtained from the response surface information. Finally, a specific case is analysed, showing through CFD simulations that temperatures in the machine are reduced by including wafters in the design.

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1. Introduction

Power density and rotation speed in electric machines have augmented significantly in recent years for many applications. This trend is resulting in an increase in losses for small volumes, and the cooling system is turning out to be a crucial aspect of the design. There are many options that provide very good cooling capabilities; liquid cooling through a jacket over the stator back iron is a widespread option [1–4], and direct oil-cooled systems provide very effective cooling throughout the machine [5,6], although it creates extra friction losses which could be very limiting as the rotation speed increases. Moreover, there are many combinations of both systems in the literature. For example, Equipmake Ltd. [7] proposed a dual cooling system that pushes oil through the slots and air through the rotor, Porsche [8] manufactured a 95 hp motor cooled with an oil jacket combined with an air induction system, and Lim in [9] developed an oil spray cooling system for in-wheel motors in electric vehicles.

This article focuses on totally enclosed cooling systems, which are widely used for traction applications, such as electric vehicles or trains [10]. This cooling arrangement shows significant limitations when it comes to rotor cooling [11], and the design also turns the end windings into a limiting factor, as they often become a
hotspot in the machine [12]. However, many solutions to these problems are available in the literature: Polikarpova [13] included potting to enhance the heat transfer from the end windings to the water jacket; Micallef [14] proposed the attachment of some wafers in a cooling system. This article, therefore, focuses on obtaining a design procedure and some design criteria for this zone, which is usually very critical in traction applications. How
ever, the lack of information about their design complicates their implementation in new designs.

Dissecting wafters in a cooling system. This article, therefore, focuses on obtaining a design procedure and some design criteria for this element in order to maximize the convective heat transfer in the end windings and minimize the possible hotspots in this zone.

The proposed design methodology focuses on wound windings, which are the most extended winding topology for these kinds of applications. However, new trends in this field, such as hairpin [20] or coil-form windings [21], are gaining ground. Therefore, an independent study of each kind of topology should be carried out in further research.

The entire study has been conducted via CFD simulations. The CFD model used in this article has been previously validated with experimental measurements, and it has been employed along with statistical tools with the aim of generating a second-order response surface model that is capable of predicting the influence of different parameters that define the wafers on the convective heat transfer in the end windings of the machine. Thus, this paper presents an innovative approach to designing wafers for totally enclosed machines, with the aim of reducing the temperatures in the machine and increasing the overall efficiency of the system.

2. CFD model

As the flow pattern in the end space is not predictable, it would be almost impossible to analytically determine the airflow in this zone. Therefore, a reliable CFD model which could accurately represent the effect of wafers in the end space of an electric machine is presented. The electric machine modelled is described in the next section.
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