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A Review on The Thermal Analysis of Air Flow Gap

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Abstract

More than half of all electrical energy is consumed by motors and generators in an industrialized country. This energy is lost and converted to heat. This heat produced by the losses has adverse effect on the lifetime and performance of a machine. A machine has to be operated at a given temperature to achieve maximum efficiency, therefore heat transfer study of machines is of special interest to rotating machines manufacturers. In this paper we can investigate the heat transfer in the air-gap between the rotor and the stator of a simplified induction motor using Computational Fluid Dynamics. We can consider different air-gap widths and rotation speeds to explore the change in air-gap heat transfer when changing the air-gap width and the rotation speed.

Keywords: Computational fluid dynamics, directly cooled electric machines, finite element analysis, and heat transfer.

I. Introduction

The design of an electric machine is not an easy task due to the multi-physics phenomena that have to be considered, that is, electromagnetic, mechanical and thermal. The thermal phenomena are of great importance due to their effects over the electromagnetic, sometimes mechanical properties of the building materials for various components of the machine. The most temperature sensitive materials within an electric machine are the insulation materials. In case of over temperatures these materials begin to suffer irreversible changes and so the lifetime of the machine is strongly reduced. In the motor industry there is a general rule of thumb, based upon the Arrhenius Equation of chemical reaction time versus temperature, stating that for every 10 degrees Centigrade over the insulation class temperature, life expectancy can be cut in half. Another temperature sensitive material is the copper that makes the stator windings. The rotor side is formed by the permanent magnets, rotor hub, shaft and bearings. The rotor heating sources can be neglected in comparison with stator ones. In effect the warmer side is in general the stator side. The torque generated by this type of electrical machines is provided bythe permanent magnets energy. Knowing that magnets are temperature sensitive, the heating process within the air-gap is crucial. Thermal analyses of electrical machines are easily performed using thermal networks enclosing thermal resistances and thermal capacitances. For the computation of thermal resistances that model convective heat transfers are required: the geometrical dimensions and the heat transfer coefficients. Thus the objective of the analysis is to compute the heat transfer coefficient of the air-gap.

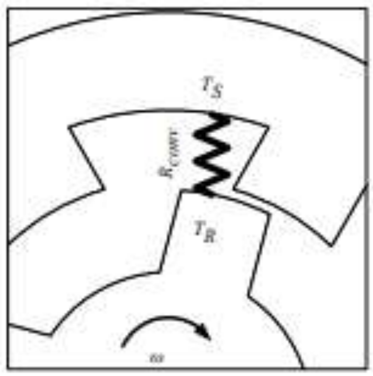

Figure: 1 Air-gap equivalent thermal resistance

II. Literature review

MdLokmanHosain et al. [1]In this paper we investigate the heat transfer in the air-gap between the rotor and the stator of a simplified induction motor using Computational Fluid Dynamics. We consider three different air-gap widths and rotation speeds to explore the change in air-gap heat transfer when changing the air-gap width and the rotation speed. The simulated average heat transfer coefficients for all the models are in good agreement with the correlations from published literature. The Taylor-Couette vertical flow pattern is observed in the air-gap in our simulation results for the models with large air-gaps. The numerical results show that the presence of Taylor-Couette vortices in the air-gap enhance the heat transfer. The heat transfer coefficient increases with the increase in the rotation speed and decreases with the decrease in the air-gap width.

Jun Lin et al. [2] In this paper presented by the High speed and high efficiency synchronized electric motors are favored in the automotive industry and turbo machinery industry worldwide because of the demands placed on efficiency. Herein an electric motor thermal control system using cooling air which enters from the drive end of the motor and exits from the non-drive end of the motor as the rotor experiences dissipates heat is addressed using CFD. Analyses using CFD can help to find the appropriate mass flow rate and windage losses while satisfying temperature requirements on the motor. Here, the air flow through a small annular gap is fed at 620 L/min (0.011 kg/sec) as the rotor spins at 100,000 rpm (10,472 rad/sec) and the rotor dissipates 200 W. The CFD results are compared with experimental results. Based upon the CFD findings, a novel heat transfer correlation suitable for large axial Reynolds number, large Taylor number, small annular gap Taylor-Couette flows subject to axial cross-flow is proposed herein.

PietroRomanazzi et al. [3]This work presents firstly a review of the literature including the most relevant correlations for this geometry, and secondly, numerical CFD simulations of air-gap heat transfer for a typical configuration. A new correlation has been derived: $\math bf {Nu=0.181\ Ta_m^{0.207}}$. Switched reluctance machines (SRMs) have recently become popular in the automotive market as they are a good alternative to the permanent magnet machines commonly employed for an electric powertrain. Lumped parameter thermal networks are usually used for thermal analysis of motors due to their low computational cost and relatively accurate results. A critical aspect to be modelled is the rotor-stator air-gap heat transfer, and this is particularly challenging in an SRM due to the salient pole geometry.

David Howey et al. [4]This paper reviews the convective heat transfer within the air gap of both cylindrical and disk geometry rotating electrical machines, including worked examples relevant to fractional horsepower electrical machines. Thermal analysis of electrical machines is important because torque density is limited by maximum temperature. Knowledge of surface convective heat transfer coefficients is necessary for accurate thermal modeling, for example, using lumped parameter models. There exists a wide body of relevant literature, but much of it has traditionally been in other application areas, dominated by mechanical engineers, such as gas turbine design. Particular attention is therefore given to the explanation of the relevant no dimensional parameters and to the presentation of measured convective heat transfer correlations for a wide variety of situations from laminar to turbulent flow at small and large gap sizes for both radial-flux and axial-flux electrical machines.

MaunuKuosa et al. [5]This work deals with the cooling of high-speed electric machines, such as motors and generators, through an air gap. It consists of numerical and experimental modeling of gas flow and heat transfer in an annular channel. Velocity and temperature profiles are modeled in the air gap of a high-speed test machine. Friction and heat transfer coefficients are presented in a large velocity range. The goals are reached acceptably using numerical and experimental research. The velocity field by the numerical method does not match in every respect the estimated flow mode. The absence of secondary Taylor vortices is evident when using time averaged numerical simulation.

III. Rotating electrical machines

The main task of a rotating electrical machine is to convert mechanical energy into electrical energy, or electrical into mechanical. The first application is called generator operation, whereas the second is motor operation. In principle, every rotating electrical machine can be operated in both modes, even though it is designed and declared as a generator or a motor. The conversion of energy is based upon electromagnetic physical effects. They express themselves on the mechanical side as forces in magnetic fields, and on the electrical side as voltages induced by magnetic fields. The further transport of the energy is performed on the mechanical side via a torque, which is applied to a shaft. On the electrical side, a single-phase AC or multi-phase AC current system performs the required stationary energy transport. The three-phase AC system has established itself as the main system worldwide.

In conventional thermal power plants another step is added: the conversion of chemical energy by combustion into mechanical energy to drive either a steam or a gas turbine. High-speed generators for these power plants are called turbogenerators or turbine generators.

IV. Motor energy savings

It may be mentioned that energy can be saved in different ways for different the industrial energy using machineries with different energy savings strategies. These strategies are broadly classified in three ways:

Using regulations (voluntary, mandatory, mixed, standards, labels, education, soft loan, incentives)

With the application of technology (VSD, power factor improvement, new technology)

By housekeeping (maintenance, switching of, reduce standby losses, auditing)

V. Conclusion

This review paper could be useful for motor designers,operators, energy managers and motor manufacturers to fullyunderstand energy saving opportunities in electric motors andfurther to take proper energy saving measures to enhance energyefficiency in buildings. They could be help designers adopt properdesign options and concepts in the decision-making process duringthe initial planning and design stages and help operators to use advanced control algorithms in practicaloperations to reduce the global energy consumption in electricmotors and enhance control stability and environmental sustainability. It could also be useful for the government to evaluate the current electric motor energy policies.

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