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Heat transfer characteristics of external ventilated path in compact high-voltage motor

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ABSTRACT

This paper investigates the heat transfer characteristics of the external ventilated path of a compact, 6 kV, 4-pole, 2500 kW motor using flow-thermal coordination mechanism. A computational model is set up and validated by experimental test results. A series of simulation is performed. It is found that the deflection angle α and outlet angle β of the fan blades are the key parameters affecting the efficiency of the cooling effect of the fan. Optimal measures are adopted by changing the deflection angle and outlet angle of fan blades. External fan efficiency is improved from 28.80% to 29.96% and outlet flow is increased by 0.08 m^3/s by optimizing the deflection angle α and outlet angle β. According to the optimization results of external fan, heat transfer characteristics and temperature distribution of the cooler is obtained by the fluid and temperature coupling field. The cooler is optimized by adjusting the height of the windshield, increasing the number of the windshield, changing the shape of inclined plate. It is found that the temperature of hyperthermal fluid of inner ventilated path is decreased from 75 °C to 53.7 °C; at the same time the temperature of cryogenic fluid of external ventilated path is increased from 23 °C to 49.4 °C. The outlet temperature of internal fluid of post-optimized cooler is dropped by 3 °C, and the external fluid temperature is increased by 2.5 °C. The performance of fan and the cooling effect is improved. The results from this study can provide an effective method for structural optimal design of compact high-voltage motors.

1. Introduction

With the development of the technologies, design of electric motors with high efficiency and high power density become popular. A compact high-voltage motor has the advantages of compact structure, high power density and high electromagnetic load. However, the increase of power density is bound to cause more serious overheating problem, which will reduce the motor capacity and efficiency. As a solution, controlling the range of temperature rise is a key factor affecting the capacity and efficiency of the overall design[1]. Therefore, it is necessary to analyze the fluid field and temperature field accurately and improve the cooling system capacity to ensure reliable operation of motor. The ventilated structure of a compact high-voltage motor is divided into two: internal and external ventilated path. The external ventilated path mainly takes away the excess heat inside the motor and become the key area to research fluid flow and heat transfer characteristic [2]. At present, many researchers focus their research interests on heat transfer and cooling of motor. Chang et al. [3] studied the thermal characteristics of enclosed air-to-air cooled motor using experimental and numerical simulation methods and found that the optimal design of cooling fan may improve the operation reliability of the motor. Li [4] studied a permanent magnet electric motor with a centrifugal impeller and he found that the cooling air flow was proportional to the speed of the motor; and the rotational speed is inversely proportional to the external load; the heat transfer of armature surface indicated that the radial temperature change was slight but the axial change was noticeable.

The effect of cooling fan were studied in detail by a number of researchers [5–7]. It was found that the blade thickness of the fan had great influence on the performance and cooling effect of ventilated structure. Modelling three-dimensional (3D) temperature field of Totally Enclosed Fan Cooled (TEFC) motor were used to analyze the interaction effect between rotor-bar damage and motor temperature [8–10] and it was found that the higher the temperature was, the larger the thermal stress was, and the uneven heat stress directly led to broken bar fault and influenced the motor temperature rise and life.

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A 3-D coupled-field finite-element method for prediction of the temperature rise in air-cooled induction motors, considering the effect of rotor rotation on air convection, was proposed and validated by experimental tests by Zhang et al. [11]. The multi-component fluid model can solve the problem that the velocity on interface between fluid and solid. A combined 2D-3D finite-element method was used to analyze temperature rise of high-speed permanent-magnet machine [12]. The thermal convection coefficient and air temperature rise was estimated by 2D multiphasic method and the temperature rise distribution in whole solid domain of the machine was determined by the 3D numerical heat-transfer method; and it was found that the method can get an accurate estimation of the local temperature rises. Kim et al. [13] investigated the influence of air-gap flow heating on the thermal characteristics of stator and windings in large-capacity induction motors using numerical simulation. Air-gap flow heating phenomena were defined and classified into three states: under-heating, over-heating, and super-heating and further research was carried out to identify the influence of the over-heating and super-heating states of the air–gap flow on the stator and windings. A thermal model of direct cooling motor was established by Nategh et al. [14] using the lumped parameter and limited computational fluid dynamics (CFD) method. Experimental evaluation showed that the temperature distribution and hot-spot temperatures in the end winding under different loss levels and coolant flow velocity can be predicted accurately by the proposed lumped parameter thermal model. Torriano et al. [15] studied the effect of rotation on heat transfer mechanisms in rotating machines using a hybrid numerical-experimental approach. The results from their study showed that an asymmetric profile in the tangential direction closer to the trailing edge due to the presence of a flow recirculation zone and the heat transfer profiles indicated that the highest values of heat transfer coefficient were in an intermediate region. The results from their study also showed that the heat transfer coefficients along the pole face at 300 rpm average about four times those at 50 rpm. A coupled analytical and numerical method was presented to study thermal characteristics of a 37 kW induction motor by Nair et al. [16]. Their thermal network and 3D numerical model can be used to predict the accurate temperature distribution of the motor.

Although there were fruitful research results on fluid flow and heat transfer of electrical machine, there are few studies are found on fluid flow and heat transfer of the external ventilated path in high-voltage motors. In this research, the fluid flow and heat transfer characteristics of the external ventilated path for a compact, 6 kV, 4-pole, 2500 kW motor is modelled and analyzed based on the flow-thermal synergistic mechanism. An optimal external ventilated path and the simulation is presented. In addition, the accuracy and rationality of the modelling simulation results are verified by the experiment.

2. Methodology

The external ventilated path of a compact high-voltage motor includes an external fan and a cooler. The cooler is a place in which the heat exchange will happen between the hot air of internal ventilated path and the cold air of external ventilated path. The temperature of cryogenic fluid is increased while that of hyperthermal fluid is decreased. The ventilated system of compact high-voltage motor is shown in Fig. 1.

In Fig. 1, Ventilation and heat dissipation structure of motor can be divided into internal ventilated path (blue border) and external ventilated path (orange border). The internal ventilated path is a closed structure and the external ventilated path is connected to the air by the box wall of cooler. The green arrows represent the flow direction of internal ventilated path fluid, whereas the red and dotted arrows represent the flow direction of the external ventilated path fluid. The heat transfer between internal and external fluid takes place in the cooler [17]. Under the action of the internal fan, the internal hyperthermal fluid of internal ventilated path (green arrows) flows, and under the action of the external fan, the cryogenic fluid of external ventilated path (red arrows) flows. The internal ventilated path fluid enters into the external ventilated path through the outlet of internal ventilated path and is cooled by the cooling pipes which the external ventilated path fluid passed through, then returns to internal ventilated path through its inlet. After heat transfer in the cooler, the cryogenic fluid of external ventilated path takes away the heat and flows into the external air. The compact high-voltage motor prototype is shown in Fig. 2. The basic parameters and related dimensions of the motor prototype are shown in Table 1.

2.1. Mathematic model of the external ventilated path

The fluid flow is governed by the laws of conservation of physics, including the law of mass conservation, the law of

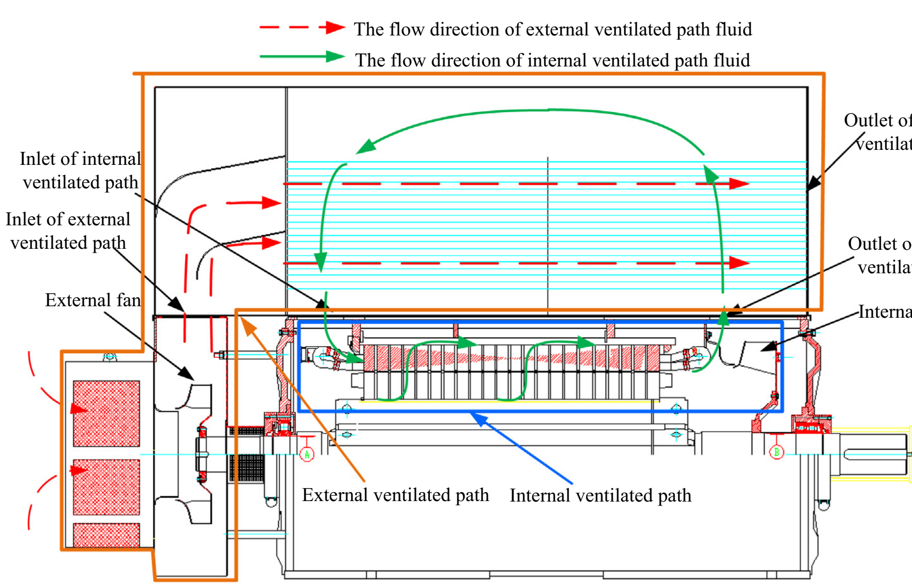

Fig. 1. Ventilated path structure of compact high voltage motor.