Ventilation Structure Improvement of Large Motors Using 3-D Multi-physical Coupled-Field Finite-Element Analysis

Yujiao ZHANG, Jiangjun RUAN, Tao HUANG, and Xiaoping YANG

School of Electrical Engineering, Wuhan University, 430072, China
jiao_zyj@163.com

Abstract —The design of electrical machines must include a thermal analysis coupled with the magnetic and fluid analysis. However, the traditional equivalent lumped circuits method cannot accurately considerate the rotation-effects on air convection. This paper investigates a 3-D coupled-field finite-element method (FEM) used a novel multicomponent fluid model to calculate the temperature distributions in air-cooled asynchronous induction motors. Through the coupled-field calculation, we propose a new ventilation structure of a 15-phase motor to improve the cooling performance.

I. INTRODUCTION

During the design stage, the thermal analysis plays a key role. A correct prediction of the temperature rise in each part of the machine will lead to the maximum exploitation of the materials and the highest performance of the machine [1]. Furthermore, the thermal analysis of induction motors, due to the complexity of air course and the influence of rotation upon air-flow, cannot be accurately evaluated by using traditional lumped circuits together with empirical curves method. Therefore, a coupled analysis of eddy-current, fluid and thermal fields is mandatory to compute the temperature rise [2].

Large-capacity induction motors need large amounts of air for cooling as they produce large losses. Useful research has been carried out concerning cooling and ventilation of motors [3]. In the motors with the axial and radial ventilation system, axial fans are placed on both sides of the motor. Cooling air taken in from the exterior to the interior by axial fans is sent to exothermic parts. Then, the air is vented through the radial paths inside the iron core. Moreover, the influence of centrifugal force and Coriolis force caused by rotation upon air-flow in the air gap must be considered [2]. However, according to no-slip boundary condition in fluid dynamic theory, rotation velocity on interface between air gap and rotor cannot be applied directly. To deal with this problem in fluid field analysis, we propose a novel multicomponent fluid model, in which all rotor parts are taken as fluids under some constraint conditions.

In addition, in this paper, magnetic saturation and nonlinear resistivity with temperature are also taken into account. During the design stage of a 15-phase 14-pole 10MW asynchronous motor, according to the motor parameters provided by the motor designers, the 3-D model is established to calculate the temperature distributions. The results show that it is thus necessary to improve the ventilation structure to decrease stator windings temperature below the permissible insulation material temperature. Furthermore, the simulated results of the improved model with rotor axial paths are compared with those of original model. Then, the maximum temperature rise of stator windings decreases by 27%. Therefore, the cooling performance is improved.

II. FORMULATION

Starting from the 3-D FEM model of a motor, eddy-current and fluid simulations are carried out to obtain the losses of every element and air-flow velocity of every node. The thermal computation is tightly coupled to the electro-magnetic and fluid-dynamical results. The resistivity of stator windings and squirrel cage is updated in accordance to the thermal field calculation result until the difference of temperature between two adjacent steps is less than 0.01℃.

Under above restrictions, the fluid equations of rotor components can be simplified as:

$$\frac{\partial \upsilon_\theta}{\partial \theta} = 0, \upsilon_\theta = \omega r \tag{1}$$

$$-\rho_2 \frac{\upsilon_\theta^2}{r} = -\frac{\partial p}{\partial r} \tag{2}$$

$$0 = \frac{\partial}{\partial r}\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\upsilon_\theta\right)\right] \tag{3}$$

where ρ_2 is the actual density of rotating components. Obviously, viscosity coefficient doesn't affect the results.

III. CALCULATIONS OF A 15-PHASE MOTOR

A 15-phase 14-pole 10MW asynchronous motor structure is during the design stage. According to the parameters provided by designer, the 3-D computed model is shown in Fig. 1.

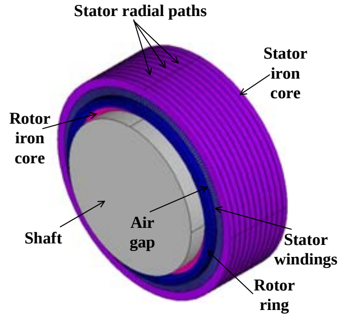

Fig. 1. 3-D Model of 15-phase motor.

Although the influence of end windings cannot be ignored, because of the complexity of its structure and large amount of computation, it wasn't considered temporarily in this study stage. The model is meshed with prism-shaped elements. There are 1,106,786 elements and 565,989 nodes.

In the computation of the eddy-current field, the rated source current is 343.4 A. The rated frequency of current is 23.57 Hz. Considering the influence of rotor rotation, the frequency (*f*) is converted into *f*×slip. In the computation of the fluid and thermal field, total air volume of design is 4.54 m^3/s, and pressure on outlet boundary is defined as a standard atmospheric pressure. The rated rotational speed was applied to rotor and shaft. Considering the low conductivity of insulation material, the thermal conductivity of stator windings is anisotropic. The ambient temperature is set to 45℃.

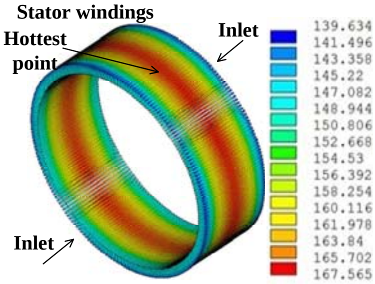

Fig. 2. Temperature distribution of stator windings.

Due to narrow air gap and rotation of rotor, cooling air is difficult to reach the central motor. Moreover, the cooling performance of rotor ventilation ducts must be improved. Fig. 2 illustrates that the hottest points are at the center of stator windings.

IV. VENTILATION STRUCTURE IMPROVEMENT

To improve the cooling performance, we propose a different ventilation structure. As shown in Fig. 3, there are radial paths of air ducts in the stator and rotor iron cores. When a rotor rotates, axial fans and rotor radial air paths provide cooling air inside the motor. Air flows from rotor axial paths to rotor radial paths, air gap and stator radial paths, and then to the outside of the stator iron core.

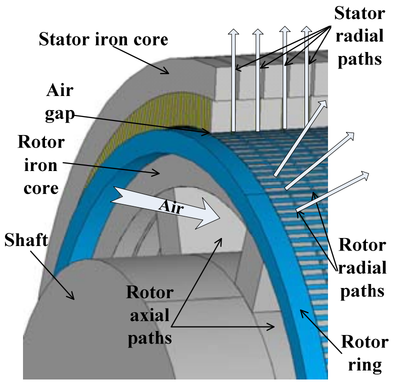

Fig. 3. Air-flow near iron core in the new structure.

Using the methodology mentioned in Section II, the coupled-fields of the new model are calculated. The air velocity distribution in the each radial ventilation duct is identical, as shown in Fig. 4. From the results of temperature, the maximum temperature of stator windings is 134℃.

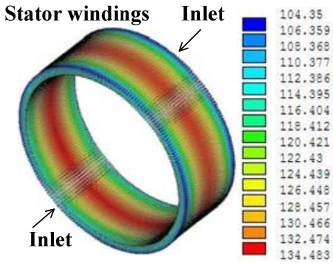

Fig. 4. Temperature distribution of stator windings.

From the results, the maximum temperature rise of the stator windings decreased 27% compared with that of the original motor. Furthermore, according to IEC 62114-2001 (Electrical insulation systems -Thermal classification), as shown in Table III, the permissible insulation material thermal classification reduces from class H to class B. Thus, it is found that the cooling performance of new motor is improved by the ventilation structure with rotor axial paths.

V. CONCLUSION

This paper proposes a 3-D coupled-field analysis to predict temperature distribution in air-cooled asynchronous induction motor. Furthermore, a novel multicomponent fluid model is proposed to deal with the influence of rotor rotation upon the air convection. For a motor during design stage, we put forward a new ventilation structure with rotor axial paths. The cooling performance is greatly improved.

VI. REFERENCES

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