

Research on Winding Temperature Field Equivalent Modeling in Outer Rotor PMSM Stator Slot

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Abstract—Accurate calculation of temperature field of outer rotor PMSM is particularly important, as it determines the overall performance and operational stability. Due to complex structure of the winding part in stator slot, the temperature field encounters huge challenges. For this reason, this paper conducts research on the winding part in stator slot. Firstly, in order to reduce difficulty of modeling, based on the principle of constant thermal resistance, the windings in motor slot are equivalent to large conductors, which improves the calculation accuracy and shortens the calculation time at the same time. Secondly, based on finite element simulation calculation, the feasibility of the models before and after the equivalence is verified, and the influence rules of factors such as heat flux density and boundary conditions on temperature field distribution of windings in the slot are analyzed. Finally, a 24-slot and 20-pole starter motor model was taken as research object, and the temperature field experimental tests under different working conditions were carried out to verify the effectiveness of the method.

Keywords: Outer rotor PMSM, Equivalence of winding, Temperature field, Equivalent thermal conductivity calculation

I. INTRODUCTION

OUTER ROTOR PMSM are widely used in numerous fields such as industrial production and transportation. During operation of the motor, the temperature rise of windings in the slot is an extremely crucial parameter. Excessively high winding temperatures will not only accelerate the aging of insulating materials but also shorten service life of the motor [1-2]. Due to complex structure of the traditional winding part in the slot, there are disadvantages such as a large scale of finite element calculation and low calculation efficiency. Therefore, equivalent treatment of the windings in the slot is carried out to improve the calculation efficiency on the premise of ensuring the calculation accuracy.

In conclusion, An equivalent treatment method for winding temperature field in the motor slot is proposed in this paper based on the principle of constant thermal resistance.

II. MODELING OF EQUIVALENT OF WINDINGS

The refined model of windings within slot is depicted in Fig.1. This model comprises stator, air gap, slot wedge, insulation, copper, and enameled wire. It also exhibits a partial enlarged view of windings in slot, along with a schematic diagram of a single winding.

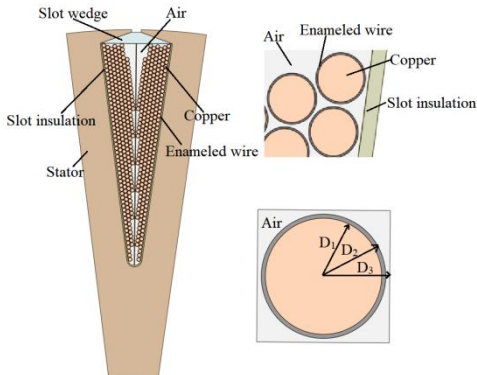


Fig 1. Schematic diagram of the windings in stator slot.

Considering the existence of copper, air gaps, and enameled wire within windings in slot, it is suggested to equivalently integrate these three components into a single entity for calculating the equivalent thermal conductivity. Since the transverse thermal conductivity has a substantial effect while the longitudinal thermal conductivity has a negligible impact in winding slot model, it is assumed here that the transverse and longitudinal thermal conductivities are equal, which also simplifies the subsequent computations.

$$\begin{cases} D_{air\min} = D_3 - D_2 \\ D_{air\max} = \sqrt{2}D_3 - D_2 \\ \lambda_{eq\max} = D_3 / (D_1 / \lambda_{cu} + (D_2 - D_1) / \lambda_{enameled\ wire} + (D_{air\min} / \lambda_{air})) \\ \lambda_{eq\min} = \sqrt{2}D_3 / (D_1 / \lambda_{cu} + (D_2 - D_1) / \lambda_{enameled\ wire} + (D_{air\max} / \lambda_{air})) \\ \lambda_{eq} = (\lambda_{eq\min} + \lambda_{eq\max}) / 2 \\ \lambda_x = \lambda_y = ((a_1 + a_2) / 4 + D_4 / 2) / ((a_1 + a_2) / 4 / \lambda_{eq} + D_4 / \lambda_{insulation}) \\ W_{eq} = W_1 \cdot S_1 \cdot L / (S_{eq} \cdot L) \end{cases} \quad (1)$$

Where, D_1 is inner diameter of winding. D_2 - D_1 stands for the thickness of enameled wire. $D_{air\min}$ is minimum air gap thickness between windings, while $D_{air\max}$ is maximum air gap thickness between windings. D_4 is the thickness of the insulation layer. λ_{cu} is thermal conductivity of copper, λ_{wire} is thermal conductivity of enameled wire, λ_{air} is thermal conductivity of air, and $\lambda_{insulation}$ stands for thermal conductivity of insulation. a_1 is the length of the upper side of stator slot, and a_2 is the length of the lower side of stator slot.

Since air, enameled wire, and copper in slot are equivalent to an integrated piece of copper, based on the principle of constant loss, the heat flux density is corrected through relevant formulas. Given that it is a two-dimensional model, the axial length is considered as a unit length ($L = 1m$). Here, W_1 is original thermal conductivity, S_1 is area of the original copper, and S_{eq} is area of the copper after equivalence.

According to the calculation results, the equivalent thermal conductivity of copper is 0.1614 (W/(m·K)), and the equivalent heat flux density of copper is 160540 (W/m³).

III. SIMULATION VERIFICATION AND OVERALL TEMPERATURE

A. Simulation Verification

By calculating equivalent thermal conductivity and equivalent heat flux density of copper, simulations of refined model and equivalent model were carried out for the windings in stator slot. As shown in Fig.2, the maximum temperature error between refined model windings and equivalent model is 0.3%, and average temperature error is 0.8%.

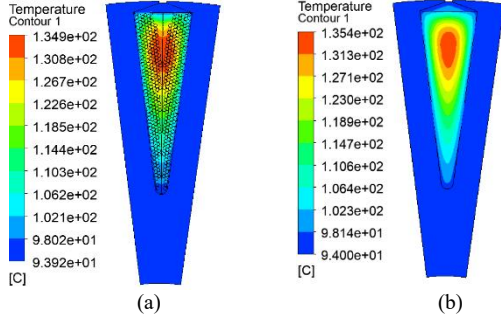


Fig 2. Comparison of the refined model and the equivalent Model. (a) Refined model. (b) Equivalent model.

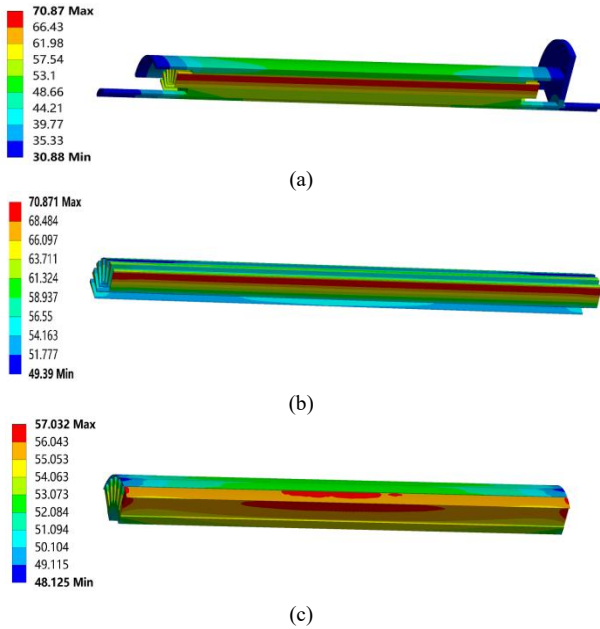


Fig 3. Cloud chart of temperature field distribution under 40% duty cycle of Power-on. (a) Overall. (b) Windings. (c) Stator

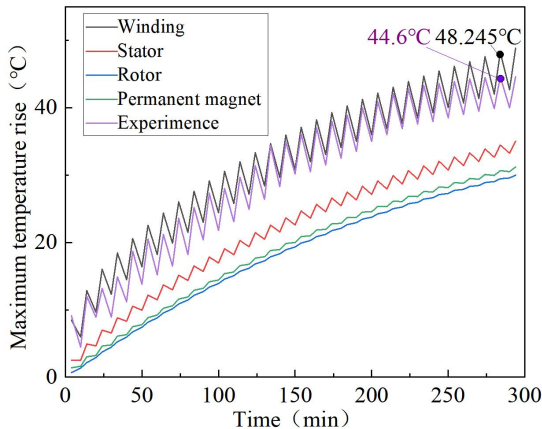


Fig 4. Comparison chart of the maximum temperature rise between simulation and experiment

The obtained thermal conductivity was used for three-dimensional finite element simulation. The overall temperature distribution is shown in Fig 3(a), the winding temperature distribution is presented in Fig 3(b), and the stator temperature distribution is demonstrated in Fig 3(c). By comparing the results of the finite element simulation with those of the experiment, it can be found that the distribution law of the winding temperature rise is consistent with the experiment, and the error is relatively small at the same time.

IV. EXPERIMENTAL AND SIMULATION COMPARISON ANALYSIS

A. Experimental Platform

The experimental platform of SPMSM is set up to verify the validity of improved model as shown in Fig. 5 (c). In order to test no-load back EMF, transmission belt is applied to connect magnetic powder brake for transmitting power and controlling speed. The rotor and stator of SPMSM with 20-poles and 24-slots for crane are shown in Fig. 5(a) and (b).

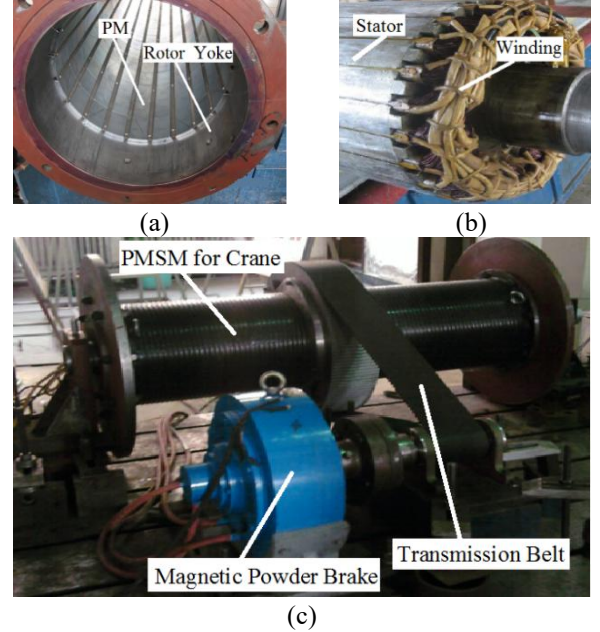


Fig 5. Prototype of SPMSM. (a) Rotor (b) Stator (c) Experimental platform.

V. CONCLUSION

An equivalent method applicable to the calculation of the temperature field of windings in slot, with a focus on a prototype of an outer-rotor PMSM for bar starters. The reliability of the method is verified by combining the experimental results with simulation results. The research findings provide new ideas for the equivalent calculation of temperature field of windings in stator slot.

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