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Numerical calculation and analysis of temperature field for stator transposition bar in hydro-generator

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ABSTRACT

Aiming at the problem that the temperature field in the stator bar with transposition strands is difficult for analysis, a numerical method of evaluating the temperature field of the stator transposition bar is presented. The corresponding heat transfer coefficients of the convective heat transfer surfaces are obtained on the basis of the fluid velocity in radial ventilation groove, and the temperature value of the discrete points in stator transposition bar is obtained by the finite volume method. Additionally, the current phase of upper and lower bar in a single slot is taken into account. In order to validate the presented method, a 250 MW air cooled hydro-generator is taken as an example, and the solving model is established. The copper loss of stator bar is calculated by the presented method. The temperature distribution of stator transposition bar is analyzed and compared in different cases, and the validity of the presented method is verified by evaluating the temperature deviation between the numerical results and the test values.

1. Introduction

The stator bar in hydro-generator consists of a plurality of flat strands that are welded together in the end part, with the purpose of reducing the eddy current loss produced by skin effect [1,2]. However, the induced electromotive force of each strand is different because of the disparity of leakage magnetic field that each strand located, and circulating current will appears among parallel strands [3–5], resulting in uneven temperature distribution of strands, local overheating and even insulation breakdown [6,7]. The electromagnetic load is increasing accompany with the growth of the generator capacity, which exacerbates the severity of the above problem. Thus, in the calculation of the temperature field, aside from the basic copper loss, the heat sources of stator bar also involve circulating current loss and eddy current loss [8]. To suppress the circulating current loss, different transposition types have been used in stator bar depending on the characteristics of generator [9–11]. Because of the complex structure of transposition strands, the temperature field in the stator bar with transposition strands is difficult for analysis. For the double-layer winding in a single stator slot, there are two cases in the relationship of current phase between upper and lower bar when the short pitch is utilized in stator winding [12], one is the same (we call it case 1 in the following part), the other is different, in the latter case, the current phase of upper and lower bar differ by 60° (we call it case 2 in the following part). The slot leakage magnetic field is different owing to the diversity of current phase, the copper loss and temperature field of stator transposition bar in the two cases should be calculated separately.

Currently, many scholars have done numerous researches on the stator temperature field. A 400 MW evaporation cooling hydro-generator at Lijiaxia Power Station was selected to calculate the stator temperature field in paper [13], the solving model with half tooth in the circumferential direction and entire length in the axial direction was established. The stator temperature field under different operating mode was given. However, the transposition structure of stator bar was neglected in the solving model. In addition, it was assumed that the eddy current effect has the same effect on each strand, that is, the copper loss of each strand was the same, which was inconsistent with the truth. The paper [14] took a 350 MW air cooled generator as an example, the influence of current phase of upper and lower bar on the eddy current loss was considered, and the copper loss of winding was calculated by the finite element method. Two half tooth in the circumferential direction and a single core segment in the axial direction were selected to calculate the temperature distribution of stator, then the temperature of stator bar was compared with the test value. Nevertheless, the computational model of stator bar was simplified as a whole block, the actual transposition path of strands was ignored. Only one core segment was included in the axial direction, which cannot

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reflect the temperature distribution in stator bar along the axial direction. The paper [15] calculated the temperature field of the model with transposition structure and the baseline model without transposition structure under the same condition. Compared with the experimental results, the calculation results of transposition model are more accurate. However, the case that the current phase of upper and lower bar is different was not under consideration. In summary, the current phase of stator bar and the actual transposition structure of strands have not taken into account simultaneously in the existing literature, which cannot reflect the temperature distribution of each strand fully and accurately.

In order to solve the above problems, a numerical method of evaluating the temperature field of the stator bar with transposition strands is presented, and the current phase of upper and lower bar was taken into account. A 250 MW hydro-generator adopts double radial ventilation cooling system without fan is selected as an example, the stator bar with the transposition type of 0°/360°/0°. The solving model of fluid field in the radial ventilation groove and temperature field in the stator bar with transposition strands is established, the copper loss of the stator bar is determined by the presented method. The corresponding heat transfer coefficients of convective heat transfer surfaces are obtained on the basis of the fluid velocity in radial ventilation groove, and the temperature field of stator transposition bar is obtained by the finite volume method. We analyzed and compared the temperature distribution of stator transposition bar in different cases. In contrast to the test values, the validity of the presented method is verified. The conclusions obtained provide a theoretical basis for the future design of hydro-generator.

2. Solving domain model and solving method

2.1. Physical model of solving domain

In this paper, the 250 MW hydro-generator is designed with double radial ventilation cooling system without fan, and the heat resources generated by the stator bar and iron core are mainly absorbed by the cooling air flowing through the radial ventilation groove. The ventilation groove located between two core segments, has a number of 52, and arranged in the axial direction evenly, the height of each ventilation groove is 6 mm. The main parameters of the analyzed hydro-generator are given in Table 1.

For the reason of periodic symmetry exists in the hydro-generator along the circumferential direction, two half tooth in the circumferential direction and entire length (including the end part) in the axial direction are selected as the solving domain, as shown in Fig. 1, including stator core, insulation, wedge and stator transposition bar, in which the bar with 0°/360°/0° transposition type, namely, the bar is twisted by 360° in slot part, whereas the end part is not twisted. Three typical strands of upper bar in slot part have chosen to describe the transposition path in Fig. 2, the lower bar is the same as the upper bar. From Fig. 2, we can see that strands evenly distributed in two rows, as the stator bar adopt 0°/360°/0° transposition type, and each strand

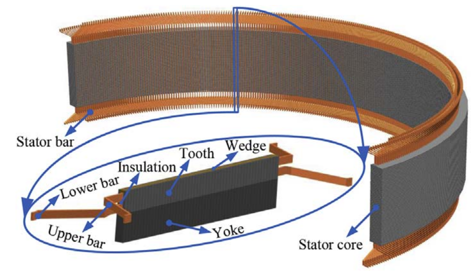

Fig. 1. Physical model of solving domain.

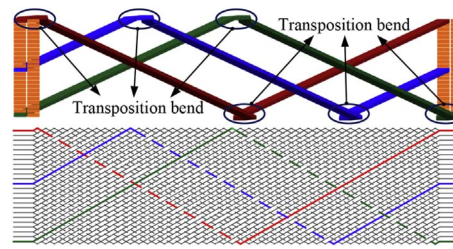

Fig. 2. Transposition structure of strand in slot part.

changes twice, so the number of transposition bend is equal to 2 times the number of strand. Once the transposition bend appears in the strand, the strand path change from one row to another, and finally back to the original position in the radial direction. So then, the circulating current among strands caused by the leakage magnetic field in slot part can be inhibited effectively.

Table 1
Main parameters of the 250 MW hydro-generator.

Parameters	Value
Rated power (MW)	250
Rated voltage (V)	15750
Rated current (A)	10182.5
Rated speed (r/min)	115.4
Rated power factor	0.9
Effective core length (mm)	1590
Half-turn coil length(mm)	3112
Number of strands in single bar	48
Number of bars in single slot	2

2.2. Assumptions and boundary conditions

To simplify the analysis, we make the following assumptions without changing the physical process.

1) For the Reynolds coefficient of the fluid in generator is larger than 2300, the fluid velocity distribution in radial ventilation groove is solved by the turbulence model.
2) The influences of gravity and buoyancy on the large air-cooled synchronous generator are ignored at the standard atmospheric pressure.
3) The fluid velocity in radial ventilation groove is much smaller than the sound velocity, namely, the Mach number is very small. Therefore, the fluid in radial ventilation groove is treated as incompressible fluid.
4) It is assumed that the wedge has the same width as the slot, which is in close contact with iron core. The performance of the insulation (strand insulation, layer insulation and stack insulation) is the same as that of the main insulation.

The boundary conditions are set as follows depending on the characteristics of the solving domain.

1) The entrance of radial ventilation groove is the velocity inlet. The fluid is perpendicular to the entrance, with the velocity of 17.5 m/s.
2) The outlet of fluid is the pressure outlet, and the pressure is the standard atmospheric pressure.
3) The boundary condition of adiabatic surfaces

$$\left.\frac{\partial T}{\partial n}\right|_{S_1} = 0 \tag{1}$$

Where T is the steady temperature of each node, S_1 represents the adiabatic surfaces, which comprise the side surfaces of stator core in the circumferential direction and the end connection surfaces in stator transposition bar.