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Analysis of the Loss and Heat on Damper Bars in Large Tubular Hydro-Generator base on the 3D Electromagnetic-Temperature field Calculation

Abstract. In order to research the losses and heat of damper bars thoroughly, a 3D moving electromagnetic field FE model of tubular hydro-generator and a 3D temperature field FE model of the rotor are built respectively. Furthermore, according to the different operating conditions, the compositive calculations about the losses and temperatures of the damper bars of a 36MW tubular hydro-generator are carried out, and the data are compared with the test. The results show that the computation precision is satisfied.

*Streszczenie. Badano straty i nagrzewanie w prętach tłumika hydrogeneratora wykorzystując 3D model elektromagnetyczny. Badano rozkład temperatury oraz pola elektromagnetycznego. (**Analiza strat i nagrzewania w prętach tłumika turbogeneratora bazujące na obliczeniach 3D temperatury I pola elektromagnetycznego**)*

Keywords: 3D calculation, analysis, loss, heat, damper bar, tubular hydro-generator
Słowa kluczowe: turbogenerator, nagrzewanie.

Introduction

Damper winding is one of the key components of hydro-generator and plays an important role for the safety and stability of generator and power system. The tubular hydro-generator is a good type of hydro-generator which is suitable for exploiting and utilizing the hydraulic resources with low water head and large flowrate. Compared with the axial flowing hydro-generator with the same capability, tubular hydro-generator can economize the project investment 10-25% and increase 3-5% of the power every year, it has then been applied widely at the hydropower stations whose water head is lower than 20m [1]. However, the electromagnetic and cooling designs of the tubular hydro-generators are more difficult because of its limited inner space and then the more possibility of over heat. In recent years, heavy broken-down failures of damper bars in some large tubular hydro-generators operating at different power stations occurred due to the high temperature at the rated load [2]. To improve the generator design and avoid these serious failures, the amount and distribution of losses and temperatures within the rotor of the tubular hydro-generators need to be computed more accurately.

Copper losses of field winding and damper bars, as well as iron core losses of rotor lamination, exist within the rotor. For the complex rotor structure of hydro-generator, all of these losses are difficult to compute accurately except the loss of field winding. When the movement of rotor is considered, the heat dissipation condition of the rotor components are more difficult to confirm precisely. Though FE method has been widely used in the temperature field calculation of generators [3-6], the studies in the available literature refers to FE calculation of damper bars losses and temperatures in large tubular hydro-generators are scarce.

In the study of analyze the currents and losses and heat of rotor and damper bar, the reference [7], [8] use a permeance model with Fourier expansion approach to predict the damper winding currents. And an analytical algorithm based on equivalent network is adopted in reference [9] to analyze the damper winding currents and losses when the generator is operated at rated and no-load conditions. In reference [10], a combined numerical and analytical method for the computation of unbalanced magnetic pulls, damper bar currents and losses of laminated low speed hydro-generators in eccentricity conditions under no-load is proposed. And the rotor temperature distribution of hydro-generator is calculated in fluent and temperature field method in reference [11].

In order to research the losses and heat thoroughly and avoid the broken-down failure of damper bars in large tubular hydro- generators, a 3D moving electromagnetic field FE model and a 3D temperature field FE model are established respectively in this paper. The important factors, such as the end region structure, the rotor motion and non-linearity of the time-varying electromagnetic field, the anisotropic heat conduction of the rotor core lamination and different heat dissipation conditions on the windward and lee side of the poles, are considered. Furthermore, according different operating conditions, compositive calculations about the losses and temperatures of the damper bars of a 36MW tubular hydro-generator are carried out. And the results are compared with the test.

Calculation models

The basic data of the generator are showed in Table 1.

According to the periodicity and symmetry of magnetic field, the area of a pair of poles with half axial length is chosen as the electromagnetic field calculation region, as shown in Fig. 1,and the whole stator coils shown in Fig. 2.

Table 1. The basic data of the hydro-generator

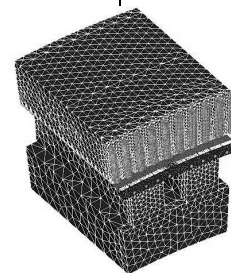| Parameter	Value
Rated power (MW)	36
Rated voltage (kV)	10.5
Rated current (A)	2151
Power factor	0.92
Number of magnetic poles	72

Fig.1. The problem region and meshes of 3D electromagnetic field

Fig.2. The whole stator coils

Considering the saturation of iron core, the governing equation of nonlinear time-varying electromagnetic moving field is:

$$\nabla \times (v\nabla \times \mathbf{A}) + \sigma\left[\frac{\partial \mathbf{A}}{\partial t} - \mathbf{V} \times (\nabla \times \mathbf{A})\right] = \mathbf{J_s}$$

(1)

where A is vector magnetic potential, Js is source current density, v is reluctivity, V is velocity and σ is conductivity.

Because of the symmetric structure of the rotor pole and its ventilation system, the distribution of rotor temperature field is mirror symmetric on the both sides of the rotor shaft middle profile. Therefore, an half axial section of the rotor, which consist of rotor core, damper winding, field winding and its bracket, et al, are selected as the problem region for the 3D temperature field solving, and the region including 256256 elements as shown in Fig. 3.

Considering the anisotropic heat conduction condition of rotor core, the boundary value problem of 3D steady temperature field can be expressed as follows:

$$(2) \begin{cases} \dfrac{\partial}{\partial x}(\lambda_x \dfrac{\partial T}{\partial x}) + \dfrac{\partial}{\partial y}(\lambda_y \dfrac{\partial T}{\partial y}) + \dfrac{\partial}{\partial z}(\lambda_z \dfrac{\partial T}{\partial z}) = -q_V \\ \lambda \dfrac{\partial T}{\partial n}\Big|_{S_2} = 0 \\ \lambda \dfrac{\partial T}{\partial n}\Big|_{S_3} = -\alpha(T - T_f) \end{cases}$$

where T is temperature, λ_x, λ_y, λ_z are heat conductivity on each direction, q_v is the heat source density which is obtained by losses calculation mentioned above, S_2 are the rotor middle profile and the interface between rotor core and rim related with the thermal insulation boundary condition, S_3 are the outside surfaces of the rotor related with the heat dissipation boundary condition, α is the heat dissipation coefficient of S_3, and T_f is the environment air temperature.
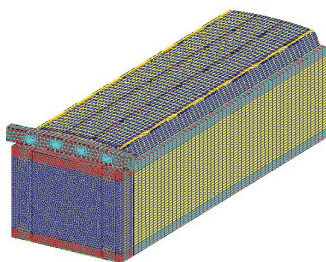

Fig.3. The problem region and meshes of 3D temperature field

Computation results and discussions

Based on the models established above, the compositive computations of the 3D moving electromagnetic field FE model and 3D temperature field FE model of the 36MW tubular hydro-generator are carried out. There are 4 damper bars on each pole shoe. For easy discussion of the computing results, the damper bar on the lee side is numbered 1st and the damper bar on the windward is numbered 4th.
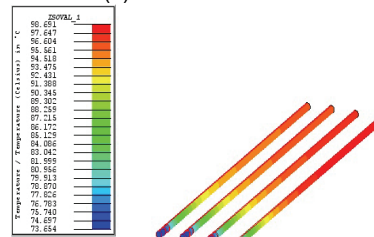
Fig. 4 gives the electromagnetic field and the temperature distributions on the no load and rated load of the generator respectively. Table 2 gives the losses and temperatures of the damper bars of these 2 operating conditions.
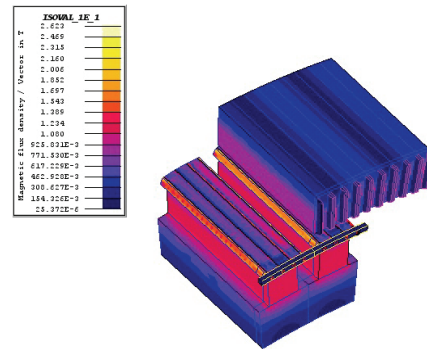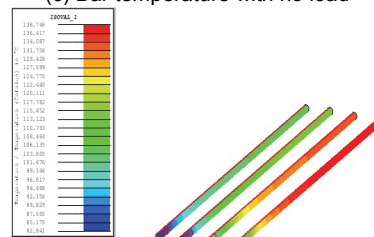

(a) Field with no load
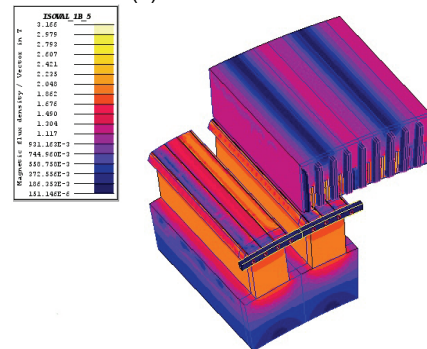
(b) Field with rated load

(c) Bar temperature with no load

(d) Bar temperature with rated load

Fig. 4 Electromagnetic field and temperature distributions of damper bars

Table 2. Losses and temperature of the damper bars with different operating conditions

Operation condition	Loss (W)					Temperature (℃)	
	P_1	P_2	P_3	P_4	$\sum P$	T_{max}	T_{min}
No load	102	56	56	101	315	99	74
Rated load	519	424	158	100	1261	139	83

where P1-P4 and $\sum P$ are the losses of the 1th-4th damper bar and the total losses of the damper bars respectively, T_{max} and T_{min} are the maximal and minimal temperature of the damper bars respectively.

Table 2 show the loss and the temperature of the damper bars increase obviously when the operating conditions of the generator change from no load to rated load. At the rated load, the maximal temperature is 1.4 times higher than that of no load, that is to say the temperature increases 40 ℃. The results show that the operating conditions influence the loss and heat of the damper bars obviously.

And Fig. 4 and Table 2 show that the distribution of the magnetic field about the central axis of the pole is symmetric when the generator operates with no load, and the eddy current and loss of the damper bar are then basically symmetrical about the pole center axis. The losses of the 1th and 4th damper bar are roughly equal, the losses of the 2th and 3th damper bar are roughly equal, too. Because of the armature reaction, the distribution of the airgap magnetic field is distorted when the generator operates with rated load. The magnetic field on the windward is weakened while it is strengthened on the lee side. The symmetry of the eddy current and loss distribution of the damper bars will no longer existed. The eddy current and loss of the 1th damper bar are significantly larger than those of the 4th damper bar.

Based on the 3D moving electromagnetic field FE model, the current density distribution of damper bar is got, as shown in Fig.5. It shows that the current densitydistribution of damper bar is uneven. The current and loss density of damper bar close to the center section of axial of dmaper bar are greater than those of damper bars at the region close to the end region . The reason is that the flux density of the end region is smaller than the flux density near the center section of axial of the generator , which is shown in Fig. 6.
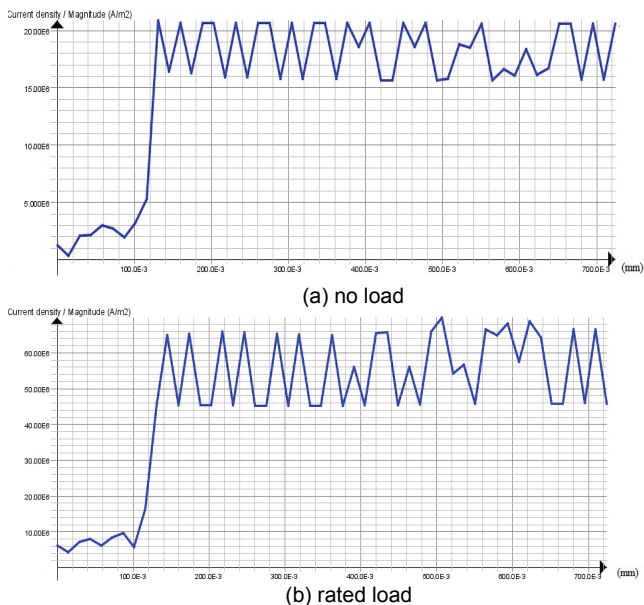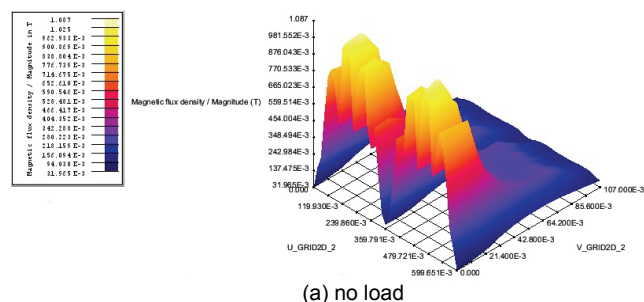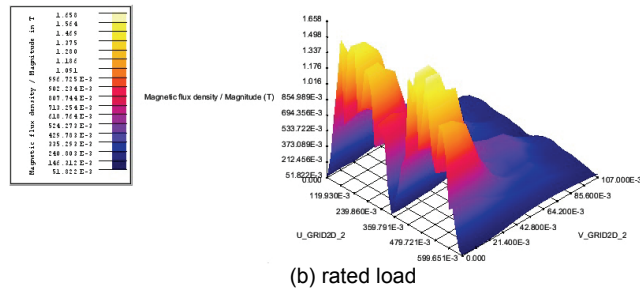

(a) no load

(b) rated load

Fig. 5 The magnitude of current density along the aix of damper bar(the 1st damper bar)

(a) no load

(b) rated load

Fig. 6 The magnitude of air gap flux density of the end region

Besides, the dissipation condition on the lee side is weak than that on the windward, and the dissipation condition on the middle profile is weak than that on the end profile.

Based on above reasons， The temperature of the damper bars located near the lee side is higher than that of located near the windward. The maximum temperature is at the middle of damper bar which near the lee side of the rotor pole. So in this paper ,the maximal damper bar temperature occurs at the axis middle of the 1th damper bar and the minimal damper bar temperature occurs at the end of the 4th damper bar.

Verification of the results

To verify the correctness of the calculation models in this paper, the temperature test of the field winding is carried out at this 36MW tubular hydro-generator . The environmental air temperature is 47.6 ℃ and the average temperature of field winding tested is 110 ℃ with the rated load of the generator. To compare with the test data, more temperatures of the rotor parts, including damper bar, field winding and iron core, are obtained by the compositive calculations of the 3D moving electromagnetic field FE model and 3D anisotropic steady temperature field FE model. The calculated average temperature of field winding is 107℃ and is well agreed with the test dada. The relative error between the calculation and the test is less than 2.7%.

Conclusion

The losses and heat distributions of the damper bars in one pole are uneven with the rated load. The current and loss density of damper bar close to the center of pole are greater than those of damper bars at the region close to the end part of pole. The loss and temperature of the damper bars near the lee side are higher than that of the windward.

The 3D moving electromagnetic field FE model of the hydro-generator and 3D temperature field FE model of rotor are implemented, the factors such as magnetic field of end region, the rotor motion and nonlinearity of the time-varying electromagnetic field, the anisotropic heat conduction of the rotor core lamination and different heat dissipation conditions on the windward and lee side of the poles are considered. It obtain more accurate results of loss and heat computation of hydro-generator damper bars.

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