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Numerical Calculation of Fluid Field as well as Influence on Thermal Field of Hydro-generator with consideration of Rotor Rotating

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Abstract: - The rotor of hydro-generator is something like a cyclone and the fluid field produced by high speed rotation is very complex. The numerical method is applied in this paper to compute the fluid field generated by the rotation of rotor and the distribution of fluid field is obtained. The continuity equation to describe flowage of coercible gas is presented as analysis model and the corresponding Navier-Stokes equations and equation of conservation of momentum is given. For a 320MW hydro-generator, the velocity distribution and fluid field distribution is calculated and the results are discussed in details, subsequently, the influence of fluid distribution on the thermal distribution is also analyzed. The results can provide theoretic supports for the cooling system calculation and the optimal design and safe operation of hydro-generator both will benefit from these analysis.

Key-Words: - Hydro-generator; Numerical; Finite volume method; Fluid field; Thermal field; Coercible gas

1 Introduction

With the increasing unit capacity of hydro-generator, the thermal load in rotor and stator grows rapidly, and there is more demand for performance of cooling system. Traditionally, the wind path method is usually adopted to simplify cooling system when cooling fluid field is analyzed [1]. By this way, the simplified model need to be modified by many tests, but the final calculated results still can not describe the exact distribution of fluid field in each part of electrical machine, which limits the effect of theoretical calculation on engineering greatly. Today, taking the advantages of the rapid development of computer technology and numerical calculation methods, the fluid field can be used to simulate the distribution of fluid accurately.

It is still main cooling method for hydro-generator by taking air as coolant to cool the surface of stator and rotor core. Therefore, if the fluid field distribution in each parts of hydro-generator can be calculated accurately, the results will guide the cooling system design directly.

The rotation of rotor not only cools the rotor pole effectively, but also it can produce very high pressure head which squeeze the coolant into stator radial ventilating grooves and cool the stator core [2].

Based on field theories, finite volume method is applied to calculate rotor and stator fluid field for a hydro-generator. The distribution of rotor fluid field is presented and the influence of rotor fluid field on stator fluid field as well as thermal field is discussed.

2 The Calculation Model of Fluid Field in Hydro generator

2.1 Mathematic Model for Fluid Field

Generally, the fans are not equipped at the two end parts of rotor for large hydro-generator and the power for air cycle is provided by wind pressure generated by rotor rotation. Due to the short rotor core and long diameter, the tangential rotating speed is high. Therefore, when the cooling regions in rotor pole and air gap are analyzed, the air could be treated as coercible gas.

Because the fluid field we discussed is a special time during generator stable operation, the flowage of air can be regarded as steady state [3]. Therefore, the continuity equation is [4]

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

Where u , v and w are velocity components along *x, y* and *z* respectively.

When air is taken as coolant, the gravity and buoyancy both can be neglected. The Navier-Stokes equations [4] can be written as follows.

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho uu)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}-S_u$$
$$=\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial u}{\partial z}\right)-\frac{\partial p}{\partial x}$$
$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho vu)}{\partial x}+\frac{\partial(\rho vv)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}-S_v$$
$$=\frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial v}{\partial z}\right)-\frac{\partial p}{\partial y}$$
$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho wu)}{\partial x}+\frac{\partial(\rho wv)}{\partial y}+\frac{\partial(\rho ww)}{\partial z}-S_w$$
$$=\frac{\partial}{\partial x}\left(\mu\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial z}\right)-\frac{\partial p}{\partial z} \quad (2)$$

Where ρ is the density of fluid, μ is kinematic viscosity, p is pressure of fluid, S_u, S_v and S_w are generalized source items of equation of conservation of momentum.

For moving coercible gas with high speed, the equation of conservation of momentum is [4]

$$\frac{\partial(\rho T)}{\partial t}+\frac{\partial(\rho uT)}{\partial x}+\frac{\partial(\rho vT)}{\partial y}+\frac{\partial(\rho wT)}{\partial z}-S_T$$
$$=\frac{\partial}{\partial x}\left(\frac{\lambda_l}{c_p}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\lambda_l}{c_p}\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{\lambda_l}{c_p}\frac{\partial T}{\partial z}\right) \quad (3)$$

Where c_p is specific heat of fluid, and T is temperature, λ_l is radiating coefficient of fluid, S_T is viscous dissipation item.

2.2 Solved Region

From the ventilating structure of hydro-generator it can be seen that cooling air flow into air gap through two paths: some through radial ventilating gap in rotor yoke, the others through end part [5]. At last, the air flow into cooling unit through stator ventilating grooves.

In this paper, the fluid field is analyzed by 2D model, thus, only the first case is discussed. The cross-section of fluid field with stator radial ventilating grooves is shown in Fig.1.

Due to the periodic variation of fluid field with the distribution of rotor poles, a periodic time is selected to be analyzed and the fluid field distribution in whole region will obtained subsequently.

A 320MW hydro-generator of Longyang Gorge Hydrostation is discussed and the generator has 48 rotor poles and 630 stator slots. For simplicity, we think that a pole correspond 13 slots. The radial central line of two rotor poles is selected as periodic boundary, so the solved region for fluid field in a periodic time can be shown as Fig.2.

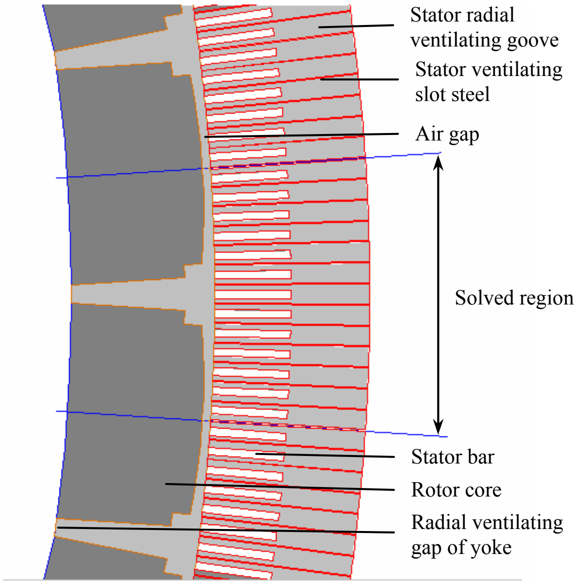

Fig.1 Fluid field of stator and rotor

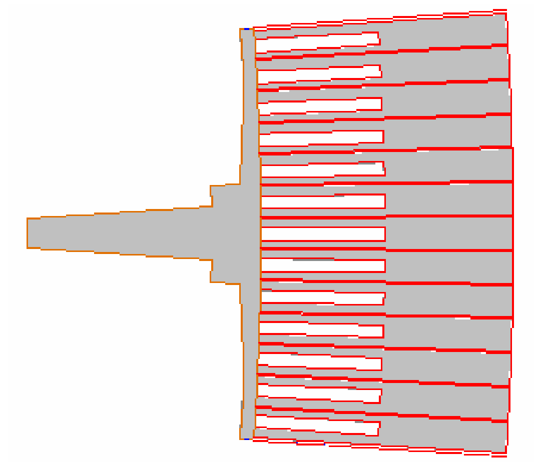

Fig.2 The solved region for fluid field

2.3 Basic Hypothesis and Boundary Conditions

For simplicity, some basic hypothesizes are presented as follows.

(1) The magnetic pole of rotor has smooth surface.

(2) The width of slot wedge of stator is equal to that of strands and the surface in air gap side is in the same surface with end part of stator teeth.

(3) The pressures at the stator radial ventilating grooves are equal to each other.

The finite volume method is adopted to discretize the governing equation by two order upwind format, and the discretized equation is solved iteratively [4]. The corresponding boundary conditions are as follows.

(1) The wall rotation speed of rotor is 125rpm.

(2) The boundary along the central line of two rotor poles is interacting periodic boundary.

(3) The radial ventilating gap of rotor yoke is pressure input boundary and the pressure equal to standard atmosphere pressure.

(4) The outlet of stator radial ventilating groove is pressure output boundary and the pressure equal to standard atmosphere pressure.

(5) The surfaces of stator bar and ventilating channel steel are both non-slip wall boundaries.

3 Calculation Results of Fluid Field

3.1 Distribution of Fluid Velocity

The velocity distribution of fluid is shown in Fig.3. The rotor is rotating anticlockwise, and we can see that the largest velocity locates above the windward surface of magnetic pole and the velocity above leeward surface is smaller. The windward surface of magnetic pole supplies the energy for the moving of fluid, and the largest velocity is up to 110m/s. The outer-diameter of magnetic pole equal 5.9m, and the outer-diameter of rotor yoke is 5.48m. At rated load ω=125rmp, and the velocity of magnetic pole: $v=2\pi R\omega/60$, so the velocity of pole from bottom to top is 71.70~77.19m/s. By comparison, we find that the relative velocity of fluid above the leeward surface is smaller, which affects the cooling efficiency of magnetic pole directly.

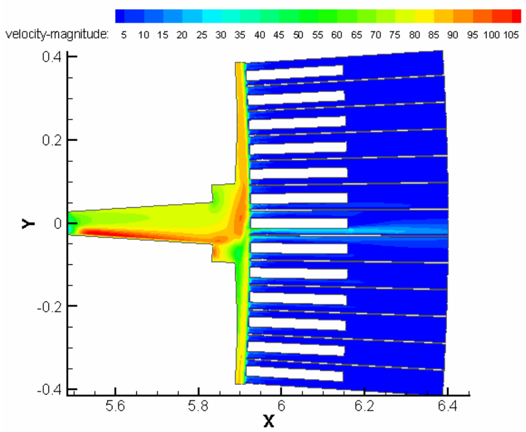

Fig.3 Velocity distribution of fluid

The fluid in the rotor-stator gap and between two magnetic poles is rotating with the rotor, and the velocity is mainly the circumferential direction. Because of the special structure of radial ventilation duct, the affect to velocity distribution in the radial duct is limited for the rotor rotating, and there is little fluid pressed into the radial duct. Only the radial duct that is faced the gap between two poles has larger fluid velocity, because of centrifugal effect of rotor the fluid between two poles is pressed into this radial duct. The fluid quantity into every radial duct can be gained by computing the outlet fluid velocity, and the outlet velocity of ducts is shown in Fig.4.

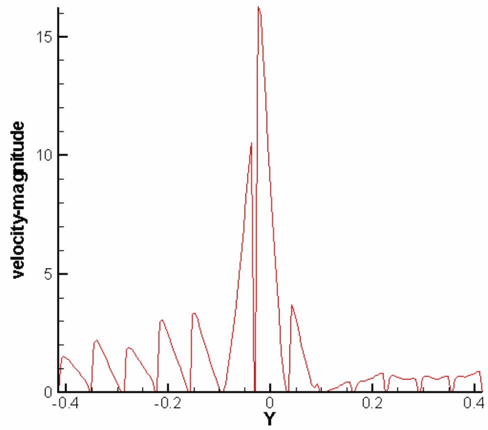

Fig.4 Outlet velocity of ducts

In Fig.4 we find that the fluid velocity of duct faced the gap between two poles is larger than other ducts clearly, and the fluid quantity into this duct is more than other ducts at this moment.

3.2 Distribution of Fluid Field in Different Parts

The computing region includes one rotor period and 13 radial ducts, and all ducts have the same structure, so the radial duct can be regarded as periodic object. Using periodic boundary conditions we can gain the whole velocity distribution only computing the rotor rotating round one duct. For the convenience of computation and analysis we select the front and back 1/2 duct as the computing object.

The velocity distributions of front and back 1/2 duct are shown in Fig.5 and Fig.6.

By comparison of the velocity distribution we know that the fluid velocity in the rotor-stator gap and between two magnetic poles has little difference, and only the larger velocity duct is changing with the rotating of rotor.

4 The Influence of Rotor Rotating on Thermal Field

In steady state of hydro-generator, the velocity distribution of fluid in the rotor-stator gap and between two magnetic poles is invariable on the whole, so the cooling analysis of magnetic pole can be regarded as a steady condition. The magnetic pole is the main heat source of rotor, and the cooling efficiency affects the capacity of generator directly. Magnetic poles transfer heat to cooling air by convection heat transfer mode, so the fluid velocity of surface decides the cooling. According to the fluid velocity distribution the relative velocity of windward surface is larger than leeward surface, so the cooling efficiency is better also. Therefore the cooling of leeward surface should be the main problem for hydro-generator.

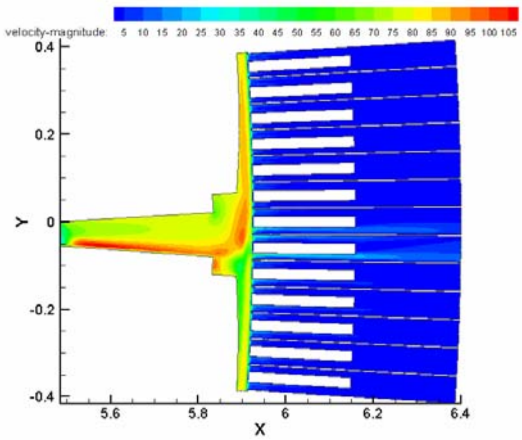

Fig.5 Front 1/2 duct condition

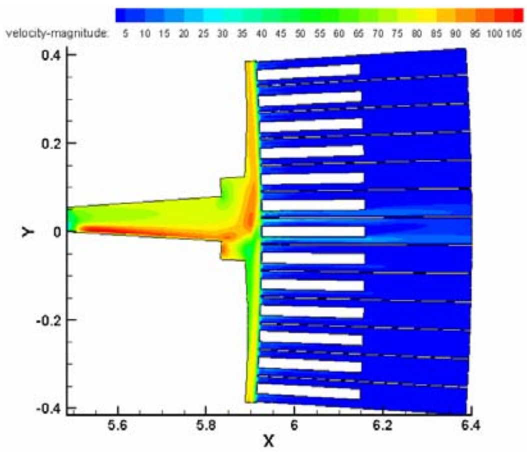

Fig.6 Back 1/2 duct condition

According to Fig.4, the influences of rotor rotating to fluid field in stator radial duct focus only on one or two radial ducts, which show as a periodic change for stator, and the period T=60/(125*48)=0.01s. The thermal field of stator should be affected by this periodic change, but the period is only 0.01s. According to the transient heat conduction theory [6], the frequency is higher and value is limited, so we can use the average velocity to compute the thermal field of stator by steady-state heat conduction mode.

The cooling airs of stator come mainly from the ending rotor-stator gap, when we compute the inlet velocity of radial duct, which can be gained by using total cooling air quantity to divide the total inlet surface.

5 Conclusion

(1) According to the fluid velocity distribution, the relative velocity of windward surface is larger than leeward surface so the cooling efficiency is better also.

(2) The influences of rotating rotor to stator fluid field are smaller, and the inlet velocity of radial duct can be replaced by average value.

(3) The thermal field computation of rotor and stator can be regarded as steady-state problem.

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