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Simulating the Temperature Field of Steam Turbine with the Rapid Hot Air Cooling Method

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Abstract: Rapid hot air cooling after the shutdown of steam turbine is widely used scheme in practice. In this paper, on the basis of the variable temperature and flow devices (double-variable), a new method is designed to produce such rapid hot air cooling steam turbines. Taking 300 MW steam turbine for example, this paper utilizes Ansys software to compute the flow of variable air and the temperature fields of cylinders according to rapid hot air cooling, traditional hot air cooling and the natural cooling method respectively. The result shows that it enlarges the flow and decreases the cooling time, while the temperature gap is increased between the upper and lower cylinders as well as the inner and outer ones. Compared with traditional methods, this new one has certain advantages like its high cooling speed, uniform temperature field, and lower temperature gap both in the inner/outer cylinders and in that of its axial direction.

Keywords: rapid cooling; temperature field of steam turbine; Ansys

1 Introduction

S. Hother [1] created a set of double cooling device, the one to produce cooling gas so as to cool down the inner cylinder and rotors, the other to cool down the inner/outer cylinder, in which their flows are regulated by the swelling levels of rotor/stator and inner/outer cylinder. On the structural design of Ultra-super critical steam turbine, Shi Jinyuan[2] aired his views about choosing a suitable cooling parameter, analyzing the finite elements of spare part temperature field and stress field, measuring and verifying their cooling efficiency. All the former researches tell us that the safety of forced cooling is guaranteed, and it will be promising to further our study if enhancing a severer control on air temperature and flow parameters.

2 The optimization calculation for rapid cooling

In the flowing forward cooling process, hot air initially gets to the cylinder high-temperature section, which is safe and easy to access because of its much less thermal shock on cylinders. And it has become a major method applied by larger units. Therefore, it chooses the flowing forward cooling method for calculating in this paper.

As the figure 1 show, the hot air making apparatus include conveying appliance, combustion apparatus, induced air apparatus and control system. The thermocouple of control system is equipped in the hot air chamber, while programmable control system connects thermocouple and gas control valve. The other programmable control system connects the flowmeter and flowmeter, as well as blowing-in control valve. The setting value of programmable control system is designed by the hot air chamber temperature and steam turbine one. Instead of electricity, the equipment applies fuel to generate heat to hot up air. The method can not only conserve energy, but also demand the air temperature and flow rate request [3].

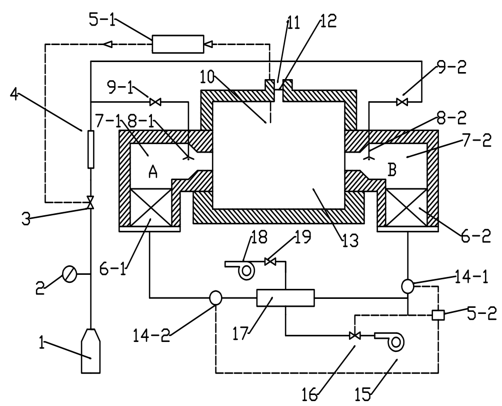

Figure 1. Hot air generator

1- fuel gas bottle、2- pressure gauge、3- gas control valve、4-flowmeter 、 9-1-Solenid Valve 一 、 9-2Solenid Valve 、 8-1burner、8-2 burner 、6-1heat accumulator、6-2 heat accumulator 、7-1firebox、7-2 firebox、13- hot air chamber、15- ventilator、16- blowing-in control valve、17- four-way valve、14-1- flowmeter、14-2- flowmeter、12-hot air outlet damper、11-hot air outlet pipe、18- induced draft fan 、19- induced air relay valve、10- thermocouple、5-1- programmable control system

3 The simulation of temperature field inrapid cooling

3.1 The rapid double-variable device cooling

On the basis of the double-variable device, the sub-interval cooling could come true: coordinate the temperature of the cooling air as long as the cylinder's

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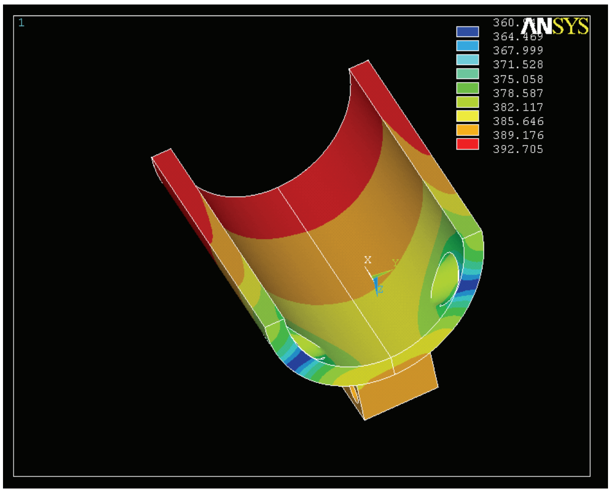
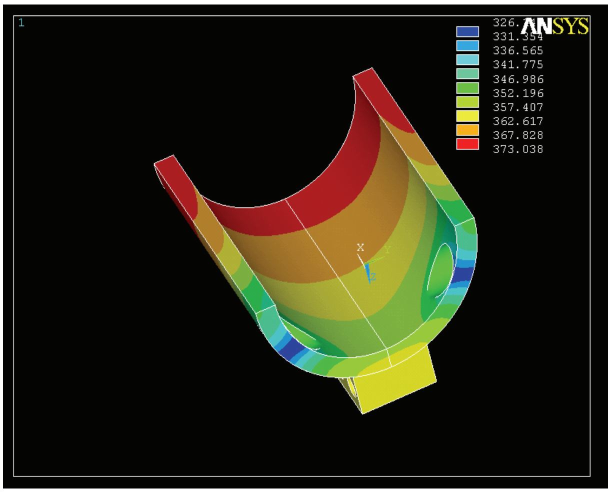
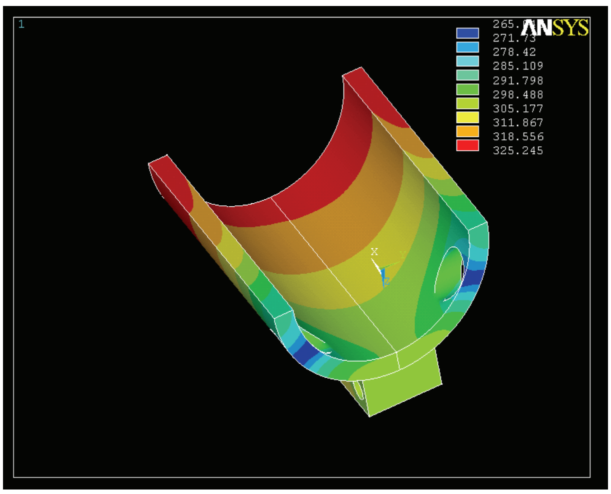
temperature drops by a certain quantity, to keep it with a difference of 50℃ between the cooling air and the cylinder.



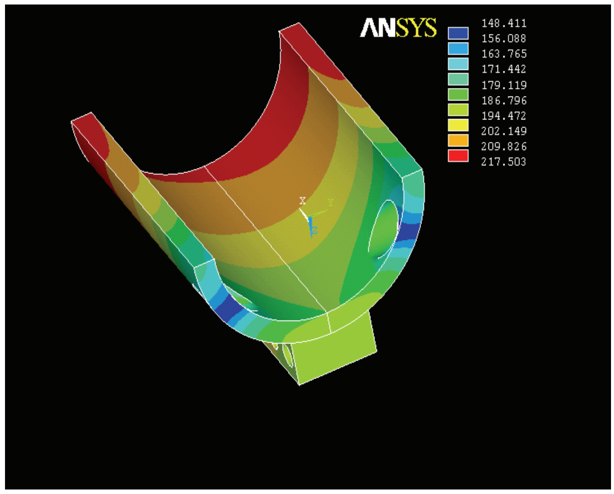
I—7h



II—14h



III—21h



IV—29h

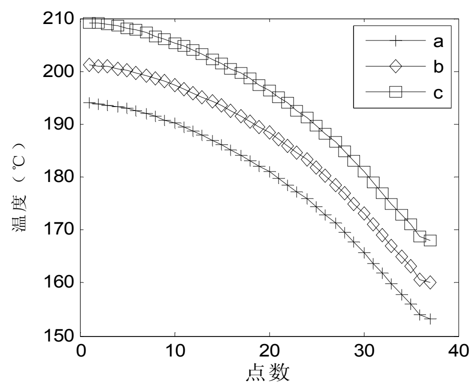
Figure 2. Four different temperature fields of the rapid temperature-variable cooling

To simplify modeling the temperature field, the relationship between the fitting heat transfer coefficient y and the temperature x would be:

$$y=23.59+0.031*(350-x) \tag{6}$$

Four points in the rapid cooling process are picked out here to study the temperature field as what figure 3 tells: that is 7h, 14h, 21h, and 29h. Figure3 shows each section.

37 dots are selected from the medium lines of all the cylinders, by which the temperature curve will be drawn with Matlab software.



II—50m^3 / min rapid temperature-variable cooling

a—temperature of the lower-outer cylinder wall

b—temperature of the upper-inner cylinder wall

c—temperature of the upper-outer cylinder wall

Figure3. The temperature curve of cylinders

At the seventh hour of the rapid temperature-variable cooling, the axial temperature stepladder of the cylinder appears a little bit small, during which the metal temperature of the inlet is 313℃ while the outlet is 352℃, with a max axial temperature difference of 39℃. At the fourteenth hour, the inlet shows 243℃ while the outlet 287℃, with a max axial temperature gap of 44℃. At the twenty-first hour, the lowest temperature of the inlet is 192℃ while the highest of the outlet is 244℃, and 52℃ is the max axial temperature gap. Till the twenty-ninth hour when the cooing ends, the lowest temperature of the inlet is 149.9℃ while the outlet 216℃ and the max temperature gap 67℃. All of these illustrate that the axial temperature gap gets more and more obvious as the cooling goes on, and it reaches to the maximum when it comes to its end. Compared with 122℃ axial temperature gap of the traditional cooling method, the temperature-variable device gains a much less temperature gap in its axial direction.

At the seventh hour, the upper and lower cylinders are symmetric in distribution, the temperature gap between which is magnified gradually as the cooling continues. Until the last minutes of the cooling process, as figure 4-II presents, the temperature gap between the upper and lower cylinder reaches 15℃. For the reason that higher temperature air is usually inclined to ascend while the lower temperature air inclined to descend in motion, the lower temperature air gathers into the lower cylinder while the higher temperature air is fond of staying in the upper one. Henceforth there will be a temperature gap between the cooling air in the upper and lower cylinders, which leads to the unbalance of cooling in the upper/lower cylinder, bringing a larger and larger temperature gap as the cooling deepens.

3.2 The temperature field in flow rate-variable cylinder

The flow rate of cooling air exerts great influence on the coefficient of heat transfer. Consequently, the following part will focus on altering the air flow rate of this double-variable device to analyze its influence on cooling. To get the modeling work easier, the coefficient of heat transfer will be fitted as straight line:

When the flow rate is 40m^3/min, the coefficient of heat transfer y and the temperature x:

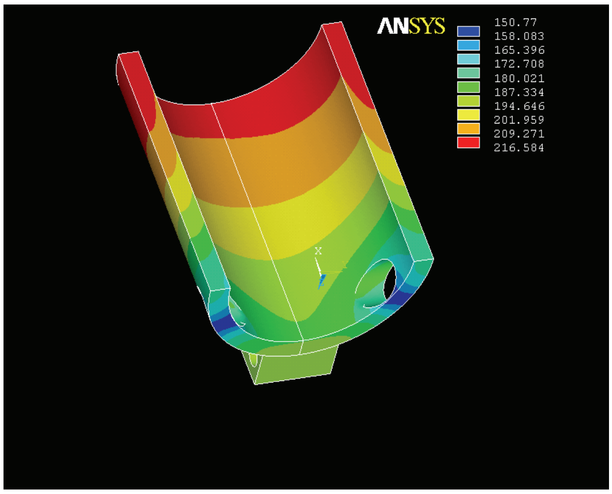
$$y=19.82+0.026*(350-x) \qquad (7)$$

When the flow rate is 60m^3/min, the coefficient of heat transfer y and the temperature x:

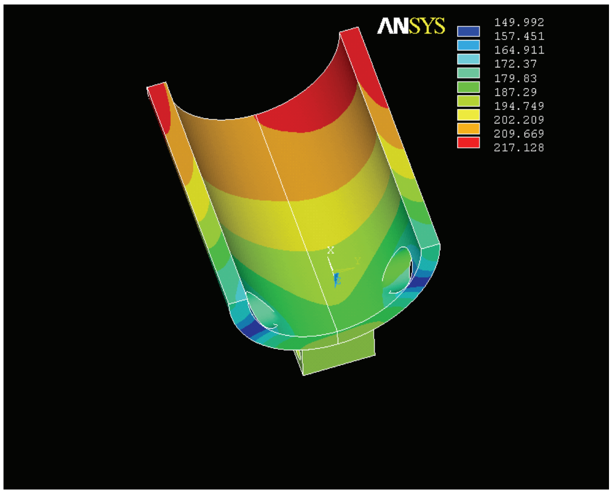
$$y=27.36+0.36*(350-x) \qquad (8)$$

Applying the Ansys software and exerting transient convection supporting load, figure 5 shows the temperature fields of this two flow rate when it ends:

On these two flow rate types, the cooling time they will spend are 40.98h and 21.93h separately. The figure tells that the flow rate increases while the cooling time decreases, and the distribution of temperature with the flow rate of 50m^3/min is just similar to figure 3.

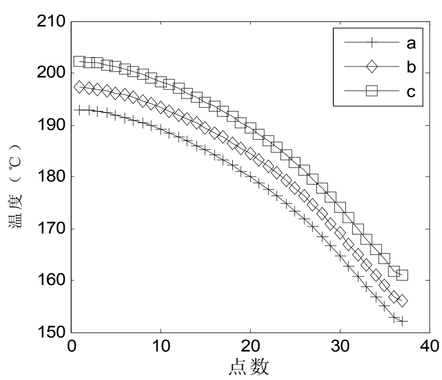


I—40m^3/min Double-variable device cooling



II—60m^3/min Double-variable device cooling

Figure 4. The temperature field distribution of cylinder under different flow rate conditions



I—40m^3/min Double-variable device cooling

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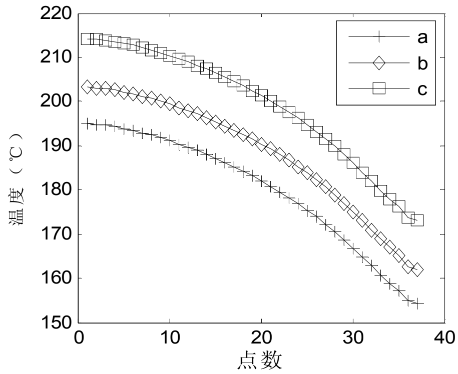

II—60m^3/min Double-variable device cooling
a—temperature of the lower-outer cylinder wall
b—temperature of the upper-inner cylinder wall
c—temperature of the upper-outer cylinder wall

Figure 5. The temperature curves of three straight lines

When the flow rate is 40m^3/min, the temperature gap between the upper and lower cylinder will show as 10℃ while the inner/outer cylinder 4℃; in figure 4-Ⅱ, when the flow rate reaches 50m^3/min, the difference of the upper/lower cylinder is 15℃ while the inner/outer one 8℃; in the same way, when the flow rate is 60m^3/min, 23℃ temperature gap appears in the upper/lower cylinder, 11℃ in the inner/outer cylinder. It is demonstrated that the hot air accumulated in the upper cylinder grows in number, so does the lower temperature air in the lower cylinder, with the increasing of the flow rate. The result for this is that the cooling speed of the upper and lower cylinder differs a lot, and the temperature gap grows quite larger.

3 Conclusion

1) In the traditional cooling method, it takes 34.6h in all, and the highest temperature of the outlet reaches 272℃, the max axial temperature gap takes to be 122℃, with 40℃ upper/lower cylinder temperature gap and 18℃ in the inner/outer cylinder.

In the temperature-variable cooing method, it takes 29.07h in all, with a 67℃ max axial temperature gap, 15℃ upper/lower cylinder temperature gap and 8℃ in the inner/outer cylinder.

2) In the double-variable cooing method, when the flow rate shows as 40 m^3/min, 50m^3/min, and 60m^3/min in sequence, their cooling time will be 40.98h, 29.01h, and 21.93h respectively, which illustrates that the cooling time decreases as the flow rate increases in number.

3) When the flow rate is 60m^3/min, the temperature-variable cooling method needs much less cooling time, with a lower temperature gap and higher security. It is thereby demonstrated to be a more economical and reasonable cooling method.

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