Research on the Temperature Distribution of the Hollow Conductors in the Self-circulating Evaporative Inner Cooling System for High Power Rectifier Equipment

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Abstract. In the evaporative inner cooling system for high power rectifier equipment, the thyristor and quick fuse are both cooled double-sided via hollow conductors. Different from the previous study on the system with single structure, the self-circulating system for high power rectifier equipment has composite structure. Then the system with composite structure may show different heat transfer characteristics. So in this paper, the temperature distribution of the horizontal and vertical hollow conductors in the self-circulating system was studied through theoretical analysis and simulation.

1. Introduction
The evaporative cooling system utilizes the latent of coolant to take away heat load. When the inner evaporative cooling technology applies on the high power rectifier equipment, the system consists vertical hollow conductors and horizontal hollow conductors. The feasibility of self-circulation has been proved through experiment study.

In the self-circulating system with composite structure, the heat loaded on parallel vertical and horizontal passages are different. According with the balance relationship of circulating force and flow resistance, the heat transfer characteristics of the parallel passages are different.

So in this paper, aiming to research the heat transfer characteristics in the self-circulating system with composite structure, the temperature distribution of the hollow conductors was studied through theoretical analysis and simulation.

2. Theoretical analysis
Taking an example of three-phase bridge full-controlled rectifier, the inner evaporative cooling system for high power rectifier equipment is consist of condenser, vertical hollow conductors, horizontal hollow conductor and other connection tube. The structure is shown in fig.1.

As is shown in this figure, the evaporative coolant flows in the hollow conductors and absorbs the heat loss generated by thyristors and quick fuses. Then the temperature of coolant may rise. When the temperature reaches to the saturated boiling point according to the local pressure, the liquid coolant may change to gas.

In previous study, the feasibility has been proved that the composite system with different structures can achieve self-circulation. So in the system, due to the circulating force from the density difference between liquid coolant and gas coolant, it can maintain circulation without external pump.
In this paper, theoretical model was built on the minimum parallel unit, which includes two vertical hollow conductors and one horizontal hollow conductor.

For self-circulating system, the steady performance depends on the balance relationship between flow resistance and driving force.

\[ P_{\text{drive}} = P_{\text{resistance}} \]  \hspace{1cm} (1)

\[ P_{\text{drive-n}} = \rho_{\text{in}} \cdot g(L_n + L_{\text{out-n}}) - \rho_{\text{in}} \cdot gL_{\text{in-n}} - \rho_{\text{out-n}} \cdot gL_{\text{out-n}} \]  \hspace{1cm} (2)

\[ P_{\text{resistance-n}} = \Delta P_n + \Delta P_{\text{local-n}} \]  \hspace{1cm} (3)

The flow resistance is consisted of resistance along the way and local resistance. In this paper, the homogeneous theoretical model of two-phase flow was chosen to calculate the resistance pressure drop along the way.

\[ \Delta P = \frac{2 \bar{f}_p}{D} \frac{G^2}{\rho_g} L = \frac{2 \bar{f}_p}{D} G^2 \cdot D_{hp} \cdot L \]  \hspace{1cm} (4)

And the local resistance can be calculated as follow.

\[ \Delta P = \epsilon \cdot \frac{G^2}{2 \rho_l} \left[ 1 + \left( \frac{\rho_l}{\rho_g} - 1 \right) x \right] \]  \hspace{1cm} (5)

\[ \epsilon = C_{jb} \]  \hspace{1cm} (6)

\[ C_{jb} = 1 + C \left[ \frac{x(1-x)(1 + \frac{\rho_l}{\rho_g})(1 - \frac{\rho_l}{\rho_g})^{0.5}}{1 + x(\frac{\rho_l}{\rho_g} - 1)} \right] \]  \hspace{1cm} (7)

Then the arc-length continuation method was chosen to study the steady performance of the three hollow conductors. And the flow rate of every conductor at different condition can be got. The results shown in table 1 can provide the boundary condition for further simulation.

| Table 1. The calculated result of mass flow rate |
|-----------------------------------------------|
| heat load | m1(kg/s) | m2(kg/s) | m3(kg/s) |
|-----------|---------|---------|---------|
| 0.7Qn     | 0.325   | 0.31    | 0.33    |
| 0.8Qn     | 0.33    | 0.32    | 0.32    |
| 0.9Qn     | 0.335   | 0.325   | 0.315   |
| 1.0Qn     | 0.338   | 0.328   | 0.31    |
| 1.1Qn     | 0.334   | 0.33    | 0.3     |

Based on the results of flow result, the heat transfer coefficient of single-phase section and two-phase section in different flow passages can be calculated accordingly. Then the theoretical results of temperature distribution can be got.
3. Simulation

In this paper, Eulerian model was chosen as the multiphase model, thermal phase change model was chosen as the evaporation-condensation model.

Then define the property of evaporative coolant, and set the boundary of inlet and outlet. Here, the total mass flow rate was set as the inlet boundary condition. And the boundary of outlet was set outflow. When the output current of the rectifier equipment is 5550A, which is the rated current, the flow field and temperature distribution of the three hollow conductors can be got as follow.

The heat loss generated by thyristor is larger than quick fuse, so the two vertical flow passages in hollow connecting conductor for thyristor has larger void fraction than others. In self-circulating system, the operation state depends on the dynamic equilibrium between circulating driving force and flow resistance. So it means this two vertical flow passages may provide larger circulating driving force, and the flow rate distributed to this two passages may larger than others. However, as is shown in above figures, the results were not the case. It means the boundary condition setting of inlet here cannot simulate the actual condition very well.

Then aiming to simulate the temperature distribution more profitably, the model was built as follow and the mass flow rate of each passaged at inlet was set according with above calculated results, which is shown in table1. And then when the output current of the rectifier equipment is 5550A, the flow field and temperature distribution of the three hollow conductors can be got as follow.
As is shown in above figures, the temperature of thyristors is lower than 60℃, and the temperature difference of all the parallel hollow conductors is lower than 10℃. So to the rectifier equipment with self-circulating evaporative cooling system with composite structure, the temperature level is low and the temperature distribution is uniform.

4. Conclusion and Discussion
Based on the theoretical analysis of the self-circulating system with composite structure, the temperature distribution was studied through simulation. And simulation results show that the conductors have uniform temperature along the flow direction, and the temperature level of the three hollow conductors are equivalent. Moreover, based on the advantages of self-regulation and self-adaption, the system can...
keep a good cooling effect with the increase of heat load. So it may provide a good choice for solve the cooling problem of high power rectifier equipment.

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