Effect of HP heater emergency hydrophobic leakage on performance test results and unit economy

Wei Zheng1,*, Xueqing Lu2, Yue Han1, Li Li3, Lingkai Zhu1, Junshan Guo1, Panfeng Shang1, Jinxu Lao1, Junqi Ding1

1State Grid Shandong Electric Power Research Institute, Jinan, China
2Shandong University of Science and Technology, Qingdao, China
3State Grid of China Technology College, Jinan, China

*Corresponding author e-mail: zw0927@126.com

Abstract. During the performance test of the unit, the HP heater emergency hydrophobic leakage will lead to errors in the calculation of the flow flowing through the turbine, thus causing deviation in the calculation of the test results. The influence of the main flow benchmark of feed water flow and condensate flow at the deaerator inlet on the test results is given by an example. The effect of the HP heater emergency hydrophobic leakage on the economy of the unit itself is analyzed by the equivalent heat drop method. It is concluded that when the condensate flow at the deaerator inlet is the main flow benchmark, the result deviation of the test results is much greater than that of the leakage on the economy of the unit itself.

1. Introduction

HP heater is an indispensable part of the feed water heating system of thermal power units. It uses steam which has been used in steam turbine to heat feed water, reduces the condensation loss of steam in condenser, and improves the operation economy of power plants.

For power plant feed water heating system, HP heater requires water drainage to be self-current in normal operation, in order to minimize the difference of feed water heat absorption temperature and reduce the loss of working capacity [2][3]. However, in actual operation, in order to ensure that the water level of high-pressure heater is controlled within the normal liquid level range, a set of critical drainage pipes should be designed. When the water level of HP heater exceeds a certain high value, the drainage reaches the deaerator or condenser directly through the critical drainage pipes, so as to maintain the water level of HP heater, protect the steam turbine from water shock and ensure the safe operation of the unit. HP heater emergency drainage pipeline is generally controlled by pneumatic valve. A set of manual stop valve is designed before and after pneumatic valve. The manual stop valves are in full open state, but the tightness of pneumatic valves is poor, most of them can not be closed. Such a part of steam leaks into deaerator or condenser through critical drainage pipeline, especially high temperature and high pressure drainage leakage, which causes a lot of heat loss and affects unit operation economy. If the manual stop valve is not closed during the unit performance test, the test results will be distorted.
2. Effect of HP heater emergency hydrophobic leakage on Performance Test Results

Domestic steam turbine performance tests generally adopt American Society of Mechanical Engineers standards or national standards, which require strict isolation of the system during the performance test in order to reduce measurement errors. For the leakage flow, it can be measured by the changes of water storage capacity of condensers, deaerators and other regenerative heaters, drums, steam-water separators and any other water storage points in the system, which can meet the requirements of the test standards. However, for the internal leakage flow, such as the flow in and out of the turbine cycle, the flow through the bypass of the equipment is easily neglected, resulting in the error of flow measurement through the turbine, thus affecting the accuracy of the test results. The HP heater emergency hydrophobic leakage is the internal flow that must be isolated in the performance test.

2.1. HP Heater Drainage System

Taking a domestic imported 300MW unit in a power plant as an example, the influence of HP heater emergency hydrophobic leakage on the performance test results of the unit is introduced. The type of the steam turbine which produced by Shanghai Steam Turbine Plant is N300/16.8-538/538. It is subcritical, primary reheat, single shaft, double cylinder, double exhaust and extractive condensing steam turbine. The regenerative system is arranged in three high pressure heaters-four low pressure heaters-one deaerator mode. The HP drainage system is shown in Fig. 1. No. 1 HP heater is the last stage heater, and the normal drainage is from No. 1 HP heater to the deaerator. In order to ensure safe operation, the three HP heaters are separately equipped with an emergency hydrophobic pipe to the drainage expansion vessel, and then enter the condenser heat well. The deaerator is equipped with overflow pipe and emergency hydrophobic pipe, and the emergency hydrophobic directly enters the condenser. The HP heater emergency hydrophobic pipes are equipped with a set of regulating valve and manual stop valves that before and after the regulating valve.

2.2. Performance test results

Two kinds of flow benchmarks are usually used in the steam turbine performance test to calculate the test results. One is the feed water flow, the other is the condensate water flow at the deaerator inlet. The following formula is used for calculating the heat consumption rate of steam turbine and the coal consumption rate of unit.

\[
H_t = \frac{G_{fw}(l_{ms}-l_{fw})+G_{cr}(l_{hrh}-l_{cr})+G_{sh2}(l_{ms}-l_{sh2})+G_{rhs}(l_{hrh}-l_{rhs})}{p_e}
\]  

(1)

\[
B_f = \frac{H_t}{29.308\eta_h\eta_p}
\]  

(2)
In the formula, $H_c$ is heat consumption rate of steam turbine, $kJ/(kW.h)$; $G_{fw}$, $G_{crh}$, $G_{shs}$, $G_{rhs}$ are respectively feed water flow, cold reheat steam flow, superheater desuperheating water flow and reheater desuperheating water flow, $t/h$; $I_{ms}$, $I_{fw}$, $I_{hrh}$, $I_{cr}$, $I_{shs}$, $I_{rhs}$ are respectively main steam enthalpy, feed water enthalpy, reheat steam enthalpy, cold reheat steam enthalpy, superheater desuperheating Water enthalpy and reheater desuperheating Water enthalpy, $kJ/kg$; $P_e$ is the active power of generator, $MW$; $B_f$ is the coal consumption rate of unit, $g/(kW.h)$; $\eta_b$ is boiler efficiency, $\%$; $\eta_p$ is pipeline efficiency, $\%$.

Under rated conditions, the influence of emergency hydrophobic leakage of HP heater on test results is calculated by feedwater flow and condensate flow, respectively. The calculation results are shown in Table 1 when the emergency hydrophobic leakage is 10 t/h.

**Table 1.** Influence of HP emergency hydrophobic leakage on test results.

| Flow benchmark | Result                        | Heat consumption rate $kJ/(kW.h)$ | Coal Consumption Rate for Power Generation $g/(kW.h)$ |
|----------------|-------------------------------|----------------------------------|-----------------------------------------------|
| Feed water     | Leakage is not considered     | 8273.00                          | 309.93                                        |
|                | NO.1 HP heater Emergency      | 8272.00                          | 309.89                                        |
|                | hydrophobic leakage is 10t/h  |                                  | Deviation 1.00                                | 0.04                                          |
| Condensate     | Leakage is not considered     | 8273.00                          | 309.93                                        |
| water flow at  | NO.1 HP heater Emergency      | 8182.94                          | 306.55                                        |
| the deaerator  | hydrophobic leakage is 10t/h  |                                  | Deviation 90.06                                | 3.37                                          |
| inlet          | NO.2 HP heater Emergency      | 8177.71                          | 306.36                                        |
|                | hydrophobic leakage is 10t/h  |                                  | Deviation 95.29                                | 3.57                                          |
|                | NO.3 HP heater Emergency      | 8170.79                          | 306.10                                        |
|                | hydrophobic leakage is 10t/h  |                                  | Deviation 102.21                               | 3.83                                          |

When the flow benchmark is feed water, NO.1 HP heater emergency hydrophobic leakage will cause the calculation of NO.2 HP heater intake steam flow to be small, the calculation of reheater heat absorption to be large, and the heat consumption rate to be high. However, it has little influence on the test results. NO.1 HP heater emergency hydrophobic leakage for 10 t/h will lead to an increase in heat consumption rate of 1 kJ/(kW.h) and coal consumption rate of 0.04 g/(kW.h); NO.1 and NO.2 HP heater emergency hydrophobic leakage does not affect the calculated value of circulating heat absorption, so it has no influence on the calculation of test results.

When the flow benchmark is Condensate water flow at the deaerator inlet, The HP heater emergency hydrophobic leakage will increase the heat entering deaerator during the calculation of deaerator heat balance, thus resulting in larger feed water flow and higher heat consumption. NO.1 HP heater emergency hydrophobic leakage for 10 t/h will lead to an increase in heat consumption rate of 90.06 kJ/(kW.h) and coal consumption rate of 3.37 g/(kW.h). NO.2 HP heater emergency hydrophobic leakage for 10 t/h will lead to an increase in heat consumption rate of 95.29 kJ/(kW.h) and coal consumption rate of 3.57 g/(kW.h). NO.3 HP heater emergency hydrophobic leakage for 10 t/h will lead to an increase in heat consumption rate of 102.21 kJ/(kW.h) and coal consumption rate of 3.83 g/(kW.h).

Therefore, when the performance test is based on the feed water flow, HP heater emergency hydrophobic leakage has little influence on the calculation of the test results; when the performance test is based on the condensate flow at the deaerator inlet, any HP heater emergency hydrophobic leakage will lead to the calculation of the test results being too large.
3. The influence of HP heater emergency hydrophobic leakage on the economy of the unit itself

3.1. Calculating Model of Equivalent Heat Drop Method

The HP heater emergency hydrophobic leakage will result in deviation of performance test results, which does not represent the impact on unit economy. Because HP heater emergency hydrophobic leakage is not easy to measure, it is difficult to quantitatively analyze its influence by thermodynamic test method. Equivalent thermal drop method is one of the main methods for quantitative calculation of thermal system of thermal power units in China. [7]. This paper uses this method to analyze the impact of HP heater emergency hydrophobic leakage on the economy of the unit itself.

The changes of work and heat absorption caused by HP heater emergency hydrophobic leakage are expressed by the following formulas:

\[ \Delta H = \alpha_f \left( \sum_{r=j+1}^m \gamma_r \eta^0_r + \sum_{r=m+1}^n \tau_r \eta^0_r \right) \]  
\[ \Delta Q = \alpha_f \sum_{r=j+1}^m \frac{\gamma_r \Delta q_{n-r}}{q_r} \]  

In the formula, \( \alpha_f \) is the proportion of HP heater emergency hydrophobic leakage to the main steam flow; \( \gamma_r \) is the drainage heat of the upper heater \( r \) in heater \( r-1 \); \( \eta^0_r \) is extraction efficiency of \( r \)-stage using the variable heat calculation method; \( \tau_r \) is the enthalpy rise of heater \( r \); \( m \) is the number of the extraction stage where the deaerator is located; \( q_r \) is the exhaust heat of the extraction stage \( r \); \( \Delta Q_{n-r} \) is the heat change caused by extraction section \( r \) squeezing out 1 kg steam in the reheater.

The effect of any local change in the thermodynamic system on the unit economy, i.e. the relative change of the unit thermal economy \( \delta \eta_l \) is expressed by the following formulas.

\[ \delta \eta_l = \frac{\Delta H - \Delta Q}{H + \Delta H} \]  

In the formula, \( \Delta H \) is the variation of work; \( \Delta Q \) is the variation of circulating heat absorption; \( \eta_l \) is the circulating heat efficiency of steam turbine generator set.

3.2. Calculation Results

Taking a domestic imported 300MW unit as an example, the effects of #1, #2, #3 HP heater emergency hydrophobic leakage on unit economy are calculated by equivalent heat drop method, respectively. The results are shown in Table 2. 10 t/h of #1, #2, #3 HP heater emergency hydrophobic leakage will increase the coal consumption rate by 0.63g/(kW.h), 0.43g/(kW.h), 0.31g/(kW.h), respectively.

Table 2. Influence of HP heater emergency hydrophobic leakage on the unit economy

| Item | Variation of work \( \Delta H \) kJ/kg | Variation of circulating heat absorption \( \Delta Q \) kJ/kg | Relative variation of device efficiency \( \delta \eta_l \) | Relative variation of heat consumption rate \( \Delta q \) kJ/(kW.h) | Relative variation of coal consumption rate \( \Delta b \) g/(kW.h) |
|------|-----------------------------------|----------------|----------------|------------------|------------------|
| NO.1 HP heater Emergency hydrophobic leakage is 10t/h | 2.76 | 0.51 | 0.002117 | 16.71 | 0.63 |
| NO.2 HP heater Emergency hydrophobic leakage is 10t/h | 1.73 | 0 | 0.001449 | 11.44 | 0.43 |
| NO.3 HP heater Emergency hydrophobic leakage is 10t/h | 1.26 | 0 | 0.001053 | 8.32 | 0.31 |
4. Conclusion

In unit performance test, HP heater emergency hydrophobic leakage will cause errors in calculation of flow through steam turbine, resulting in deviation in calculation of test results. When the feed water flow is the flow benchmark, it has less influence on the results; when the condensate water flow at the deaerator inlet is the flow benchmark, it has greater influence.

Equivalent heat drop method is used to analyze the influence of HP heater emergency hydrophobic leakage on the unit economy. When the performance test is carried out on the basis of condensate flow at the deaerator inlet, the deviation of test results caused by calculation is much greater than that caused by leakage on the economy of the unit itself.

In order to ensure the accuracy of performance test results and the economy of unit operation, the power plant can take advantage of the opportunity of unit maintenance to replace the leaking emergency hydrophobic pneumatic regulating valve, or to change the manual stop valve before the regulating valve into an electric stop valve with better tightness. The electric stop with automatic signal can ensure the safe operation of the unit at the same time.

References

[1] Tikuan Zheng, Thermal Power Plant, China Electric Power Press, BeiJing, 2003.
[2] Junfen Wu, Talking about HP drainage System, Annual Conference on HVAC Dynamics in Zhejiang Province and Annual Conference on HVAC in Hangzhou, PP. 212-214.
[3] Weihong Guan, Wei Zhang, Yanqin Kang, Improvement and analysis on HP heater critical hydrophobic Watergate mistakenly opened in 330MW units, Northeast Electric Power Technology, 2014(11), PP. 15-16.
[4] Delin Li, Haoran Chen, Wanjun Tian, Experimental research on drainage system and operation mode of introduced 300MW steam turbine, Excellent Papers Collection of Anhui Institute of Electrical Engineering, 2002-2003, PP. 213-216.
[5] ASME PTC6-2004, Steam Turbines Performance Test Codes.
[6] GB/T 8117-2008, Steam Turbines Thermal Performance Test Acceptance Codes.
[7] Wanchao Lin, Theory of energy saving in thermal system of thermal power plant, Xi’an Jiaotong University Press, Xi’an, 1994.