The vacuum system reform and test of the super-critical 600mw unit

Tao YAN, Zhonghai WAN, Jin LU, Wen CHEN, Wen CAI
Jiang Xi Electric Power Science & Research Institute, Nanchang 330096, Jiangxi Province, China

Abstract: The deficiencies of the designed vacuum system of the super-critical unit is pointed out in this paper, and then it is reformed by the steam ejector. The experimental results show that the vacuum of the condenser can be improved, the coal consumption can be reduced and the plant electricity consumption can be lowered dramatically at a small cost of the steam energy consumption. Meanwhile, the water-ring vacuum pumps cavitation problems can be solved.

1. Introduction
The typical configuration of the super-critical 600MW unit vacuum system is often equipped with two low pressure cylinders, two condensers, and three 50% capacity water-ring vacuum pumps. The running method of the water ring vacuum pumps is 2 pumps run with 1 backup. The water-ring vacuum pumps is usually designed to meet the demands of start-up and shut-off conditions, which will bring about a large margin of the vacuum pumps output, and unnecessary power consumption. On the other hand, as the ambient temperature increases, the risk of the vacuum pumps cavitation risks will also increase, which will lower the reliability of the unit. In this paper, the steam injector is used to reform the vacuum system.

2. Mathematical model of condenser vacuum
Under the start-up and shut-off conditions, the condenser vacuum is produced by the large output of vacuum pumps. Meanwhile, the vacuum is formed through the way when steam becomes water while the turbine is loaded. They are very different.

The mathematical models of the condenser vacuum are shown in equation 1, 2, and 3 when the turbine is loaded.

\[ p_c = f(t_0, \Delta t, \sigma t) \]  
(1)
\[ \Delta t = \frac{h_t - h_f}{c_p D_w / D_c} \]  
(2)
\[ \sigma t = \frac{\Delta t}{\Delta K e^{cD_w}} - 1 \]  
(3)

As:
\[ p_c \] - vacuum of condenser
\[ t_0 \] - inlet water temperature of the condenser
\[ \Delta t \] - the water temperature increase of the condenser
\[ \sigma t \] - the temperature difference of the condenser
3. Reform necessity

3.1. Large amount of power consumption
There are two profiles of the vacuum pumps as it is analyzed above, listed in Table 1.

| profile      | status | Volume of non-condensate gas of the condenser | The output of vacuum pumps |
|--------------|--------|-----------------------------------------------|----------------------------|
| 1. Run up or shut off | instant | large                                        | big                         |
| 2. load      | steady | little                                        | small                       |

The water-ring vacuum pumps are designed according to the 1st profile, however, time for the turbine run-up and shut-off is very short, as the turbine often operates in the 2nd profile, therefore, this will lead vacuum pumps to a large amount of power consumption. On the other hand, the super-critical 600MW unit vacuum system has two condensers, which determines the unit must operate two vacuum pumps while another one is backup, resulting in much more power consumption.

3.2. Low economic performance and reliability
As analyzed above, it can be seen that the vacuum pumps of the condenser is affected by the ambient temperature, determined by the steam saturation pressure corresponding to the sealed cooling water temperature. It is known that the ambient temperature is higher in summer than in winter, which will bring about cavitation phenomenon, resulting in decreasing the unit economy, increasing pumps vibration, and decreasing the unit reliability.

4. Reform and test
With the auxiliary steam as the power steam, vacuum of the condenser is produced through sucking mixed gas by the steam injector, then the steam is condensed into water, who flows to the hot well of the condenser, and the remaining non-condensing gas will be pumped out by a small vacuum pump. The outlet pressure of the steam injector is designed 10 – 13kPa (a), which is higher than before to avoid the vacuum pump cavitation. It is shown in figure 1.
Figure 1. Reform resolution for the vacuum system

After the reform, those original 3 vacuum pumps are set to backup to fulfill the needs during the unit start-up and shut-off. In order to compare the reform effectiveness, test is conducted as below, in which the first two hours of each profile are set for the original vacuum system while the left two hours for the reformed system. Test results are shown in table 2.

| Profile | 600MW | 540MW | 450MW | 350MW |
|---------|-------|-------|-------|-------|
| Vacuum (kPa) | -92.64 | -92.80 | -93.17 | -93.52 | -93.83 | -94.43 | -95.01 | -95.87 |
| Vacuum pump current (A) | 375.2 | 67.6 | 373.6 | 67.6 | 370.7 | 67.6 | 368.5 | 67.6 |
| Steam consumption (kg/h) | 0 | 662 | 0 | 738 | 0 | 845 | 0 | 986 |

Tips: the left column of each profile is the results before reform, while the right is after reform.

Table 2. Test results before and after the reform

Figure 2. The vacuum of the condenser before and after the reform.

Figure 3. Current of vacuum pumps before and after the reform.
From the test results we can see that after reform, the vacuum of the condenser is increased significantly, vacuum pump current decreased dramatically, with an expense of a small amount of steam. As can be seen from the figure, conclusion can be found that with the load reduction, vacuum of the condenser increase more while vacuum pump current cuts steadily and steam consumption increases slightly.

5. Thermal economy

From the above test results, it can be seen that the vacuum of the unit is increased by 0.49kPa on average, resulting in the coal consumption rate of the unit reduced by about 1.29g / kW.h after the vacuum system reform. According to the available 5000 hours one year, it will bring about saving 1.7 million RMB, the vacuum pumps current reduces about 304.4A on average, which will lead to the annual energy-saving income of about 330,000RMB. With the steam injector consumption of auxiliary steam about 807.75kg/h averagely, it will cost about 280,000RMB. Totally, after the vacuum system reform, it will bring about 1.78 million RMB. Most important of all, it brings about not only saving money, but also reducing energy consumption and cutting coal emission.

6. Conclusion

It is reasonable for the vacuum system reform mentioned in this article. After the vacuum system reform, the vacuum of the condenser will be increased higher, with coal consumption reduced, and power consumption decreased, through which energy consumption of the power plant reduces and coal emission cuts. Meanwhile, it will avoid the vacuum pumps cavitation, which improves the safety and reliability of the unit operation.

Reference

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