Analysis of the Reasons for Insufficient Output of an Ultra-supercritical Unit

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Abstract. An ultra-supercritical steam turbine unit is N660-25/600/600 type intermediate reheat, single-shaft, three-cylinder four-row steam and double-pressure condensing steam turbine manufactured by Dongfang Steam Turbine Co., Ltd. Through relevant certification, the nameplate capacity of the unit was expanded to 700MW. Since the winter of this year, the unit has had insufficient output. According to the historical data of the site, the reasons for the insufficient output of the unit were analyzed. The diagnosis conclusion is that the reduction of the flow area of the high-pressure cylinder is the main reason for the limited output of the unit.

1. Introduction
The high and medium pressure cylinders of the unit are combined with the cylinder and flow to the opposite double-layer cylinder structure; there are two low-pressure cylinders, A-LP and B-LP, which are double-split type, and each low-pressure part has a separate inner cylinder.

The number of flow passages of the unit is arranged as follows: the total number of flow stages is 42: the number of flow stages of the high pressure cylinder is 1+7; the number of flow stages of the medium pressure cylinder is 6; the number of flow stages of the low pressure cylinder is 2×2×7. Since the winter of this year, Unit 1 has had insufficient output. According to the historical data of the site, the reasons for the insufficient output of Unit 1 were analyzed.

2. Field test conditions
According to the principle of steam turbine, the DCS historical data is extracted (the high-load cylinder main valve position command position is similar to the high-load working condition parameter).

| Item                  | July 27, 2017 | April 2, 2018 | January 5, 2019 |
|-----------------------|--------------|--------------|-----------------|
| Unit load (MW)        | 700.376      | 688.024      | 675.722         |
| Total valve position command (%) | 100.25     | 99.96        | 99.56           |
3. Analysis process and diagnosis basis
It can be seen from Table 2 that the efficiency of the high-pressure cylinder has been decreasing month by month, and the efficiency of the medium-pressure cylinder has fluctuated since the unit was put into production.

Generally speaking, when the relative internal efficiency method is used to judge whether there is a fault in the flow passage portion, the measured relative internal efficiency of each group is compared with the reference relative internal efficiency under the corresponding load to diagnose the fault occurrence location and the fault severity. However, the shortcoming of this method is that it cannot distinguish the specific type of fault - wear or blockage; on the other hand, the overall relative internal efficiency of the steam turbine and the relative internal efficiency of each group become more complicated due to the reheat phenomenon.

| Table 2. Cylinder efficiency change |
|------------------------------------|
| Item                             | July 27, 2017 | April 2, 2018 | January 5, 2019 |
|-----------------------------------|---------------|---------------|-----------------|
| Unit load (MW)                    | 700376        | 688024        | 675722          |
| Total valve position command (%)  | 100.25        | 99.96         | 99.56           |
| High pressure cylinder efficiency (%) | 83.63        | 83.16         | 82.43           |
| Medium pressure cylinder efficiency (%) | 92.90        | 92.37         | 92.97           |

4. Change and diagnosis of partial pressure ratio of flow passage
The through-flow portion of the steam turbine is the portion through which the steam flows and works, including the nozzles, the diaphragms, and the stationary and moving blades and the corresponding steam seals[1-2].

In order to facilitate the accurate analysis of the problem, the pressure of each monitoring section is taken as the demarcation point, and the flow passage part of the unit (including the steam distribution mechanism) is divided into the main adjustment section, the adjustment grade group, and the first stage of the high pressure cylinder, the second stage of the high pressure cylinder, the third stage of the medium pressure cylinder and other parts.

When there is no change in the flow passage part of the condensing steam turbine, the pressure ratio of each monitoring section of the steam turbine remains essentially the same before and after the flow change if only the working condition changes due to the flow change [3].

The high-parameter steam turbine has a small flow area and is extremely sensitive to the effects of fouling (poor water quality) and clogging (parts such as steam seals). When fouling or clogging occurs, the flow area of the turbine is reduced. If the main steam parameters are kept constant, the steam flow entering the turbine will be reduced, and the output of the unit will be reduced accordingly. In order to maintain output, it is necessary to open a large inlet valve or overpressure to enter more steam flow, which will inevitably increase the pressure drop of the fouling level or the plugging stage, that is, the pressure ratio becomes smaller.

Generally, for an impulsive steam turbine, when the pressure ratio changes by \( \geq 5\% \), the scale is considered to be fouling; for the reaction turbine, when the pressure ratio changes by \( \geq 3\% \), the scale is considered to be fouling.

It can be seen from Table 3 that compared with the data of July 27, 2010 and January 5, 2012, the pressure ratio of the first stage of the high pressure cylinder varies by more than 5%; the change of the pressure ratio of the adjustment stage and the second stage pressure ratio of the high pressure cylinder is also significantly larger than the other groups [4].

| Table 3. Change in the ratio of pressure on July 27, 2017 and January 5, 2019 |
|-------------------------------------|------------------|-----------------|-----------------|
| Item                                | July 27, 2017    | January 5, 2019 | Pressure ratio Change (%) |
|-------------------------------------|------------------|-----------------|-----------------|
| Unit load (MW)                      | 700376           | 675722          | /               |
| Total valve position command (%)    | 100.25           | 99.56           | /               |
| Item                                           | July 27, 2017 | January 5, 2019 | Pressure ratio Change (%) |
|-----------------------------------------------|---------------|-----------------|--------------------------|
| CV1 valve position (%)                        | 100.00        | 100.00          | /                        |
| CV2 valve position (%)                        | 100.00        | 100.00          | /                        |
| CV3 valve position (%)                        | 100.00        | 100.00          | /                        |
| CV4 valve position (%)                        | 72.36         | 77.97           | /                        |
| Main steam pressure (MPa)                     | 24.71         | 25.11           | /                        |
| Steam pressure after CV1 valve               | 24.11         | 24.24           | /                        |
| Steam pressure after CV2 valve               | 24.22         | 24.64           | /                        |
| Steam pressure after CV3 valve               | 24.12         | 24.27           | /                        |
| Steam pressure after CV4 valve               | 23.97         | 24.43           | /                        |
| Regulating stage pressure (MPa)              | 20.32         | 20.09           | /                        |
| No. 1 extraction pressure (MPa)              | 8.33          | 7.81            | /                        |
| No. 2 extraction pressure (MPa)              | 5.52          | 5.06            | /                        |
| Reheater steam pressure (MPa)                | 5.14          | 4.71            | /                        |
| No. 3 extraction pressure (MPa)              | 2.76          | 2.51            | /                        |
| No. 4 extraction pressure (MPa)              | 1.35          | 1.23            | /                        |
| No. 5 extraction pressure (MPa)              | 0.49          | 0.46            | /                        |
| No. 6 extraction pressure (MPa)              | 0.27          | 0.24            | /                        |
| No. 1 regulating valve pressure ratio (%)    | 97.58         | 96.54           | 1.07                     |
| No. 2 regulating valve pressure ratio (%)    | 97.99         | 98.15           | 0.16                     |
| No. 3 regulating valve pressure ratio (%)    | 97.60         | 96.65           | 0.97                     |
| No. 4 regulating valve pressure ratio (%)    | 97.00         | 97.30           | 0.31                     |
| Adjustment stage pressure ratio (%)          | 82.21         | 80.02           | 2.67                     |
| First stage pressure ratio (%)               | 41.01         | 38.89           | 5.18                     |
| Second stage group pressure ratio (%)        | 66.21         | 64.76           | 2.20                     |
| Reheater pressure ratio (%)                  | 93.20         | 93.12           | 0.09                     |
| Third stage group pressure ratio (%)         | 53.62         | 53.33           | 0.55                     |
| Fourth stage pressure ratio (%)              | 49.05         | 49.09           | -0.08                    |
| Fifth stage group pressure ratio (%)         | 36.40         | 36.98           | -1.59                    |
| Sixth stage pressure ratio (%)               | 53.91         | 53.55           | 0.67                     |

It can be seen from Table 4 that compared with the data of April 2, 2018 and January 5, 2019, the pressure ratio of the first stage of the high pressure cylinder varies by more than 3%; the change of the pressure ratio of the adjustment stage and the second stage pressure ratio of the high pressure cylinder is also significantly larger than the other groups.

Table 4. Change in the ratio of pressure on April 2, 2018 and January 5, 2019

| Item                                           | April 2, 2018 | January 5, 2019 | Pressure ratio Change (%) |
|------------------------------------------------|---------------|-----------------|--------------------------|
| Unit load (MW)                                 | 688024        | 675722          | /                        |
| Total valve position command (%)               | 99.96         | 99.56           | /                        |
| CV1 valve position (%)                         | 100.00        | 100.00          | /                        |
| CV2 valve position (%)                         | 100.00        | 100.00          | /                        |
| CV3 valve position (%)                         | 100.00        | 100.00          | /                        |
| CV4 valve position (%)                         | 87.44         | 77.97           | /                        |
| Main steam pressure (MPa)                      | 24.71         | 25.11           | /                        |
| Steam pressure after CV1 valve                | 24.11         | 24.24           | /                        |
| Steam pressure after CV2 valve                | 24.22         | 24.64           | /                        |
| Steam pressure after CV3 valve                | 24.12         | 24.27           | /                        |
| Steam pressure after CV4 valve                | 24.22         | 24.43           | /                        |
| Item                                      | April 2, 2018 | January 5, 2019 | Pressure ratio Change (%) |
|------------------------------------------|--------------|----------------|--------------------------|
| Regulating stage pressure (MPa)          | 20.39        | 20.09          | /                        |
| No.1 extraction pressure (MPa)           | 8.19         | 7.81           | /                        |
| No.2 extraction pressure (MPa)           | 5.28         | 5.06           | /                        |
| Reheat steam pressure (MPa)              | 4.92         | 4.71           | /                        |
| No.3 extraction pressure (MPa)           | 2.63         | 2.51           | /                        |
| No.4 extraction pressure (MPa)           | 1.30         | 1.23           | /                        |
| No.5 extraction pressure (MPa)           | 0.47         | 0.46           | /                        |
| No.6 extraction pressure (MPa)           | 0.25         | 0.24           | /                        |
| No. 1 regulating valve pressure ratio (%)| 97.62        | 96.54          | 1.11                     |
| No. 2 regulating valve pressure ratio (%)| 98.11        | 98.15          | -0.04                    |
| No. 3 regulating valve pressure ratio (%)| 97.73        | 96.65          | 1.11                     |
| No. 4 regulating valve pressure ratio (%)| 96.62        | 97.30          | -0.71                    |
| Adjustment stage pressure ratio (%)      | 81.38        | 80.02          | 1.67                     |
| First stage pressure ratio (%)           | 40.14        | 38.89          | 3.12                     |
| Second stage group pressure ratio (%)    | 64.49        | 64.76          | -0.41                    |
| Reheater pressure ratio (%)              | 93.15        | 93.12          | 0.04                     |
| Third stage group pressure ratio (%)     | 53.56        | 53.33          | 0.43                     |
| Fourth stage pressure ratio (%)          | 49.20        | 49.09          | 0.24                     |
| Fifth stage group pressure ratio (%)     | 36.64        | 36.98          | -0.94                    |
| Sixth stage pressure ratio (%)           | 53.66        | 53.55          | 0.22                     |

5. Other factors
Other factors affecting the output of the unit are basically in the normal range, such as the main steam pressure, the main steam temperature, the reheat steam temperature, the vacuum, the feed water temperature, the heater end difference, the pressure loss of each extraction pipeline, the system leakage, etc. [5].

6. Conclusion
By recalling the historical data before and after the fault, the cause of the reduction in unit output can’t be analysed by the change in cylinder efficiency does not accurately. The pressure ratio of the high pressure cylinder is reduced, which means that the flow area of the high pressure cylinder is reduced, and the fault point can be accurately located. The specific cause of the reduction in the area of the flow passage is also determined by the cylinder inspection.

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