Study on water erosion and preventive measures of last stage blade of steam turbine

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ABSTRACT- In the background of carbon peak and carbon neutralization, most thermal power plants are more involved in peak regulation and even in-depth peak regulation in order to absorb new energy such as wind power and Solar power. When the turbine is running under low load, the exhaust pressure decreases, which leads to the increase of exhaust humidity. More and more turbine blades have water erosion. The erosion of the last stage blades will worsen the dynamic performance of the turbine, increase the risk of the last stage blade fracture, and threaten the safe operation of the turbine. This paper studies the mechanism of the last stage blade erosion of steam turbine, and analyzes the main factors which influence the erosion with examples. Combined with the mechanism of water erosion, the relevant preventive measures are made for reference of power supply plant.

1. Introduction
With China's firm determination to deal with climate change, in order to achieve 2030 carbon peak and 2060 carbon neutralization, the power grid needs to fully absorb new energy such as wind power and photovoltaic. At present, most thermal power plants are more involved in peak regulation or even in-depth peak regulation. When the steam turbine operates under the condition of deep peak regulation, the exhaust steam pressure decreases, resulting in the increase of exhaust steam humidity, and more and more last stage blades of the steam turbine have water erosion. The water erosion of the last stage blade will deteriorate the aerodynamic performance of the dynamic and static cascades, reduce the stage efficiency, cause stress concentration due to the serrated burr formed by water erosion, and increase the risk of fracture of the last stage blade. In a word, water erosion has a great impact on the thermal economy, safety and reliability of steam turbine operation.

In literature [5], Liu Zhijiang and others briefly introduced the mechanism and serious harm of the erosion damage of the last stage long blade, and emphatically pointed out that in recent years, with the new large units participating in peak shaving operation with low load for a long time, the erosion damage of the steam outlet side of the last stage long blade has occurred quite commonly, and a wide range of erosion damage has also occurred on the steam inlet side of some units in the north, the corresponding preventive measures and the viewpoint that the strength and service life of the last stage blade should be comprehensively considered in the peak shaving operation of large units are put forward.

Yan Yupeng [6] discussed several important aspects of water erosion of metal materials of steam turbine moving blades: high-speed liquid-solid impact theory, water erosion failure mechanism, water erosion performance of materials and its experimental research. This paper introduces the research status, achievements, research means and development direction at home and abroad.

In this paper, the causes of water erosion on the steam inlet side of the last stage blade are vividly
given by using the velocity triangle, and the causes of aggravation of water erosion are analyzed through specific examples.

2. Analysis of water erosion
The last stages of the flow passage part of the low-pressure cylinder of the steam turbine are in the wet steam area, and small water droplets are entrained in the steam flow. When a part of the moving blade of the last stage of the steam turbine collides with small water droplets at high speed, high pressure will be generated. When this pressure exceeds the yield limit of the moving blade material, the blade will produce local plastic deformation and surface hardening. When this force acts on a certain part of the blade repeatedly until the fatigue limit of the blade material is reached, fatigue cracks begin to appear in some parts of the blade. When this operating condition continues, the crack will expand deeper, and finally the material at a certain part of the blade will separate from the surface to form water erosion in the shape of sawtooth.

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3. Influence of turbine operating state on blade water erosion
Because the absolute velocity of water droplets is slower than that of steam, the slower the absolute velocity \( C_1 \) is when the circumferential velocity \( u \) remains unchanged, the relative direction \( W_1 \) of water droplets entering the moving blade will change and hit the back arc of the moving blade, as shown in Fig. 1. At present, there are two common methods to reduce water erosion.

The first is to improve the water erosion resistance of the blade near the leading edge of the suction side at the top of the moving blade by means of EDM strengthening or brazing stellite alloy or local flame hardening; The second type is to design radial dehumidification tank on the surface of stationary blade and adopt hollow stationary blade dehumidification to reduce water droplets [9].

In addition to the above two types of water erosion protection measures, it can also reduce the direct impact of water droplets on the moving blade and reduce the water erosion of the blade by increasing the water droplet speed, such as increasing the static and dynamic clearance and the forward sweep of the top of the stationary blade [10].
In reference [1], the influence of inlet steam pressure and temperature changes of low pressure cylinder on final stage humidity is numerically simulated, and the results are shown in Figure 2.

![Fig.1 Inlet side velocity triangle](image1)

Fig. 1 Inlet side velocity triangle

It can be seen from Fig. 2 and Fig. 3 that with the increase of inlet steam temperature, the decrease of inlet steam pressure, the increase of exhaust steam pressure and the decrease of unit power, the humidity at the outlet of the last stage of the unit decreases gradually. This law is consistent with the theoretical analysis. The results also show that when there is no extraction dehumidification, the inlet pressure, inlet temperature and exhaust pressure have different effects on the final stage humidity.

Among them, the inlet temperature has the greatest effect on the final stage humidity, followed by the inlet pressure and the exhaust pressure.
Under the conditions of low load rate, large heating and steam extraction in winter and deep peak shaving, the steam turbine exhaust pressure is small. According to relevant research, the humidity of the last stage of LP cylinder will increase, which will aggravate the water erosion of the last stage blade of steam turbine.

4. Case analysis
The model of 1-4 units in a power plant is N300-16.7/537/537. The high and medium pressure part adopts combined cylinder and high pressure cylinder double-layer structure. The high and medium pressure steam inlet is arranged in the middle of the high and medium pressure cylinder; The two exhaust steam of the low-pressure cylinder are divided symmetrically, the length of the last stage moving blade is 851mm, and the annular exhaust steam area of the last stage blade is 2*6.69m2.

The operating load of 1-4 units is between 60% - 70% throughout the year. During the maintenance, it is found that the last stage blades of the four units are subject to water erosion in varying degrees, of which the water erosion of 3 unit is more serious, as shown in Figure 4.

![Fig.4 Water erosion diagram of last stage blade](image)

According to the data in the supervision daily statistical report, it is found that the reheat temperature of units 1-4 is generally low, and the statistical results are shown in Tab. 1.

| Units   | Mouth | Jan. | Feb. | Mar. | Apr. | May. | Ju. | Aug. | Nov. |
|---------|-------|------|------|------|------|------|-----|------|------|
| Unit 1  |       | 530  | 531  | 532  | 525  | 531  | 537 | -    | 529  |
| Unit 2  |       | 527  | 529  | 535  | 536  | 529  | -   | 538  | 535  |
| Unit 3  |       | 529  | 512  | 527  | 531  | 512  | 532 | 534  | 536  |
| Unit 4  | -     | 522  | 529  | 530  | 522  | 526  | 528 | 533  |      |

![Fig.5 Reheat temperature trend of 1-4 Units](image)

It can be seen from Tab. 1 and Fig. 5 that the average reheat temperature of unit 3 is about 11 °C lower than the design value, the maximum temperature deviation is 25 °C, the average reheat temperature of unit 4 is about 10 °C lower than the design value, and the maximum temperature...
5. Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) Under the conditions of low unit load rate, large heating steam extraction in winter and deep peak shaving, the exhaust pressure decreases, the exhaust humidity of low-pressure cylinder increases and water erosion intensifies.

(2) The inlet steam temperature of LP cylinder has a great influence on the exhaust steam humidity, followed by the inlet steam pressure and the exhaust steam pressure. Adjust the operation mode of circulating water system in time under low load or deep peak shaving to ensure that the exhaust pressure is within a reasonable range, and do not blindly pursue low exhaust pressure.

(3) The reheat temperature is low. When the efficiency of the intermediate pressure cylinder remains unchanged, the corresponding steam temperature entering the low pressure cylinder is also low. When the inlet steam temperature is low, the steam humidity at the corresponding last stage moving blade also increases, aggravating the water erosion of the last stage blade. For reducing the steam humidity of the last few stages, the reheat temperature needs to approach the design value.

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