Failure and protection of metal equipment in Pumped Storage Power Station

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Abstract. In order to ensure the safe and stable operation of pumped storage hydropower station equipment, it is very important to carry out regular maintenance of metal equipment. Because of the stress concentration, the stress state and the complex environment, the variable section of the turbine runner blade is easy to produce cracks, which endangers the safety of the equipment. By fully analyzing the characteristics, failure modes and causes of blade cracks, and putting forward effective detection, treatment and protection measures, cracks can be effectively prevented, which will play a key role in future equipment maintenance and repair.

1. Introduction

At present, thermal power generation is still the main power generation mode, photovoltaic, wind power, nuclear power and other new energy power generation modes also gradually account for a large proportion. However, the instability of photovoltaic and wind power generation requires the grid to have better peak regulation capacity. Thermal power unit has good peak regulation performance, but the severe load change and frequent start and stop caused by deep peak regulation pose a great threat to the life of thermal power unit equipment [1]. The pumped storage power station also has good peak regulation performance. At the same time, it can also minimize the load fluctuation and start stop frequency of the thermal power unit in the power grid, ensure the stable operation of the thermal power unit under better working conditions, save energy consumption, reduce harmful gas emissions, and play an important role in technology and economy [2].

The periodic maintenance of pumped storage power station equipment can discover the existing problems of the equipment in time, prevent potential risks, improve the utilization rate of the equipment and reduce the abnormal shutdown [3]. For the inspection and supervision of metal equipment of pumped storage power station, DL/T 1318-2014 specification for metal technical supervision of hydropower plant shall be implemented, and the specific requirements for equipment performance shall also refer to other regulations and standards quoted in the specification. The main parts of metal technical supervision of pumped storage power station include turbine parts, generator main parts, bolt fasteners, and other metal auxiliary structural parts and gas, water and oil pipelines. According to the regulations on maintenance of power plants issued by the former Ministry of water resources and power, the generator units are subject to two minor repairs every year and one major repair every four to six years, and the pumped storage power station is required to take the maintenance work seriously in strict accordance with the maintenance cycle and requirements, so as to achieve the required repair at maturity.
Based on the metal inspection and supervision of the pumped storage power station, this paper analyzes the failure forms and causes of the main metal parts of the pumped storage power station, and puts forward the corresponding prevention and control measures, so as to provide a basis for the safety of the equipment in the operation and maintenance process of the pumped storage power station, as well as in the maintenance process, in order to ensure the safe and stable operation of the equipment.

2. Failure cases of runner and blade

According to the provisions of DL/T 1318-2014 [4], the inspection parts of the water turbine include: large shaft, runner, discharge cone, guide vane and operating mechanism, etc.; the inspection parts of the generator include: large shaft, rotor, fan blade, frame, etc.; there are also bolt fasteners, gates, valves, pipes, etc. According to the inspection of metal parts of pumped storage power station in the industry, the main parts prone to defects and failures are runner and blade.

Itumbiara in Brazil. After the hydropower station [5] is put into operation for a short time, there are many cracks on the fixed guide vane. Through analysis, it is considered that the frequency of Kameng vortex at the outlet of the guide vane is similar to the natural frequency of the fixed guide vane, causing resonance. After 1300 hours of operation of unit 6 of Xiaolangdi Hydropower Station in China, there are 13 blades with cracks near the upper crown near the outlet of the blade, and most of them are through defects. Striation, about 100-400mm long, is one of the important reasons for the cracks [6]. It is also because the frequency of the Carmen vortex near the outlet of the blade is close to the natural frequency of the runner, and the induced vibration force causes the fatigue cracks of the blade. In a hydropower station designed by Leningrad plant in Russia [7], after six years of operation, there are many through cracks on the water edge of the blades. During the overhaul of Wuqiangxi Hydropower Station [8], 7 blades were found to have through cracks near the upper crown of the water edge of the blades. Through analysis, the cracks in the above two cases are typical damage fatigue cracks, and the main reason for the cracks is the blades Dynamic stress and residual stress.

During the overhaul of Hohhot pumped storage unit 4, a number of circular defects were found at the joint of 9 runner blades with the upper crown and lower ring, with the diameter of defects distributed between 1.1mm and 1.9mm. There are also two linear defects at the joint of blades and upper crown, with the length of 2.9mm and 2.1mm respectively, as shown in Figure 1. Such defects pose a potential threat to the safe and stable operation of the turbine.

3. Features and detection of cracks in runner and blade

Based on the research on the external environment and internal characteristics of the cracks in the industry, it is agreed that the cracks on the runner and blade can be classified into two categories [9]. One is the cracks produced by the equipment after a short period of operation, also known as unexpected abnormal damage cracks, which are mainly caused by rapid resonance, high frequency, large amplitude...
and occurrence of dynamic load. The other is the cracks on the runner and blade after a long period of operation under normal and stable working conditions, also known as the cracks generated in the expected life. Such cracks are fatigue cumulative damage cracks, which can only occur after the accumulation of fatigue damage reaches a certain degree.

3.1. Macro characteristics and on-site inspection of runner and blade cracks

Engineers and scholars have made practical and theoretical analysis on the generation of runner and blade cracks [10], and they believe that the blade fatigue cracks are most likely to occur in the following two variable cross-sections: the connection between the blade outlet edge and the upper crown, and the connection between the blade outlet edge and the lower ring, which are the parts where the maximum stress occurs and the most prone to fatigue damage.

In the actual test, the above parts are mainly subject to macro inspection and penetrant inspection. Through the surface inspection of the variable cross-section, we can find the defects such as pores and micro cracks in time to prevent accidents.

3.2. Micro characteristics and failure analysis of runner and blade cracks

According to the operation characteristics, the cracks of Francis turbine blades can be divided into regular cracks and irregular cracks. Most of the regular cracks have typical fatigue crack characteristics [11], and the fracture shape is composed of three parts: fatigue crack source area, fatigue crack growth area and instantaneous fracture area, which are "shell" or "beach" stripes. Most of the cracks are through cracks, extending to one side of the blade, with the same strike and irregular parabola shape. The angle between the cracks and the upper crown gradually changes to about 45 degrees. It is found by calculation that the angle between the direction of the maximum principal stress and the horizontal direction is about 90 degrees, approximately perpendicular to the crack section, which belongs to tensile stress. Irregular crack, irregular fracture shape, some tortoise crack, some brittle fracture, mostly due to material defects or sudden load changes.

When the cracks in blades or impellers grow and lead to failure, failure analysis is needed. Generally, the location of the crack source is determined by the micro analysis of the fracture surface, and the fracture property is defined according to the shape of the gold phase.

4. Cause analysis and prevention of runner and blade crack

4.1. High cycle fatigue failure under long term normal operation

In the long-term normal operation condition, the high cycle fatigue failure of the turbine blades with cracks is analyzed. Combined with the morphology and metallographic characteristics of the fracture, it can be seen that the fracture has typical fatigue failure characteristics. High cycle fatigue refers to the fatigue failure of parts under the cyclic load less than or far less than the material yield stress. Its main characteristics are: the stress is far less than the yield limit or strength limit of the material; brittle fracture, no significant plastic deformation; fatigue life is generally more than $10^5$ cycles. It can be judged that the runner and blade bear large alternating stress load for a long time.

At present, the main reason for the cracks of most turbine blades is the high cycle fatigue damage caused by long-term alternating load. On the one hand, it is necessary to fully consider the anti dynamic load performance of the blades in the design of the turbine, so that the runner blades can operate under small alternating stress; on the other hand, it is also necessary to consider the selection of the best materials, improve the hardness and strength of the blades, and improve their anti fatigue ability.

4.2. Unexpected abnormal damage

In the process of design and manufacture of water turbine, unexpected abnormal damage and damage require the water turbine to operate according to the design parameters. However, in the actual operation process, due to the environment, load and other factors, the operation condition will deviate from the optimal operation parameters, resulting in the excitation force frequency generated by the draft tube
vortex belt, Carmen vortex and blade channel vortex close to or equal to the natural frequency of the runner blade, which will cause the rapid resonance crack of the runner and the stress concentration part of the blade.

This kind of damage usually needs to take full account of the blade modal analysis in the design. For this kind of abnormal vibration, in order to prevent the occurrence of resonance, the modal analysis method needs to be used to make the natural frequency of the turbine blade avoid the interference force frequency such as Carmen vortex; on the other hand, try to ensure the stability of the operation condition, and carry out in the designed operation condition.

4.3. Welding residual stress causes failure of runner blade
In the manufacturing process, due to the influence of nonstandard welding process and inadequate post weld heat treatment, the runner blades still have large residual stress after being put into operation. When the residual stress is large, it will cause the runner and blades' micro cracks to expand rapidly, resulting in the cracks or fractures of the blades and accidents.

Generally, the fatigue damage of blade is caused by many factors (such as hydraulic pressure, resonance load, welding residual stress and so on). In practice, the stress of runner blade is usually less than the strength limit of blade material. However, due to the continuous action of dynamic load, the blade cracks after a long time.

5. Treatment and protection of runner and blade defects
The key to crack treatment is to find out the root cause of the crack and give the right remedy. Irregular cracks are generally easier to analyze. What is difficult is the regular cracks, and what are the reasons that play a leading role. The most powerful method is the dynamic stress test of the failure part. The frequency and amplitude of the main components of dynamic stress are decomposed from the stress spectrum, and then the corresponding hydraulic excitation source is traced out.

For the cracks that have been produced, first of all, carry out mechanical grinding to eliminate the crack defects. In order to prevent the crack from continuing to extend, crack stopping holes shall be made at both ends of the crack, and the hole diameter shall not be less than 6mm. When cleaning the crack, if there is a new growth trend, stop cleaning and add crack stopping holes.

When the grinding degree is large, repair welding shall be carried out for the damaged parts. During the repair welding process, strict welding process shall be formulated to ensure the effectiveness of welding repair from personnel, equipment and system.

At the same time, it can also spray anti-wear coating on the blade to enhance the anti-wear performance of the blade, reduce the possibility of micro cracks on the blade surface and reduce the source of cracks.

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