Cause analysis and Countermeasures for shaft fracture of closed pump

Jun Liu
State Grid Shandong Electric Power Research Institute, Jinan, China
*Corresponding author e-mail: sddlyjy@woyoxin.com

Abstract. Two 350MW supercritical wet cooling units in a power plant, the closed water pump adopts horizontal single-stage double suction split centrifugal pump. In recent two years, the shaft of the closed pump B of 1 unit has been fractured twice. In this paper, the fracture causes of the closed pump shaft are analyzed from the aspects of closed pump operation, material analysis and micro organization, and treatment measures are taken to solve the problem.

Key words: closed pump, pump shaft fracture, treatment measures.

1. Introduction
Pump is widely used in the production process of power plant, in addition to the use of a large number of types of use; as one of the main auxiliary equipment of the power plant, the pump plays an irreplaceable role in the normal operation of the unit. When the pump and its associated systems fail, they usually come down to four types: fracture, fatigue, friction and wear and leakage.

A thermal power Co., Ltd. has 2× 350MW supercritical units. The closed pump adopts horizontal single-stage double suction open centrifugal pump, with design flow of 1900 m³/h, design head of 0.45 MPa and shaft material of 40Cr. Each unit is equipped with two closed pumps. During normal operation, one is in operation and the other is standby. When one pump fails, the standby pump will start automatically and put into operation. The conveying medium (desalted water) of the closed circulating cooling water pump is taken from the condensate tank. After being pressurized by the closed circulating cooling water pump, the medium (desalted water) enters the heat exchanger of relevant equipment, and then returns to the inlet of the closed circulating cooling water pump to form a closed circulating water system. The make-up water of the system comes from the high expansion tank of the closed circulating water pump system. The design temperature of closed circulating cooling water is 38 °C, and the maximum temperature is 41 °C. The water quality of closed circulating cooling water system is desalted water, which is mainly used for cooling all rotating mechanical bearings, motors, oil coolers, generator coolers, etc.
2. Review of shaft fracture of closed pump

2.1. The shaft of B closed pump broke for the first time
On a certain day in April 2018, after the B closed pump of unit 1 completed the regular oil filling work of rotating equipment, the monitoring panel found that the bearing temperature of closed pump B was high. The local inspection showed that the operation of closed pump B was accompanied with abnormal sound, and there was a large amount of water leakage at the seal of the pump. The fracture surface of pump shaft is shown in Fig. 1.

2.2. The second fracture of pump shaft of B closed pump
In July 2019, before the pump shaft fracture, the unit load was 239.8mw, the external industrial steam supply flow was 285t / h, a condensate pump was in variable frequency operation, B closed pump was in normal operation, and a closed pump was in standby state. When water leakage is found at the shaft seal of B closed water pump, switch B closed pump to a closed water pump for operation, check the leakage of B closed water pump, tighten the cooling water union at the drive end, and start B closed water pump again, without leakage; at this time, the bearing temperature at drive end is 65.7 °C, and that at non driving end is 71.7 °C. There is an upward trend. In order to prevent the occurrence of safety accidents, close water pump B is switched to a The closed water pump was in operation, and the B closed water pump was disassembled and overhauled (the pump shaft was not broken during the disassembly). The non drive end bearing was replaced and the bearing grease at the drive end was replaced. After the center of the water pump was retested, the current was 27.9a. After three minutes of starting the closed pump B, the current decreased from 27a to 11a. The closed water pump B was shut down immediately and solved for the second time Physical examination showed that the pump shaft was broken after the disassembly.

3. Broken pump shaft description
The fracture position of the two pump shafts is in the same position, which is the maximum stress concentration position, and there is no obvious plastic deformation near the fracture position. The fracture surface of the pump shaft is shown in Fig. 2. The fracture begins with a small crack at the keyway and boss (1 crack source in the figure). During the operation of the pump shaft, under the action of alternating load stress, the crack gradually begins to expand to the center of the pump shaft (extension area 2 in the figure). Because the load alternating stress applied on the pump shaft exceeds the durability limit of the material fracture of the pump shaft, the pump shaft is finally broken instantaneously Fracture (3 fracture area in the figure). The 4 wear area in the figure is produced by friction after the fracture of pump shaft. The fracture surface of pump shaft has the trace of suspected welding, and there are ladder fracture trace and material joint on the fracture surface.
4. Fracture cause analysis

4.1. Material analysis

According to GB/t4336-2016 standard, the chemical composition of pump shaft is monitored by hand-held direct reading spectrum analyzer, and the chemical composition content of pump shaft is shown in Table 1; the chemical composition of pump shaft material meets the chemical composition requirements of 40Cr steel in GB/t3077-2015 standard.

Table 1. Chemical composition of pump shaft material.

| Element | Cr   | Mn   | Fe   | Co   | Cu   |
|---------|------|------|------|------|------|
| Content (%) | 0.953 | 0.640 | 96.63 | 0.188 | 0.028 |
| Standar dvalue | 0.8-1.10 | 0.5-0.8 | -    | -    | ≤ 0.25 |

4.2. Micro analysis

As the link between pump and motor, pump shaft plays an important role. The manufacturing process requirements of pump shaft are more strict. The lack or improper treatment of each link will lead to the decrease of hardness, strength and toughness of pump shaft. There are stepped joints on the fracture surface of the pump shaft. During the whole manufacturing process, the pump shaft is not processed in strict accordance with the process procedures, which makes the metallographic structure of the pump shaft change. The fracture initiation area was observed by scanning electron microscope (SEM), as shown in the figure, the fracture initiation area was in the shape of "mountain"; the enlarged observation of the expanded area was shown in the figure, needle like lamellar widmanstatten structure appeared in the expansion area, and a large number of ferrite formed the vulnerable surface, which sharply reduced the mechanical properties of the pump shaft.

In the process of pump manufacturing, if the heating temperature is too high or the cooling speed is too fast, it is easy to appear widmanstatten structure, which will reduce the performance of the pump shaft. When the widmanstatten structure appears in the manufacturing process of the pump shaft, if it is not treated after forging, it will be retained in the final formed pump shaft, thus leaving a potential safety hazard. It is also one of the reasons for the fracture of the pump shaft that the heat treatment process is not strictly carried out in the manufacturing process of the pump shaft.
4.3. Operation analysis

During the operation of the closed pump, all parameters should be monitored to ensure that they are within the allowable range. Vibration is one of the most important monitoring items, and safety accidents caused by vibration can be found everywhere.

The closed pump is equipped with an asynchronous motor with rated voltage of 6000V, rated current of 37.2a and rated speed of 1480r / min. Historical curves of relevant parameters of closed pump operation in 2018 and 2019 are obtained, as shown in figures 5, 6 and 7.

![Microscopic observation of crack initiation zone](image)

**Figure 3.** Microscopic observation of crack initiation zone

![Microscopic observation of extended area](image)

**Figure 4.** Microscopic observation of extended area

![Historical curve 1](image)

**Figure 5.** Historical curve 1
It can be seen from the above four figures that the current of the closed circulating water pump is unstable and fluctuates greatly during the normal operation of the closed pump. During the operation period from March 26 to April 13, 2018, the maximum current of closed pump B is 32a and the minimum is 27a; during the operation period from September 23 to October 9, 2018, the current of closed pump B is as high as 33A and the minimum is 26a; during the operation period from June 4 to June 23, 2019, the current of closed pump B is unstable, with a maximum of 32a and a minimum of 26a.

The voltage is 6.24kv, which is higher than the rated voltage, the current is about 29.9a, and the power factor is 0.811. After calculation, the actual power is 262.074kw, which is greater than 261.1kw shown on the instrument panel. The closed pump is in full load or overload state. The pump is in full load or overload condition for a long time, and the current is unstable, which is one of the factors causing fatigue fracture of pump shaft.

Under normal conditions, the pump shaft mainly bears torque, but due to the influence of impeller and shaft weight and centrifugal force caused by impeller unbalance, the pump shaft also bears a certain bending moment. After the combination of torque and bending moment, the weakest strength of pump shaft lies in the matching part of pump shaft and coupling, where the stress is the largest. When the strength of pump shaft is insufficient, the first fracture occurs here.

When the closed pump due to the current instability, the force acting on the pump shaft also changes, making the pump shaft applied an alternating load. In the operation of closed pump, under the complex stress conditions, the crack first occurs at the position where the stress is most concentrated, and the crack extends to the axis under the alternating load, and finally leads to the macro fracture of the pump shaft.
5. Preventive measures
In order to prevent the safe and stable operation of the closed pump and prevent the fracture of the pump shaft, the following protective measures should be taken:

(1) In the manufacturing process of closed pump shaft, the heat treatment process should be strictly followed to prevent the existing widmanstatten structure, network carbide and other factors affecting the performance of pump shaft.

(2) Strictly control the quality acceptance of closed pump shaft to ensure that all indexes of pump shaft meet the requirements.

(3) When the closed pump is in operation, try to keep the current stable; try to operate the pump at bep point.

(4) When the closed water pump is disassembled and overhauled, it should be carried out in strict accordance with the maintenance process standards to ensure the maintenance quality.

(5) When the closed water pump is in operation, the vibration monitoring of the pump should be done well; when it is stopped, the maintenance and repair should be done well.

6. Conclusion
Due to the unstable operation of closed pump, long-term full load (or overload) state, and the pump shaft under the load conditions, it is easy to fracture at the maximum stress concentration position of the pump shaft. As one of the important auxiliary equipment in power plant, the closed pump is of great significance to the unit safety. Therefore, it is necessary to strictly control the quality of the pump shaft and maintain the stable operation of the closed pump.

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