Cause Analysis and Treatment of Seawater leaking into Lubricating Oil System of 1000 MW Steam Turbine

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Abstract. This paper mainly analyzes the reason of seawater leaking into lubricating oil system of one 1000 MW unit in some coastal power plant in Shandong province and presents the corresponding treatment measure. Dissolving elution method is proposed to determine the chlorine ion content in the oil, to judge whether oil entrained water is cleaned. By the oil filter processing, the moisture content of turbine oil fall from 24414 mg/L to 10.1 mg/L, the chloride ion content is from 155 mg/L down to not detected. The serious pollution of the seawater leakage returns to normal in a short time, which ensured the safe operation of the unit, avoided the malignant accidents after treatment in time.

1. Introduction

Steam turbine is a kind of rotating machinery which uses steam as power and converts heat energy of steam into mechanical energy. It is the most widely used prime mover in modern thermal power plants [1]. The speed of steam turbine is up to 3000 r/min, and the cooling of bearing shell is very important. Therefore, in order to ensure the safe operation of steam turbine bearing shell at the prescribed temperature, it is necessary to cool the lubricating oil of cooling bearing shell. In order to keep the inlet temperature of bearing in normal range during the operation of turbogenerator units, oil cooler is usually used to cool the temperature of lubricating oil. For thermal power plants located in coastal areas, seawater is generally used as cooling medium to achieve the purpose of cooling lubricants.

Unit 1 of a coastal power plant in Shandong Province is a new 1000MW unit which has been put into operation for less than half a year, and the normal oil quantity of the main oil tank of the steam turbine was 47 t. On April 8, 2013, due to the leakage of the oil cooler, more than 3 tons of seawater entered into the lubricating oil system. The quality of oil was seriously polluted, and the main indicators such as appearance, moisture, particle size, rust and sludge precipitation were not qualified, which seriously threatened the safe and stable operation of the unit. In this paper, the reasons of seawater entered into oil system were analyzed, and the corresponding treatment measures were put forward. The change of chloride ion content in oil was determined by dissolution-elution method, so as to judge whether the seawater entrained into oil was clean or not, and to ensure the safety and stability of unit operation.
2. Damage of lubricating oil with water

Turbine oil system mainly provides lubricating oil for turbine bearings and turning gear, lubricating bearings and transmission parts; provide spare oil for sealing oil to regulate security system and generator [2]. The quality of steam turbine oil directly affects the safety and reliability of steam turbine operation, among which excessive water content in lubricating oil is the most serious hazard.

2.1. Deteriorated the quality of oil
Excessive water content in lubricating oil will accelerate the oxidation of oil, increase acid value, oxidation products and viscosity, emulsify lubricating oil, reduce lubricating effect, fail to achieve the purpose of cooling and lubricating bearings, and aggravate equipment aging.

2.2. Corrosion of regulation and security system
When the water in the oil contacts with the part sleeve of the regulation and the security system, it will cause the rust and jam of the part sleeve. Corrosion products produced by water were also an important source of particulate matter in oil.

2.3. Destruction of oil film
When the water content in the oil was serious, it will cause the emulsification of the oil, making the adhesion of the lubricating oil poor, affecting the formation of the oil film and damage the oil film, and can not quickly take away the heat of the shaft system, reducing the bearing capacity. If the oil film was not well established, dry friction or oil film oscillation will occur between the main shaft and bearing shell, which will cause vibration or even damage of the unit, seriously threatening the safe operation of the unit [3].

2.4. Reducing oxidation stability of oil products
Turbine oil contains various additives to improve the performance of oil products, which will hydrolyze or precipitate in the presence of water, resulting in the failure of additives in oil, also resulting in the decline or loss of corresponding functions of turbine oil, and further accelerating the deterioration and degradation of oil quality. The reduction of oxidation stability of lubricating oil will lead to equipment corrosion and oil emulsification in the process of use, and the formation of colloid and sludge in bearing passage, oil cooler, filter and main oil tank can cause equipment damage and seriously threaten equipment and personal safety.

2.5. Harm of seawater to oil system
Seawater is a very complex multi-component aqueous solution, which contains a large number of inorganic and organic substances. Most of the chemical elements dissolved in seawater are in the form of salt ions, of which sodium chloride is the main component. Seawater entering into oil system will cause serious deterioration of oil quality and serious corrosion of stainless steel in equipment. Therefore, coastal power plants must strictly prevent seawater leakaging into oil system.

3. Cause analysis of seawater entering into oil tank
At 13:00 on April 8, 2013, the operators of a coastal power plant in Shandong Province found abnormal oil level in the main oil tank of Unit 1. They immediately carried out water discharge at the bottom of the oil tank and found that the water volume of the oil tank increased abnormally. They also sampled and analyzed the lubricating oil of main engine, and found that the lubricating oil was opaque and had free water. After testing, the water mass concentration in the oil reached 24414 mg/L (standard ≤100 mg/L), and the water conductivity in the oil was 5342μS/cm. There was salt precipitated from the bottom of the bottle after the sample was stationary, as shown in Fig. 1. Preliminary judgment was that the oil cooler leaked and seawater entered into the oil system. On April 9, the mass concentration of chloride ion in the oil reached to155 mg/L. The result of sludge
precipitation test showed that a large number of salts were precipitated to the bottom of the measuring cylinder, as shown in Fig. 2.

![Fig. 1 The sample of the sea leaking into Oil](image1)

![Fig. 2 Sludge precipitation test](image2)

According to the analysis of the results of on-site inspection, test data and maintenance records of the oil cooler, the main reasons for seawater entering the main oil tank of the steam turbine are as follows.

3.1. Leakage of cooling pipe of lubricating oil cooler of main engine A, Unit 1
Through the disintegration of the water chamber of the oil cooler and the inspection of the oil injection on the right side, it was found that two cooling pipes in the outermost ring of the south side of the water chamber leaked, and the cooling pipes were titanium pipes by metallographic examination, the material of the cooling pipes was correct. Preliminary analysis considers that:

3.2. Fluid flow
Elastic excitation and turbulent buffeting induced the vibration of tube bundle, which will cause wear and tear, resulting in tube rupture and bending deformation leading to leakage failure; ②Titanium pipe wall was thinned and damaged during processing. Sediment carried in cooling water (sediment accumulated in the water chamber during inspection) was sheared away the pipe wall and caused wear and tear until it wore out and leaked. The leakage of cooling water pipe of lubricating oil cooler of unit 1 A main engine was the direct cause of seawater entering lubricating oil system.
3.3. Unreasonable design of cooling water system of oil cooler
The temperature adjusting door of lubricating oil was designed on the open return jellyfish of the oil cooler. The oil side pressure in the oil cooler should be greater than the water side pressure in normal operation. When the temperature of open water (sea water) was low in winter, the users of open water used less water, and the pressure of open jellyfish risen (water pressure 0.45 MPa, oil pressure 0.28 MPa at the outlet of the oil cooler), which caused the water pressure of the oil cooler to be higher than that of the oil pressure, and the water pressure was on the high side, which brought great potential safety hazards to the safe operation of the unit. When leakage occurred inside the oil cooler, sea water will leak into the lubricating oil system. The unreasonable design of the cooling water system of the oil cooler is the main reason for the leakage of the titanium tube.

4. Problems solving

4.1. Treatment plans
   (1) Eliminating leakage defect of main engine a oil cooler and check other cooling pipes for leakage.
   (2) The bottom of the tank was regularly checked for drainage, and combined with the conditions of the site, a centrifugal and two 4L filter-element oil filters were used to filter oil continuously for 24 hours to remove water and impurities in the oil.
   (3) Strengthening the supervision of oil quality, sampling and testing were carried out every day. The main indicators of oil quality of main engine oil tank of Unit 1, such as appearance, moisture, viscosity, demulsification degree, chloride ion and particle size, were tested. The changes of oil quality were tracked and monitored in time.
   (4) Combining with the material of the cooling water system of oil cooler, in order to avoid the corrosion of the oil system caused by chloride ions, the chloride ions in seawater entrained in the oil should be removed as far as possible. The change of chloride ion in oil was determined by dissolution elution method to judge whether the sea water in oil was clean or not.
   (5) Carrying out oil corrosion test to ensure that chloride ion in oil was not corroded to the system.
   (6) Oil filling and mixing test was carried out. Only after the mixing test was qualified, can the oil filling be progressed.

4.2. Quantitative determination of Cl- in oil by dissolution elution method
By oil filter, the purification of oil mixed with seawater was carried out. According to the physical and chemical properties of oil, the degree of oil contaminated by sea water can only be roughly judged, and the salinity of sea water can not be quantitatively assessed in turbine oil. Most of the chemical elements in seawater exist in the form of salt ions, in which sodium chloride is the main component and can be dissolved in deionized water. In this paper, chloride ion contained in seawater was extracted into deionized water by dissolution-elution method [4]. According to the change of chloride ion, it can judge whether the sea water in the oil was clean or not, and characterized the degree of oil pollution by sea water. The steps of the test method are as follows:
   (1) Measuring 50 mL test oil in 250 mL conical bottle with plug;
   (2) Taking 50 mL of pre-boiled deionized water and cool it to 70-80 ℃, and add it to the above 250 mL conical bottle with plug;
   (3) Heating and shaking for 5 minutes at 70-80 ℃;
   (4) The oil-water mixture in a 250 mL conical bottle with a plug was poured into the separating funnel and stratified statically;
   (5) A 30 mL statically stratified water solution was taken from the separating funnel in a 250 mL triangular cone bottle, deionized water was added to 100 mL, 10% potassium chromate indicator was added, and AgNO3 standard solution was used for titration to calculate the chloride ion content in the oil.
In order to verify the degree of salt elution and extraction in oil, two 50 mL oil samples were selected and eluted by adding 50 mL and 100 mL deionized water of different volume respectively. The relative deviation of chloride ion test results in oil was less than 1%, so it was judged that 1:1 elution met the test requirements.

Through the above treatment measures, after 150 hours of uninterrupted oil filtration, the oil quality indicators returned to normal, and the serious problem of leakage of the main oil tank of Unit 1 was solved. Fig. 3 and Fig. 4 are continuous monitoring trend charts of water content in unit 1 oil and chloride ion content in seawater entrained by oil (the initial zero point is 13:30 on April 8 as the first sampling time). Table 1 shows the test results of main oil quality analysis items before and after the treatment of seawater in oil system.

![Fig. 3](image)

**Fig. 3** The curve of water content in oil changing with time

![Fig. 4](image)

**Fig. 4** The curve of Cl⁻ content in oil changing with time
Tab. 1 Oil analysis program and the analysis results in the main period

| Sampling time | Analysis item | Appearance | Water content (mg/L) | Kinematic viscosity (mm²/s) | Demulsification degree(54°C) | Cl-(mg/L) | Granularity (NAS) | Corrosion test | Sludge release |
|---------------|---------------|------------|----------------------|----------------------------|-----------------------------|----------|-----------------|----------------|---------------|
| 2013-4-8 16:30 | transparent   | ≤100       | 28.8~35.2            | ≤30min                     | No standard                 | ≤8       | Nil             | Nil            | Nil            |
| 2013-4-9 8:00 | opaque        | 11111      | 31.8                 | 9.12                       | /                           | 12       | Rusty           | Salt precipitation |
| 2013-4-10 15:00 | translucent | 183        | 31.8                 | 8.18                       | 155                         | 12       | /               | /              |
| 2013-4-15 8:00 | transparent | 25.5       | 31.8                 | 9.07                       | 75.1                        | 12       | Nil             | Nil            |
| 2013-4-15 8:00 | transparent | 10.6       | 31.8                 | 10                         | 0                           | 8        | Nil             | Nil            |

4.3. Preventive measures
In order to prevent the unit oil cooler from leaking seawater into the oil system again in future operation, the following preventive measures are formulated:

(1) To formulate special measures to prevent seawater from lubricating oil system, reduce the pressure of open jellyfish pipe, and ensure that the water pressure is lower than the oil pressure.

(2) Strengthen oil supervision and increase the detection of chloride ion content in main engine oil to prevent sea water from leaking into oil system again.

(3) When repairing the small machine, the material inspection of the oil cooler system should be strengthened, and the vibration of the tube should be controlled during normal operation to prevent the tube bundle from wearing.

(4) Effective oil filter equipment is adopted to purify and filter the oil in the tank to ensure that the quality of the oil is up to standard.

(5) Strengthen business training to improve the ability of operators to analyze and judge accidents and abnormal phenomena.

5. Conclusion
For coastal power plants using seawater cooling, the material, design process and operation mode of the oil cooler are the main causes of seawater leakage into the oil cooler. In the past two years, two incidents of oil cooler leaking seawater into lubricating oil system have occurred in Shandong coastal area, thus, equipment manufacturers and power plants should pay attention to these incidents.

The results shown that the use of centrifugal oil filter and filter core oil filter immediately after seawater entered the lubricating oil system were important ways to remove moisture in oil and improve oil quality. The determination of chloride ion in seawater by dissolution-elution method was the main method to judge whether the seawater entrained in oil was clean or not. In view of the large amount of salt and organic matter in seawater, it was suggested that power plants located in coastal areas should be equipped with large oil filters with regeneration devices. This type of oil filters can completely eliminate the pollution caused by seawater leakage and improve the quality of oil products.

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