Discussion and analysis on problems of lube oil cooler and the oil cooler three way valve of a thermal power unit

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Abstract. Lube oil cooler is an important heat exchange equipment to provide suitable oil temperature for steam turbine unit. Its reliability is directly related to the normal operation of the unit. Combined with the system commissioning work, this paper finds out the problems existing in the lube oil cooler body and the oil cooler three way valve, and puts forward several improvement and optimization schemes, so as to improve the operation status of the equipment, improve the reliability of the system, and also facilitate the maintenance of the equipment, which provides a design reference for ensuring the safe and economic operation of the unit.

1. Introduction

The lubricating oil system supplies lubricating oil to the turbine-generator bearings, jacking oil pumps, and turning gear motor to support normal plant operations as well as emergency needs. The reliability of the system plays an important role in the safe and stable operation of the unit.

The lube oil cooler (LOC) is a U-shaped shell and tube heat exchanger. It has two units (A-LOC&B-LOC), and unit-2 is for back-up. In case of trouble of one oil cooler, we can switch to the other line by the three way valve. A three way valve is arranged between the two oil coolers. The valve body is furnished with main oil outlet and inlet[1].

The oil cooler three way valve has two groups of valve discs, with cam in the middle. The rotation of the valve stem drives the cam to rotate, so as to control the valve disc to move up and down. When
the valve disc is above, A-LOC puts into operation. When the valve disc is below, B-LOC is put into operation. When the valve disc is in the middle position, A-LOC and B-LOC operate in parallel, See figure 1(a) for details.

The lubricating oil system of this unit has a relatively long flushing time in the commissioning stage, the oil quality doesn't meet the acceptance standard (standard requirements: the impurity particle size grade is less than NAS 7 and the weight of impurities collected from the oil return filter is less than 0.5g/24h). Besides, the oil cooler three way valve can't be switched normally (jam or stuck) during the system operation, which affects the commissioning and safe operation of the system. So, the commissioning engineers actively put forward a variety of technical treatment measures to solve the above problems.

2. Problem for the oil cooler and valve
After repeated inspection and judgment, it is found that the flushing result doesn't meet the acceptance standard due to the structural characteristics of the oil cooler. While the three way valve can't be switched normally is caused by the valve design and selection. The specific problems are as follows.

2.1 Defects of the oil cooler
The oil cooler is a horizontal tube shell heat exchanger, the tube bundle material is copper alloy, the shell material is carbon steel, and the size of a single oil cooler is 7900mm × 1800mm × 1800mm, weighing nearly 50t. When the oil cooler needs maintenance, due to the horizontal structural characteristics of the oil cooler and the self-weight of the tube bundle, the scratch between the support plate at the lower part of the tube bundle and the shell can't be avoided, and the generated iron filings will remain in the shell. From figure 2(a) we can see the scratch on the support plate. With the operation of the system, the iron filings may scratch the bearing bush as the lubricating oil flows into the bearing bush, which brings risks to the safe operation of the unit[3]. The figure 2(b) shows the foreign matters cleaned out by the oil cooler.

![Figure 2. Scratch on the support plate and the impurity composition inside the cooler](image)

2.2 Inside O-ring falls off easily
The sealing surfaces of the disc and seat of the three way valve are respectively equipped with one O-ring (see figure 3 (a)), and a total of four O-rings are installed. Due to the effect of oil washing, the O-ring is fall off easily. In particular, once the outlet part falls off, it will directly enter into the lubricating oil pipeline (see figure 3 (b)), which may be broken into the bearing bush and plug the oil inlet, resulting in the risk of oil cut-off of turbine. As shown in figure.3, it is found that the lower sealing ring of the three way valve has been fall off.
2.3 Difficulty to switch the three way valve

In the actual operation process, the three way valve can't achieve the normal switching function, and even stuck for many times. Analyzing the structural characteristics of the valve, it is found that:

1) After disassembly, it is found that the valve stem of the three way valve has local galling and a certain degree of bending, and the contact between the valve stem and the valve body and between the valve body and the valve cover is poor.

2) According to the design requirements, the three way valve can be operated online during the operation of the system to realize the normal switching function of the oil cooler, so as to meet the operation requirements of one in use and one for standby. However, there is a differential pressure between the operating side and the standby side of the valve $\Delta P$. Pressure acts on the disc on the closed side, making it difficult for the valve to switch (figure 4). Due to the factors of oil pressure difference, stem length and operating space, the lower part nearly can't realize the switch from B-LOC to A-LOC.

3) When the O-ring falls off, the sealing function of the valve itself can't be realized. Once the oil cooler breaks down and needs to be isolated for maintenance, it can't meet the requirement of one for use and one for standby, so the system can only be shut down for treatment. The lubricating oil system must wait for the temperature of the cylinder to drop to a certain level before it can be out of operation. It will take at least three to seven days, which will bring certain economic losses and safety risks. If the oil cooler has oil cut-off due to the leakage of the tube, the risk of water entering into the lubricating oil can't be estimated[2].

3. Discussion on improvement scheme

In view of the problems existing in the oil cooler and the three way valve, several treatment schemes are put forward in combination with the actual situation. Now the schemes are introduced.

3.1 Solution to the difficulty of discharging impurities from oil cooler

In view of the problem that the oil cooler body is easy to accumulate impurities, the operation of the domestic oil cooler is investigated. After investigation, two improvement schemes are proposed as
follows:

Scheme 1: Replace the original oil cooler with plate type.

Replace the original oil cooler with plate structure oil cooler. Plate heat exchanger is installed alternately by heat transfer plate and sealing washer. Heat transfer plates are stacked in a certain order to form narrow flow channels. Cold and hot fluid flows in each channel on both sides of the plate, and heat exchange is carried out through plate. The adjacent plates form complex and narrow flow channels through contact, which strengthens the disturbance of the fluid, forms the low-speed turbulence and strengthens the heat exchange. Therefore, the heat transfer coefficient is higher than that of the shell and tube heat exchanger. The separation of the flow passage between plates of plate heat exchanger is mainly formed by the compression of sealing gasket and the sealing circumference is long. Therefore, the sealing performance isn't as reliable as that of shell and tube heat exchanger. The advantages of plate heat exchanger are compact structure and large heat exchange area per unit volume. The disadvantage is that the pressure loss per unit length is large, and the risk of leakage is high, and it can't bear high pressure. In addition, the flow path of plate type oil cooler is narrow, usually only about 2~5mm. Once large particles or fibers enter, it is easy to cause the channel blockage[4].

Scheme 2: Reform the oil cooler.

According to the structural characteristics and layout of the original oil cooler, the type of the oil cooler will not be changed, but only the body of the oil cooler will be reformed. The drain valve and pipeline are added at the shell side and end of the oil cooler. The pipeline material and valve selection shall meet the use requirements. The main pipe of the branch pipeline is connected to the oil purification device to return the purified lubricating oil to the main oil tank, see figure 5 for details.

From the perspective of equipment principle and system operation and maintenance, it is practicable to adopt the scheme of shell and tube oil cooler or plate oil cooler, but it is difficult to implement the reforming the type of the oil cooler from other influencing factors, such as design and procurement cycle, replacement cost, pipeline layout adjustment and construction modification workload[5].

Therefore, considering the actual situation of the site, it is decided to adopt the second scheme to reform the oil cooler. After the reform, the drain valve of the oil cooler is only used in the flushing stage of the lubricating oil system, and each drain valve is closed during normal operation.

3.2 Solution to the problem of three way valve

3.2.1 Treatment of inside O-ring falling off easily

Scheme: Remove the O-ring.

The opening and closing pressure difference of the three way valve is 0.39MPa (under the limit
working condition). The leakage of the valve seat after the O-ring is removed is calculated and evaluated. The specific calculation and evaluation results are as follows:

The fluid finite element analysis model is established according to the relevant data of the valve seat sealing pair of the three way valve. The opening and closing pressure difference between the valve inlet and outlet is set as 0.39MPa. Since the valve seat and the valve disc can achieve closed contact after the O-ring is removed, considering the machining error and the roughness of the sealing surface, it is estimated that the metal contact sealing surface clearance isn't more than 0.001mm. Now, the simulation calculation of leakage in this case is shown in figure 6.

![Flow field analysis of valve seat leakage after the O-ring is removed by the valve](image)

According to the analysis results, the average flow rate of the medium inlet is 36mm/s, so the leakage of the valve seat after removing the O-ring is less than 6.36m3/h, and meet the requirements.

In order to ensure the safe operation of the system, the O-ring is temporarily removed to avoid accidents caused by continuous falling off, which will affect the normal operation of the unit.

### 3.2.2 Treatment of three way valve unable to switch

In order to solve the problem that the three way valve can't realize the normal switching function during operation, three solutions are proposed for comparison and decision-making after the equipment disassembly inspection and system function analysis.

**Scheme 1: Replace the three way valve.**

Replace the original valve to a new valve with rotating disc, the structure of the new valve is shown in figure 7. The original type of three way valve needs to cut pipes for disassembly and maintenance, while, the new valve is possible to disassemble and maintains easily without cutting pipes. The valve shall be easy to switch under operating. The original type has the risk that the O-rings flow into the pipes since it has O-rings at the oil flow area, while this isn't a concern for this type of valve because O-rings aren't used. Sliding or rotating area shall not be burned out due to switching of the valve. The allowable leakage shall be less than the design requirement. However, the delivery time of three way valve is about ten months after the order is received, and also, there is no stock of it since it is built-to-order.

![Three way valve with rotating disc and medium flow direction](image)
Scheme 2: Reform the three way valve.
Remove the spool of the three-way valve, isolate the valve chamber, install a gate valve on the inlet and outlet pipes of the oil cooler, and add a gate valve between the oil coolers, a total of 5 gate valves. As shown in figure 8 below:

![Figure 8. Flow chart of three way valve reformation](image)

The reform scheme can overcome the shortcomings of the original three way valve which can't be switched online and can't isolate the fault oil cooler for maintenance. If A-LOC fails, close valve V1, V3 and V5, and open valve V2 and V4. If B-LOC fails, V2, V4 and V5 can be closed and V1 and V3 can be opened. At the same time, the parallel operation of oil cooler can be realized. If V5 is closed and the other four valves are opened, the oil cooler can be paralleled.

Scheme 3: As usual, choose the right time to deal with the valve.
According to the current state of the three way valve, temporarily put the three way valve to B-LOC, keeping B-LOC running, and take the relatively easy switch over A-LOC as the standby state, so as to reduce the risk of failure and jamming. In addition, the water quality of closed cooling water should be strictly controlled to reduce the erosion and corrosion of heat transfer tube of oil cooler. In addition, laboratory analysis of lubricating oil quality and water content and regular supervision of equipment should be carried out.

### 3.3 Analysis of scheme results

1) After adding a blowdown pipeline at the bottom and the end of the oil cooler, the oil cooler is filled with oil, and the oil is purified by oil purification device. A large number of impurities such as rust, welding slag and flocculent are collected from the inlet filter screen of the oil purification device. After reformation, the quality of lubricating oil is obviously improved, and it has passed the flushing acceptance smoothly.

2) After commercial operation and the first overhaul, no obvious scratch defects were found on each bearing bush of the turbine, indicating that the lubricating oil system was thoroughly flushed and the system was clean. The reformed oil cooler effectively ensures the safe operation of the unit.

### 4. Conclusion
The quality of installation and commissioning determines whether the unit can operate safely and stably. Adhering to the working concept of "the quality in the commissioning period is the safety in the operation period", we will not overlook any problems that affect the operation of the system. The problems found during the commissioning of the lubricating oil system, such as the unqualified flushing of the oil cooler and the abnormal switching of the three way valve, are properly solved by effective methods. The good operation performance of the unit fully proves that the reformation is sufficient and effective. At the same time, it also puts forward new requirements and new experience for the equipment selection, supervision and commissioning of subsequent units, and also facilitates the maintenance of the equipment, which provides a design reference for ensuring the safe and economic operation of the unit.
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