Research on online safety early warning technology for oil system of phase modifier

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Abstract: Lubricating oil is the blood of the machine, and health monitoring based on the quality of lubricating oil is an important means of condition based maintenance. The lubricating oil system is an important auxiliary system of the phase modifier. Metamorphic of the lubricating oil and contaminants carried by the lubricating oil will block the oil filter, scratch the seals and block or wear the components, which would cause the failure of the equipment. Particles and leakage generated when the equipment fails will also fall into the lubricating oil. Therefore, we can detect the indicators and pollutant content of the lubricating oil to speculate the equipment condition and make failure prediction. In view of the lack of operation and maintenance experience of rotating equipment in converter station staff, in order to ensure the safe and reliable operation of the converter station, this paper focuses on the research of online safety early warning technology, so as to improve the real-time and accuracy of lubricating oil diagnosis, reduce the probability of equipment failure, and improve enterprise benefits.

1. Introduction
The lubricating oil system of phase modifier is an important auxiliary system of the phase modifier. It mainly supplies lubricating oil, cooling oil and jacking oil to the bearings, turning gears, shaft-jacking devices and speed regulating system DEH. Due to the high requirements of the operation environment of the phase modifier such as heavy load, high temperature and high pressure, the lubricating oil is easy to be polluted, which will cause great losses to the safe production of the steam turbine. The wear performance and lubrication state of the machine are important components of the healthy state of the machine. The tribological state of the machine is time-varying and systematic, meanwhile, the accumulation of wear leads to the irrecoverable wear of the friction pairs of the machine [1]. In addition, the lubrication state of the friction part is closely related to the wear state. Therefore, it is necessary to master the real-time wear and lubrication state of the machine.

2. Pollution and prevention of phase modifier lubricating oil system
The oil quality of the lubricating oil system of the condenser is directly related to the safety and economy of the unit operation. The main reason for the deterioration of lubricating oil used in bearing [2].

(1) The sources of water in oil: The steam of shaft seal infiltration or wear leakage condenses into water; Water produced when moist air condenses; Water brought in during oil replenishment; Water
immersion due to heat exchanger leakage, etc. The water in the oil can destroy the continuity and strength of the oil firm, reduce the kinematic viscosity of the oil, worsen the lubrication performance, change the dynamic and static characteristics of the bearing, which can make the oil produce acid substances to corrode the components, generate iron oxide particles, and intensify the wear and metal falling off.

(2) The source of air in oil is mainly inhaled by the system under the action of oil exhaust fun, and under the operation condition of the negative pressure operation. And air dissolved in the oil will accelerate the oxidation of oil, increase the pollution of impurities, and destroy the normal lubrication effect of oil.

(3) Problems such as insufficient oil supply pressure in the oil system or insufficient oil supply caused by impurities blocking the oil circuit, need to be detected as early as possible by means of condition based maintenance, and targeted methods should be adopted to prevent damage to the oil film.

(4) Mechanical impurities in oil Sources of mechanical impurities include: ① Intrinsic contaminants in equipment manufacturing and installation, such as pipeline, oil pump, oil tank, valve, bearing, etc; ② Contaminants generated by system operation and fluid metamorphism; ③ Contaminants invading in oil tank and system during micro negative pressure operation; ④ Contaminants bringing into the system during maintenance or oil replenishment. These impurities in the system make the bearing, oil pump and other equipment wear. If it was not filtered in time, it will produce a "chain reaction", resulting in a vicious cycle of wearing.

3. Composition and characteristics of visualized lubricating oil management system

The oil monitoring system of phase modifier is developed based on the abrasive particles and physicochemical information contained in lubricating oil. This system is composed of online ferrography sensor, online viscosity sensor, micro moisture sensor and online lubricating oil quality sensor [3]. The details are as follows (see Figure 1):

(1) Image visualization online ferrography sensor;
(2) Online viscosity sensor
(3) Micro moisture sensor
(4) Online lubricating oil quality sensor

Through the above integrated sensor, the multi-dimensional monitoring of wear state and lubrication performance of major equipment can be realized, and the information fusion technology can be used to realize the judgment of machine tribology state, fault prediction and lifetime analysis, etc. At present, although there are many detection methods for lubricating oil detection, such as atomic spectrum, infrared spectrum, ferrography, particle size analysis, etc., but the equipment is expensive, and generally are offline monitoring. On the other hand, each detection only has a prominent effect on a certain characteristic. Our company has developed a new type ferrography analysis system with strong applicability in view of the shortcomings of the above oil detection. The system can detect 0.2-150μm abrasive particles, which can cover the scope of spectral analysis and magnetic plug detection, as shown in Figure 2. In this system, the percentage coverage area index of large and small particles (DL and DS) is detected by controlling the flow rate and magnetic potential parameters of the sensor, so as to give the wear quantification.
4. Composition and characteristics of visualized lubricating oil management system

4.1. Trend analysis

Through the analysis of the content and growth rate of the wear products in the oil, the wear state and development trend of its wear can be judge accurately.

The methods commonly used in the analysis of ferrography results are as follow: The trend chart is drawn with DL, DS and IS, and the wear state is judged according to the sharp rise to the curve.

① Direct reading of Large abrasive particles DL. It is sensitive to the concentration of large abrasive particles in the oil sample.

② Direct reading of small abrasive particles DS. It is sensitive to the concentration of small abrasive particles in the oil sample.

③ Wear intensity index IS. IS=DL (DL-DS), which is sensitive to both the total amount of abrasive particles in the oil sample and the concentration of large abrasive particles. Wear rate is an important indicator of wear condition. The change of mechanical wear rate will inevitably represent the change of equilibrium concentration of wear debris and deposition in lubricating oil \(^4\). In the stable normal wear stage, the two indexes should be straight lines with the same slope and parallel trend on the time curve. Once the slope steeply increases and suddenly draws close to each other, it indicates abnormal wear.

4.2. Wear characteristics analysis method

Visual ferrography technology is to use high gradient strong magnetic field to separate the mechanical wear particles and pollution impurities contained in lubricating oil orderly, and then use high-definition imaging equipment to carry out qualitative and quantitative observation on the morphology, size, density, composition and distribution of the separated particles and impurities, and judge the wear situation according to the maximum size and wear mode of wear particles, in order to determine the wear stage of mechanical equipment, predict the failure of parts and components, and determine the location and degree of wear \(^5\). Identification characteristics and formation mechanism of wear particles are shown in Table 1
| Classification         | Name                                  | Recognition features                                                                                                  | Formation mechanism                                                                 |
|-----------------------|---------------------------------------|------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Ironic Series Metal   | Normal abrasive                       | It is thin sheet, has highly polished surface and distributes along the magnetic line of force chain on the ferrograph. | It is formed by friction wear and fatigue shedding of the Pythagorean layer.          |
| Ironic Series Metal   | Running-in abrasive                   | It is long and thin, flaky, has rough surface, and organic processing trace.                                             | It is formed by the surface running in process of mechanical parts.                   |
| Ironic Series Metal   | Cutting abrasive                      | It is cutting shape, can present spiral and arc shape.                                                                   | The larger: Because of the surface damage, two body abrasive wear is produced. The smaller: Three body abrasive wear is formed by the presence of pollutants such as sand particles. |
| Ironic Series Metal   | Rolling fatigue abrasive              | Fatigue flanking particles                                                                                             | After the microcracks on the surface of the friction pair developed to connected, the material flakes to form abrasive particles. |
| Ironic Series Metal   | Rolling fatigue abrasive              | Fatigue flanking particles                                                                                             | After the microcracks on the surface of the friction pair developed to connected, the material flakes to form abrasive particles. |
| Ironic Series Metal   | Adhesive abrasive                     | It has rough surface, galling seriously, has scratched, has irregular profile and coexists with large amount of oxide. | It is caused by the adhesive wear between the tooth tip of gear meshing surface and the pitch circle, the tooth root and the pitch circle. High temperature oxidizes the surface of the abrasive and produces oxides. |
| Ironic Series Metal   | Severe sliding abrasive                | The surface is smooth with obvious parallel scratches or cracks, and the edges are straight.                            | High shear stress is produced on the relative moving surface due to high load and high speed. The mixing layer is unstable. Local adhesion produces large abrasive particles. |
| Non-ferrous metal     | Non-ferrous metal                     | The abrasive grains of non-ferrous metals can be first identified from their deposition patterns on ferrographs: 1. It does not arranged obviously according to its granularity as the ferritic metal abrasive particles, and the abrasive particles with different particle size are randomly deposited on the whole length of the ferrograph. 2. The direction of the long axis of the abrasive grains is at a certain angle with the direction of the magnetic field line, |
| Classification                      | Name                                      | Recognition features                                                                 | Formation mechanism                                                                 |
|-------------------------------------|-------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| White nonferrous metal wear particles | It refers to silver, aluminum, chromium, magnesium, molybdenum, antimony and zinc. | Taking aluminum grain as an example, it comes from aluminum position casting or aluminum alloy bearing bush, etc. |
| Copper alloy abrasive               | It presents red and yellow basic colors of different depths. | Copper alloy fiction pair.                                                            |
| Lead-tin Alloy abrasive particle    | Because the material is very soft and the melting point is very low, there is not clear edge, but it has a round melting profile, with blue or orange oxidation spots on the surface. | The lead-tin coating on the surface of babbitt sliding bearing was scratched and peeled off due to the instantaneous rupture of oil film. |
| Red iron oxide abrasive particles   | Iron trioxide polycrystalline aggregates | It is agglomerate, with large particle size and no clear edge.                         | There is water in lubricating oil.                                                   |
|                                     | Iron trioxide abrasive particles           | It is granular, and its particle size is similar to metal abrasive, with clear edge. It is orange yellow or orange red with a certain luster. | It is caused by poor lubrication and surface oxidation as well as corrosion and wear. |
| Oxide                               | Black iron oxide                          | The surface is rough and uneven with rock like particles. It is brownish black with magnetic deposition characteristics, | It is caused by serious poor lubrication and local dry friction on the surface. |
|                                     | Dark metal oxide                          | It coexists with free metal abrasive particles and is dark gray, because of the thick oxide film on the surface. | It is caused by poor lubrication, accompanied by high temperature surface oxidation. |
|                                     | Corrosive wear particles                  | It is submicron fine particles, with yellowish brown, piled up at the exit of the ferrograph sheet. | It is caused by corrosion and wear of friction metal materials caused by acid in oil or environment. |

4.3. Boundary value comparison method
The allowable limit of physical and chemical index of lubricating oil is determined based on experience (see Table 2), which is used to judge the abnormal wear of parts and predict the reminding life of the worn out parts. The allowable limits of wear predicts of lubricating oil should be analyzed according to the specific situation.
| Project               | Discrimination standard |
|-----------------------|-------------------------|
| Viscosity change      | A  | B  | C  | D  | E  |
| 0-5%                  | 1  | 2  | 3  | 4  | 5  |
| 5-10%                 | 1  | 2  | 3  | 4  | 5  |
| 10-15%                | 1  | 2  | 3  | 4  | 5  |
| 15-20%                | 1  | 2  | 3  | 4  | 5  |
| 20% and above         | 1  | 2  | 3  | 4  | 5  |
| Moisture content      | A  | B  | C  | D  | E  |
| 0-40%                 | 1  | 2  | 3  | 4  | 5  |
| 40-50%                | 1  | 2  | 3  | 4  | 5  |
| 50-60%                | 1  | 2  | 3  | 4  | 5  |
| 60-70%                | 1  | 2  | 3  | 4  | 5  |
| 80% and above         | 1  | 2  | 3  | 4  | 5  |
| Dielectric change     | A  | B  | C  | D  | E  |
| 0-0.4                 | 1  | 2  | 3  | 4  | 5  |
| 0.4-0.6               | 1  | 2  | 3  | 4  | 5  |
| 0.6-0.8               | 1  | 2  | 3  | 4  | 5  |
| 0.8-1.0               | 1  | 2  | 3  | 4  | 5  |
| 1.0 and above         | 1  | 2  | 3  | 4  | 5  |
| Judgment value        | A  | B  | C  | D  | E  |
| 1                     | 2  | 3  | 4  | 5  |

5. Application of visualized lubricating oil management system

This paper analyzes the online monitoring data of the sliding bearing of the phase modifier, and pre controls the ferrography, viscosity, moisture and temperature of the lubricating oil. Through the combination of the above sensors, the real-time tracking of the starting process of the phase modifier is realized. It is found that the sliding bearing does not form a stable oil film because of the slow rotate speed in the early stage of the starting process, and there is wear phenomenon, which can be seen in Figure 3 that the monitoring process of abrasive quantity at a, b and c. At this time, we should adjust the lubricating oil system for emergency treatment in order to reduce the wear of bearing bush. In the later period, the number of abrasive particles decrease obviously, as the point D shown in Figure 3. In figure 4, there are also obvious wear particles on the b and c two-point spectrograms, but there are basically no wear particles in the spectrograms after point d. So the comprehensive pollution degree of point d is level 2 through comprehensive diagnosis.

The practice shows that the condition monitoring of lubricating oil can put forward the corresponding treatment and solution measures according to the lubrication and wear condition of the equipment, so as to provide decision-making basis for the enterprise equipment management.
personnel to carry out lubrication management and maintenance as required and avoid serious lubrication failure and mechanical failure. Through the image analysis preprocessing function, the wear particle concentration, wear particle size, wear particle quantity, viscosity, moisture and temperature are extracted to realize the multi-dimensional monitoring of wear state and lubrication performance of major equipment, and the information fusion technology is applied to realize the judgment, failure prediction, lifetime analysis and so on of the state of machine tribology, and specific equipment maintenance measures are developed to deal with the lubricating oil as early as possible, which played an preventive role.

6. Conclusion
To sum up, it is very important to study the influence of lubricating oil on the equipment, which can effectively understand the causes of equipment failure, and propose targeted solutions to effectively improve the service life and safety of the equipment.

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