Analysis of Total Hydrocarbon Exceeding Standard in Oil Chromatogram of a 500kV Main Transformer

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Abstract. Oil chromatographic analysis is widely used in transformer fault diagnosis. However, the problem of excessive total hydrocarbons in the oil chromatogram caused by the failure of the transformer submersible pump is different from the failure of the transformer body. Technicians need to be able to accurately identify these two types of failure. For this problem, this article proposes a method of judging by manually starting and stopping the submersible pump and monitoring the change law of the transformer chromatographic data. This article first finds out suspicious submersible pumps through current data. Subsequently, the operator starts and stops the submersible pump and monitors the change law of the transformer chromatographic data. From this, the correlation between the start or stop of the submersible pump and the chromatographic data was found. Finally, the effectiveness of this method is verified by the submersible pump disassembly inspection and simulated live test.

1. Introduction
A power generation company’s main transformer phase A (model DFP-240000/500, single phase) found that the total hydrocarbons exceeded the standard during routine oil chromatographic analysis. In order to avoid damage to the transformer, the operator needs to find out the exact reason why the total hydrocarbon of the oil chromatogram exceeds the limit. This paper conducts continuous tests on site and carries out chromatographic tracking and monitoring of the main transformer. After careful analysis of the total hydrocarbon chromatographic data, this article finally concludes that the total hydrocarbon of the transformer body exceeds the standard due to the failure of the submersible pump.

Two months later, the operator conducted a disassembly inspection of the submersible pump and found that the submersible pump had an inter-turn short circuit fault. This verifies the judgment of this article. Then the operating personnel replaced the submersible pump. After replacement, the transformer is put into operation again. At this time, the chromatographic data is qualified and
stable. So far, the problem of excessive total hydrocarbons in the main transformer has been completely resolved. Obviously, the method in this article has the advantages of strong operability and clear thinking[1-3].

2. Total Hydrocarbon Exceeded

2.1. Problem of Excessive Total Hydrocarbon

A 500kV main transformer phase B of a power generation company carried out routine oil chromatography test. Compared with the last (December 12, 2019) oil chromatographic data, there is a significant increase. The total hydrocarbon content rose from 28.4 μL/L to 428.6 μL/L, exceeding the attention value (150 μL/L). The result of the three ratios is "022", showing the characteristics of high temperature and overheating fault defects (more than 700℃).

Technicians and power generation company personnel completed the investigation work of 500kV main transformer B-phase fan, submersible pump, transformer oil temperature, transformer core ground current, transformer infrared test, etc. During the inspection, it was found that the three-phase current unbalance rate reached 15.7% when the No. 1 cooler submersible pump was running. And the unbalance rate of motor DC resistance is 1.23%. No abnormality was found in other inspections. Subsequently, the No. 1 cooler submersible pump was used as a key investigation object. And on April 11th, the No. 1 cooler was stopped. Meanwhile, the oil chromatographic test was carried out every day, and its change trend was recorded and analyzed[4-6].

2.2. Chromatographic Data Analysis after Stopping the Pump

After the No. 1 cooler submersible pump was shut down (afternoon of April 11, 2020), technicians continuously monitored the oil chromatographic test data of the oil intake port at the lower part of the transformer and tracked the data. It is found that the initial chromatographic data has a big jump. Therefore, the technicians adjusted the details of the chromatographic test, including adjusting the oil volume to more than four times the dead oil volume, replacing the rubber tip for sealing the chromatograph syringe and the chromatograph injection pad to ensure no gas loss. After adjustment, the test data remained relatively stable. Then the technicians continue to track the chromatographic data of the sampling port at the bottom of the transformer body. It can be seen from the Fig. 1 that the chromatographic data is basically

![Figure 1. Chromatographic data after stopping the pump.](image-url)
Figure 2. Chromatographic data after starting the pump.

Stable after the pump is stopped, and there is a slight downward trend.

2.3. Chromatographic Data Analysis after Starting the Pump
The No. 1 submersible pump was opened on April 29. After the submersible pump was turned on, it can be seen from Fig. 2 that the chromatographic data began to show an obvious upward trend from 489.48, and once rose to 754.23.

2.4. Result Analysis of Chromatographic Data
The corresponding relationship between the start or stop of the submersible pump and the increase of the total hydrocarbon of the main transformer is very clear. This time the reason for the excessive total hydrocarbon was the failure of the submersible pump. The gas generated by the failure of the submersible pump enters the transformer body with the oil flow of the submersible pump, causing the total hydrocarbon of the main transformer to exceed the standard.

3. Failure Analysis of Transformer Submersible Pump
The operation record shows that the submersible pump thermocouple relay A phase 2 is replaced. However, the operating personnel actually replaced the No. 1 submersible pump thermocouple relay. The processing time is December 9, 2019. At that time, the No. 1 submersible pump skipped two gates, so the operator checked and replaced the thermocouple relay on site. The parameters of submersible pump are shown in Table 1.

The operator checked on the spot that the pointer of the oil flow relay was in a stopped state. Its position is correct and there is no offset. The inspection personnel reported that the pointer of the oil flow relay did not swing. The pointer states of No. 1 pump and No. 3 pump are shown in Fig. 3 and Fig. 4, respectively.

Table 1. The Parameters Of Submersible Pump.

| Numbering | A phase No. 1 pump, No. 2 pump | A phase No. 3 pump, No. 4 pump |
|-----------|--------------------------------|--------------------------------|
| Model     | 6B80-5/2.2V                    | 6B80-5/2.2V                    |
| Lift      | 5m                             | 5m                             |
| Power     | 2.2kW                          | 2.2kW                          |
The load of the submersible pump is the resistance generated by the oil and the baffle. It does not have the three-phase load problem similar to the electrical quantity. When the valve or baffle has a problem, the three-phase current of the motor will increase at the same time, and there will be no large two-phase current. This is inconsistent with the phenomenon that the two-phase currents of a and c are large on site. Therefore, it is judged that the cause of the three-phase current imbalance (a and c two-phase is large) can only be caused by a problem on the winding.

### 3.1. Analysis of Operating Current and DC Resistance

There are 12 sets of three-phase main transformer submersible pumps, two of which are replaced in 16 years. They are all used in phase A, one is No. 3 submersible pump, the other is No. 4 pump. All are currently in operation. The operating current is tested for the three-phase operating submersible pump. The test results are shown in Table II.

Operators conduct three-phase current test on three-phase main transformer operating submersible pumps (8 units). Only the current of the eight pumps No. 1 is greater than the rated current. Among them, the two-phase currents of a and c are large, and the three-phase current is unbalanced. The measured operating current shows that the A phase No. 1 pump is seriously unbalanced (15.69%). The maximum imbalance of other submersible pump current is 4.07%, and the minimum imbalance is 1.05%. It is judged that the internal winding of the submersible pump is faulty.

### Table 2. Three-phase submersible pump operating current test data.

| Phase sequence | Pump number   | a (A) | b (A) | c (A) | Imbalance rate % |
|----------------|---------------|-------|-------|-------|-----------------|
| Phase A        | No. 1 oil pump | 6.78  | 5.94  | 6.97  | 15.69           |
The operator further tested the DC resistance of the B-phase No. 2 submersible pump of the same model and the same period as the A-phase No. 1 submersible pump. They analyzed and compared the test data. By converting the line resistance of the A-phase No. 1 pump and the C-phase No. 2 pump into phase resistance, the three-phase horizontal comparison is performed. The three-phase unbalance rate of the phase resistance of the A-phase No. 1 pump is 2.47%. The three-phase unbalance rate of phase resistance of B-phase No. 2 pump is 0.46%. The data is shown in Table III. By converting the DC resistance data of A-phase No. 1 pump and C-phase No. 2 pump into the same temperature for longitudinal comparison, the operator found that the resistance change rate of the phase a and phase b of the A phase 1 pump was very small, which were 0.04% and 0.36% respectively. The c-phase resistance is obviously smaller, and the rate of change is -1.64%. The longitudinal comparison result is shown in Table IV.

### Table 3. DC resistance test result.

| Phase sequence | Pump number | Type of resistance | UV  | VW  | UW  | Imbalance rate % |
|----------------|-------------|--------------------|-----|-----|-----|------------------|
| Phase A        | No. 1 pump  | Wire resistance   | 4.0770 | 4.0420 | 4.0270 | 1.23           |
| Phase B        | No. 2 pump  | Wire resistance   | 4.3100 | 4.3090 | 4.3000 | 0.23           |

### Table 4. Three DC resistance test result

| Phase sequence | Pump number | Type of resistance | a   | b   | c   | Imbalance rate comparison |
|----------------|-------------|--------------------|-----|-----|-----|--------------------------|
| Phase A        | No. 1 oil pump | Phase resistance | 2.1505 | 2.1595 | 2.1495 |                             |
| Phase B        | No. 2 oil pump | Phase resistance | 2.1514 | 2.1673 | 2.1143 |                             |
| Change rate comparison | /       | /                 | 0.04 | 0.36 | -1.64 |                           |
The resistance unbalance rate of the DC resistance line of pump 1 is 1.23%. Its phase resistance change rate is -1.64%. The values are greater than the unbalance rate of other pumps. It shows that there is a short circuit fault in the A phase No. 1 submersible pump.

3.2. Analysis of Winding Problems in Submersible Pump
Through the investigation of the No. 1 submersible pump manufacturer, it is confirmed that the No. 1 submersible pump winding is star connection. The operator analyzes the windings of the submersible pump by establishing a simulation model. This simulation model is shown in Fig. 5. The model uses a three-phase 380V power supply. One-phase load adopts LC series structure. According to the actual test running current and DC resistance test data, the operator sets the RL load standard value: $R=2\ \Omega$, $L=0.2H$. It is assumed that there is an abnormality in the internal winding (such as a short circuit between overheating turns or a short circuit between phases). It is divided into two situations for discussion.

3.2.1. Short circuit between winding turns
It can be assumed that the first case is a short circuit between turns of a single winding. According to the calculation, the DC resistance of the phase C winding changes the most. Since the DC resistance data is much smaller than the inductance value, the influence of the DC resistance change is ignored during simulation. It is assumed that the abnormality of the C-phase winding causes the inductance to decrease. By setting the value of L in RL3 to 0.15H and the remaining parameters unchanged, the circuit waveform can be obtained as shown in Fig. 6. The three colors of yellow, green and red represent each phase of A/B/C, the dotted line is the current when the three-phase load is symmetrical.

It can be seen from the curve in Fig. 6 that the C phase current increases significantly. The A/B phase current does not change significantly. Obviously, this is inconsistent with the actual current test result.
3.2.2. Short circuit between winding phases

It is assumed that there is an interphase short circuit between the A and C phase windings. The inductance value has decreased. By setting the value of L in RL1 to 0.18H, the value of L in RL3 to 0.15H, and the other parameters unchanged, the waveform can be obtained as shown in Fig. 7. Similarly, the three colors of yellow, green and red represent each phase of A/B/C, and the black dotted line is the current when the three-phase load is symmetrical.

It can be seen from the curve in Fig. 7 that the A and C phase currents increase. The phase B current does not change significantly. It is more consistent with actual test results. Combining with DC resistance and simulation analysis, it can be known that an inter-phase short circuit occurred with the a-phase winding after an inter-turn short circuit occurred inside the c-phase winding of the A-phase No. 1 submersible pump. This includes failures caused by wear of a and c phases at the same part respectively. The disassembly inspection of Phase A No. 1 submersible pump is shown in Fig. 8.
3.3. Power-on Simulation Test of Submersible Pump

The operator conducts a power-on simulation test on the submersible pump. At the same time, the measured current values of the three-phase windings of the pump are 9.85A for phase a; 3.74A for phase b; and 8.93A for phase c. The three-phase current data law is consistent with the test law during operation. Severe smoke and heat occurred in phase C of the submersible pump after power on, as shown in Figs. 9 to 11. This indicates that there is a short circuit in the phase C winding of the submersible pump. Moreover, there is wear and tear on the submersible pump.

![Figure 9](image1.png)  
**Figure 9.** No smoke before power on.

![Figure 10](image2.png)  
**Figure 10.** Smoke appears after power on.

![Figure 11](image3.png)  
**Figure 11.** Insulation heating occurs after power on.

3.4. Field verification through replacement of submersible pump

A power generation company replaced the submersible pump on the phase B of the 500kV main transformer based on the analysis conclusion in this paper. Phase B of the 500kV main transformer was put into operation on June 19, 2020. After being put into operation, the operating parameters
of the main transformer are normal. At the same time, the operating personnel track the chromatographic data of the main transformer. The sampling cycle is implemented in accordance with the standards of the new transformer. That is to do offline chromatographic detection on the first day, 4 days, 10 days, and 30 days after commissioning. The monitored data were 30.2 μ L/L; 43.7 μ L/L; 45 μ L/L. These data are relatively stable (less than the attention value required by the standard 150 μ L/L). After more than one month of operation, the total hydrocarbon content is 52.2 μ L. At present, the main transformer has been transferred to the normal inspection cycle of 3 months each time. The main transformer resumes normal operation.

4. Conclusion
In this article, the oil chromatographic analysis shows that there is a clear correspondence between the start or stop of the submersible pump and the total hydrocarbon growth of the main transformer. Therefore, the excessive total hydrocarbon of the main transformer is not caused by the fault of the transformer body. Instead, it was caused by the failure of the submersible pump. Through further simulation analysis and actual testing, this paper found that the cause of the failure of the submersible pump is that its winding has a short circuit. Therefore, the short-circuit failure of the submersible pump winding is the real reason for the total hydrocarbon of the main transformer exceeding the standard.

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