Analysis on Material Defects of Circuit Breaker Oil and Gas Pipelines

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Abstract. The circuit breaker oil and gas pipeline was closely connected with its hydraulic mechanism and SF6 insulation system, and was an important accessory related to the mechanism's power and insulation performance. Aiming at the current high-pressure tubing fracture of the oil and gas pipeline of the circuit breaker, the cracking of the SF6 three-way valve interface bolt and the connecting pipe, the chemical composition, mechanical properties, metallographic structure and fracture morphology of each accessory were analyzed from the material point of view, and the material composition was found poor, excessive hardness and abnormal metallographic structure were the main reasons for the failure of circuit breaker oil and gas pipeline components, and technical supervision suggestions had been put forward from the aspects of network check and operation and maintenance inspections.

1. Introduction
Due to their stable chemical properties, hydraulic oil and SF6 gas are widely used in hydraulic power devices and high-voltage insulation devices of electric power equipment[1]. The most common ones are circuit breakers, such as hydraulic transmission mechanisms and arc extinguishing chambers[2]. Because of its special characteristics such as flow and volatilization, oil and gas need to be serviced in a closed system. The transmission pipeline or detection pipeline in the closed system is indispensable, but it is usually not used as the core component of the equipment by manufacturers and equipment. The owner’s attention has caused more problems in the quality of the oil and gas pipelines than in the oil and gas itself[3-7].

From the perspective of material science, this article analyzes the causes and hazards of circuit breaker oil and gas pipelines in the power grid system, and provides technical reference for its operation, maintenance and technical supervision.

2. High-pressure pipeline
The hydraulic mechanism of the circuit breaker is composed of electric motors, oil pumps, high-pressure oil pipes, working cylinders, and nitrogen pressure storage barrels. The high-pressure oil pipeline connecting the nitrogen pressure storage barrel and the working cylinder bears great oil pressure. Cracks in the maintenance position will inevitably lead to the leakage of high-pressure oil,
which will cause the rapid decrease of the oil pressure of the operating circuit breaker, and the frequent pressure of the oil pump, even if it is found in time, a forced stop is required. If it is not found in time, it will cause the circuit breaker mechanism to be unable to operate without voltage, which is more harmful.

In October 2016, metal supervisory technicians carried out a full shutdown overhaul technical renovation project for a 220kV substation, and found that the 600 circuit breaker B phase mechanism could not build pressure, and the high-pressure oil pipeline leaked oil from the connection between the nitrogen pressure storage barrel and the working cylinder. The structure model of the circuit breaker is LW10B-252, and it was put into operation in 2001. Further macro inspection revealed that the high-pressure oil pipe and the working cylinder are connected by threads. In order to facilitate the installation and connection between the oil pipe and the working cylinder, a nut boss is designed between the thread and the oil pipe, but there is no rounded transition between the oil pipe and the boss. This part is the fractured part of the tubing without obvious plastic deformation, as shown in Figure 1.

The tubing was made of cast iron, and there was no data to verify the specific grade. After sampling the fracture of the tubing wall, it was analyzed under a scanning electron microscope. The micro-component energy spectrum (EDS) test found that there were obvious inclusions in the fracture. The inclusions were mainly composed of Ca, Si, Al, O and other elements, as shown in Figure 2. The presence of inclusions could significantly reduce the mechanical properties of tubing materials, and was conducive to the initiation and propagation of cracks.

From the above test results, the main reason for the breakage of the high-voltage tubing of the circuit breaker was the presence of impurities in the tubing wall, which reduced the mechanical properties of the tubing material, and the transition between the tubing and the nut boss was not rounded, and there was stress concentration and deterioration the stress distribution of the tubing.
3. SF6 three-way valve interface bolt

The three-way valve of the circuit breaker is the key to ensure the normal opening and closing of the circuit breaker's gas circuit and the SF6 density relay. It provides a guarantee for verification and replacement of the SF6 density relay, and can provide a convenient way to supply air to the circuit breaker body. The normal and reliable operation of the three-way valve of the circuit breaker is the key to ensuring the air chamber and air circuit sealing of the circuit breaker. It is widely used in the power system, and its quality directly affects the stable operation of the circuit breaker.

The SF6 air pressure of the 508 circuit breaker in a 220kV substation dropped. The maintenance personnel made up the air on site and checked for leaks. It was found that the three-way valve interface bolt and the copper pipe joint of the three-phase circuit breaker were leaking. The SF6 air pressure of the 514 circuit breaker in the same substation was reduced. Gas and leak detection found that there was gas leakage from the three-way valve interface bolt to the copper pipe joint of the three-phase circuit breaker. The leakage position of the two circuit breakers was the same, and both were products of the same supplier.

Macro inspection of 508 and 514 circuit breaker three-way valve interface bolts revealed obvious cracks on the surface. The cracks were relatively small and penetrate from the bolt surface to the inside of the seal ring groove, as shown in Figure 3.

The direct-reading quantitative spectrometer was used to detect the chemical composition of the interface bolts. The C content was 0.13%. The specific element content was shown in Table 1 below. According to the material report provided by the supplier, the design material of the interface bolt was 0Cr18Ni9, and the implementation standard was GB/T1220-2007 "Stainless Steel Rod". Compared with the standard, the carbon element content of the interface bolt was significantly higher than the maximum value required by the standard by 0.08%, which did not conform to the standard. At the same time, the hardness of the bolt was tested, and its Vickers hardness value was 331HV, which was also greater than the maximum Vickers hardness value of 200HV specified in the GB/T1220-2007 "Stainless Steel Rod" standard. Further analysis of the microstructure of the failed bolt showed that the structure had a certain directionality. There were many band-like structures and different grain sizes. The size of some large grains was about 500μm, while the size of some small grains was about 500μm. It was 10μm, the mixed crystal structure was obvious, and the metallographic structure was shown in Figure 4.

Based on the above test results, the microstructure of the three-way valve interface bolt of the circuit breaker had different grain sizes and a certain directionality, indicating that the microstructure was still a processed structure. The reason was that the heat treatment system was improper or not heat treated. In addition, the carbon content of the interface bolt was higher than the standard value, and the chemical composition was unqualified. The increase in the carbon content of the interface bolt and the
improper heat treatment system would cause the hardness of the stainless steel material to be higher and the brittleness would increase, which would eventually cause the interface bolt to crack during use.

Figure 4. Metallographic microstructure of interface bolt.

Table 1. Interface bolt composition test results.

| Element | Content/% | Standard/% |
|---------|-----------|------------|
| C       | 0.13      | ≤0.08      |
| S       | 0.01      | ≤0.030     |
| P       | 0.01      | ≤0.045     |
| Mn      | 0.89      | ≤2.00      |
| Cr      | 17.23     | 17.00~19.00|
| Ni      | 8.15      | 8.00~10.00 |
| Si      | 0.64      | ≤1.00      |

4. SF6 connecting pipe
The gas in the SF6 connecting pipe is an important arc extinguishing medium and insulating medium for the circuit breaker. It has a rated value of air pressure strength. Maintaining the rated air pressure for a long time is of great significance to ensure the reliable arc extinguishing of the circuit breaker.

Figure 5. Leakage position of circuit breaker SF6 connecting pipe.

A 220kV substation 620 circuit breaker issued a low air pressure alarm signal. The maintenance personnel checked the circuit breaker and found that the indicated air pressure of the SF6 meter was 0.47 MPa, which was lower than the alarm air pressure of 0.48 MPa, and the alarm signal disappeared after the air supply reached 0.57 MPa. The circuit breaker model was LW15-220, and it was put into operation in 2006. Since then, the circuit breaker would send out an alarm signal about every two
months to make up for it. The technical supervisor judged that the circuit breaker's SF6 gas pipeline had leaks from the number of gas supplements and the time interval.

Figure 6(a). Morphology of loose defects  Figure 6(b). Morphology of Pb block.

The FLIR GF306 infrared leak detector and soapy water were used to detect leaks at the joints of the 620 circuit breaker SF6 gas connection pipeline. It was found that there was obvious gas leakage in the copper pipe at the junction of the mechanism exhaust valve and the gas tank, as shown in Figure 5. The design material of the copper tube was HPb59-3. The composition analysis of the leaking through copper tube showed that the Cu and Pb contents were 52.34% and 4.72%, respectively, which did not comply with GB/T 5231-2012 "Processing copper and copper alloy grades and chemical composition" standard requirement. Further analysis of the microstructure of the copper tube showed that there were a large number of loose defects in the matrix structure, and part of the excess Pb was not melted and concentrated into a block distribution, as shown in Figure 6. Pb is basically insoluble in brass alloys, and is usually distributed as a free isolated phase in solid solution. When the Pb content exceeds 3.5%, it is difficult to completely disperse and evenly distribute in the solid solution during the smelting and casting process. The copper pipe Pb content reaches 4.72%, and the excessive Pb will segregate at the solid solution grain boundary, thus making the brass mechanical The performance drops sharply, which can easily cause cracking and fracture of the product.

5. Conclusion
The circuit breaker oil and gas pipeline is closely connected with its hydraulic mechanism and SF6 insulation system. It is a pipeline for oil and gas transmission and supervision. Although it is not the main core component of the circuit breaker, its function and status are still very important. In view of the above-mentioned problems existing in circuit breaker oil and gas pipelines, it is recommended to strengthen its network supervision and operation inspection to avoid circuit breaker failure due to material defects of oil and gas pipelines.

1) Carry out the technical supervision of the high-pressure oil pipe of the hydraulic mechanism of the circuit breaker in a targeted manner, check the appearance of the oil pipe 100% macroscopically, and conduct metallographic tests on the spare parts of the high-pressure oil pipe if possible.

2) Strengthen the material testing and hardness testing of the SF6 three-way valve interface bolts. The newly connected circuit breakers must be checked in strict accordance with the national standard GB/T1220-2007 "Stainless Steel Rods". The interface bolts with unqualified composition and unqualified hardness shall be replaced. The SF6 three-way valve interface bolts of the circuit breaker that have been put into operation can be subjected to 10% color penetration sampling inspection, and 100% full inspection is found for cracks.

3) Take the newly-connected circuit breaker SF6 connecting pipe pipe port spare parts for material inspection and metallographic test to ensure that the quality of the newly-connected SF6 connecting
pipe is qualified. In the operation and maintenance, the monitoring of the SF6 air pressure of the circuit breaker was strengthened, and the pipeline port of the connecting pipe was checked when a leak was found.

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