Cause Analysis of the Crooked High Voltage End Fittings for a 220kV Composite Insulator in-service

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Abstract: The high voltage end fitting for an in-service 220kV composite insulator was found to be crooked by the transmission line inspector, and the deformed cause was then investigated by digital X-ray imaging, chemical composition analysis, metallographic observation and mechanical properties testing in this paper. The results indicated that both the material quality and mechanical properties of the composite insulator high voltage (HV) end fitting met the standard requirements. And the main reason for the crooking of HV end fitting was the effect of abnormal force, such as falling from high position, impact of heavy objects. At last, it was advised that the supervision on the installation quality of fittings and the inspection of in-service composite insulator fittings should be strengthened. In addition, composite insulator with deformed or fractured end fitting should be timely handled, avoiding similar metal section failures.

1. Introduction

Composite insulator is of great significance to ensure the safe and efficient operation of power system. In recent years, composite insulator is widely applied in medium voltage and high voltage transmission lines due to its excellent performances of mechanical and anti-pollution flashover, etc [1, 2]. As a common insulating component in power system, composite insulator is mainly composed of silicone rubber insulation layer, epoxy resin fiber-reinforced core and metal end fitting [3, 4]. Metal end fitting is always made of hot dip galvanized cast steels, high voltage (HV) end fitting and low voltage (LV) end fitting, which are joint with the core by hydraulic pressed. During operation, the composite insulator is often bore very high axial loading, and this loading is mainly transmitted to the tower and conductor through the both side end fittings [5]. Therefore, the quality of fittings is directly related to the safe operation of composite insulators. Stress distribution near the pressing area of end fittings and core was investigated by Kumosa [6, 7], the results revealed that the pressing interface between the end fittings and core of composite insulator was most prone to occur mechanical failures. Zhang et al [8] studied the defect mechanism of composite insulator end fittings in acid wet settlement areas. The results revealed that the emission of SO₂ was an important inducement for the defect formation of the end fittings. Besides, the zinc coating on the surface of end fittings was also seriously damaged due to acid medium, seriously reducing the stress load of the end fittings, which was considered to be the main reason for end fitting corrosion and acid etched brittle fracture of core. In addition, improper end fitting compositions and process parameters during transmission line construction will have a great impact on the operation performance of composite insulators, which may lead to broken accidents.

In July 2019, the HV end fitting of an in-service 220kV composite insulator was found to be crooked by the transmission line inspector. The total length of the transmission line was 18.036km,
and the type of the used composite insulator is FXBW-220/100, the conductor model is LGJ-400/25, which was put into operation on January 2013. In this paper, the detection methods of digital X-ray imaging technology, chemical composition analysis, metallographic observation and mechanical properties testing were utilized to find out the crooking reason of the HV end fittings, and the research results were deemed to provide technical guidance for the safe operation of transmission lines.

2. Experimental results and analysis

2.1. Macromorphology observation and analysis

At first, it can be found from Fig. 1(a) that the site photos that the deformed fittings are HV end fitting of composite insulator on conductor side. Besides, the whole insulator has been obviously deviated and the HV end fitting is not in the normal position on the wire side. Next, the macroscopic morphology observation of deformed end fitting is carried out in laboratory, and the results revealed that no obvious corrosion and wear marks are found on the whole HV end fitting and the galvanized layer is nearly intact, while a concavity defect can be easily observed on the inside of the HV end fitting surface, as shown in Fig. 1(b). The length of the HV end fitting is measured to be 120mm, it can be informed that the model of insulator HV end fitting is Q16×122-100 according to standard of JB/T 9677-1999 [9], and the steel number is #40 steel or 35MN steel. Then, in order to determine the material quality of HV end fitting, the chemical composition was analyzed by using the SPECTROMAXx type Direct-Reading spectrometer according to standard of GB/T 4336-2016 [10], the test data is listed in Table 1. It can be seen that the chemical composition of HV end fitting is perfectly consistent with that of #40 steel in the standard.

![Figure.1 Scene photo and macromorphology of the crooked HV end fitting](image)

(a) scene photo (b) macrophoto of HV end fitting

| Element | C   | Si  | Mn  | Cr  | Ni  | Cu  | P   | S   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| Measured Value | 0.44 | 0.26 | 0.76 | 0.08 | 0.01 | 0.01 | 0.14 | 0.003 |
| GB/T 699-2015 | 0.37~ | 0.17~ | 0.50~ | ≤0.25 | ≤0.30 | ≤0.25 | ≤0.035 | ≤0.035 |

2.2. X-ray digital imaging and analysis

As a new method of nondestructive testing technology, X-ray digital imaging system can be used to check the internal defects of composite insulator [11, 12]. Then X-ray digital detection is carried out to confirm whether there are any defects in the HV end fitting, as well as whether the bonding interface between the HV end fitting and the sheath is destroyed due to crooking. As shown in Fig. (2a), the
bonding interface between sheath and core, sheath and HV end fitting is of good quality, no obvious holes, microcracks or other defects are detected. By increasing the exposure time, it can be observed in Fig. (2b) that the position of the mandrel inserted into the end fitting meets the standard requirements. In addition, there are no obvious cracks and other defects found inside the HV end fitting.

![Figure 2. X-ray digital imaging of the HV side of composite insulator](image)

(a) short-term exposure (b) long-term exposure

2.3. Microstructure observation and analysis

It can be found Figure 3(a) and Figure 3(b) that the microstructure of the of the HV end fitting is mainly equiaxed ferrites and pearlitic, in which the morphology of pearlite is clear, carbides are distributed in lamellar and no abnormal structures are found. In addition, the banded structure is rated as C series 1. However, the grains in the deformed region are found to be elongated along the crooking direction of the HV end fitting, as shown in Figure 3(c). Besides, a microcrack is also found to be formed at the edge of pit and no other abnormal structures.

![Figure 3. Microstructures of the HV end fitting with different positions](image)

(a) whole (b) local enlarged (c) crooked edge
2.4. Hardness measurement and analysis

According to the standard requirements of the GB/T 231.1-2018) [13], the brinell hardness of the crooked end fitting is then measured by using of the Nexus 3001xlm-imp Automatic Brinell type hardness tester. The measurement result reveals that the brinell hardness of the crooked end fitting is 198 HBW. After conversion, the mechanical tensile failure load of the HV end fitting is calculated to be 129.4kn, which is met the standard requirement of JB/T 9677-1999 [9].

3. Conclusions and suggestions

The results of macromorphology observation shown that a concavity defect was formed inside of the crooking part of the HV end fitting, and no other mechanical or wear damage features were found. The chemical composition analysis results indicated that the material quality of the HV end fitting was #40 steel, meeting the standard requirements. The microstructure of the HV end fitting of the composite insulator was mainly equiaxed ferrites and pearlites, the morphology of pearlites is obvious and the carbides were distributed in lamellar, and the the banded structure is rated as C series 1. The matrix of the crooked part of HV end fitting was also mainly consisted of ferrites and pearlites, however, the ferrite grains were obviously stretched along the deformation direction. Besides, no inclusions and abnormal structures were found. The test results of mechanical properties show that the brinell hardness and the converted mechanical tensile failure load of the HV end fitting were all met the standard requirements.

From the above comprehensive analysis above, it was considered that the HV end fitting of the deformed composite insulator was mainly related to the action of the external forces. It was deduced that the composite insulator was dropped from high position during the construction of transmission line, and the HV end just came into contact with the ground, causing the crooking of the HV end fitting. Another possibility was that the HV end fitting might crooked during the loading or transportation process of composite insulator.

Finally, several suggestions for safe and stable operation of the transmission systems were given as follow. First of all, supervisions of the installation quality of the end fittings in the transmission line should be strengthened. Second, the inspections of the in-service composite insulator end fittings should also be strengthened. Nevertheless, as long as the end fittings of composite insulator are found to be abnormal, extraordinary attentions must be paid during the continuous operation process. If the operation condition of the end fittings will further worsen and seriously threaten the safe operation of the composite insulator, replacement should be carried out immediately.

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