Corrosion failure analysis on cotter pins used for fittings of 500kV transmission tower

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Abstract. Transmission line is an important part of power system and plays a key role in the process of power transmission and distribution. As the skeleton of the transmission line, the reliability of the transmission tower is an important guarantee for the safe and stable operation of the power grid. In this paper, the corroded cotter pins of fittings used for 500kV transmission tower was investigated by means of macro-morphology inspection, chemical composition analysis, scanning electron micrograph analysis, microstructure analysis and energy spectrum analysis. The result showed that the misuse of material for cotter pins and sulfide discharged from industrial production were the main causes of corrosion of the cotter pins.

1. Introduction
Cotter pin is usually used in the bolt of fitting for transmission tower, which mainly plays the role of limit. If the cotter pin falls off due to corrosion failure, the fittings and its connecting line would be disconnected or dropped, resulting in a large-area power failure trip accident. Usually, the replacement of the cotter pin requires power-cut operation at high altitude, which is extremely inconvenient. Therefore, the anti-corrosion quality of cotter pin should be strictly controlled to avoid its corrosion failure, so as to save the cost of operation and maintenance[1-3].

During the UAV inspection of a 500kV transmission line, it is found that some cotter pins used for fittings of cross arm and ground wire hanging point were seriously corroded. The transmission line, which has been put into operation for 6 years, is located in a heavy industrial park with numerous coal-chemical and other highly polluting enterprises around it. In order to ensure the safe and stable operation of transmission lines and prevent recurrence of similar corrosion failure, in this paper, different physical and chemical test methods were adopted to investigate the corrosion mechanism and analyze the corrosion reason of the seriously corroded cotter pins used for fittings of 500kV transmission tower.

2. Experiment results and analysis
2.1. Macroscopic observation
Figure 1 shows the macro-morphology of the corroded cotter pins used in fittings for 500kV transmission tower and the cotter pins have seriously rusted. It is clearly seen that yellowish-brown
corrosion products are distributed on the surface of the cotter pins in lamellar form and some of them have fallen off. In addition, there are a lot of corrosion pits on the surface of the cotter pin, without obvious mechanical damage and plastic deformation.

![Image of cotter pins](image1.png)

(a) Entirety                                             (b) Serious corrosion region

Figure 1. The macro morphology of the corroded cotter pins.

2.2. Metallographic structure Analysis

Figure 2 shows the metallographic microstructures of the corroded cotter pin. It could be seen that the metallographic structures of the corroded cotter pin are mainly massive ferrite and a mass of diffused carbides, without abnormal microstructure, which is completely inconsistent with the microstructure characteristics of austenitic stainless steel. Additionally, there are many corrosion pits in different sizes and depths on the surface of the corroded cotter pin.

![Image of metallographic structures](image2.png)

(a) The matrix                                            (b) The corrosion pit

Figure 2. The metallographic structure of the corroded cotter pins.

2.3. Chemical composition analysis

Energy dispersive analyzer (EDS) was used to analyze the composition of the corroded cotter pin, and the test results were shown in Figure 3 and Table 1. It could be seen that the main components of the base metal for the cotter pin are iron and carbon, and there were no austenite forming elements such as manganese and nickel, and chromium which could enhance the corrosion resistance of steel, was also not found. Thus, it could be judged that the cotter pin was made of ordinary carbon steel, rather than austenitic stainless steel.

![Image of EDS analysis](image3.png)

(a) Entirety                                             (b) Serious corrosion region

Figure 1. The macro morphology of the corroded cotter pins.
Figure 3. The energy spectrum analysis result for the base metal of the corroded cotter pin.

Table 1. Energy spectrum analysis result of corrosion products (wt%)

| Chemical element | Fe  | C  |
|------------------|-----|----|
| Test values      | 95.02 | 4.98 |

2.4. Microstructure and energy spectrum analysis of corrosion products

Figure 4 shows the micro morphology of the corrosion products sampled from the corroded cotter pin and it is clearly seen that the corrosion products are dense and lamellar, accompanied by a large number of massive particles with different sizes.

Figure 4. The SEM morphology of corrosion products for the corroded cotter pin

The chemical compositions of the corrosion products on the surface of the corroded cotter pin are analyzed by energy spectrum analyzer, and the testing result is shown in Figure and table 2. The result shows that the corrosion products of the cotter pin are mainly composed of iron, oxygen, silicon, sulfur and aluminum, which should be iron oxide and ferrous sulfate. And silicon and aluminum elements on the surface of the cotter pin should exist in the form of oxide, which is mainly caused by the adsorption of sand on its surface.
4. Hardness testing

Hardness test was carried out on the corroded cotter pin samples, and its hardness value was determined between 191 and 199 HBW, meeting the standard requirement that the hardness value of the cotter pin should not be less than 130 HBW.

3. Analysis and discussion

According to the relevant standards, the cotter pin should be made of austenitic stainless steel, and its hardness value should not be less than 130HBW. Because of the high content of chromium in stainless steel, the electrode potential of iron-based solid solution would be increased. At the same time, chromium could be passivated due to the absorption of iron electrons, which would effectively prevent the occurrence of electrochemical corrosion. However, the chemical composition of the base metal for the corroded cotter pin only contains iron and carbon, and there were no austenite forming elements such as manganese and nickel. Meanwhile chromium which could enhance the corrosion resistance of steel, was not found. Additionally, its metallographic structures of are mainly massive ferrite and a mass of diffused carbides, which is completely inconsistent with the microstructure characteristics of austenitic stainless steel. Therefore it could be judged that the cotter pin was made of ordinary carbon steel, rather than austenitic stainless steel, which leads to inadequate anti-corrosion performance[4-8].

In addition, there are many heavy industrial enterprises around the transmission line. For many years, the flue gas and dust discharged from industrial production have led to a high content of corrosive gases such as sulfur dioxide in the atmospheric environment. Once the rainwater or moisture adsorbs on the surface of the cotter pin to form a thin liquid film, the sulfur dioxide in the air would dissolve into it. Under the action of oxidant and sunlight, sulfur dioxide generates sulfuric acid through chemical reaction and would react with iron to produce water-soluble ferrous sulfate. At the same time, ferrous sulfate would hydrolyze to produce sulfuric acid again after dissolving in water, and the newly generated sulfuric acid would react with iron to produce ferrous sulfate. According to the above cycle mode, the cotter pin would be corroded and consumed continuously until complete failure[9-12].

4. Conclusions

In this paper, the reason and mechanism for corrosion damage of the cotter pin used for the 500kV transmission tower fitting were systematically investigated and analyzed. Through comparing and
analyzing the experimental results, the following conclusions are drawn.

1) Due to the misuse of materials, the corrosion resistance of the cotter pin is seriously reduced, which could not meet the corrosion protection requirements of the service environment. In addition, the long-term industrial pollution makes the strong corrosive gas and dust in the atmospheric environment around the transmission line extremely high, resulting in the rapid corrosion damage of the cotter pin.

2) In the heavy industrial pollution area, more and more attention should be paid to the inspection of the cotter pin used for 500kV transmission tower fitting, and the seriously corroded ones should be replaced in time to ensure the safety and stability of transmission lines.

3) The material identification should be conducted for the cotter pin in use of the same batch, so as to prevent unqualified cotter pins from being used in power grid equipment.

4) Before putting into operation, the chemical composition analysis and hardness testing of the cotter pin should be tested to prevent its premature failure due to insufficient corrosion resistance and elasticity[13-15].

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