U-shaped Hanging Ring Fracture Failure Analysis in 220kV Transmission Line

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Abstract. The U-shaped hanging ring was fractured in B phase fault tripping of a 220kV transmission line. They are analyzed by using macroscopic inspection of fracture, hardness test, chemical composition analysis, fittings load calculation, metallographic structure analysis and scanning electron microscopy analysis. The results show that there is a current flowing through the ground wire when the high-speed rail passes through. Poor contact between the U-shaped hanging ring and the clamp steel anchor caused heating and then high temperature wear. Long-term operation eventually led to fracture.

1.Introduction
U-shaped hanging ring and clamp steel anchor are the general electric power fittings of transmission lines. The U-shaped hanging rings are usually used to fix the connecting insulator or steel strand with the tower in the overhead power line and substation. Clamp steel anchors are used to fix conductors to the insulator strings of non-linear towers, and also to fix the conductors of cable towers. Therefore, it plays a very important role in the safe and stable operation of high voltage transmission lines[1][4].

In the power line, power fittings are important components related to the safe operation of the line. Failure or damage of the fittings will lead to the destruction of the line and power failure. Therefore, the high reliability of the metal fittings is required[6][7].

2.Fault situation
B phase of a 220kV line had a fault trip. Failure inspection found that the overhead ground wire connecting metal on the left side of the terminal tower of the traction station was heated and burned. As a result, the overhead ground wire fell off and tripped on the wire. The overhead ground wire on the right side was connected with the iron tower with a hot red spot when the high-speed railway passed by, as shown in Figure 1.Terminal tower type was DJC31A-21, with 63m of front side gap, ground wire type XGJ-100, tension-clamp type NY-100G, U-shaped hanging ring type U-10. The material of steel anchor and hanging ring was Q235A. The line was put into operation in November 2009.
3. **Experimental analysis**

3.1 **Macroscopic inspection**

There was no obvious corrosion on the surface of U-shaped ring and steel anchor at the fault. U-shaped ring had been completely disconnected at the bottom, with obvious wear marks at the fracture site and high temperature discoloration marks, as shown in Figure 2 and Figure 3. The inside of the contact area between the steel anchor and the U ring was worn and thinned seriously. The steel ring of whole steel anchor had high temperature discoloration, as shown in Figure 4.

3.2. **Metallographic structure analysis**

The metallographic structure of samples from the fracture and far away from the fracture of U-shaped hanging ring was analyzed by electric spark wire cutting. It was found that the metallographic structure near the fracture was abnormal, which was superheated Weystenite structure [5], as shown
in Fig. 5. For the structure far away from the fracture was ferrite and pearlite which belongs to normal Q235A forging organization, as shown in Figure 6.

3.3. Chemical composition analysis

The composition of U-shaped ring and clamped steel anchor both met the requirements of the standard of GB/T 700-2006 Carbon Structural Steel [2]. The specific test results are detailed in Table 1.

| Element | Requirement | U-ring | Steel anchor | Notes |
|---------|-------------|--------|--------------|-------|
| C       | ≤0.22       | 0.16   | 0.17         |       |
| Mn      | ≤1.40       | 1.22   | 1.17         |       |
| P       | ≤0.045      | 0.042  | 0.039        |       |
| S       | ≤0.050      | 0.038  | 0.041        |       |
| Si      | ≤0.35       | 0.25   | 0.28         |       |

According to GB/T 700-2006 Carbon Structural Steel

3.4. Hardness test

Vickers hardness tests were carried out near and far from the fracture of the U-shaped hanging ring[3]. The average hardness was respectively 135.2HV and 105.6HV. The microhardness of the abnormal tissue near the fracture was higher than that of the normal tissue. See Table 2 for detailed results.

| Location          | 1#  | 2#  | 3#  | 4#  | 5#  | Avg. |
|-------------------|-----|-----|-----|-----|-----|------|
| Far from fracture | 110 | 108 | 102 | 103 | 105 | 105.6|
| Fracture place    | 135 | 136 | 134 | 135 | 136 | 135.2|

3.5. Fittings load calculation

According to the data of ground line spacing and release stress provided by the fault occurrence unit, finite element software MidasCivil8.65 was used to simulate the mechanical calculation of the ground wire. The stress cloud diagram is shown in Figure 7. The U-shaped ring and the steel anchor of the ground wire had the maximum stress, with the axial tension 21.6kN.

3.6. Scanning electron microscopy analysis (SEM)

SEM was used to analyze the worn surface morphology of U-shaped ring [8-9], and the sampling location was shown in Figure 4. The wear surface showed obvious adhesive wear characteristics. At high multiples, it was found that the wear surface had crack characteristics. The surface had the feature of the spherical metal block being scratched, which was a spherical metal formed by the rapid solidification after the rapid melting of metal and bruised in the subsequent wear process. The worn surface of U-shaped ring is shown in Figure 7.
4. Cause analysis

The composition of U-shaped hanging ring and clamp steel anchor was normal. The microstructure far away from the fracture was typical Q235A ferrite and pearlite, indicating that the quality of the fitting itself was qualified.

U-ring and steel anchor failed at the contact force. The fracture showed high temperature discoloration. Metallographic microstructure was found abnormal at near the fracture, which was obviously different from that far away from the fracture. And the Vickers hardness at the site was higher than that of normal tissue. These indicated that there was high temperature in the site, which exceeded the AC1 transition temperature of the Fe-C phase diagram (727°C). Meanwhile, during the fault inspection, it was found that there was a hot red spot in the same part on the right side, and it was determined that there was heat caused by current, which further supported the existence of high temperature in the place. In addition, according to the data provided by the traction station, the downline current of the overhead ground wire grounding leads is about 70 A when the high-speed railway is not passed. When the high-speed railway passed, the ground potential rises, the current in this part should instantly increase, and the temperature at the contact point between the ground steel anchor and the tower hanging ring will further rise.

At the same time, the U-ring and the steel anchor belonged to the flexible connection. According to the mechanical analysis, the axial tension at this place reached 21.6kN. And friction would occur between U-ring and steel anchor contact point in daily operation. The materials of U-shaped ring and steel anchor were both Q235A, which could adapt to wear conditions at normal temperature. But at high temperature, the strength and hardness of the material would decrease, and the higher the temperature, the more severe the deterioration, and the more the wear at the contact parts. The line has been in operation for 10 years since it was put into operation in 2009. The long-term operation eventually led to the wear and fracture failure of the contact parts.

5. Hidden perils Troubleshooting

5.1. The situation

In view of the province's high-speed railway and subway traction stations in similar working conditions, there are 192 power supply lines using U-shaped hanging rings and clamp steel anchors. There are 56 lines of 220 kV. The investigation details are as follows: 114 lines with hidden dangers, including 38 lines of 220 kV. There are mainly two types of hidden dangers, the connection between the ground grid of terminal tower and the inland network of the station and the direct short connection between the overhead ground wire and the inland network of the station. The details are shown in Fig.8-9.
5.2. Management suggestions

In view of the existing two types of hidden dangers, the direct short connection between the overhead ground line and the inland network of the station and the connection between the ground network of the terminal tower and the inland network of the station, the treatment suggestions are put forward respectively.

(1) The overhead ground line directly connected with the station's inland network

There are 114 lines in the province that are directly connected with the inland network of stations by overhead ground lines, 38 lines of 220 kV. There are 7 lines with the ground wire metal ablation at the same time. It is suggested to replace the ground wire with ablation. During the replacement, a plurality of pre-twisted wires should be installed at the connecting part of the metal to carry out shunt, so as to improve the conductivity of the connecting part of the metal. This scheme can reduce the probability of electrical corrosion of the metal by reducing the current passing through the metal.

There are three types of direct short connection between overhead ground wire and station interior network. Short connection between insulator gap, ground grid through grounding and gate frame without insulator for overhead ground wire. Cutting off the current path between ground grid and ground wire of traction station can effectively eliminate the hidden danger.

a) In view of the insulator gap short connection, it is suggested to negotiate with the railway department to dismantle the short connection device and restore the discharge gap, so as to ensure the effective insulation of the insulator.

b) In view of the case that the grounding leads down to the ground grid, it is suggested to consult with the railway department to dismantle the grounding leads down to the ground wire and make the ground wire be grounded through the ground insulator.

c) In view of the situation that the overhead ground wire does not pass through the insulator door frame, it is suggested to install ground insulator with gap between the ground wire and the door frame.

(2) Terminal tower ground network connected with the station interior network

There are 19 lines in the province that are connected to the ground network of the terminal tower and the inland network of the station, 9 lines of 220 kV. There are 17 lines in which the ground line of terminal tower is connected with the inland network of station, and the overhead ground line is directly connected with the inland network. For the connection between the ground network of the terminal tower and the inland network of the station, it is suggested to excavate the grounding of the related lines and disconnect the connection between the ground network of the terminal tower and the traction station. In view of the situation that the overhead ground wire is directly connected with the inland network of the station at the same time, corresponding measures should be taken to the connection between the gate frame and the ground wire of the traction station according to the short-connecting mode, and the direct connection between the ground wire and the inland network of the station should be cut off.
6. Conclusions and Suggestions

6.1. Conclusions
The experimental results show that the material, metallography, hardness and other performance indexes of U-shaped hanging ring and clamp steel anchor were qualified.

The main reason for the fracture was that the current in the ground wire of the high-speed railway passed through. The U-shaped ring and the steel anchor got hot due to poor contact, and then wore at high temperature. After long-term operation, the U-shaped ring finally fractured and failed.

6.2. Suggestions
(1) In view of the province's high-speed railway and subway traction stations in similar working conditions, the power supply lines using U-shaped hanging rings and clamp steel anchors should be checked for potential hazards and made targeted governance of hidden dangers in the line.

(2) Troubleshoot other metal fittings in the terminal tower ground lines of high-speed railway and subway traction stations in the province, and take targeted measures.

(3) Install a current drainage wire at the connection between the U-shaped hanging ring and clamp steel anchor, which is conducive to overcurrent and avoid high temperature wear due to heat caused by poor contact.

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