Fracture Failure Analysis for Wave Trap Hanging Ring in 220kV Line

HUANG Rong¹, XIE Yi², FENG Chao², CAO Xianhui¹, WANG Jun²

¹Hunan Xiangdian Test&research Institute Company Limited, Changsha 410004, Hunan, China;
²Power Science Research Institute, State Grid Hunan Electric Power Company Limited, Changsha 410007, Hunan, China;
HUANG Rong: huangr15@hn.sgcc.com.cn

Abstract. The failure cause of the fracture in wave trap hanging ring in A-phase fault tripping of a 220kV line was analyzed by using macroscopic inspection of fracture, chemical composition analysis, hardness test, metallographic structure analysis and fittings load calculation. The results show that the main causes of hanging ring fracture were unqualified material and welding quality.

1. Introduction

Wave traps are universal hardware fittings in power transmission lines. They are used in series with power transmission lines to provide wave impedance at certain frequencies or bands and to provide signal channels for power carrier communication. As an indispensable high frequency communication element for carrier communication and high frequency (HF) protection, wave traps prevent leakage of HF current to other branchers and reduce HF energy loss. When the line fails, the high frequency signal disappears, the high frequency protection triggers without time limit and then the failure is removed immediately.

In recent years, misoperation of relay protection caused by failures of wave traps often occurs. First, because line inspection or preventive test of wave traps generally need to power off the line and demolish the wave traps from the line and hang down on the ground. But the wave traps have some features of high weight, large volume and high installation location and plus some substation sites are narrow small, close to other live part and the lift truck can not get close to the operating point. So it is difficult for periodic inspection of wave traps. Secondly, the failures of the wave traps are often highly concealed and are affected by the position and environment of the power line, which makes it impossible to effectively test and maintain the line wave traps during operation, thus bringing great difficulties to the operations, analysis and judgment.

Therefore, the power hardware fittings play an important role in maintaining power transmission lines security and reliability. The failure or damage of hardware fittings will lead to the destruction and power off of the line. So the hardware fittings must have high reliability.

2. Failure Condition

At the beginning of 2020, in a power supply company of State Grid, A-phase of 602 circuit breaker in a 220kV line fault tripped and then three-phase tripped after reclosing. The operation and maintenance inspectors found that one side of the 602 wave trap hanging ring was broken. The fracture is shown in the Figure 1, Figure 2 and Figure 3. The line was put into operation in September 2004, with parameters...
of 2×300mm² aluminium cable steel reinforced strand and length of 125.91 km. The line was equipped with two sets of microcomputer protection, the first set was Xu Ji electric optical differential protection device with the type of WXH803A/P, the second set was Nanrui relaying high frequency protection device with the type of 602PCS902. The fault wave trap was 602 A-phase wave trap with the type of XZK-1250-1.0/31.5-JT. The manufacturer was Hunan Jinshi Electric Power Equipment Co., LTD. It left the factory on March, 2014.

3. Experimental Analysis

3.1. Macroscopic Examination

There was no obvious corrosion on the surface of the 602 wave trap hanging ring, which had slight bending and obvious old and new cracks in the fracture internal. The fracture of the wave trap hanging ring is shown in Figure 3. The fracture of the hanging ring was located at the welding joint, and obvious plastic deformation was seen at the straight section near the welding joint. There was a large area of unfused groove near the straight section of the hanging ring welds, as marked in Figure 4. The weld quality was obviously unqualified. In accordance with GB 2314-2016 《General Technical Conditions for Electric Hardware Fittings》[1] and DL/T 768.6-2002 《Manufacturing Quality of Electric Hardware Fittings -- Part 6: Welding Parts》[2], welding shall be carried out in terms of the structural requirements of full penetration. Serious defects such as lack of penetration, lack of fusion and edge biting shall not be allowed in the welds.
3.2. Chemical composition analysis

Chemical composition of broken hanging ring was analyzed. The inferior stainless steel material with high manganese in place of nickel was used. Mn content was 7.33%, Cr and Ni contents were lower than the standard values. According to GB 2314-2016 《General Technical Conditions for Electric Hardware Fittings》, the material selection of stainless steel materials should refer to the GB/T 1220-2007 《Stainless Steel bar》 [3]. The material didn’t comply with the requirement of GB/T 1220-2007 《Stainless Steel bar》, specific test results see Table 1.

| Element | Std. | No.1 | No.2 | Notes |
|---------|------|------|------|-------|
| C/%     | ≤0.12| 0.15 | 0.11 |       |
| Si/%    | ≤1.00| 0.30 | 0.31 |       |
| P/%     | ≤0.035| 0.0265 | 0.0262 | According to 1220-2007 《Stainless Steel bar》 |
| S/%     | ≤0.030| 0.0055 | 0.0058 |       |
| Mn/%    | ≤2.0 | 7.32 | 7.34 |       |
| Ni/%    | 8.00~11.00 | 3.88 | 3.95 |       |
| Cr/%    | 17.00~19.00 | 11.5 | 11.2 |       |

This material had poor toughness and poor anti-fatigue ability, which led to fatigue damage and internal cracks of the rings under long-term operation. In addition, there were strong winds and heavy rains in the fault area during the period of occurrence, which led to the deterioration of internal cracks in the wave trap hanging ring. The right of the hanging ring was broken, and the left insulator string drove the wave trap to swing, which discharged the Type A bracket discharge and caused circuit tripping.

3.3. Hardness test

Weld and base materials of fracture samples and contrast samples of wave trap hanging ring were inspected by microhardness. The microhardness of base and weld material of fracture sample were about 271.2 HV and 283.2 HV, while the contrast ones were about 262.5 HV and 267.7 HV, meeting the standard hardness requirements of DL/T 768.6-2002 《Manufacturing Quality of Electric Hardware Fittings -- Part 6: Welding Parts》, specific testing data are shown in Table 2.
Table 2. Hardness test results

| No. | Position      | Hardness values (HV0.02) | Notes                                                                 |
|-----|---------------|--------------------------|----------------------------------------------------------------------|
|     |               |                          | Notes                                                                 |
|     |               | 1 | 2 | 3 | 4 | 5 | AVG. |
| #1  | Fracture      | 275.6 | 272.0 | 268.5 | 272.8 | 267.1 | 271.2 |
|     | substrate     |                |                          | According to DL/T 768.6-2002 《Manufacturing Quality of Electric Hardware Fittings -- Part 6: Welding Parts》, Weld hardness ≤ 350HB (Equiv. 368HV), & Weld hardness ≤ base hardness + 100 |
| #2  | Fracture      | 282.5 | 278.7 | 280.8 | 285.8 | 288.3 | 283.2 |
|     | weld          |                |                          |                                                                      |
| #3  | Contrast      | 261.5 | 257.5 | 263.2 | 266.5 | 264.0 | 262.5 |
|     | substrate     |                |                          |                                                                      |
| #4  | Contrast      | 262.6 | 261.2 | 271.4 | 268.2 | 275.2 | 267.7 |
|     | weld          |                |                          |                                                                      |

3.4. Metallographic analysis

Metallographic analysis was performed on the weld and base materials of fracture sample and contrast ones of the wave trap hanging ring. The fracture samples of the hanging ring were all austenite and acicular martensite, which were inconsistent with the typical austenite stainless steel structure, as shown in Figure 5-Figure 8. The metallographic structure didn’t meet the requirements of GB/T 1220-2007 《Stainless Steel bar》.
3.5. Fittings load calculation

Based on the data of weight size and height hanging on the gantry provided by failure company, finite element analysis of hanging ring was carried out by software Ansys19.0, stress nephogram is shown in Figure 9. The stress was concentrated in the welding position of the ring, with maximum mises stress of 42.3Mpa, well below its yield stress.

4. Cause analysis

(1) The hanging ring was made of unqualified stainless steel with high manganese instead of nickel, resulting in poor comprehensive mechanical properties of the hanging ring.

(2) The welds of the hanging ring had unfused groove and poor welding quality. Stress was concentrated in the unfused groove in long-term operation, eventually cracks developed.
5. Hazards investigation

5.1. Investigation situation
Carried out the hidden trouble detection of the existing wave trap within the scope of this power supply company, involved 4 substations, 9 lines (including four 220kV lines, one 110kV line and four 35kV lines), among which three 220kV lines' wave traps were in operation, and the wave traps of other lines were retired out but not demolished.

5.2 Corrective and preventive actions
(1) Use the high power telescope to observe the connection points of the wave traps. If finding hazards, power off immediately. Remove all the retired wave traps combined with power failure.
   (2) Hold the expanded analysis meeting of substation to draw lessons from the incident. First, Conduct failure process and inspection training for the operation and maintenance personnel to ensure that the first and second equipment inspection in place according to the standard. Secondly, organize experts to interpret the protection tripping and fault recording information, sort out the key points in the information, and improve the field analysis and judgment ability of operation and maintenance personnel. Thirdly, according to the type and model of equipment, organize maintenance personnel to carry out comprehensive analysis and discussion of the difficulties and blind points in the maintenance process. Eliminate the situation of missing inspection in the maintenance process, strengthen the training of maintenance personnel, improve the maintenance skills and the ability to find problems. Fourthly, strictly implement the relevant regulations, conduct routine inspection of wave traps in accordance with the standard, check the wave traps whenever power failure especially the stressed part, so as to prevent similar incidents happening again.

6. Conclusions and recommendations

6.1. Conclusions
The unqualified material and weld quality of the wave trap hanging ring were the main causes of the fracture.

6.2. Recommendations
(1) Replace the hanging rings in the same batch, and conduct metal tests on the other batch. At the same time, carry out management work to the quality problem of wave trap hanging rings in other substations of this province. Prevent nonconforming metal products from entering the grid, and eliminate or reduce the operation accidents and faults.
   (2) It's suggested to strengthen the quality inspection of the equipment entering into the grid. The construction unit should conduct self-inspection strictly in accordance with the grid standards, and the operation maintenance personnel should strengthen the intermediate acceptance of the infrastructure projects, especially the whole process acceptance of concealed works and key technics, so as to ensure zero defects of the equipment in operation.
   (3) During the operation of the equipment, X-ray on-line crack detection would be used to conduct on the metal suspension parts.

Author brief introduction:
Huang Rong (1988-), female, Changsha, Hunan province, bachelor degree, engineer, graduated from Central South University, majoring in materials and science engineering. Research interests include metal material detection, testing, failure and fault analysis for grid.

References:
[1] GB 2314-2016, General Technical Conditions for Electric Hardware Fittings. China Standard Press, Beijing.
[2] DL/T 768.6-2002, Manufacturing Quality of Electric Hardware Fittings -- Part 6: Welding Parts. China Electric Power Press, Beijing.
[3] GB/T 1220-2007, Stainless Steel bar. China Standard Press, Beijing.
[4] GB/T 7330-2008, Wave traps for AC Power System. China Standard Press, Beijing.
[5] Dong Ji R. (2011) Manual of Electrical Fittings (Third edition). China Electric Power Press, Beijing.
[6] Li Jionghui. (2006) Metallographic map of metallic materials. Machinery Industry Press, Beijing.
[7] Liao Jingyu. (2003) Failure analysis of metal components. Chemical Industry Press, Beijing.