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Failure Analysis on Phase B Adjustable Mechanisms of 220KV Lateral 2801 Switch in Da Yuan Substation

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Abstract. In this paper, the failure of the switch operation caused by a screw breaking of adjustable mechanisms is analyzed. A number of tests, such as macroscopic examination, chemical composition analysis, metallographic test, scanning electron microscope analysis and hardness test, were carried out on the fracture screw sample. From the perspective of metal analysis, it is verified that the failure of the sample is due to the failure of material, resulting in corrosion fracture in the coastal industrial environment and tensile stress interaction. Put forward the checkpoint, do a good job in metal technical supervision, strengthen the quality acceptance and management of the equipment and its parts in the power grid, then, the chances of a similar accident can be reduced.

1. Introduction

October 29, 2017, 500kV Da Yuan Substation 220kV III section bus was overhauled at intervals. From the operation to the maintenance, it was found that the screw parts of the phase B adjustable mechanisms of the 220kV lateral 2801 switch were broken. The manufacturer of the switch is CHANGGAO ELECTRIC GROUP CO., LTD. in Hunan, and the model is GW17A-252IIDW. The design material of the adjustable mechanisms screw is 0Cr18Ni9. The equipment was set out in October 1, 2007, the manufacturing No. 0710252, and was put into operation in November 11, 2008. Then we test and analyze the screw of the adjustable mechanisms in order to find out the cause of its fracture. During the whole test, we analyzed the broken screw sample and a new one to be replaced, and compared them.

2. Test

In the analysis of the samples, we take physics and chemistry methods to check and determine, such as macroscopic examination, chemical composition analysis, metallographic test, scanning electron microscope analysis and hardness test. These test are on the base of occupation standard and Chinese Standard, including "GB/T 233 steel and alloy chemical analysis method", "GB/T 11170 -2008 Stainless steel-Determination of multi-element contents-Spark discharge atomic emission spectrometric method (routine method)", "GB/T 1220-2007 Stainless steel bars","GB/T 13298-2015 Inspection methods of microstructure for metals","GB/T 13299-1991 steel microstructure evaluation method","GB 231.1-2009 metallic materials Brinell hardness test - part one: Test Method". The main test instruments are Axio Observer A1m metalloscope, ZEISS EVO18 scanning electron microscope, UH250 Brinell hardness tester and XMET alloy analyzer.

2.1 Macroscopic Examination

The scene photo of the switch and the broken adjustable mechanism are shown in Fig.1.The screw of the adjustable mechanism mainly withstands the pulling force when the switch is in the closing state. The macroscopic morphology of the broken screw and the new screw are shown in Fig.2. The fracture is smooth and perpendicular to the axis of the screw. Corrosion products are covered at the fracture surface, and obvious corrosion pits are visible on the outer surface of the fracture screw. As a comparison, the new screw overall presents a silver white metallic luster and no rust.

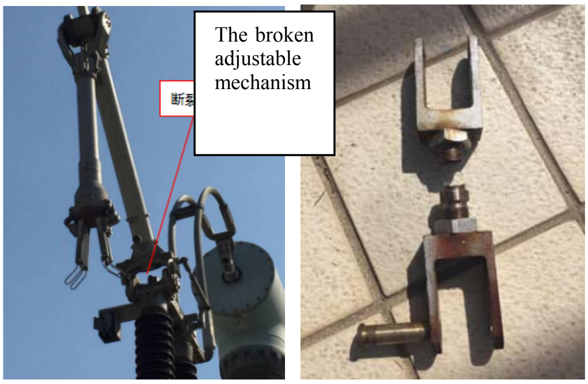

Fig. 1 The scene photo of the switch and the broken adjustable mechanism

Fig. 2 The macroscopic morphology of the broken screw and the new screw

2.2 Chemical Composition Analysis

The chemical compositions of samples are analyzed. The results are shown in Table 1[1].

The content of Cr elements and Ni elements in the fracture screw are low, the content of C elements is seriously high, and the content of Mn elements is high. The results of chemical composition analysis do not meet the requirements of the relevant standards for the material of 0Cr18Ni9. As a contrast, the chemical element content of the new screw is within the standard range, and in accordance with the requirements.

Table 1 The chemical composition of the checked screw wt%

Constituen	Fracture screw	New screw	Technical requirements for GB/T 1220-2007 to 0Cr18Ni9
C	0.23	0.05	≤0.08
S	0.018	0.014	≤0.030
Si	0.49	0.40	≤1.00
P	0.031	0.027	≤0.045
Mn	3.06	1.08	≤2.00
Cr	16.90	18.20	18.00～20.00
Ni	6.92	8.10	8.00～11.00

2.3 Metallographic Test

The intersecting surface of the fracture screw and the new screw are made into metallographic samples, etched with FeCl3 hydrochloric acid solution, and observed and photographed under the metallographic microscope[2]. The results were shown in Fig.3. It is known that the metallographic structure of the fracture screw and the new screw are austenite, and there is no obvious carbide or inclusion particles precipitated on the grain boundary.

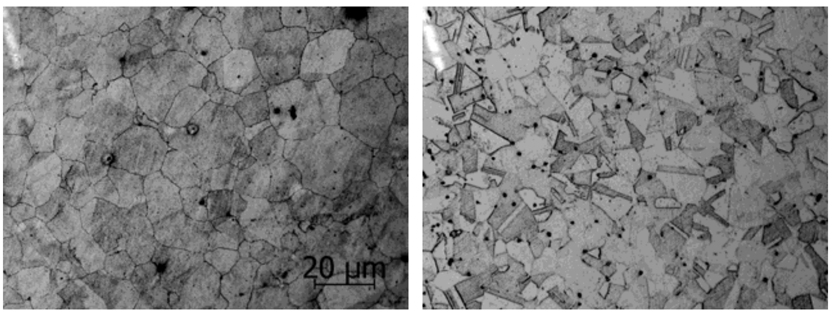

Fig.3.Microstructure of metallographic structure of the fracture screw and the new screw

2.4 Scanning Electron Microscope Analysis

The fracture surface is analyzed by scanning electron microscope (SEM), and the surface micromorphology and corrosion product composition are observed. The micromorphology of the screw fracture is shown in Fig.4. The X ray energy spectrum analysis of the corrosion products on the fracture surface is shown in Fig.5.

From Fig.4., we can see that the fracture surface of the fracture screw is intercrystalline fracture, and the grain appears in the shape of ice candy, and there is obvious secondary crack, which indicates that the fracture form is brittle rupture[3]. The analysis results of fracture corrosion products show that the corrosion products mainly contain Fe, Cr, Mn, O, S, Cl, Ni, Al and other elements, indicating that sulfide and chloride directly promote the corrosion of austenitic stainless steel.

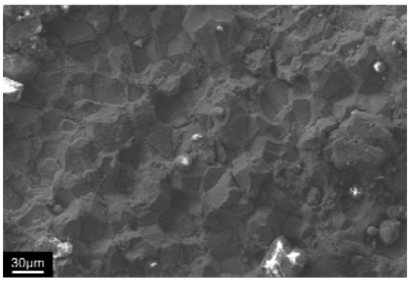

Fig.4. The micromorphology of the screw fracture by SEM

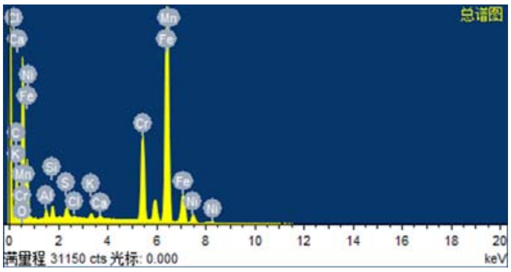

Fig.5. The components analysis of corrosion products of the screw fracture

The intersecting surface of the stainless steel screw is analyzed in the backscatter mode of the scanning electron microscopy (SEM). The micro-crack morphology of the surface is shown in Fig.6. and Fig.7. It can be seen that there are internal cracks in the failure parts, the cracks originate from the edge of the parts, and expand along the grain boundaries. These cracks have typical characteristics of stress corrosion cracking[4].

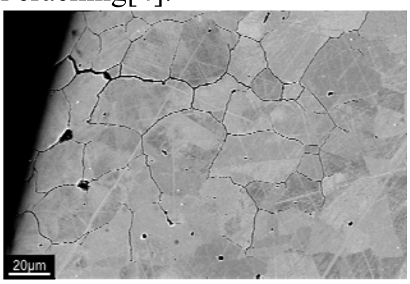

Fig.6. Crack initiation area of stainless steel screw intersecting surface edge

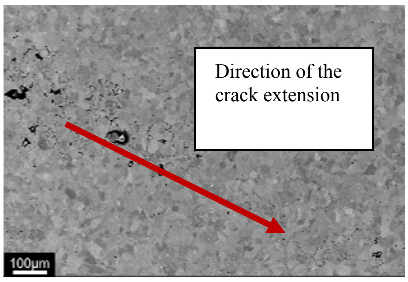

Fig.7. Crack extension of stainless stee l screw intersecting surface

2.5 Hardness Test

According to the provisions of "GB 231.1-2009 metallic materials Brinell hardness test - part one: Test Method", Brinell hardness tests on the intersecting surface of the fracture screw and the new screw are carried out on UH250 type brovin hardness tester. The test results are shown in Table 2. The results show that the Brinell hardness value of the fracture screw is high, which does not meet the technical requirements of the relevant standards. The value of the new screw is normal, which is within the standard range[5].

Table 2. Brinell hardness test results on the fracture screw and the new screw HBW 2.5/187.5

Measuring point	1	2	3	average
Intersecting surface of the fracture screw	198	200	190	196
Intersecting surface of the new screw	184	187	183	185
Technical requirements for GB/T 1220-2007 to 0Cr18Ni9	≤187HBW			

3. Analyses and Discussion

(1) The results of the macroscopic morphology show that the screw failure is brittle rupture and the corrosion of the outer surface indicates that the corrosion resistance of the raw material is poor. Combined with scanning electron microscope analysis, the fracture of the screw has typical characteristic of intercrystalline fracture, and the corrosion products of fracture contain S and Cl elements. The sulfur and chloride ions in the atmosphere are involved in the corrosion process of the screw.

(2) The results of metallographic specimen show that the metallographic structure of the fracture screw and the new screw are austenite, and there is no obvious carbide or inclusion particles precipitated on the grain boundary.

(3) The microstructure analysis results show that there are cracks in the microstructure of the fracture intersecting surface, and expand along the grain boundary, which has the characteristics of stress corrosion cracking.

(4) The chemical composition analysis results show that the chemical composition of the new screw is normal, but the Cr and Ni content of the fracture screw are low, and the C and Mn content are high. Cr element is the main element of stainless steel to obtain corrosion resistance. The low content of Cr, which reduces the corrosion resistance and the passivation ability of stainless steel, makes the pitting corrosion easy to expand, and becomes a micro crack.The low content of Ni leads to the instability of austenite, martensitic structure is easily formed in the process-cycle, and the toughness of the material is reduced. The high content of C is easy to form carbides with Cr, which greatly reduces the corrosion resistance of stainless steel. The high content of Mn will form metallic mixtures with C and S, which destroy the binding force between grains and reduces the corrosion resistance of stainless steel[6].

According to the requirements of Table 3 for "GB/T3098.6-2000 mechanical properties of fasteners - stainless steel bolts, screws and studs", in the case of intercrystalline corrosion tendency, it is recommended according to ISO 3651-1 or ISO 3651-2. In this case, a stable A3 or A5 stainless steel, or a A2 or A4 stainless steel with a carbon content of no more than 0.1%, is recommended. The grouping and chemical composition of the stainless steel are as follows:

Table 3. The grouping and chemical composition of the stainless steel

Category		**Austenite**				
Group		A1	A2	A3	A4	A5
Chemical composition	C	0.12	0.1	0.08	0.08	0.08
	Si	1	1	1	1	1
	Mn	6.5	2	2	2	2
	P	0.2	0.05	0.045	0.045	0.045
	S	0.15-0.35	0.03	0.03	0.03	0.03
	Cr	16-19	15-20	17-19	16-18.5	16-18.5
	Mo	0.7	-	-	2-3	2-3
	Ni	5-10	8-19	9-12	10-15	10.5-14
	Cu	1.75-2.25	4	1	1	1

The above table shows that the Ni content of A2-A4 austenitic stainless steel is at least 8%, and the maximum value of the Mn content is not more than 2%. The stainless steel screw material may belong to A1 stainless steel according to the measurement results. A1 steel is specially designed for mechanical processing. The steel has high sulfur content and low corrosion resistance.

(5) The hardness test results show that the Brinell hardness value of the new screw-intersecting surface is normal, but the Brinell hardness value of the fracture-intersecting surface is obviously high, indicating that its plasticity and toughness are poor. The high hardness is related to the high content of C and Mn in the raw material of the fracture screw and cold hardening in the forging process.

According to the above macroscopic morphology, microstructure, chemical composition analysis and hardness test data, it is shown that the screw failure of the adjustable mechanisms is stress corrosion cracking. The main reasons for the failure come from two aspects of the environment and the material itself. The main reasons are as follows:

On the one hand, the substation is located in the Heshi town of Quanzhou which has the characteristics of the seaside-orientated industries, which provides two kinds of corrosion medium, sulfur and chloride ions. 0Cr18Ni9 stainless steel has stress corrosion sensitivity to corrosive environment such as sulfur and chloride ions in atmospheric environment. On the other hand, the screw of the adjustable mechanism mainly withstands the pulling force when the switch is in the closing state. These two factors cause the stress corrosion fracture of the screw.

(2) The material components of the fracture screw are not qualified in the process of manufacture. The low Cr and Ni content and high C and Mn content greatly reduce the corrosion resistance of stainless steel, especially the intergranular corrosion resistance, thus promoting the stress corrosion cracking process of the screw.

For phase B Adjustable Mechanisms of 220kV Lateral 2801 Switch in 500kV Da Yuan Substation, the chemical composition of the material used for the screw does not meet the requirements, resulting in the degradation of the material. The screw finally gets corrosion fracture because of the coastal industrial environment and tensile stress interaction.

4. Suggestions and Preventive Measures

(1) Replace the adjustable mechanisms of the same batch with the invalid sample. If the conditions are limited and failed to replace in time, the tracking and inspection should be strengthened, and the hidden danger should be eliminated in time.

(2) Strengthen the quality acceptance and management of the equipment and its parts in the power grid. For the newly replaced adjustable mechanisms, the manufacturer should be required to provide the chemical composition analysis report and the mechanical performance report on the hardness and so on.

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