Analysis on corrugated pipe break in the expansion joint of a turbo-generator set

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Abstract. In a power plant, the bellows of the lower part of the expansion joint for pumping and heating of the NO.8 turbo-generator unit broken, and the internal guide plate was teared along the welding seam. Through observation of macroscopic morphology, hardness analysis, metallographic examination, energy spectrum analysis and other means, the corrugated pipe material itself unqualified performance, stress corrosion cracking, corrosion and other reasons were eliminated. According to the micro-characteristics of fatigue fracture and the service environment of the bellows, it is concluded that the main reason of break is the fatigue cracking of the bellows under the impact of the air flow and vibration.

Keywords. Steam turbine generator set, corrugated pipe, break.

1. Introduction
On December 30, 2018, the unit load of 8# turbo-generator set was 504MW, heating extraction flow was 204t/h, heating extraction steam pressure was 0.18MPa, temperature was 258℃. Through on-site inspection, it was found that corrugated pipe had crack in extraction steam heating expansion section lower part. The crackle corrugated pipe fell off in the next morning, as shown in figure 1. The internal guide plate was torn along the welding seam and had scratches.

The unit was put into operation on November 23, 2018. Expansion joint adopts universal hinge type after quick closing valve of extraction steam, expansion joint bellows is made of SUS316L, double-layer structure. The detached part is located in the outer layer, with a design thickness of 1.2mm. The inner layer is in contact with steam, and the outer layer is wrapped with insulation cotton. The design pressure is 0.48MPa, the temperature is 282℃, and the compensation angle is 5°.
2. Experimental study

In order to analyze the reason of corrugated pipe fracture, a piece of broken corrugated pipe was analyzed by means of macroscopic examination, microstructure analysis and energy spectrum analysis.

2.1. Macroscopic examination

Macro picture of the detached expansion joint corrugated pipe debris was shown in figure 2, the fragment length was about 80mm, and the thickness was 1.1mm. Macroscopically, no obvious plastic deformation was found in the debris, which showed brittle fracture characteristics. The overall thickness of the debris was uniform, no obvious thinning was observed near the fracture, and no obvious signs of corrosion were found on the internal and external surfaces of the debris. Most of the fracture area was flat with wear marks and sharp edges. Most of the fracture area had slight oxidation, showing a slightly yellowish white bright metallic luster, and black oxidation traces were found in local areas (shown in figure 3).

Figure 1. Schematic diagram of corrugated pipe falling off.

Figure 2. Macro photoes of falling corrugated pipe debris.

Figure 3. Macroscopic morphology of fracture location.
2.2. Hardness test

Vickers hardness (HV5) test was carried out on the fragments, and the results were shown in table 1. At the same time, the hardness requirements of SUS316L material in the standard JIS G4304-2005 *hot rolled stainless steel plate, sheet and strip* were compared. The results showed that the vickers hardness value of the fragments met the above standards.

| Position  | Test results /HV | Average value |
|-----------|------------------|---------------|
| Position 1| 168 174 173 170 | 171           |
| Position 2| 188 187 188 184 | 187           |
| JIS G4304-2005 | ≤200HV       |               |

2.3. Metallographic examination

Metallographic examination for debris sampling could be seen in figure 4. The matrix structure was twin austenite + a few banded or granular ferrite, grain size was about 8~10 grade (as shown in figure 4a and 4b). One side of the section was not smooth, and there were transgranular secondary cracks (as shown in figure 4c and 4d). On the other side of the fracture, there were many locally-concentrated zigzag microcracks near the inner wall (as shown in figure 4e and 4f), but no obvious corrosion pits or other signs.

![Microstructure of debris](image_url)

**Table 1.** Vickers hardness test results of the fragments.

**Figure 4.** Microstructure of debris.
2.4. Microanalysis of fracture

The microscopic morphology of the fracture was observed by sampling from the upper right area of figure 1b, as shown in figure 5. It can be clearly seen that the fracture appeared two areas with different colors. The upper area A was darker and turns black after oxidation; The area B below showed a bright white posterior fracture (shown in figure 5a). The surface of fracture A in the region was severely oxidized and the original surface morphology of the fracture disappeared (shown in figure 5b and 5c). There was no obvious oxidation phenomenon on the surface of fracture B in the region, showing the quasi-cleavage brittle fracture characteristics, and more fatigue bands can be observed, which were typical microscopic characteristics of fatigue fracture. The small spacing of fatigue bands indicated that the stress causing fatigue fracture was relatively small (shown in figure 5d and 5e).

![Figure 5. Microanalysis of fracture.](image-url)
2.5. Energy spectrum analysis near the fracture
The black and white areas near the fracture were sampled for energy spectrum analysis, and the results were shown in figure 6 and 7. The results showed that the macroscopically black areas mainly contained iron and chromium oxides, and a small amount of Si, Mo, Ni elements, no corrosive elements S, Cl and so on were found. The white bright color area was mainly composed of iron and chromium elements, containing a small amount of Si, Mo, Ni and O elements. The oxide content was obviously very low, and no corrosive elements such as S and Cl were found.

![Figure 6. Results of spectrum analysis in black area.](image1)

![Figure 7. Results of spectrum analysis in white area.](image2)
3. Analysis and discussion

(1) There was no obvious macroscopic plastic deformation and brittle fracture feature in the detached corrugated pipe with expansion joints. The overall thickness of the debris was uniform, no obvious thinning was observed near the fracture, and no obvious signs of corrosion were found on the internal and external surfaces of the debris. Most of the fracture area was flat with wear marks and sharp edges. Most of the fracture area had a slight oxidation, a slightly yellow white bright metallic luster, several areas found black oxidation traces. Thus it can be seen that the shedding of the corrugated has no obvious relationship with mechanical damage such as surface corrosion or impact. Multiple regions found traces of black oxidation, the characteristics of the stainless steel high temperature oxidation on macroscopic, the operation of the corrugated tube temperature about 282 ℃ can be judged, and the formation of the black oxide may be formed in the corrugated pipe before the operation of high temperature processing stage.

(2) Vickers hardness (HV5) test results showed that the vickers hardness value of the fragments met the JIS G4304-2005 standards. The matrix structure was twin austenite and a few banded or granular ferrite, grain size was about 8~10 grade. The microstructure and grain size were all meet the requirements. The possibility of corrugated pipe cracking caused by unqualified material performance can be basically eliminated.

(3) From metallographic examination, we can see that one side of the section was not smooth, and there were transgranular secondary cracks. On the other side of the fracture, there were many locally-concentrated zigzag microcracks near the inner wall, but no obvious corrosion pits or other signs. The possibility of stress corrosion cracking can be basically eliminated according to the crack morphology [1, 2].

(4) Through energy spectrum analysis, the macroscopically black areas mainly contained iron and chromium oxides, no corrosive elements S, Cl and so on were found. So the cracking of the corrugated pipe was independent of corrosion [3].

(5) Scanning electron microscopy (SEM) showed that most of the fracture area was badly worn, and the fracture microstructure disappeared. On the macroscopic view of the fracture, the area showing black oxidation can be seen its serious oxidation morphology on the microscopic view. The locations where local oxidation was not obvious or wear was not serious showed quasi-cleavage brittle fracture characteristics, and more fatigue bands can be observed, which were typical microcosmic characteristics of fatigue fracture. The small spacing of fatigue bands indicated that the stress level leading to fatigue fracture was relatively low [4, 5].

According to the field feedback, the guide plate inside the expansion joint was damaged, and the corrugated pipe will vibrate under the impact of the air flow. Considering that the crack growth morphology and fracture morphology were consistent with the characteristics of vibration fatigue fracture, it can be seen that vibration was the main cause of fatigue cracking.

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