Cracking failure analysis of convection tube of heat recovery steam generator

Facai Ren¹ and Xiaoying Tang¹

¹Shanghai Institute of Special Equipment Inspection and Technical Research, Shanghai 200062, PR China
Corresponding author e-mail: caifaren@163.com

Abstract. The failure causes of cracks on a convection tube of heat recovery steam generator were analyzed by the optical microscope and scanning electron microscope analysis. The results show that the circumferential crack of the convection tube belongs to fatigue fracture. The micro-crack defect on the surface of fracture promotes the fatigue crack propagation.

1. Introduction
Crack defect appeared on the surface of the convection tube of heat recovery steam generator. The appearance of cracks seriously affects the safe operation of heat recovery steam generator. To avoid accidents, the cause of cracking failure should be revealed.

In the past, some researchers investigated the crack failures of different components. Hu et al. [1] investigated the failure causes of a crack on a high-speed train bolster. The results showed that the crack source was the micro-holes caused by the deficiencies in welding procedure. Ravindranath et al. [2] investigated the root cause of the failure of stainless steel 304L air cooler tubes in a petrochemical company. The results showed that the failure of the tube was due to chloride stress corrosion cracking. Salehnejad et al. [3] analyzed the crack failure causes of exhaust manifold of a diesel engine. The results showed that the assumed crack didn’t propagate during worst work condition. Wu et al. [4] developed a framework for simulating stress corrosion cracking of full-size cable bolts. The results showed that galvanising improved the resistance of cable bolts to stress corrosion cracking and delayed the cable bolt failure. Yu et al. [5] investigated the longitudinal-crack of double-shoulder tool joint by experimental and numerical methods. The results showed that decrease of thread taper of double-shoulder joint could effectively avoid the failure accident caused by longitudinal-crack. Zhang et al. [6] investigated the crack failure of a handhole flange. The results showed that the main reasons for the cracking were liquation crack and sensitization of flange materials. Sun et al. [7] analyzed the fracture of the TBM cutterhead. The results showed that the proposed method was feasible to calculate the multiple cracks failure process under the dynamic loading.

In this paper, cracking failure analysis on convection tube of heat recovery steam generator was studied. The main causes of convection tube failure are determined.

2. Macroscopic morphology
The cracking convection tube of heat recovery steam generator is shown in Fig. 1(a). The convection tube is connected with the upper and lower drums by fillet welding on the inner wall of the drum. The diameter and the thickness of the tube is 51 mm and 3 mm, respectively. The material of the tube is 20

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steel. As shown in Fig. 1(b), the circumferential crack on the inner wall of the tube is located at the root of fillet weld. The crack is about 12 mm away from the end face.

3. Results and Discussions

3.1. Chemical composition analysis

The chemical composition of convection tube of heat recovery steam generator is shown in Table 1. The results show that all element contents meet 20 steel requirements referring to GB 3087-1999.

| Element | C   | S   | Si  | Mn  | P   | Cr  | Ni  | Cu  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| Tube    | 0.18| 0.007| 0.23| 1.29| 0.010| 0.04| 0.05| 0.13|
| 20 (GB 3087-1999) | 0.17-0.23 | ≤0.035 | 0.17-0.37 | 0.35-0.65 | ≤0.035 | ≤0.25 | ≤0.25 | ≤0.25 |

3.2. Metallographic microstructure analysis

Longitudinal and transverse specimens were intercepted at the fracture surface. After grinding and polishing, the specimens were observed and analyzed with different magnification under the optical microscope. As shown in Fig. 2, cracks and pits with different morphologies originating from the inner wall were observed in different regions.

The metallographic microstructure of the convection tube is shown in Fig. 3. The morphology near the tube fracture is shown in Fig. 3(a). As shown in Fig. 3(b), the metallographic structure of the superheated zone at fillet weld is Widmanstatten ferrite + pearlite. The metallographic structure of superheated zone and normalized zone is shown in Fig. 3(c), the left is superheated zone, and the right is normalized zone. The metallographic structure is fine grain ferrite + pearlite. The cross-section metallographic structure of the tube is ferrite + pearlite as shown in Fig. 3(d).
3.3. SEM Micromorphology analysis

The SEM morphology of the convection tube is shown in Fig. 4. As shown in Fig. 4(a) and 4(b), there are some cracks on the inner wall of the convection tube. Crack parallel to the fracture is observed in the edge of the inner wall fracture as shown in Fig. 4(c). Area A represents the inner wall and area B represents the fracture. Typical morphologies of oxygen corrosion pits were observed on the inner surface as shown in Fig. 4(d).

![Figure 4. SEM morphology of the convection tube inner wall.](image-url)
The SEM morphology of the convection tube fracture is shown in Fig. 5. The dimple pattern can be observed on the fracture surface.

![SEM morphology of the convection tube fracture](image)

Figure 5. SEM morphology of the convection tube fracture.

4. Conclusion
The circumferential crack of the convection tube belongs to fatigue fracture. During the operation of heat recovery steam generator, fatigue cracks are easily induced by material defects such as micro-cracks on the surface of fracture.

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