Design and Application of the Protection Casing in Boiler of Power Plant

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Abstract. Based on the load characteristics and failure mode of the protective casing in boiler in power plant, its design principle and management strategy were put forward. The protective casing shall be configured in the areas with different temperature medium mixing, such as boiler drum water supply pipe, recycling pipe, balance vessel pipe, superheater and desuperheater header, desuperheater spray pipe, etc. The structure and material of the casing shall be able to avoid the thermal stress directly acting on the component body. In terms of application management, visual inspection and nondestructive surface testing shall be carried out for the casing and its connecting areas in which the key parts of inspection included stress concentration areas, such as welding joints, grooves, hole edges and welding defects during equipment maintenance. Different methods such as grinding and welding and reaming and replacement and others are used to deal with casing defects according to its severity. The feasibility and reliability of the above design principles and application and management strategies were proved by several engineering examples.

1. Introduction
It is necessary to mix different temperature media such water or steam in some components of the utility boiler in order to control temperature of the media and ensure normal circulation of boiler water or steam. Generally, protective casing is used in the media mixed area so that the thermal stress produced by the media temperature difference acts on the inner tube of the casing instead of the component body[1-3]. Chinese national standard GB / T 16507.3-2013 requires that "where the connecting pipe (such as water supply pipe, dosing pipe, etc.) probably causes local thermal fatigue of the drum wall, the casing shall be installed at the place passing through the drum wall". In fact, in addition to the drum, other components of boiler also have local thermal fatigue caused by different temperature media mixing. However, the relevant standards do not specify the components that need to be equipped with protective casing for power plant boilers. In addition, it also lacks systematic research on application and management of protective casing except for a few isolated engineering cases. According to the load characteristics and failure mode of the protective casing of the utility boiler, its design principle is put forward and application and management strategy is summarized in the aspects of inspection, repair and transformation, and the engineering example is listed for further explanation in this paper.

2. Analysis of Load Characteristics and Failure Mode of Protective Casing
If a cylinder is fixed in a circular tube with different temperatures and no relatively sliding each other, the thermal stresses in the cylinder and the circular tube the thermal stress can be described by formula (1) [4]:

\[ \tau = \frac{4 E_2}{(D + d) \ln \frac{D}{d}} \left( \frac{T_2 - T_1}{T_2 - T_1} \right) \]
\[
\sigma_c = \frac{\alpha_c T_c - \alpha_e T_e}{E_c A_c} E_c A_c \\
\sigma_t = \frac{\alpha_t T_t - \alpha_e T_e}{E_t A_t} E_t A_t
\]

That, 
\(\sigma_c, \sigma_t\): thermal stress of cylinder and tube respectively. 
\(\alpha_c, \alpha_t\): coefficient of linear expansion of cylinder and tube respectively. 
\(T_c, T_t\): temperature of cylinder and tube respectively. 
\(E_c, E_t\): modulus of elasticity of cylinder and tube, respectively. 
\(A_c, A_t\): cross section area of cylinder and tube, respectively.

It can be seen from formula (1), the thermal stress is mainly related to structural type of components and wall thickness and temperature difference. The greater the structural restraint, the thicker the wall thickness and the greater the temperature difference between the fluids, the greater the thermal stress produced in this area. For power plant boiler components, medium mixing forms alternating fatigue load which causes thermal fatigue damage in components during operation. In order to avoid this kind of damage, one method is to reduce the thickness of components or media temperature difference. Another method is to configure protective casing structure. Sometimes the former method can’t be used in engineering because of structural reasons or operation requirements. The protective structure can make the mixing area of different temperature medium far away from the component body, and the thermal stress is generated on the socket and inner pipe of the casing. Because the thin-walled structure can be used for both the casing socket and the inner pipe, the thermal stress is greatly reduced, and it is also easy to repair or replace after the thermal fatigue damage or damage occurs.

The failure characteristics of thermal fatigue damage have been fully mastered based on a large number of studies [5-6], for example as follows.

Cracks usually originate from the stress concentration regions of component, such as groove, pipe hole edge, weld toe of welded joint and other structural discontinuities or defects such as incomplete penetration and undercut of joints. When there are some defects in the structure, such as cracks and slag inclusions in the weld, the thermal fatigue cracks may also sprout from these defects. Fig. 1 shows the crack on the inner wall of the casing pipe hole of the steam drum water supply pipe of a power station, which is located at the edge of the pipe hole with the strongest stress concentration.

Crack initiation from multiple regions simultaneously. As shown in Fig. 1, there are many radial thermal fatigue cracks around the casing pipe hole in a drum of a boiler after 27 years operation.

Thermal stress controls crack growth rate. Giant temperature gradient usually forms only one or several main cracks, while small temperature gradient often forms crack group with mud-crack pattern.
3. Design Principle of Protective Casing
The following basic principles shall be followed for the configuration of protective casing according to thermal fatigue crack mechanism and occurrence of failure cases in the project.

Protective casing structure shall be designed in all areas where the medium with different temperature are mixed, such as boiler drum recycling pipe, water supply pipe, dosing pipe, balance pipe, desuperheater spray pipe of superheat and reheat system, etc.

Material of casing should be the same or similar to the component body to reduce additional thermal stress caused by dissimilar metals, as shown in formula (1).

Full penetration structure should be adopted in the casing socket as far as possible. The stress concentration of the structure without penetration may accelerate the initiation of thermal fatigue crack.

Extension length of the pipe in the casing shall be enough to ensure that the mixing area of different temperature media is far away from the component body as far as possible. Fig. 2 shows cracks in an economizer recirculation pipe casing hole in a boiler drum. The short inner pipe length led to the mixture of the recycled water and the drum water on the inner wall of the drum. Therefore, serious thermal fatigue damage occurs in the tube hole area.

4. Application and Management Strategy of Protective Casing

4.1. Inspection and Testing
The inspection methods of protective casings include visual inspection and surface nondestructive testing because its damage mainly is thermal fatigue and the area of damage mainly is in the area of stress concentration, usually on the surface of component body. Surface nondestructive testing usually adopts magnetic particle testing or liquid penetrant testing. They are also used to confirm suspected defects found in the visual inspection. The key regions to be inspected are structural discontinuities, such as grooves, holes, welded joints, etc.

4.2. Repair and Transformation
The casing with defects found in the inspection can be repaired by the following methods.

4.2.1. Grinding and cleaning. The mechanical grinding method can be used to eliminate the shallow thermal fatigue cracks. If the residual wall thickness after grinding meets the design minimum wall thickness requirements that repair welding was not necessary.

4.2.2. Welding repair. The welding repair method can be used to deal with the cracks which the minimum wall thickness can’t meet the strength requirements after remove the cracked parts. Welding process should be carefully selected due to the thermal fatigue damage in the repair area. For example, tempering weld bead technology[7-8] can be used to repair the case of grinding depth < 10.5mm, so as to avoid PWHT and reduce damage of PWHT to the material.

4.2.3. Reaming repair. If there is serious thermal fatigue damage in the area of casing nozzle seat, the method of reaming can be used to remove the seriously aged pipe hole area, expand the original pipe hole and redesign a new socket.

4.2.4. Add protective casing. Protective casing can be redesigned in regions which there is a mixture of different temperature media.

5. Engineering Examples

5.1. Cracks in the Economizer Recycling Pipe Sleeve in a Drum

5.1.1. Defects. After 27 years operation of a power generation boiler, cracks were produced in the casing hole of the recycling pipe of the economizer on the drum, as shown in Figure 3. The circumferential cracks of the pipe hole presented radial distribution with a maximum length of 120mm
and mud-crack pattern by cracks connection each other. The directional cracks of the inner wall of the pipe hole presented parallel distribution, and one of the cracks penetrated the fillet weld of the casing pipe joint resulted in the leakage of the steam drum.

**Figure 3.** cracks in the recirculation pipe hole of a drum economizer

**Figure 4.** Schematic diagram of new casing structure after defect removal and reaming in Figure 3

5.1.2. **Cause analysis.** The recycle pipe socket of the economizer consisted of a casing and an inner pipe according to the design. However, it was found during leakage inspection that the inner pipe in the socket was not installed the manufacturing. Temperature difference between two media, that feed water temperature by the recycle pipe of the economizer 150~250 °C, and drum working medium temperature 320 °C, resulted in giant thermal stress at the recycling pipe hole. Due to the lack of inner tube, this alternating stress directly acted on the drum wall. Under the action of long-term alternating stress, the fatigue crack first appeared in the most intense stress concentration part of the tube wall (such as the intersection of the inner wall of the tube hole and the wall of the tube hole, the weld toe of the fillet weld), and gradually expanded along the thickness of the weld, the inner wall of the tube hole and the direction of the tube hole, and finally led to leakage through the wall or fillet weld of the tube.

5.1.3 **Repair.** The method of reaming was selected, that is, enlarging the recirculation pipe hole to 113mm, and a new casing structure were designed, as shown in Figure 4. The detail repair process is as follows. First remove the defects found by mechanical grinding. Then enlarge the casing pipe hole to 113mm. The third, welding pit. GTAW and SMAW were selected for pit welded repairing with TIG-J50 wire and J507RH welding rod and preheat to 180~ 200 °C before welding. And then, casing fillet welding and butt joint welding. The welding process was the same as pit welded repairing. Last PWHT. Local PWHT were carried out for fillet weld of heating rope. Heating ropes were arranged around the fillet weld as a center with holding temperature 580 °C and holding time 120min.

5.1.4 **Inspection after operation.** No defects were found in the repaired area through visual inspection and surface NDT after 4 years of operation.

5.2. **Fracture of a Spray Pipe of Superheater Desuperheater**

5.2.1. **Equipment structure and defects.** Superheated Steam quality reduction for spray pipe of superheated desuperheater fracture was found in a boiler in a power plant. The desuperheater adopted the protective casing structure to separate lower temperature feed water away from desuperheater cylinder, as shown in Fig. 5 (a). The superheated steam temperature is 450 °C, and the feed water temperature is 170 °C. The following problems were found in the protective casing structure. First, high restraint between casing and water spray pipe. The casing and the water spray pipe can’t expand
freely in longitudinal direction because welded connection between the casing and the cylinder and the water spray pipe each other. Thermal stress caused by temperature difference between two media was applied to casing pipe and the water spray pipe, and additional stress was also borne by the blocked expansion during spraying. Another reason, unreasonable structure of the sealing welding of casing and water spray pipe. The casing and water spray pipe formed a partially closed chamber because both ends of the casing were welded with the water spray pipe. The great additional stress generated from the change of chamber gas pressure with the change of spray pipe temperature.

![Diagram](image)

**Figure 5.** structural diagram of desuperheater spray system(1. Desuperheater shell 2. Weld 3. Spray pipe casing 4. Spray pipe 5. Spray pipe connecting flange)

5.2.2. *Defect repair and structural improvement.* Remove the inner wall crack of the tube hole of the desuperheater, enlarge the hole diameter, and redesign the spray pipe socket. The improved protective casing structure was shown in Figure 5 (b). Casing structure was still adopted for pipe socket but with low restriction between casing and water spray pipe. Meanwhile, penetration structure was adopted for welding of casing and desuperheater cylinder. After the renovation and repair, no obvious defects were found in this area after 9 years of operation.

6. **Conclusion**

Protective casing should be set on the parts with different temperature medium mixed in the utility boiler to avoid large thermal stress which would cause thermal fatigue damage and damage to the local area. In general, these components include boiler drum water supply pipe, recycling pipe, balance vessel pipe, superheater and desuperheater header desuperheater spray pipe, etc.

The protective casing should be inspected through visual inspection and surface nondestructive testing along with the equipment maintenance cycle. Key inspection regions include stress concentration areas, such as holes, grooves, welded joints, or welding defects such as cracks and slag inclusions.

The repair methods of protective casing such as grinding and welding and reaming and adding casing can be selected according to the severity of the defect arising from operation.

7. **Reference**

[1] Chen Yingzi, Fang Deming, Pan Baisong. Cause analysis and improvement measures for welding crack of boiler water inlet pipe. *Mechanical design and manufacturing*, 2008,12:122-123

[2] Xu Meizhen, Wu Jian. The necessity and implementation of adding protective casing to boiler recirculation pipe. *Equipment management and maintenance*, 2003,12:28.

[3] Liu Wei, Yang Ling, Fuyang. Cause analysis of cracks in CB boiler water supply casing. *China special equipment safety*, 2011,27 (3): 59
[4] Taira Shuji 1984 *Thermal stress and thermal fatigue: basic theory and design application* (Beijing - National Defense Industry Press) P5

[5] He Jinrui 1988 *High temperature fatigue of metals* (Beijing: Science Press) P206

[6] Warwick M. P., Ken U. S., Philip Bendeich. The use of a simplified analytical expression for metastable thermal stress analysis and its application to creep–fatigue damage of a 2.25Cr 1Mo thick walled component *International Journal of Fatigue, 2010, 32(2)*: 368-375.

[7] Chen zhongbing, Li Jialiang, Zhang Hanbo, et al. Application of tempering weld bead technology in repair of defective or damaged parts *Welding, 2018, 8*: 6-11

[8] Walter J Sperko. Exploring temper bead welding *Welding Journal, 2005, 84(7)*: 37-40.