Engineering Failure Analysis 37 (2014) 42–52

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Failure analysis on abnormal wall thinning of heat-transfer titanium tubes of condensers in nuclear power plant Part II: Erosion and cavitation corrosion

Fei-Jun Chen, Cheng Yao, Zhen-Guo Yang *

Department of Materials Science, Fudan University, Shanghai 200433, PR China

ARTICLE INFO

Article history:
Received 24 March 2013
Accepted 19 November 2013
Available online 4 December 2013

Keywords:
Titanium tube
Wall thinning
Failure analysis
Erosion
Cavitation corrosion

ABSTRACT

In Part I of the failure analysis on abnormal wall thinning of heat-transfer titanium tubes used in condensers in nuclear power plant, we analyzed the causes and mechanisms of abnormal thinning that commonly happened at the contact part between the tubes and the support plates. This kind of failure was the mainstream failure type in our case and the main causes were found to be eccentric contact wear and three-body contact wear rooted in processing defect of internal borings, corrosion products deposit and sagging, and foreign particles. However, there were still some individual failure tubes with different failure sites and modes and were located under the bypass pipes at the shoulder of the tube tower instead of in its lower part, obviously telling another failure story. In Part II of the failure analysis, material analysis, metallographic examination, mechanical performance tests, macro- and microstructure analysis and composition analysis were conducted. The failure causes were found to be erosion and cavitation corrosion and the synergetic effect of them. Finally, corresponding countermeasures were suggested.

1. Introduction

Since nuclear power was utilized, safety concerns have never stopped to bother us. From the disaster of Chernobyl in Russia decades ago, to the nuclear leak in Fukushima in the last two years, historical lessons written in blood have taught us that every detail in a nuclear power station is of critical importance and not a single tiniest potential peril can be ignored.

The heat-transfer titanium tubes in condensers of the two 700 MW CANDU units in China – the first and only two pressurized heavy water reactor (PHWR) units in the country – have encountered abnormal tube wall thinning. With a design life of 40 years, the condensers were forced to temporarily stop operation after only 8 years in service because unexpected wall thinning problems were found on the heat-transfer titanium tubes, bringing about heavy economic loss and potential safety threat. Our team was asked to conduct failure analysis of the tubes. The tubes are made of industrial pure titanium in correspondence to Chinese brand TA1, with the length of 17370 mm, and specifications of 25.4 mm × 0.5 mm (outside diameter × wall thickness). All these specifications have also been mentioned in Part I [1] of the failure analysis.

Among the dozens of tube samples we got, most of them presented similar failure modes at similar positions. After detailed analysis by various techniques, we primarily ascribed most of the failure cases to eccentric contact wear and three-body contact wear rooted in processing defect of internal borings, corrosion products deposit and sagging, and foreign particles, discussed in Part I [1] of the failure analysis. However, we still found another kind of failure case with distinct appearance and failure positions. When we conducted inspection inside the condenser, we discovered the bypass pipes,

* Corresponding author. Tel.: +86 21 65642523; fax: +86 21 65103056.
E-mail address: zgyang@fudan.edu.cn (Z.-G. Yang).

1350-6307/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engfailanal.2013.11.002

Fig. 1. Bypass pipes.

which were designed for shock mitigation of high pressure steam during start and stop (Fig. 1). As illustrated by the tube arrangement diagram shown in Fig. 2, within the tower-like structure of 9922 heat transfer titanium tubes in each condenser, samples in Part II are located at the tower shoulder under the bypass pipes while the samples we analyzed in Part I [1] were all in the lower part of the tower. So we decided that these special tubes must tell another failure story, which was discussed in the current Part II of the failure analysis.

After detailed characterization and analysis, the root cause of the failure was found to be erosion, cavitation corrosion and the synergetic effect of them. Previous work in our lab on the finite element modeling of erosion [5,6] has been reported but in the current failure case, we are more concerned about the erosion mechanism in real engineering application. Actually, cavitation corrosion of pure titanium and titanium alloys in electrolyte solutions has been reported [2,3]. And cavitation phenomenon of commercially pure titanium has been studied in the lab [4]. But cavitation corrosion of pure titanium tubes industrially utilized has been rarely touched upon. What's more, erosion and cavitation corrosion interacted and aggravated the wall thinning of titanium tube in our case, which is a relatively novel discovery.

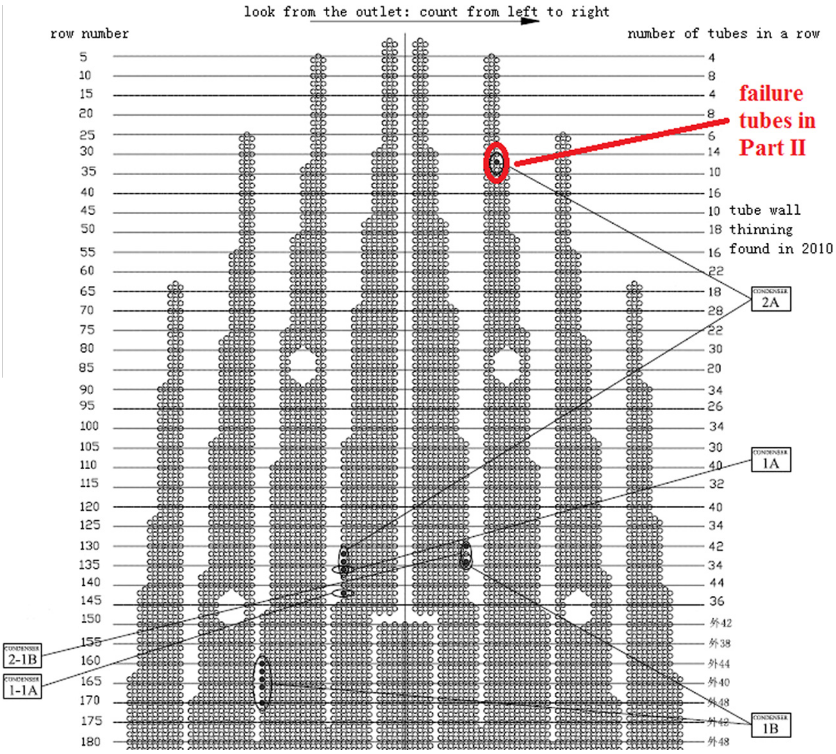

Fig. 2. Schematic illustration of the location of failure tubes in Part II in the condenser.