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A prediction method for the general corrosion behavior of Alloy 690 steam generator tube using eddy current testing

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HIGHLIGHTS

- A corrosion test for the tubes with different levels of eddy current noise was conducted.
- A relationship between the corrosion rate and the eddy current noise of tubes was explored.
- Corrosion rate was closely correlated to the tube noise of a rotating pancake probe.
- Corrosion rate was not related to the tube noise measured using a bobbin probe.

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ABSTRACT

The purpose of this work is to develop an eddy current testing method to predict the general corrosion behavior of Alloy 690 steam generator tubes. A corrosion test was conducted for tubes with different levels of eddy current noise in simulated primary water at 330 °C, and their corrosion behavior was correlated with the tube noise measured using bobbin and rotating probes. The corrosion behavior was closely correlated with the tube noise measured using a rotating probe. However, there was no correlation between the corrosion behavior and the tube noise measured using a bobbin probe. The tube noise value measured using a rotating pancake coil probe is suggested to be a significant parameter in estimating the general corrosion behavior of tubes.

1. Introduction

Alloy 600 steam generator tubes in pressurized water reactors (PWRs) have experienced various types of corrosion degradations such as pitting, intergranular attack, and stress corrosion cracking. As a result of these corrosion damages, Alloy 600 has been replaced with thermally treated (TT) Alloy 690 with a higher chromium concentration of 30%. Since their first application to steam generators in 1989, no corrosion damages in Alloy 690TT tubes have been observed in the field (Steahle and Gorman, 2003). Nevertheless, nickel-based Alloy 690TT still sustains general corrosion in the primary water of PWRs. The inner surface of Alloy 690TT tubing is exposed to the primary water during operation. Consequently, nickel and its oxide particles are released from the corroded surface of steam generator tubes into the primary water. Cobalt is also released from steam generator tubes that contain cobalt as an impurity element.

Released nickel (Ni-58) and cobalt (Co-59) are activated to Co-58 and Co-60, respectively, in the reactor core by a neutron flux (Fruzetti, 2007). These activated corrosion products are the primary source of high radiation fields and occupational radiation exposure (Ocken, 1990). In addition, some of the corrosion products redeposit on the surface of fuel cladding, hinder heat transfer, increase the corrosion rate of the fuel cladding, and finally induce an axial offset anomaly (Byers and Deshon, 2004; Henshaw et al., 2006). This phenomenon can decrease core shutdown margin, and thus lead to a down-rating of a plant.

Recently, many researchers have reported that the surface states of Alloy 690 tubes affect the formation of corrosion products and their release in simulated primary water environments. The corrosion rate and oxide morphology of Alloy 690TT depend greatly on the surface roughness (Seo et al., 2014; Zhang et al., 2012; Huang et al., 2012). Pre-oxidation under oxygen or humidified hydrogen atmospheres was effective in decreasing the release of Ni from Alloy

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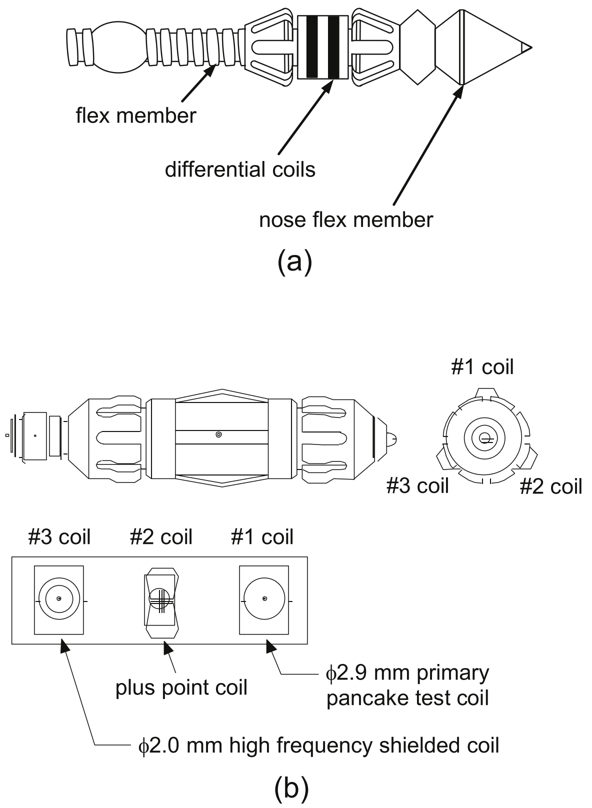

Fig. 1. Schematic of (a) a bobbin probe and (b) a 3-coil motorized rotating probe.

690TT (Bobin-Vastra et al., 1997; Guinard et al., 2000; Kanzaki et al., 2010). The corrosion rates of Alloy 690 and 304 stainless steel were also lowered by electropolishing (Guinard et al., 1997; Ziemniak et al., 2008). The influence of the surface state such as cold-working, surface impurities, and grain size on the corrosion release rate has been noticed (Carrette et al., 2006). However, the exact effect of each metallurgical parameter could not be discerned (Clauzel et al., 2010).

Meanwhile, the surface states of steam generator tubes affect the noise level of eddy current testing (ECT) (García-Martín et al., 2011; Hur et al., 2014). Noise signals arising from the tubes degrade the probability of detection and sizing accuracy of defects (Hur et al., 2014; Bakhtiari et al., 2009). Therefore, tube noise level is limited by specifying a minimum acceptance signal-to-noise ratio, which is measured using a bobbin coil probe (Wolfe, 2014).

The above background reveals that the surface state of tubes affects the corrosion behavior, tube noise, and detectability and sizing accuracy of defects. However, there has been no study on the corrosion behavior of tubes for different tube noise. This work focuses on the effect of eddy current noise on the general corrosion rate of Alloy 690TT tubes in primary water at 330 °C. Based on a relationship between the noise and the corrosion rate, a prediction method for the corrosion behavior of Alloy 690TT tubes will also be suggested.

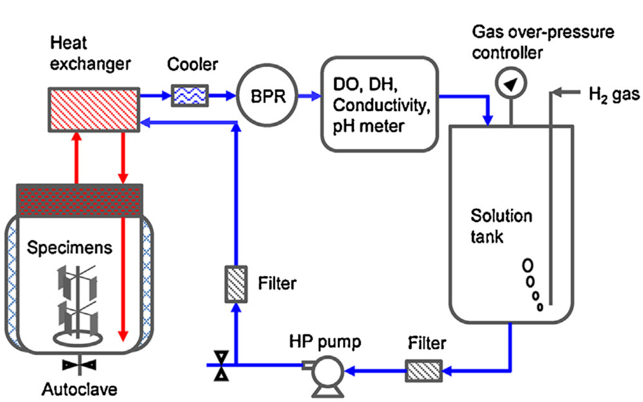

Fig. 2. Schematic of the primary water recirculating system used for the corrosion tests.

2. Experimental

2.1. Material selection

The material for steam generator tubes used in this work was Alloy 690TT with a nominal outer diameter of 19.05 mm and a nominal wall thickness of 1.07 mm. These tubes were manufactured from the same heat by using the pilgering process. Three tubes with different noise levels were selected by bobbin probe inspection.

The inner surface roughness of each tube was measured using a non-contacting surface profiler. In this study, root mean square roughness (R_q) is used as a surface roughness parameter.

2.2. Tube noise measurement

The ECT signals were acquired through the Zetec MIZ-70 digital data acquisition system by using a conventional bobbin coil probe and a conventional 3-coil motorized rotating probe, which are used for in-service inspection of PWRs. Fig. 1 shows

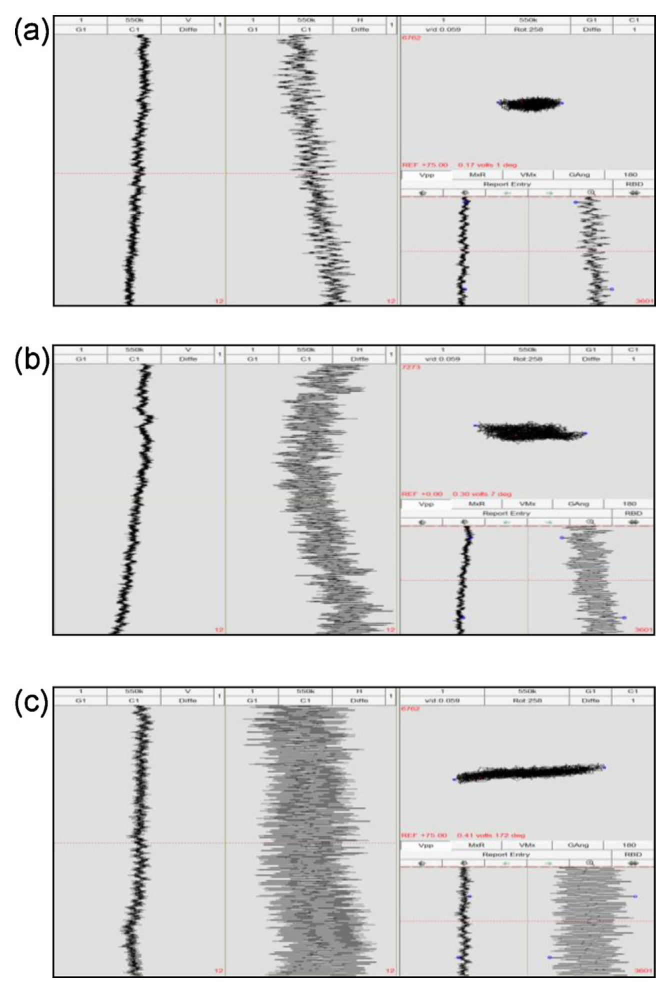

Fig. 3. Noise signals measured by a bobbin coil probe: (a) tube A, (b) tube B, and tube C.