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Correlation between General Corrosion Behavior and Eddy Current Noise of Alloy 690 Steam Generator Tube

Do Haeng Hur[*], Myung Sik Choi, Deok Hyun Lee, Hee-Sang Shim
Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon, 305-353, Republic of Korea
[*]Corresponding author: dhhur@kaeri.re.kr

1. Introduction

Nickel and its oxides are released from the surface of steam generator tubes into the primary water. Released nickel and cobalt is activated to Co-58 and Co-60 in the reactor core by a neutron flux, respectively. These activated corrosion products are the main source of high radiation fields and occupational radiation exposure. In addition, some of the corrosion products redeposit on the fuel cladding, hinder the heat transfer, increase the corrosion rate of the fuel cladding, and finally induce an axial offset anomaly. 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 corrosion product formation and its release in simulated primary water environments [1,2]. Meanwhile, the surface states of steam generator tubes affect the noise level of eddy current testing [3,4]. Noise signals arising from the tubes degrade the probability of detection and sizing accuracy of the defects [4,5].

However, study for corrosion behavior with different tube noise is not available up to now. This work is focused on the effect of eddy current noise on the general corrosion rate of Alloy 690TT tube in primary water at 330℃. Based on a relationship between the noise and corrosion rate, a prediction method for the corrosion behavior of Alloy 690TT tube will also be suggested.

2. Experimental

2.1 Material selection

The steam generator tube material 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 using pilgering process. The tubes with 3-different noise levels were selected by the bobbin probe inspection.

2.2 Corrosion test

Corrosion test was conducted in simulated primary water containing 2.0 ppm Li as LiOH and 1200 ppm B as H_3BO_3 at 330℃ for 500 h. Dissolved oxygen and hydrogen content was maintained below 5 ppb and at 35 cm^3 STP/kg H_2O, respectively.

Descale methodology was employed to determine the general corrosion rate of Alloy 690TT. After the corrosion test, the oxidized specimens were descaled using a two-step alkaline permanganate and ammonium citrate process. A detailed test system and descaling procedure are given elsewhere [1].

2.3 Tube noise measurement

The eddy current signals were acquired using the Zetec MIZ-70 digital data acquisition system with a conventional bobbin and 3-coil rotating probe, which are used for in-service inspection in PWRs.

The signal amplitude of bobbin probe was calibrated to produce a peak-to-peak value of 4 V at all test frequencies of 150, 300, 550 and 700 kHz in differential mode from the four 20% flat-bottom outer diameter holes in the ASME standard. The phase angle was adjusted to 40 degrees from the 100% hole of the ASME standard. In the case of rotating probe, the signal from the axial through-wall EDM notch of a 9.525 mm length was calibrated to be an amplitude of 20 V and a phase angle of 30 degrees at all the test frequencies.

3. Results and Discussion

3.1 Material characteristics

Fig. 1 shows the bobbin coil signals of the tubes with different noise levels at a test frequency of 550 kHz in differential mode. The average peak-to-peak amplitude of each tube was 0.14 V (tube A), 0.26 V (tube B) and 0.40 V (tube C), corresponding to 30, 15 and 10 in signal-to-noise ratio.

Fig. 2 shows the C-scan of the horizontal component of noise measured at 300 kHz using the rotating probe. Tube A shows a smooth surface state, and tube C also has a relatively uniform surface. However, tube B has several ridges and valleys along the tube length. The maximum amplitudes of the horizontal component of each noise were measured. The noise level increased in the following order: tube A < tube C < tube B.

3.2 Correlation between corrosion rate and noise

Fig. 3 shows the corrosion rate of Alloy 690TT tubes in simulated primary water at 330℃ for 500 h. Corrosion rate increased in the order: tube A < tube C < tube B. All tube specimens were exposed to the same environment. In addition, three tubes have the same chemical composition, a similar surface roughness value and microstructure. Therefore, the difference in the corrosion rate can be attributed to the macroscopic surface irregularities.

To find a correlation between the corrosion rate and tube noise, noise amplitudes measured using bobbin probe were also superimposed in Fig. 3. The corrosion rate was not related to the bobbin coil noise at all test frequencies. This can be attributed to a non-surface riding and non-rotating characteristics of the bobbin probe.

However, the rotating probe noise showed a meaningful relevance to the corrosion rate, as shown in Fig. 4. Especially, the corrosion rate was reasonably well correlated with the noise variation of pancake coil. On the contrary, plus point coil showed a slight deviation with a scatter. Plus point coil has two coils wound perpendicular to each other. With this configuration, lift-off and magnetic effect due to geometric changes are significantly reduced [6]. Therefore, plus point coil is relatively insensible to the inner surface irregularity. This indicates that a pancake coil is much more suitable to measure a tube noise, although a plus coil is excellent to sense the orientation of a crack.

4. Conclusions

The corrosion behavior was closely correlated to the tube noise measured using a rotating probe, while it was not related to the noise measured using a bobbin probe. It is suggested that the tube noise value measured using a rotating pancake coil probe can be a decisive measure to estimate the corrosion behavior of tubing.

ACKNOWLEDGEMENTS

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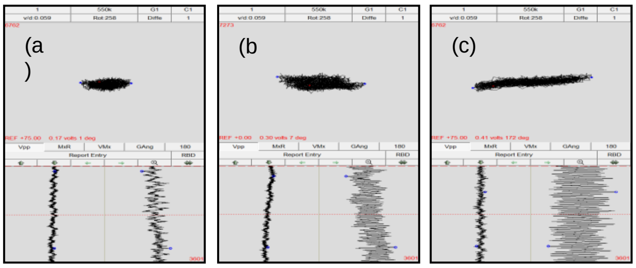
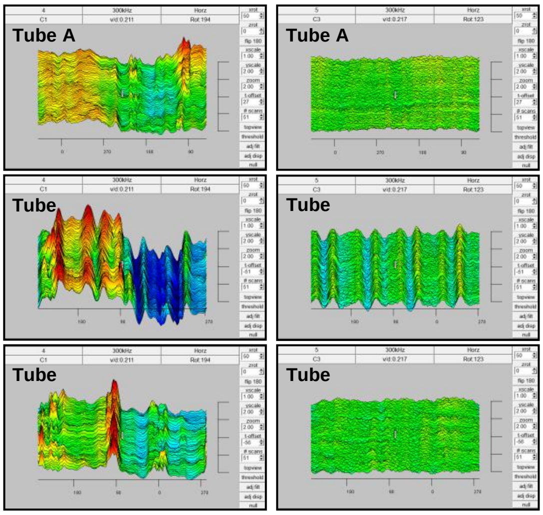


Fig. 1. Noise signals measured by bobbin coil probe: (a) tube A, (b) tube B and tube C.



(a

(b

Fig. 2. Noise signals measured by rotating probe: (a) pancake coil and (b) plus point coil.

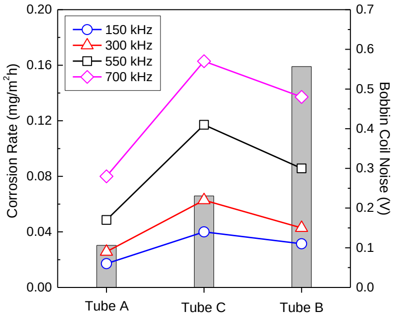
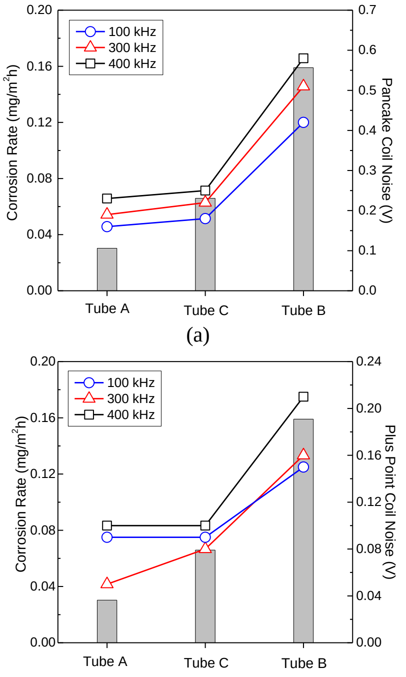


Fig. 3. Relationship between corrosion rate and tube noise measured by bobbin coil probe.



(a)

(b)

Fig. 4. Relationship between corrosion rate and tube noise measured by rotating probe: (a) pancake coil and (b) plus point coil.