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INFLUENCE OF SIGNAL-TO-NOISE RATIO ON EDDY CURRENT SIGNALS OF CRACKS IN STEAM GENERATOR TUBES

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This work presents the influence of noise originating from the tube itself on the detectability and sizing accuracy for laboratory-induced outer diameter axial cracks in nuclear steam generator tubes. The variations of signal amplitude and phase angle of the same cracks were analyzed when increasing the signal-to-noise ratio of the tube itself from 9 to 18. It was experimentally verified that the detectability for small cracks was enhanced by increasing the signal-to-noise ratio. The phase angle also rotated to a value representing the actual position and depth of a crack when increasing the signal-to-noise ratio.

KEYWORDS : Signal-to-Noise Ratio, Detectability, Sizing Accuracy, Eddy Current Test, Stress Corrosion Crack

1. INTRODUCTION

Steam generator tubing is a pressure boundary between a primary coolant system and a secondary coolant system in a pressurized water reactor (PWR). These tubes have been affected by corrosion degradation such as stress corrosion cracking, intergranular attack, and pitting, and by mechanical damage such as wear and fatigue. Therefore, the detection and characterization of these defects is very important for the safety and integrity of steam generators. The eddy current test (ECT) method is widely used to detect new defects occurring in steam generator tubes and to monitor the growth of the pre-existing flaws during an in-service inspection.

The detection capability and sizing accuracy of a flaw depends on the quality of the eddy current (EC) signals. The EC signals generated from the tubes contain an undesirable signal, i.e., noise. Common noise sources are tube support structures, corrosion products, changes in tube dimensions and geometry, and probe wobble and lift-off [1-3]. The probe response associated with the material property variations, non-uniform surface conditions, and electronic noise from the test equipment can also be categorized as a noise source [1,4]. These noise signals complicate the detection and interpretation of flaw signals. In detail, the noise signal distorts the phase angle and the amplitude of the defect signal. Several approaches have been implemented to reduce the noise and hence enhance the signal quality, including signal processing techniques [5,6], probe design modification [7], and the tube fabrication process [8].

This paper examines the influence of the noise originating from the tube itself on the detectability and sizing accuracy for outer diameter (OD) axial cracks in steam generator tubes. The influence of the signal-to-noise (S/N) ratio is discussed from the viewpoint of the phase angle and amplitude of the crack signals.

2. EXPERIMENTAL METHODS

Alloy 600 steam generator tubes with an outer diameter of 19.04 mm and a wall thickness of 1.06 mm were used to induce outer diameter axial cracks in a laboratory. The tubes were manufactured using a pilgering process, and finally mill-annealed at 1070ºC. Each tube specimen was 20 cm long. To make a single axial crack, the OD surface of the tube was masked except an area for crack initiation. The tubes were internally pressurized at a pressure of about 200 bar, and then exposed to an oxidizing solution of 0.1M sodium tetrathionate at room temperature. The crack was made on the OD free span of a clean and straight tube. Thus, there was no interference from either tube geometry changes or sludge.

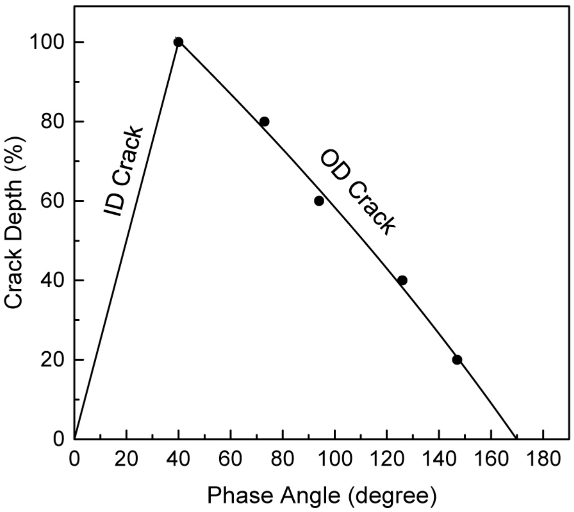

Fig. 1. Relationship Curve of Signal Phase Angle Versus Crack Depth.

The ECT signals were acquired using the Zetec MIZ-70 digital data acquisition system with a conventional bobbin coil probe, which is used for in-service inspection in PWRs. The probe is inserted into the inside of the tube and is moved along the length of the tube at a pulling speed without rotation. In this work, the tube specimens were inspected at a pulling speed of 30.5 cm/sec. The signal amplitude was calibrated to produce a peak-to-peak value of 4 V at 550 kHz in differential mode from the four 20% flat-bottom OD holes in the ASME standard. The phase angle was adjusted to 40 degrees from the 100% hole of the ASME standard. A relationship curve of the signal phase angle versus crack depth was developed using the ASME standard with 20, 40, 60, 80, and 100% OD holes. This method is standardized by ASME Code Section V, Article 8, Appendix I. The depth and position of cracks were evaluated using this curve, as shown in Fig 1. According to this curve, the phase angle of a through-wall defect is 40 degrees. The reference signal amplitude used to calculate the S/N ratio was 3.73 V, which was established according to the guidelines specified in reference 9.

To precisely evaluate the effect of the S/N ratio on the detection and characterization of a defect, only the level of noise should be changed, while the length and depth of the defect are fixed in a tube. To achieve this condition, the inner surface of the original tube with an OD crack was polished using silicon carbide paper with #400 grit. The EC signals were acquired again. The S/N ratio of the original tube was about 9, but the S/N ratio of the polished tube was enhanced to about 18 through this process.

Finally, the cracks were destructively examined to measure their actual length and depth using scanning electron microscopy (SEM). The overall experimental procedures are summarized in Fig. 2.

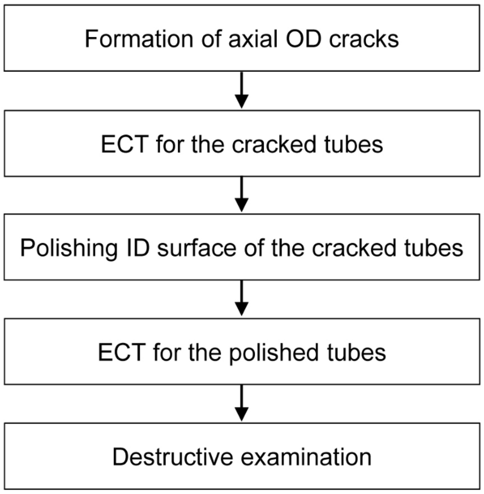

Fig. 2. Overall Experimental Procedures.

3. RESULTS AND DISCUSSION

Fig. 3 shows the fracture surface of OD axial cracks observed using SEM. The laboratory-induced cracks initiated and propagated along the grain boundaries, showing nearly the same nature of stress corrosion cracks occurring in operating steam generator tubes. Therefore, it was verified that these cracks are adequate for an evaluation of the detectability and sizing accuracy. The measured length and depth of each crack are summarized in Table 1.

Fig. 4 shows the EC signals of the original tubes with cracks A, B, and C at a test frequency of 550 kHz. The magnitudes of the crack signals were very small and thus these specimens were adequate to evaluate the detection and characterization capability of cracks at an early stage. The noise level of each tube was measured to be in the range of 0.42~0.44 V. Thus, the S/N ratio was calculated to be about 9 on all three tubes. Fig. 4(a) shows the EC signal of crack A with a length of 2.25 mm and a depth of 62.2%. V_{max} and V_{pp} of the crack signal were measured to be 0.06 V and 0.28 V, respectively. Here, V_{max} and V_{pp} indicate the vertical component and peak-to-peak amplitude of a crack signal, respectively. V_{pp} incorporates the noise signal, and this crack is also located on the trace toward the negative direction of the large noise signal. Therefore, V_{pp} was measured to be large, although V_{max} was very small. Fig. 4(b) shows the EC signal of crack B with a length of 1.64 mm and a depth of 68.9%. Although a V_{max} score of 0.09 V was very small, V_{pp} was measured to have a large value of 0.21 V. This is because the crack was generated on the trace toward the positive direction of the large noise signal. Fig. 4(c) shows the EC signal of crack C with a length of 2.88 mm and a depth of 88.7%. V_{max} and V_{pp} of this crack signal were measured to have similar values of 0.12 V and 0.13 V, respectively. That is, the signal amplitude V_{pp} was not affected by the noise.