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Relationship between Steam Generator Tube Noise and Eddy Current Inspection Capability of Stress Corrosion Cracks

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1. Introduction

The Detection capability and sizing accuracy of a flaw occurring in steam generator tubes depends on the quality of the eddy current (EC) signals. The EC signals generated from the tubes contain an unwanted noise signal. Noise sources are tube support structures, corrosion products, changes in tube dimensions and geometry, probe wobble, lift-off, material property variations, non-uniform surface conditions, and electronic noise from the test equipment [1]. These noise signals interfere with the detection and interpretation of flaw signals.

It has been proposed that the in-service inspection frequency be extended dependent on the tubing material [2]. Recently, steam generator tube manufacturing specifications including the S/N ratio are also getting strengthened [3]. Therefore, the intrinsic noise level of the manufactured tube itself should be minimized, although the noise added in a steam generator during operation can be unavoidable.

This paper presents the effect of the noise signals originated from the tube itself on the detection and characterization capability of outer diameter (OD) axial cracks in steam generator tubes.

2. Experimental Methods

Alloy 600 tubes with an OD of 19.04 mm and a wall thickness of 1.06 mm were used to induce OD axial cracks in a laboratory. The tubes were manufactured using a pilgering process, and finally mill-annealed at 1070℃. 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 0.1M sodium tetrathionate solution at room temperature.

The EC signals were acquired using a conventional bobbin coil. 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 be 40 degrees from the 100% hole of the ASME standard. A relationship curve of the phase angle versus crack depth was developed by using the ASME standard with 20, 40, 60, 80, and 100% OD hole. The reference signal amplitude used to calculate the S/N ratio was 3.73 V, which was established according to the guidelines specified elsewhere [4].

To precisely evaluate the effect of the S/N ratio on the detection and characterization of a defect, only the noise magnitude should be canged, while the length and depth of the defect are fixed. To achieve this condition, the inner surface of the tube with an OD crack was polished using silicon carbide paper. Then, the EC signals were acquired again. Finally, the cracks were destructively examined to measure the actual length and depth of cracks using scanning electron microscopy.

3. Results and Discussion

Fig. 1 shows the fracture surface of OD axial cracks observed using SEM. The laboratory-induced cracks initiated and propagated along the grain boundaries, which shows nearly the same nature of stress corrosion cracks occurring in operating steam generator tubes.

(a)
(b)
(c)

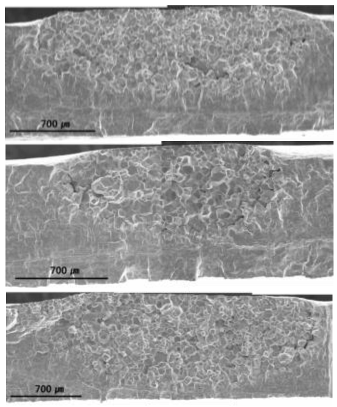

Fig. 1. Fracture surface of (a) crack A, (b) crack B and (c) crack C.

Fig. 2 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 so that these specimens were adequate to evaluate the detection and characterization capability of cracks in an early stage. The noise level of the each tube was measured to be a range of 0.42~0.44 V. So, the S/N ratio was calculated to be about 9 on all three tubes.

Fig. 3 shows the EC signals of the polished tubes with cracks A, B and C at a test frequency of 550 kHz. In comparison with the original signals in Fig. 2, it was noted that the level of noise decreased by about a factor of 2. The noise level of the each tube was measured to be a range of 0.20~0.23 V. Thus, the S/N ratio was calculated to be about 18 on all three polished tubes. The increase of the S/N ratio can be attributed to a partial removal of pilgering noise.

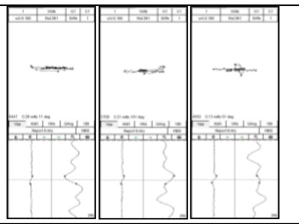

Fig. 2. Bobbin signals of (a) crack A, (b) crack B and (c) crack C at an S/N ratio of 9.

Fig. 3. Bobbin signals of (a) crack A, (b) crack B and (c) crack C at an S/N ratio of 18.

Table 1 Amplitude of crack signal with tube S/N ratio.

Tube	S/N = 9		S/N = 18	
	V_{max}/V_{noise}	V_{pp}/V_{noise}	V_{max}/V_{noise}	V_{pp}/V_{noise}
Crack A	0.14	0.65	0.33	0.35
Crack B	0.21	0.50	0.48	0.48
Crack C	0.27	0.30	0.57	0.57

The V_{max} to V_{noise} ratio and V_{pp} to V_{noise} ratio are summarized in Table 1. The value of V_{max}/V_{noise} increased more than double when increasing the S/N ratio from 9 to 18. This increase is entirely due to the decrease of the noise level, since the values of V_{max} were not affected by the polishing process. Because the detection capability is basically related to V_{max}, it was experimentally verified that detectability for small cracks is enhanced by increasing the S/N ratio of the tube itself. It should be noted that the value of V_{max}/V_{noise} is nearly the same as that of V_{pp}/V_{noise} at an S/N ratio of 18, although they have no correlation at an S/N ratio of 9. This means that the effect of noise on V_{pp} is negligible at a higher S/N ratio. Consequently, it was verified that sizing accuracy is also improved by increasing the S/N ratio of the tube itself because the sizing of a defect is based on the phase angle measurement of V_{pp}.

Table 2 shows the variation of the phase angle of each crack with the tube S/N ratios. The phase angle of crack A at an S/N ratio of 9 was 11 degrees, corresponding to an inner diameter (ID) defect with a depth of 28%. This indicates that the noise led to a false estimation of the crack position from the OD side to the ID side. However, it showed a phase angle of 99 degrees at an S/N ratio of 18, indicating an OD defect with a depth of 59%. In the case of crack B at an S/N ratio of 9, the phase angle of 161 degrees was too large to be evaluated as an OD defect. However, its phase angle at an S/N ratio of 18 moved to 126 degrees, indicating an OD defect with a depth of 38%. The result shown in Table 2 indicates that the phase angle rotated to a value representing the actual position and depth of a crack when increasing the S/N ratio of the tube itself.

Bakhtiari et al. reported that the simulated composite noise results in significant degradation of detection and sizing capability, by using various algorithms for the simulation, superposition, and measurement of noise [1]. To the best of the author's knowledge, however, this paper is the first experimental work using real stress corrosion cracks to verify the effect of the S/N ratio on the capability of detection and characterization. In addition, early detection and accurate characterization for a shallow defect are crucial to assure the tube integrity. In this regard, the crack size and corresponding EC signals used in this work were small enough to evaluate the cracks in the early stage. The results in this paper also provide experiment-based data to verify the validity for the requirement strengthening trend of tube manufacturing specifications.

Table 2 Phase angle of crack signal with tube S/N ratio.

Tube	Actual crack depth (%)	S/N = 9		S/N = 18	
		Phase angle (deg)	Depth from phase angle (%)	Phase angle (deg)	Depth from phase angle (%)
Crack A	62.2	11	ID 28	99	OD 59
Crack B	68.9	161	OD 8	126	OD 38
Crack C	88.7	61	OD 86	89	OD 67

4. Conclusions

The effect of tube noise on the detection and characterization capability of cracks was investigated using the laboratory-grown axial stress corrosion cracks on the OD side of steam generator tubes. The value of V_{max}/V_{noise} increased more than double and the value of V_{max}/V_{noise} became nearly the same as that of V_{pp}/V_{noise} when increasing the S/N ratio of the tube itself from 9 to 18. The phase angle rotated to a value representing the actual position and depth of a crack with increasing the S/N ratio.

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