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Laboratory-Grown Axial Cracks in the Secondary Side of Steam Generator Tubes

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1. Introduction

Eddy current testing (ECT) is widely used to detect various types of defects occurring in nuclear steam generator tubes and to monitor the growth of pre-existing flaws during an in-service inspection.

Therefore, its reliability of detection and sizing accuracy for defects should be validated. It can be accomplished by comparing the ECT results with the destructive examination results of pulled tubes from operating steam generators. However, this method has several disadvantages such as a radiation exposure, extended overhaul period, and limited number of pulled tubes.

Therefore laboratory-grown defects which is just similar to the actual defects are an alternative to overcome these problems. So, we have established precise techniques for manufacturing various types of flaws such as stress corrosion crack, intergranular attack and pitting. We can also control the location, direction, depth and length of the target defects[1,2]. In this work, the signal characteristics of ECT are investigated using laboratory-manufactured axial cracks on the outer diameter (OD) side of a free span. The depth and length correlations between the ECT results and destructive results are also presented.

2. Experimental Methods

Steam generator tubes of high temperature mill-annealed Alloy 600 with a nominal outer diameter of 19.05mm and a nominal wall thickness of 1.07mm, were used to manufacture cracks.

Axial cracks were grown in an oxidized solution to have an intergranular path, the same as the actual defects in operating steam generators. These defects were made on the OD free span of clean tube. That is, they were not interfered from both geometry changes and sludge.

ECT was performed using a conventional rotating probe. This probe consisted of a plus point coil, a pancake coil and a high frequency pancake coil separately mounted on the same circumference.

The tubes were inspected at a pulling speed of 5.08 mm/sec and at a rotating rate of 600 rpm. The signal from an axial through-wall electric discharge machining notch with a length of 9.52 mm was calibrated to be an amplitude of 20 volts and a phase angle of 30 degrees at 300 kHz.

After the eddy current data acquisition, the defective tubes were internally pressurized to measure the leak pressure of the cracks using a high pressure pump. Finally the tubes were destructively examined to measure the depth and length of the cracks.

3. Results and Discussion

3.1 Comparison with Actual Cracks

Laboratory-grown cracks and actual cracks should have similar features such as eddy current signals characteristic and crack morphology. The similarity between a laboratory-grown crack and an actual crack was compared using the data obtained from a defective tube in an operating steam generator. Fig. 1 shows the ECT data of the OD axial crack in the plant tube by plus coil, which was a 7.2 mm long axial crack. Fig. 2 shows the eddy current signals of a 6.6 mm crack produced in laboratory. Both the signal response on the impedance plane and the C-scan were similar to those of the real crack in the pulled tube. Furthermore, the laboratory cracks were grown in the axial direction without side branches. The cracking mode showed also intergranular path. Therefore, the similarity of the laboratory-grown cracks to the real cracks was validated.

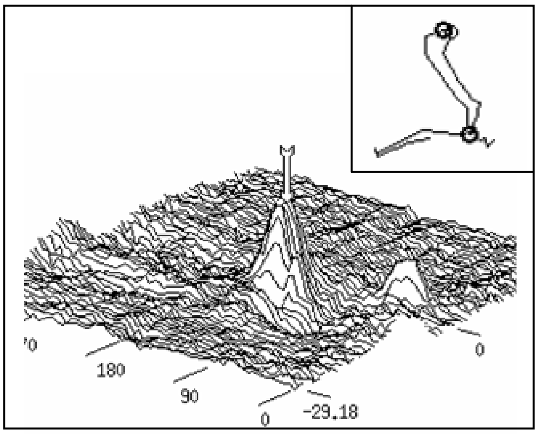

Figure 1. ECT data of a plant tube with an axial crack by plus coil.

3.2 Depth and Length Correlation

Crack depth and length are the main parameters of sizing a crack using ECT. Crack depth was estimated based on the phase angle to flaw depth correlation of plus coil at frequencies of 300 kHz and 400 kHz. These results were directly compared with the destructive results. As shown in Figure 3, the crack depth estimation from the phase angle resulted in very low reliability, regardless of the test frequencies.

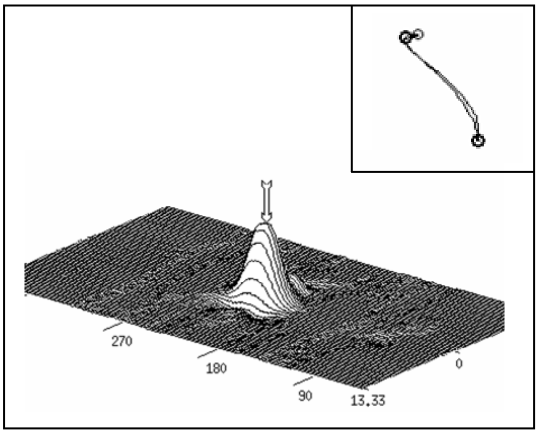

Figure 2. ECT data of a defective tube with a circumferential through-wall crack by plus coil.

Crack length measured using ECT and destructive examination was also reviewed. ECT crack length was estimated on a single line scan with the highest voltage along the crack direction, using plus point coil probe data at 300 kHz. It was defined from the initiation point of the signal to the termination point, of which base reference was noise level from the tubes. The result showed that the ECT crack length was not comparable to the actual length. Therefore, new techniques are needed to precisely measure the depth and length of circumferential cracks.

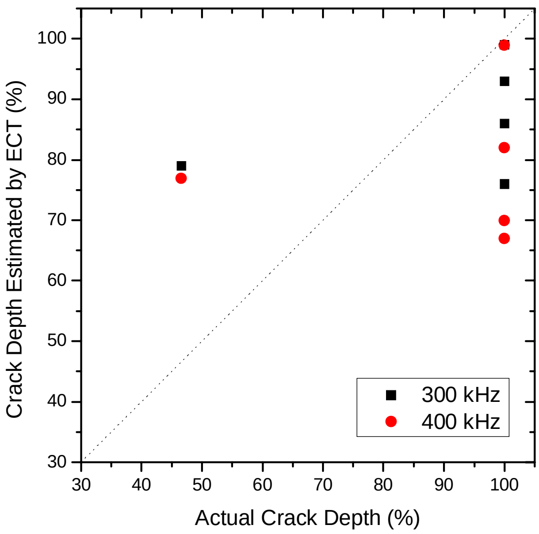

Figure 3. Crack depth correlation between the ECT results and destructive results.

3.3 Leak Pressure

A through-wall crack consist of a through-wall and non-through-wall part. Therefore, leak pressure depend on the through-wall length, although a total crack length are the same. In this work, leak starting pressure of the axial cracks were measured. The axial cracks with a through-wall length of 0.4～1.4 mm did not leak by an internal pressurization up to 3,000 psig.

4. Conclusions

Laboratory-grown secondary side axial cracks showed the characteristic features of the actual cracks from an operating steam generator, such as its surface morphology and signal response. The crack depth and length estimated by the ECT resulted in a poor relationship with the destructive results. Therefore new techniques to improve the sizing accuracy for the depth and length of axial cracks are now under development.

REFERENCES

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