Laboratory-Grown Circumferential Cracks in Steam Generator Tubes

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1. Introduction

Eddy current testing (ECT) method is widely used to detect various types of flaws occurring in the nuclear steam generator tubes. Therefore, the reliability of detection and sizing accuracy of defects should be validated. It can be accomplished by comparing the ECT results with the destructive examination results of the defective tubes. Previously, the tubes with defects were supplied by removal from steam generators. However, this method has several disadvantages such as a radiation exposure, extended overhaul period, and limited number of pulled tubes.

We have established the 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. In this work, the signal characteristics of ECT are investigated using the laboratory-manufactured circumferential cracks on the outer diameter (OD) side of the free span. The depth and length correlations between the ECT results and destructive results are also presented.

2. Experimental Methods

High temperature mill-annealed Alloy 600 tubes with a nominal OD of 19.05 mm and a nominal wall thickness of 1.07 mm were used to manufacture the defects.

Circumferential cracks were grown in an oxidized solution to have an intergranular path, the same as the real defects. These defects were made on the OD free span of the 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 in 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 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 real cracks

The similarity of the laboratory-grown crack to the real crack was compared first using the data obtained from the previously pulled tube from an operating steam generator[1]. Fig. 1 shows the ECT data of the OD circumferential crack in the pulled tube by plus coil, which was 18.5 mm long through-wall. Fig. 2 shows the eddy current signals of a through-wall crack with a maximum arc length of 3.2 mm by plus coil. Both the signal response on the impedance plane and the behavior of the vertical component were similar to those of the real crack in the pulled tube. Furthermore, the cracks were grown in a circumferential direction without side branches. Therefore, the similarity of the laboratory-grown crack to the real crack was validated.

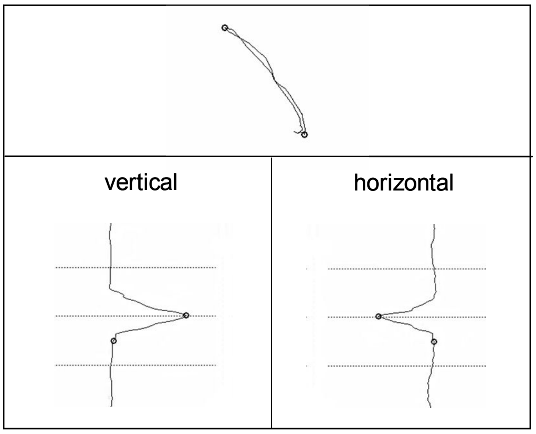

Figure 1. ECT data of a pulled tube with a circumferential through-wall crack by plus coil.

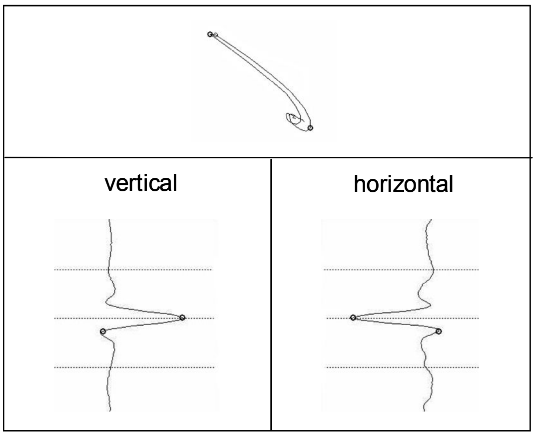

Figure 2. ECT data of a defective tube with a circumferential through-wall crack by plus coil.

3.2 Depth and Length Correlation

The 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 in Figure 3. The crack depth estimation from the phase angle resulted in little reliability, regardless of the test frequencies.

Crack length was measured 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. The result showed that the ECT crack length was overestimated with increasing the signal amplitude. Therefore, new techniques are needed to precisely measure the depth and length of circumferential cracks.

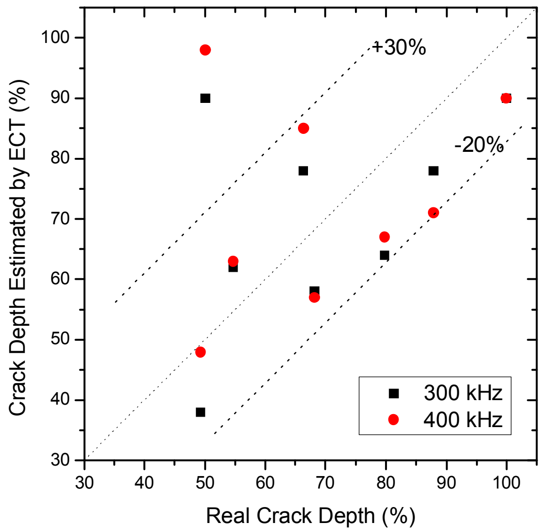

Figure 3. Crack depth correlation between the ECT results and destructive results.

3.3 Detection Limit and Integrity

The signal amplitude from a crack is a function of depth, length and opening of the crack. Therefore, a detection limit can not be specified as a constant value. Nevertheless, of 8 cracks manufactured in this work, one crack appeared to be near the status of a detection limit, size of which was 50.1% deep and 5.1 mm long. Considering that this crack signal was not perturbed by shape changes and sludge, the actual limit will have a larger value than this.

All cracks were not leaked by an internal pressurization up to 6,200 psi, except that the through-wall crack 3.19 mm long started leaking at a pressure of 380 psi. Even a crack with a depth of 80% and a length of 4.4 mm was not leaked at an internal pressure of 6,200 psi.

4. Conclusions

Circumferential cracks manufactured in laboratory showed the characteristic features of a real crack from an operating steam generator, such as surface morphology and signal response. The crack depth and length estimated by ECT resulted in a poor relationship with the destructive results. Therefore new techniques to improve sizing accuracy for the depth and length of circumferential cracks are now under development. For future work, we will investigate the effect of shape changes and sludge on the detection and sizing accuracy.

REFERENCES

[1] J.H. Han, et al., Examination and analysis on steam generator tubes pulled from Yonggwang Unit 4, KAERI/CR-168/2003, Daejeon, 2003.