Development of a Technique and an Automated Program for Discriminating Through-Wall Cracks in Steam Generator Tubes Using Eddy Current Signals

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1. Introduction

Steam generator tubes in pressurized water reactors have been affected by corrosion degradation such as stress corrosion cracking and pitting and by mechanical damage such as wear and fatigue. Eddy current test method is world-widely used to detect new defects occurring on the tubes and to monitor the growth of the pre-existing flaws during the in-service inspection. Among the various defects, through-wall cracks regardless of the primary side and the secondary side of the tube induce a leakage of the radioactive primary water to the secondary water and eventually a tube rupture event. Therefore to prevent a leakage of the radioactive coolant or a tube rupture accident, it is necessary in advance to detect the tubes with through-wall cracks.

The through-wall cracked tubes can be identified using the in-situ pressure test; a leakage or a decrease in the pressure occurs from the tube with the through-wall cracks by pressurization to the primary side of a tube[1]. However, this mechanical method needs additional inspection facility, cost and time. In addition, the tubes with cracks should be plugged after the pressure test since the cracks are plastically deformed by the pressurization. The through-wall length of a crack can not be also measured by this method.

In this study, a new nondestructive technique to discriminate a through-wall crack and to measure a through-wall length of a through-wall crack is described, based on the analysis of the characteristics in the eddy current signals obtained during the in-service inspection.

2. Experimental Methods

Steam generator tubes of Alloy 600 HTMA, with a nominal outer diameter of 19.05mm and a nominal wall thickness of 1.07mm, were used. Two types of axial notches were machined on each tube by electric discharge machining (EDM) method; axial notches of a 7mm length with depths of 20, 40, 60, 80 and 100% (through-wall) from the inner and outer surfaces and axial notches ranging from 2 to 7mm length with through-wall depth. The width of the all notches was 0.15mm. Also, the axial fatigue cracks on the inner surface of the tube were manufactured to verify the results obtained by the EDM notches.

The ECT signals of all the tube specimens were obtained by the Zetec MIZ-30A digital data acquisition system with a 3-coil MRPC probe(+Point 610-115/36/S80). The tubes were inspected at a pulling rate of 0.2inch/sec and at a rotating rate of 300rpm. The signal from the axial through-wall EDM notch of a 7mm length was calibrated to be an amplitude of 20 volts and a phase angle of 30 degrees at 300 kHz.

2. Results and Discussion

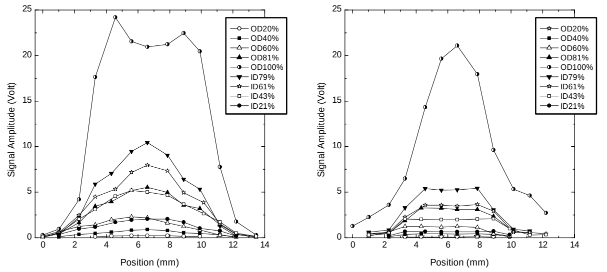
2.1 Characteristic Profile of the Signal Amplitude

Fig. 1 shows the distribution of the signal amplitude at a frequency of 300kHz along the EDM notch length of 7mm. In the case of pancake coil, the through-wall notch shows a M-shape distribution having the maximum signal amplitude at both ends of the notch, while the non-through-wall notches both OD and ID surfaces exhibit a bell shape having a maximum signal amplitude at the center of the notches. On the contrary, the distribution in the signal amplitude of plus coil at 300kHz shows a reverse profile. The through-wall notch shows a bell shape distribution and the non-through-wall notches exhibit a semi-M shape. These characteristic profiles were also observed at the other frequencies of 100 and 400kHz.

From the above results, an important criterion for discriminating whether an axial crack is through-wall or not can be derived. That is, an axial crack showing a M-shape distribution of the signal amplitude by pancake coil along the crack length and showing a bell shape profile by plus coil is through-wall.

The same results were also obtained using the shorter length notches with through-wall depth than 7mm length. All the through-wall notches with a length of 2~7mm showed a M-shape distribution of the signal amplitude by pancake coil along the notch length and a bell shape distribution by plus coil. Another important result is that the through-wall length of a through-wall crack can be measured from the M-shape profile. In the M-shape profile by pancake coil, the distance between the both ends of the maximum signal amplitude corresponds to the through-wall length of a crack.

From the above results, it is clear that the distribution of the signal amplitude from pancake coil and plus coil shows a different characteristic feature along the crack length. Therefore, the distribution profile of the difference value between the signal amplitude of pancake coil and that of plus coil would reveal the characteristic profile more clearly. Fig. 2 illustrates the difference value between the signal amplitude of pancake coil and that of plus coil along the notch length ranging from 2 to 7mm. It can be seen that the M-shape profile of each through-wall notch became more clearly characterized.



(a) (b)

Fig. 1 Distribution profiles of the signal amplitude by (a) pancake coil and by (b) plus coil at a frequency of 300kHz along the EDM notch length of 7mm.

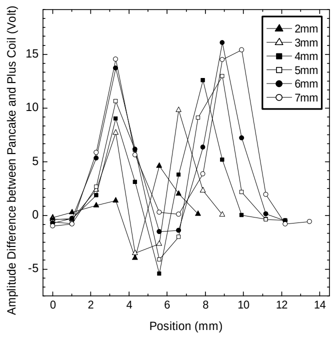


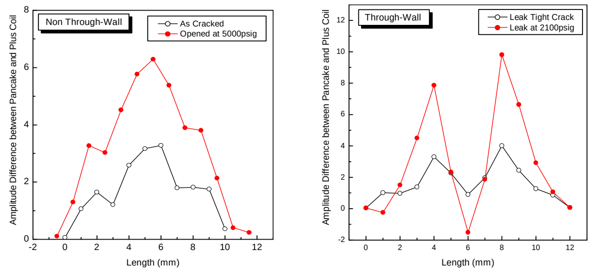
Fig. 2 Distribution profiles of the signal amplitude difference between pancake coil and plus coil at a frequency of 300kHz along the EDM notch length.

2.2 Verification Using Real Cracks

In order to verify the developed technique, it was applied to the tight axial fatigue crack. The effect of the crack deformation by the pressurization on the signal amplitude was also examined. Fig. 3(a) shows the results obtained from the non through-wall axial crack. The amplitude difference curve of a bell shape is observed, which is characteristic of a non through-wall crack. In addition, the signal amplitude increased by the internal pressurization to 5,000psi, especially by about 2 times at the center of the crack. The increase in the signal amplitude is attributed to the crack opening.

In the case of a through-wall axial crack with a through-wall length of 5.5mm, it shows the amplitude difference profile of a M-shape, which is characteristic of a through-wall crack, as shown in Fig. 3(b). The distance between the both peaks of the maximum signal amplitude was 4.1mm, similar to the actual through-wall length of 5.5mm. The crack was leak-tight up to the internal pressurization of 2,000psig. The onset of a leak happened at 2,100psig resulted in an increase of the amplitude by about more than 2 times.

From the Fig. 3, it is clearly verified that the through-wall crack can be easily discriminated from the non-through wall crack by its characteristic M-shape curve of the signal amplitude from the eddy current test. It should be also noted that the pressurization of the in-situ pressure test performing to detect a tube with a through-wall crack induces a plastic deformation of the crack, resulting in a remarkable increase of the signal amplitude.



(a) (b)

Fig. 3 Verification of the M-shape criterion using the axial fatigue cracks with (a) non-through-wall depth and (b) through-wall depth.

2.3 Development of an Automated Evaluation System

An automated evaluation system was developed to implement this technique in the field evaluation during the in-service inspection. This system consists of three parts; a Zetec ECT instrument, a control PC and special-purpose software where the data analysis algorithms of the M-shape profile criterion are implemented. The system can transfer the ECT signals acquired by a Zetec MIZ-30 or MIZ-70 instrument to the control PC, and the software which runs on Windows reconstructs the amplitude difference scan images in an automated fashion. Then, if user selects an area that includes a suspicious flaw, the software automatically invokes and displays the M-shape profile along the central line of the selected flaw.

3. Conclusions

A new eddy current technique for discriminating whether an axial crack is through-wall or not was developed and verified using the EDM notches and real fatigue cracks. An axial crack showing a M-shape distribution of the signal amplitude by pancake coil along the crack length and showing a bell shape profile by plus coil is through-wall. A non-through-wall crack shows a reverse trend. The through-wall length of a crack can also be measured from the distance between the peaks of a M-shape curve. In addition, It was verified that the internal pressurization of the in-situ pressure test induces a plastic deformation of the crack, resulting in a remarkable increase of the signal amplitude.

REFERENCES

[1] In-Situ Pressure Test Guide Lines, EPRI TR-107620, EPRI, 1998.