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Steam Generator Tube Inspection of Nuclear Power Plants using Ultrasonic Testing

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1. Introduction

Most of heat exchanger tube in nuclear power plant inspected by eddy current method [1]. Eddy current examination techniques used to inspect steam generator tubing provide a good screening for tube integrity but lack the ability to accurately size certain flaw mechanisms. Due to this sizing uncertainty, conservative decisions must be made on dispositioning indications resulting in premature plugging and reduced inspection cycle lengths. It has been presumed that ultrasonic examination techniques could provide better sizing and characterization. However, technology limitations and lack of qualified techniques have limited the use of the technology.

Recently, various inspection technique is available on steam generator tube such as remote field eddy current and ultrasonic methods. Each of these techniques has its merits and limitations. Electromagnetic techniques are very useful to locate areas of concern but sizing is hard because of the difficult interpretation of an electric signal. On the other hand, ultrasonic methods are very accurate in measuring wall loss damage and are reliable for detecting cracks [2]. Additionally ultrasound methods is not affected by support plates or tube sheets and variation of electrical conductivity or permeability[3]. The need to develop specialized ultrasonic tools for steam generator tube inspection was necessary considering the limitations of electromagnetic techniques to some common inspection problems. These problems the sizing of wall loss in carbon steel tubes near the tube sheet or support plate, sizing internal erosion damage, and crack detection. This paper will present an ultrasonic tube inspection technique for steam generator tubing in nuclear power plant and verify inspection reliability for artificial flaw embedded to tube outside and through holes.

2. Experimental Setup

The flaw characteristics of steam generator tube are complex and various orientations. For this reason, multi array ultrasonic transducer module is designed with five ultrasonic elements. There are one normal incident angle, two circumferential oriented transducers and two axial oriented transducers. Each transducer embedded in inspection module designed with ultrasonic ray tracing modeling for 45^0 incident angle. The frequency of five transducers is 15MHz and each transducer is focused element on middle of tube thickness. The detail information of each transducer is listed on Table 1.

Ch. no	Focal distance (mm)	Beam diameter (mm)	Depth of field (mm)	Center frequency (MHz)
O° Normal	10	0.51	11.6	14.7
45° DN	14.1	0.36	6.4	14.1
45 ° UP	13.8	0.33	6.7	13.8
45 ° CW	15.5	0.30	6.2	15.5
45 ° CCW	14.7	0.30	6.7	14.7

Figure 1 depicts the transducer module and position of each transducer used this experiment.

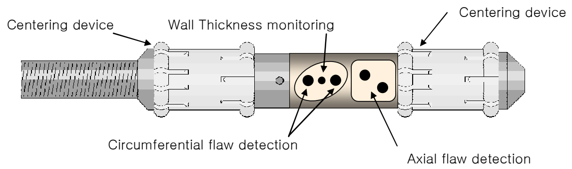

Figure 1. Transducer configuration for steam generator tube inspection

The experimental system is configured with pulse-receive (Tomoscan III, RD-tech), motor drive unit and Helicoidal scanner. A schematic diagram of steam generator tube inspection system is illustrated in Figure 2.

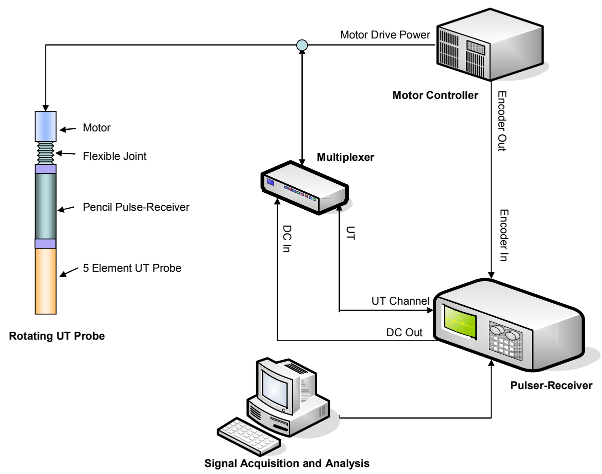

Figure 2. Schematic diagram of the experimental system

3. Data analysis and reliability evaluation

To study the steam generator tube inspection using ultrasound testing, various kinds of flaw embedded on flawed tube. Table 2 shows the information of all flaws.

Table 2. Dimensions of the each EDM flaws embedded in steam generator tube

No	Location	Flaw Orientation	Depth [%]	Width [mm]	Length [mm]
1	N/A	Axial	100	0.15	10
2	N/A	Hole	100	0.1	0.1
3	N/A	Hole	100	0.2	9.53
4	N/A	Hole	100	0.4	9.54
5	N/A	Hole	100	0.6	9.54
6	OD	Axial	20	0.15	2.0
7	OD	Axial	40	0.15	2
8	OD	Axial	60	0.15	2
9	OD	Axial	80	0.15	2
10	OD	Circ.	20	0.15	2
11	OD	Circ.	40	0.15	2
12	OD	Circ.	60	0.15	2
13	OD	Circ.	80	0.15	2
14	OD	45° Skew	20	0.15	2
15	OD	45° Skew	40	0.15	2
16	OD	45° Skew	60	0.15	2
17	OD	45° Skew	80	0.15	2
18	OD	Wear	20	5.0	7.0
19	OD	Wear	40	7.0	7.0
20	OD	Wear	60	7.0	7.0
21	OD	Wear	80	7.0	7.0

The steam generator tube is made by Inconel 600 and ultrasonic longitudinal velocity is 5.720mm/μs, transverse velocity is 3.078mm/μs. The outside diameter is 22.22mm and thickness is 1.27mm.

The experiment result shows all the flaws are detected and can be measurable. The data in figure 3 demonstrate the result from artificial flaws. This signal layout shows the C-scan image of normal incident angle transducer. The horizontal direction is along the tube circumferential direction and vertical axis is axial direction. From this, it is clear that we can identify and measure shape and dimensions.

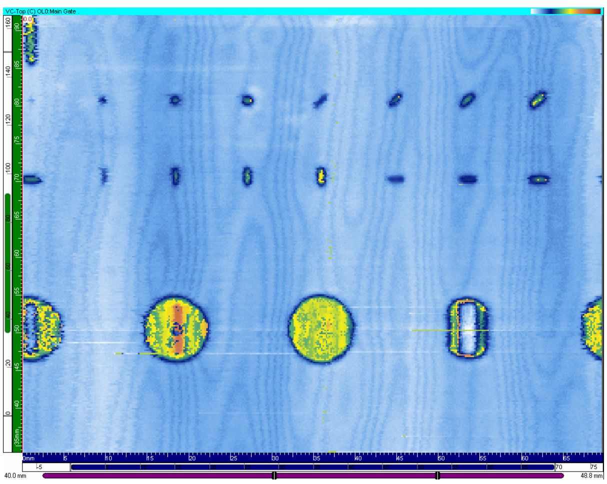

Figure 3. The C-scan signal from steam generator tube included various kind of flaws.

Data analysis is preformed with analysis software. Fig 4 shows measurement error with respect actual flaw size.

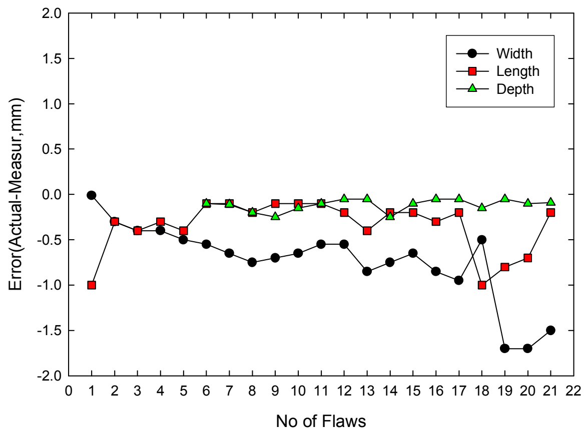

Figure 4. The comparison of evaluated flaw sizing errors based on flaw length, width and depth for each flaws.

As can be seen Figure 4, measurement accuracy is very close to actual flaw dimensions. The measurement result for width is larger than other dimensions. The depth measurement is most accurate dimension. The RMSE(Root Mean Square Error) of each dimension is calculated. The RMSE for width is 0.92mm, for length is 0.66mm and depth is 0.34mm.

4. Conclusion

The ultrasonic inspection technique for steam generator tube flaw sizing was suggested. Using ultrasonic technique as a sizing tool to supplement eddy current or RFT is desirable in situations where the flaw depth and extent detection is unreliable by electromagnetic techniques. The ultrasonic testing is possible accurate flaw sizing and measuring wall loss damage for heat exchanger tube. From the experimental results, it is expected that if the ultrasonic test is put to practical use in the steam generator tube inspection, the inspection accuracy will be improved.

REFERENCES

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