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Development of Sizing Technique for Axial ODSCC in Steam Generator Tubes

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1. Introduction

It is necessary to evaluate the depth and length of the crack in steam generator tubes in order to complete the condition monitoring and the operational assessment of the Steam Generator Management Program. Various methods have been used to size crack indications from eddy current data during the in-service inspection in nuclear power plants. However, sizing results have had uncertainties due to its difficulty and ambiguity. Many trials to develop crack-sizing techniques have been made in many countries. The qualified technique has not been developed yet. KEPRI (Korea Electric Power Research Institute) has been developing crack-sizing techniques by utilizing Kori Unit 1 Retired Steam Generators (RSG). The crack-sizing technique for axial ODSCC (Outside Diameter Stress Corrosion Cracking) has been developed by KEPRI through the round robin tests. The developed technique can be used in the Steam Generator Management Program after being qualified by the peer review process.

2. Methods and Results

There are various methods to size axial ODSCC indications such as phase-based or amplitude-based. Many factors, for example frequency and calibration type, have influence on the sizing results from eddy current data. Key factors were determined and six different methods were proposed through some laboratory tests as shown in Table 1.

Table 1. Proposed Sizing-Methods for Axial ODSCC

Channel	Frequency (Hz)	Calibration Type	Calibration Points (%)
P1	400	Amplitude	100, 60, 40
P2	400	Amplitude	100, 60, 20
P3	300	Amplitude	100, 60, 40
P4	300	Amplitude	100, 60, 20
P5	400	Phase	100, 60, 40
P6	300	Phase	100, 60, 40

In channel P1, the calibration process is as follows. Voltage normalization for raw channels is performed in the main lissajous window and is set on the 100% axial notch at 20 volts. An additional process channel will be required for the amplitude calibration curve. This channel will be a duplicate of the 400 kHz raw channel and the axial notch response will be in the positive direction. This channel will be used to establish the amplitude peak_peak measured response linear curve based on the channel P1 using 100%, 60%, 40% axial notches. In channel P2 to P6, the calibration processes are similar to channel P1.

Kori Unit 1 RSGs were used for this study because they have various types of crack indication. The eddy current tests were carried out to identify the tubes with crack and collected data were analyzed by KEPRI and KHNP (Korea Hydro & Nuclear Power Co.) analysts. Segments with flaws were pulled out by KPS (Korea Plant Service & Engineering). The eddy current tests were performed again for those segments after pulling. They are being examined destructively by KAERI (Korea Atomic Energy Research Institute). Figure 1 shows an example of results for the destructive examination.

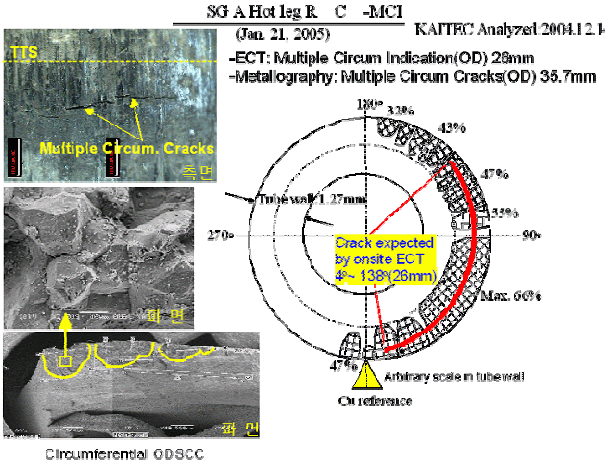

Figure 1. Example of Destructive Examination

The round robin tests for six proposed methods were carried out by domestic analysts who have participated in the in-service inspection in nuclear power plants. They are certified level II or level III in accordance with their employer's written practices. They are also qualified data analysts (QDA) in accordance with EPRI (Electric Power Research Institute) guidelines[1].

Ten independent teams participated in the round robin tests. Each team consisted of two analysts. One individual was designated as the "Primary Sizing Analyst" and the other as an "Independent Reviewer". The independent reviewer should review the primary results and correct them if necessary.

Results for the six methods were analyzed statistically in order to develop the most reliable sizing method for axial ODSCC indications from eddy current tests. Depth sizing results for the different methods are shown in Figure 2 to Figure 4, respectively. X-axes in these

figures represent the analyzed maximum depth by the eddy current method. Y-axes represent the destructive examination results as the ground truths.

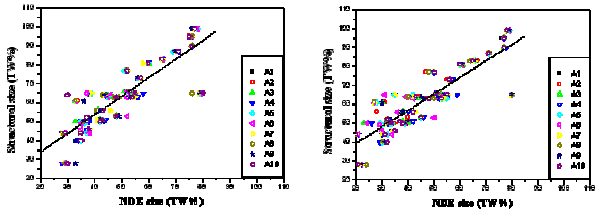

Figure 2. Results of Round Robin Test for Ch P1 and P2

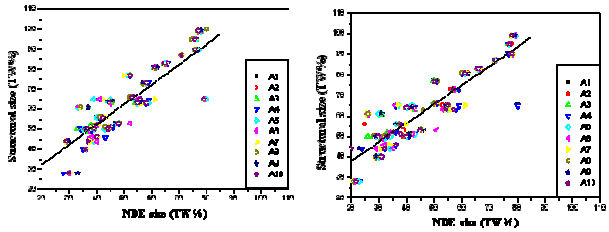

Figure 3. Results of Round Robin Test for Ch P3 and P4

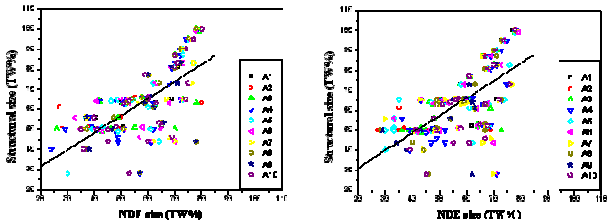

Figure 4. Results of Round Robin Test for Ch P5 and P6

Linear regression equations used in this study are as follows[2]:

$$V_T = b_0 + b_1 V_M + Z_T s_T \quad (1)$$

where, V_T : technique size
V_M : NDE measured size
b_0, b_1 : parameters in linear regression
s_T : regression error in analyst relationship
Z_T : random variable from standard normal distribution

$$V_R = c_0 + c_1 V_T + Z_R s_R \quad (2)$$

where, V_R : technique size
c_0, c_1 : parameters in linear regression
s_R : regression error in analyst relationship

$$V_R = a_0 + a_1 V_M + Z_E s_E \quad (3)$$

where, a_0, a_1 : parameters in linear regression with

$$a_0 = c_0 + c_1 b_0 \text{ and } a_1 = c_1 b_1$$

s_E : regression error in the relationship between structural size and NDE measured size with

$$s_E = \sqrt{(c_1 s_T)^2 + s_R^2}$$

The results of linear regression for round robin tests are shown in Table 2 and Figure 2. They show that the channel P4 is the most reliable sizing method for axial ODSCC indications from eddy current tests.

Table 2. Results of the Linear Regressions for six cases

Channel	a_0	a_1	r^2	RMSE
P1	14.399	0.980	0.760	8.347
P2	21.960	0.871	0.786	7.900
P3	12.124	1.003	0.759	8.420
P4	19.435	0.926	0.843	6.871
P5	14.306	0.851	0.428	13.176
P6	13.815	0.870	0.404	13.678

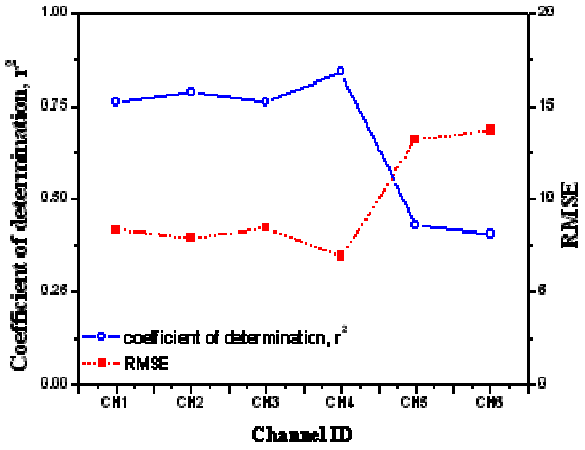

Figure 2. Results of Linear Regression for Round Robin Tests

3. Conclusion

KEPRI developed the sizing technique for axial ODSCC indications from eddy current tests. Six different methods were determined by laboratory tests based on frequency, calibration points and calibration type. Round robin tests for these proposed methods were carried out by qualified domestic analysts using Kori Unit 1 RSGs. Results show that the channel P4 is the most reliable technique for axial ODSCC, which is the amplitude-based calibration with points of 100%, 60%, 20% notches at 300 kHz. This technique is expected to use in the Steam Generator Management Program after being qualified by the peer review process.

REFERENCES

[1] Electric Power Research Institute, Pressurized Water Reactor Steam Generator Examination Guidelines, Appendix G: Rev. 6, 2002.
[2] H. S. Chung et al., Eddy Current Round Robin Program for Kori Unit 1 Retired Steam Generators, KEPRI TM.S04.P2007.076, 2007.