Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Axial PWSCC Sizing Technique in Steam Generator Tubes

Chan-Hee Cho, Dong-Hyun Jee, Jee-Hong Jung, Hee-Jong Lee
Korea Electric Power Research Institute, Nuclear Power Lab., 65 Munji-Ro, Yuseong-Gu, Daejeon 305-380,
Corresponding author: chancho@kepri.re.kr

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 uncertainties due to its difficulty and ambiguity. Many trials to develop crack-sizing techniques have been made in many countries. However, reliable outcomes have not been established. 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 PWSCC (Primary Water 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 analyzed by the peer review group.

2. Methods and Results

There are various methods to evaluate the depth and length of axial PWSCC 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 13 different methods were proposed through some laboratory tests as shown in Table 1.

Table 1. Proposed Sizing Methods for Axial PWSCC

CH	Fq (Hz)	Calibration Type	Calibration Points (%)	Liz
P1	400	Amplitude	100, 60, 20	C-Scan
P2	300	Amplitude	100, 60, 20	C-Scan
P3	300	Amplitude	100, 60, 40	C-Scan
P4	400	Phase	100, 60, 20	C-Scan
P5	300	Phase	100, 60, 20	C-Scan
P6	300	Phase	100, 60, 40	C-Scan
P7	300	A-MD-P	1 pt WS	C-Scan
P8	400	Amplitude	100,60,20	Main
P9	300	Amplitude	100,60,20	Main
P10	300	Amplitude	100,60,40	Main
P11	400	Phase	100,60,20	Main
P12	300	Phase	100,60,20	Main
P13	300	Phase	100,60,40	Main

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 P1 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 using 100%, 60%, and 20% ID axial notches. In channel P2 to P13 except P7, the calibration processes are similar to channel P1. In channel P7, the calibration process is the same as channel P6. In addition, phase and amplitude measurements are performed on the lissajous response from the circumferential lissajous windows. Careful analysis should be performed watching specifically for any change in the lissajous signal. Record a zero percent call prior to the first call of the indication and after the last call. Record only those indications which provide a flaw-like lissajous response at a maximum of 10 degree increments. At maximum amplitude measure the % TW based on the phase curve, then in a process channel establish a linear curve using the amplitude and %TW values extrapolated to zero.

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 were examined destructively by KAERI (Korea Atomic Energy Research Institute).

The round robin tests for 13 proposed methods were carried out by domestic analysts who have participated in the in-service inspection in the nuclear power plant. They are certified ET level II or level III in accordance with their employer's written practices. All participants for the round robin test are also certified as the qualified data analyst (QDA) in accordance with EPRI (Electric Power Research Institute) guidelines [1].

Ten independent teams participated in this round robin test. 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 thirteen methods were analyzed statistically in order to develop the most reliable sizing method for axial PWSCC indications from eddy current tests. Maximum depth sizing results for the different methods are shown in Figure 1 and Figure 2, 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 truth.

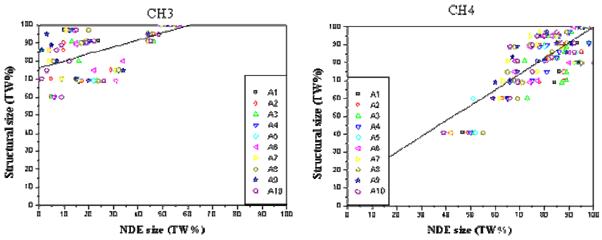

Figure 1. Results of Round Robin Test for Ch P3 and P4

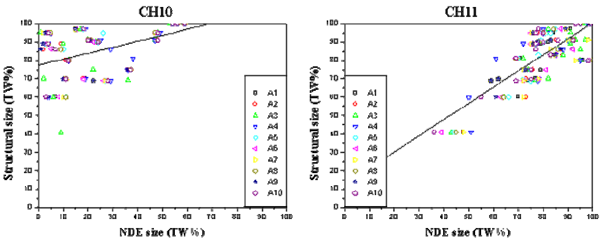

Figure 2. Results of Round Robin Test for Ch P10 and P11

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 3. They show that the channel P4 and P11 are the most reliable sizing methods for axial PWSCC indications from eddy current tests.

Table 2. Results of the Linear Regressions for 13 cases

Channel	a_0	a_1	r^2	RMSE
P1	62.202	0.673	0.372	11.982
P2	64.411	0.585	0.302	12.421
P3	76.087	0.389	0.379	9.467
P4	12.322	0.878	0.635	9.126
P5	29.703	0.667	0.354	12.146
P6	29.695	0.663	0.370	12.001
P7	39.486	0.538	0.260	13.002
P8	62.017	0.649	0.349	11.694
P9	62.017	0.649	0.349	11.964
P10	77.504	0.324	0.245	10.983
P11	12.725	0.879	0.644	8.848
P12	23.159	0.759	0.494	10.546
P13	25.976	0.726	0.515	10.321

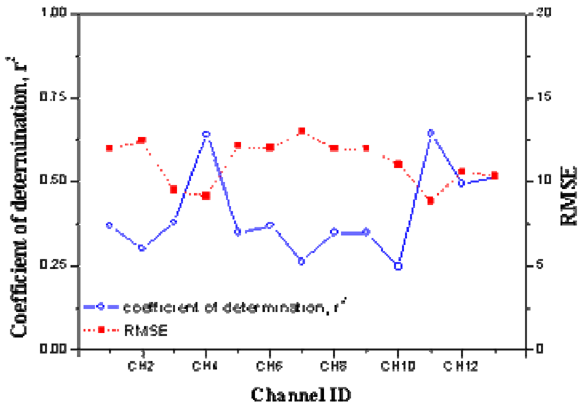

Figure 3. Results of Linear Regression for Round Robin Tests

3. Conclusion

KEPRI developed the sizing technique for axial PWSCC indications from eddy current tests. Thirteen different methods were selected by laboratory tests based on frequency, calibration points and calibration type. Round robin tests for these proposed methods were carried out by qualified analysts using Kori Unit 1 RSGs. Results show that the channel P4 and P11 are the most reliable techniques for axial PWSCC, which are the phase-based calibration with points of 100%, 60%, 20% notches at 300 kHz in the C-scan or main lissajous. These techniques are expected to be used in the Steam Generator Management Program after being analyzed 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.