Transactions, SMiRT-24
BEXCO, Busan, Korea - August 20-25, 2017
Division VIII

ANALYSIS OF THE INFLUENCE FACTORS ON STEAM GENERATOR TUBE DEGRDATION TREND

Yong-Seok Kang[1], Kuk-Hee Lee[2], and Dong-Man Shin[2]

[1] Principal Researcher, Central Research Institute, Korea Hydro & Nuclear Power, Korea
[2] Senior Researcher, Central Research Institute, Korea Hydro & Nuclear Power, Korea

ABSTRACT

Axial out-diameter stress corrosion cracking (ODSCC) is increasing rapidly in the Korean nuclear power plants. Utilities need to accurately predict progression of corrosion occurrence to steam generator tubes. Statistical analysis of steam generator tube degradation is one of issues in Korean steam generator industry. The Weibull distribution has been used to predict of steam generator tube degradation trend. However, different behaviour exhibited from the plants which are operating under the same conditions. It is estimated that the improvement of the corrosion environment by chemical cleaning and the change of probability of detection (POD) affect the degradation trend. The variation of the flaw size and the eddy current signal were analysed before and after chemical cleaning for two identical designed and manufactured power plants. The POD curve reflecting the influence of the noise introduced into the inspection signal was derived and the importance of noise monitoring was confirmed.

INTRODUCTION

The most susceptible degradation mechanism is axial ODSCC at tube support plates with Mill-annealed Alloy 600 tubing material in Korean steam generators. The cause of SCC in the steam generator tube is the weakness of tube materials, operating environment, and residual stress. In addition to difference in material characteristics chemical cleaning timing also presumed to have an influence on the degradation trend. Due to the stress corrosion cracking, some steam generators equipped with Alloy 600MA tubing have already been replaced and some are in preparation for replacement. There is a growing interest in analysing the causes of defects, establishing mitigation measures, and forecasting future defects. The Weibull cumulative distribution function has been used to predict of steam generator tube degradation trend. This statistical function has been found to be reliable and easy to use. However, during the prediction of degradation trend the different behaviour exhibited from the plants which are operating under the same conditions.

In this study, the variation of defects due to the chemical cleaning of the steam generator was examined, and the POD curve reflecting the noise of the eddy current signal was derived.

COMMON CAUSES OF STRESS CORROSION CRACKING

The causes of stress corrosion cracking in the steam generator tubes are known to be combinations of corrosion susceptibility, residual stress and corrosive operating environment [Chung et al. (2013)]. However, there are cases in which defects occur in different ways between steam generators that are designed and operated in the same way. In this case, it is considered that the sludge deposition on the secondary side of the steam generator is influential. When the sludge is deposited between tube and tube support plate or on the surface of tube, the corrosion environment is formed and the temperature at this area locally rises, thereby promoting the generation of corrosion cracks and growth.

EVALUATION OF STATISTICAL DISTRIBUTIONS

As the defects of the steam generator tubes increases, interest in prediction of the occurrence of defects is increasing. Statistical distribution function can be widely used to make predictions of steam generator tubes such as Normal, Weibull, Log-normal, Extreme value, Logistic. Each of the distribution includes adjustable parameters that allow the distribution to be fitted to the data. None of the distributions were consistently the best in every case. However, the Weibull and the log-normal were regarded as most suitable for steam generator tube degradation analyses [EPRI (1991)]. The general form of the Weibull cumulative distribution functions is as follows.

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\theta} \right)^b \right] \quad (1)$$

Where:

$F(t)$: the fraction failed at time t

t : time (EFPY)

θ : scale parameter. It is equal to the time at which 63.2% of the tubes have failed

b : shape (or slope) parameter. It controls the shape of the failure distribution

This can be accomplished as described below.

$$\frac{1}{1 - F(t)} = \exp\left(\frac{t}{\theta} \right)^b \quad (2)$$

Natural logarithms can be taken twice of equation to give the following:

$$\ln \ln \frac{1}{1 - F(t)} = b(\ln(t)) - b(\ln(\theta)) \quad (3)$$

Equation (3) has the form y=bx + c, and represents a straight line with slope of b and intercept c on a Cartesian x, y plot. This permits cumulative Weibull distribution functions to be represented as straight lines on Weibull plots. The Weibull functions are known to be easy use and to make relatively accurate predictions. However, this method has a disadvantage that it does not accurately reflect inherent degradation characteristics of individual facilities such as chemical cleaning effect and POD change.

CHEMICAL CLEANING EFFECTS ON CRACK GROWTH

It is known that the chemical cleaning of the steam generator influence on degradation trend of the steam generator tubes. In order to analyse the SCC occurrence characteristics of the steam generator tube after the chemical cleaning, the size distribution of crack during the consecutive cycles before and after the chemical cleaning was compared. Figure 1 and 2 compare the ODSCC sizes detected in the same designed CE type steam generators by operating cycles. The red line is the cycle in which the chemical cleaning performed, and the blue line shows the next cycle of cleaning. Comparing the crack depth distribution, it can be seen that the cracks in the next cycle after cleaning are shallower than in the cleaning cycle. However, the degree of difference was not the same in both plants. The difference in the decrease of the defect depth distribution of the plant B is larger than that of the plant A. Figure 3 and 4 compares the size distribution of the Bobbin amplitude for the flaw signals detected at the chemical cleaning cycle and at the next cycle. Figure 3 shows that the number and size of defects in the next cycle of cleaning increased more than before. On the other hand, in the case of figure 4, the number and size of defects decreased after cleaning. Therefore, when predicting the trend of degradation, it is necessary to reflect the unique characteristics of each plant as the prediction results may be different even in case of the same designed plants.

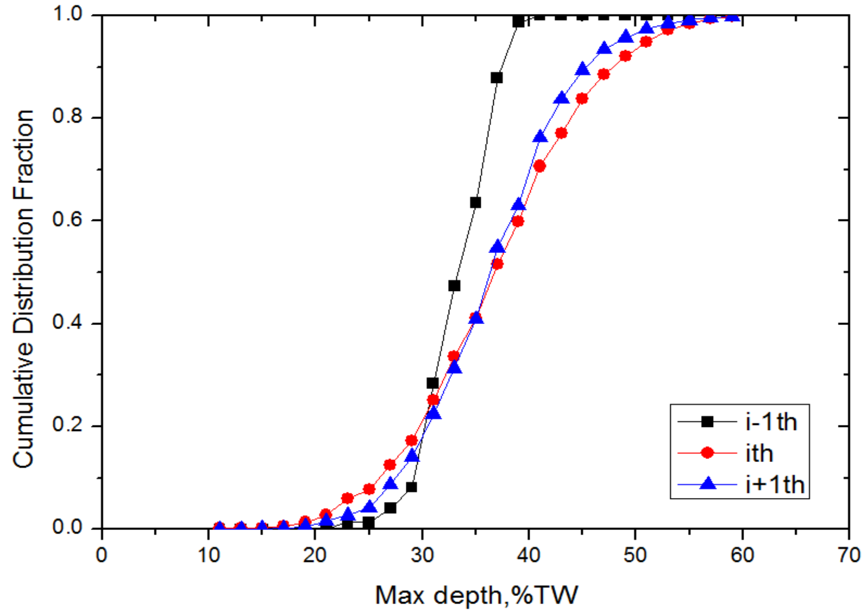

Figure 1. Comparison of maximum depth of Plant A.

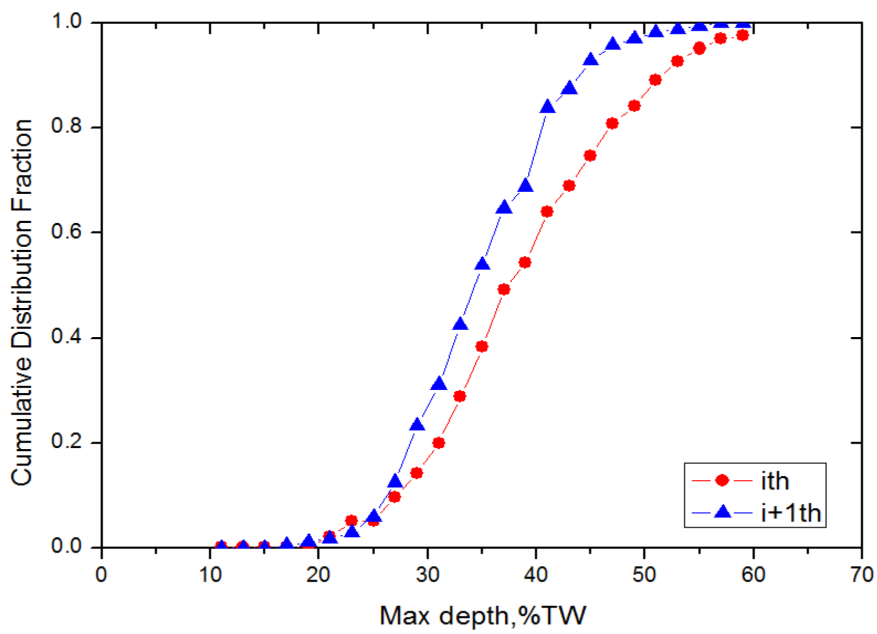

Figure 2. Comparison of maximum depth of Plant B.

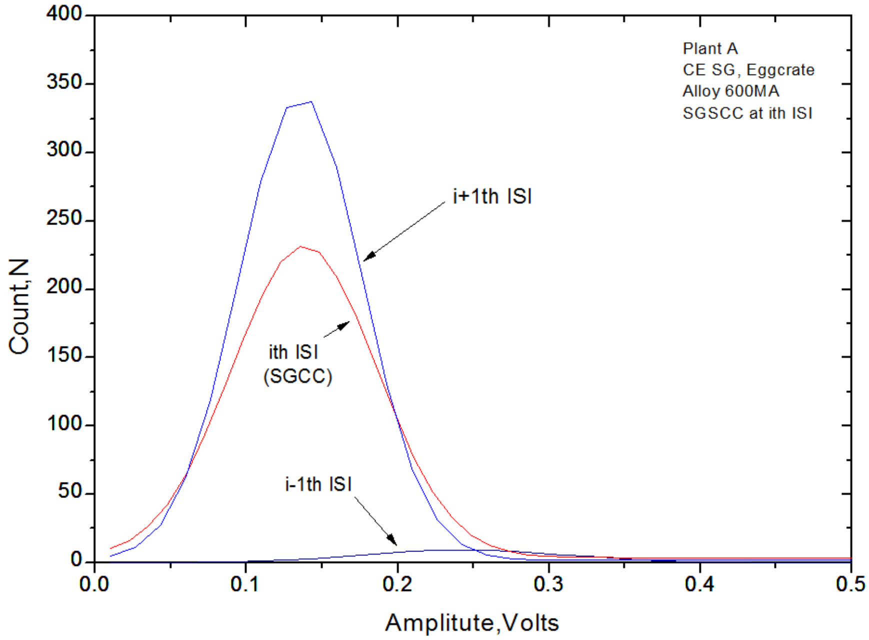

Figure 3. Bobbin signal amplitude of Plant A.

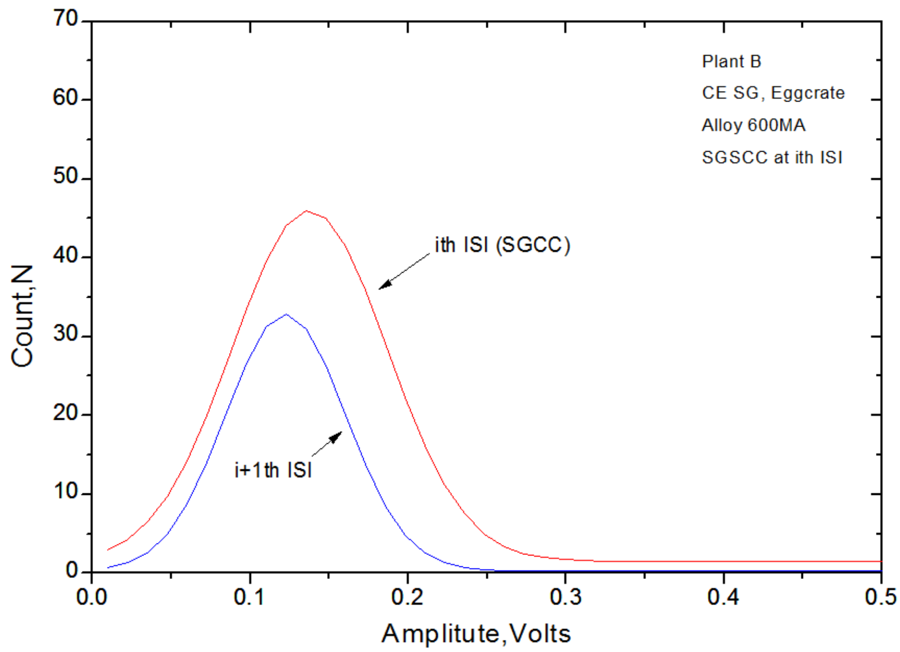

Figure 4. Bobbin signal amplitude of Plant B.

EVALUATION OF NDE SIGNAL NOISE EFFECTR ON POD

Figure 3 and figure 4 show that there are many very small signals whose amplitude is less than 0.1 volts. Generally, if the size of the defect is small, it is difficult to detect the defects. Therefore, when there are many small defects, the number of defects detected depends on the POD performance. For this reason, it is important to determine the POD performance when predicting the degradation trend of the steam generator tubes. The logistic or the log-logistic function was determined to be the most appropriate for generic use [EPRI (2016)]. The equation of the log-logistic function is as follows.

$$POD(S) = \frac{1}{1+\exp[-(a+b\log S)]} \tag{4}$$

Where, *S* is crack depth (0 ~ 100%TW); *a* and *b* are mode parameters. The rage of POD is from 0 to 1.

If noise is introduced into the eddy current signal, the masking effect may affect the POD. As a countermeasure to this, the recently revised steam generator guidelines recommend implementation of noise measurement and monitoring. To understand noise effect on POD, we measured sample noise signal on steam generator tubes in the field. The following figure 5 shows eddy current sample signals for noise measurement of the CE type steam generator with the support plate. In the figure 5, the left side is the signal of the chemical cleaning cycle and the right side is the signal of the next cycle of chemical cleaning.

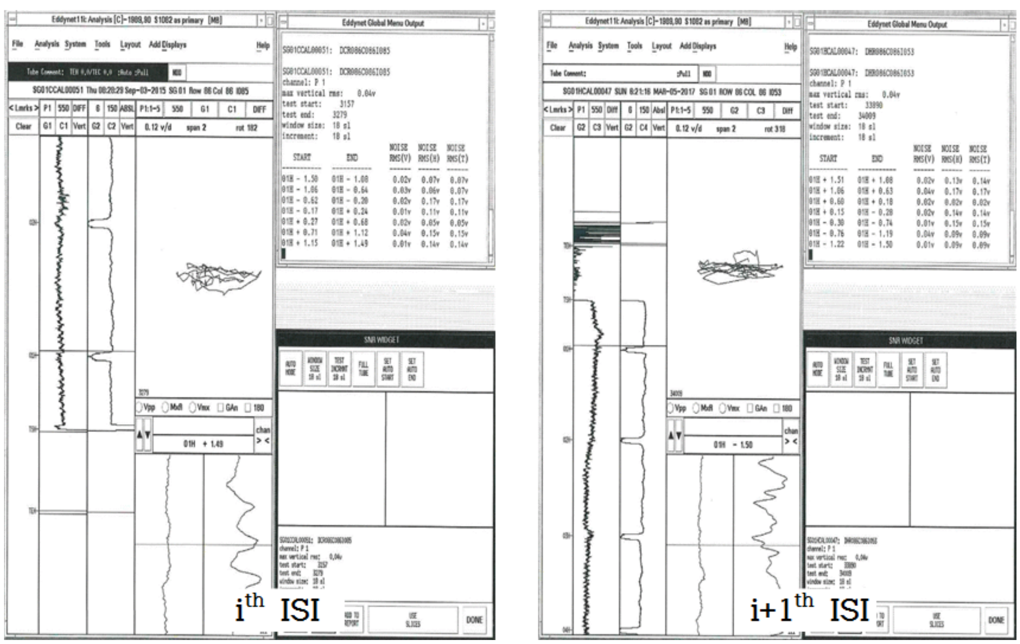

Figure 5. EC noise signal i^{th} vs $i+1^{th}$ cycles

Figure 6 shows the Bobbin amplitude size distribution for two consecutive cycles to derive the POD curve reflecting the effect of noise. As in the previous figure, the red line is the cycle in which the chemical cleaning was performed, and the blue line shows the next cycle of cleaning. The data of the after chemical cleaning show that the magnitude of the amplitude is small and the quantity of the detected indications is smaller than that before cleaning. It can be seen that the POD of the next cycle is improved as compared with the cleaning cycle. It is considered that the number of cracks is increased because the sludge accumulated in the tube is removed by chemical cleaning, and the probability of detection the flaw is improved and even the smaller defect is detected.

MAPOD-R® software developed by EPRI was used to derive the POD curve. Noise data and Ahat model are required for MAPOD operation. Figure 7 shows the signal amplitude curves for the defect depth changes obtained by Mote Carlo simulations.

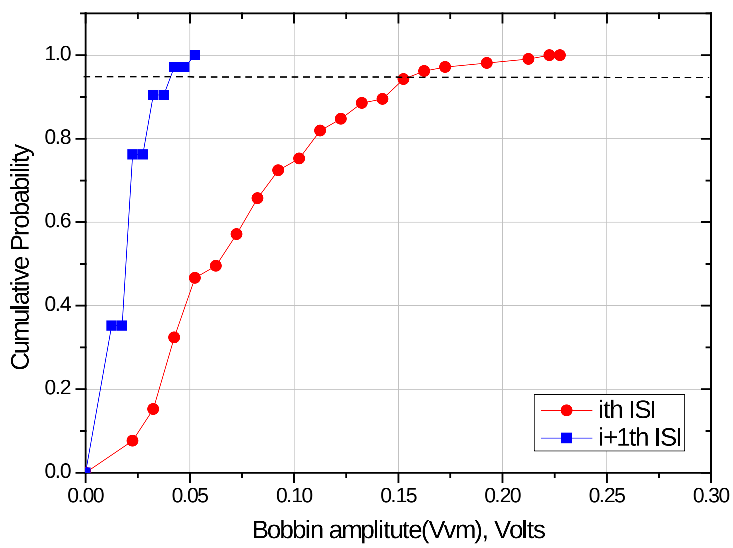

Figure 6. Noise distribution to plant B.

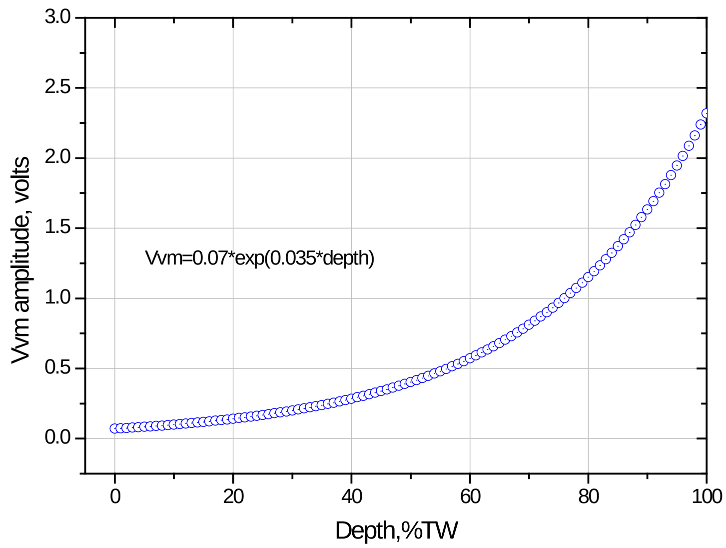

Figure 7. Monte Carlo simulated voltages

The POD curve obtained by the MAPOD-R® software is shown in the figure 8. The red line is the result of the cleaning cycle and the blue line shows the result of the next cycle. It can be expected that more accurate prediction results can be obtained by using the POD curve reflecting the influence of noise. Therefore, although the Weibull function is useful for forecasting trends, it is necessary to consider the inherent characteristics of the steam generator or the operating environment changes when performing the trend prediction. Measuring and monitoring noise level will help to obtain more accurate degradation forecast results by reflecting the change of operation condition of the steam generators.

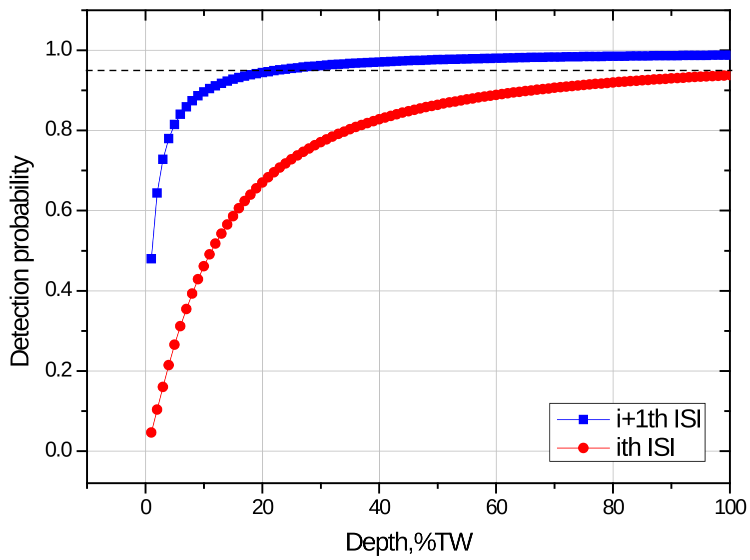

Figure 8. Comparison of POD curve to plant B.

CONCLUSION

Statistical analysis of steam generator tube degradation is one of the issues in Korean nuclear industry. It is reported that there is a difference in the degradation characteristics between steam generators designed, manufactured and operated under the same conditions. If all conditions are the same, the degradation trend is presumed to be different due to the difference in corrosion environment and the performance of the eddy current inspection. Application of chemical cleaning to steam generator is presumed to affect the generation and growth of cracks. Noise may be introduced into the inspection signal, which may affect the probability of detection. The importance of noise measurement and monitoring of the inspection signal has recently been emphasized. POD variation is an important factor in predicting the degradation trend of the steam generator tube. It is necessary to continuously develop the technology for noise measurement and monitoring of the inspection signal of the steam generator tube.

REFERENCES

Chung, H et al. (2013), *A Review on the ODSCC of Steam Generator Tubes in Korean NPPs,* Nuclear Engineering and Technology, 45 513-000.

EPRI (1991), *Statistical Analysis of Steam Generator Tube Degradation*, NP-7493, California, USA.

EPRI (2016), *Steam Generator Management Program: Steam Generator Integrity Assessment Guidelines, Revision 4,* California, USA.