Korea’s Recent Experience with ODSCC in Alloy 600HTMA Steam Generator Tubing

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Abstract

Twenty-four nuclear power plants are in operation and three power plants are under construction in Korea. There are four power plants with steam generator (SG) tubes of Alloy 600 high temperature mill annealed (HTMA) material. Hanul Unit 3 and Unit 4 replaced the steam generator due to occurrence of the outer diameter stress corrosion cracking (ODSCC) at the steam generator support plate area. In general, Alloy 600HTMA tubes are known to be vulnerable to stress corrosion cracking. CE-type SG with Alloy 600MA tubes experience cracks in the tubesheets, top of tubesheet, tube support plate, upper freespan, and structures at the hotleg. In particular, as the number of years of operation of the nuclear power plant increases, the quantity of ODSCC generated at the region of the tube support plate increases rapidly. As a result, SGs of some power plants have been replaced early, and Hanbit 3, 4, 5, and 6 power plants are also preparing to replace their SGs. ODSCC is the biggest threat to steam generator life management. This paper introduces a cracking signal with related eddy current data and effective analysis methods for detection of crack are suggested according to tube support plate region.

1. Introduction

In Korea Nuclear Power Plants, CE-type SG tube with Alloy 600 HTMA material was first introduced at Hanbit 3 Unit in March 1995 and subsequently used at six power plants. Recently, Hanul 3 and Hanul 4 SGs with Alloy 600 HTMA have been replaced early before the designed lifetime due to many cracks generated on the tube support plate. There are currently four power plants using Alloy 600 HTMA. Table 1 shows the specific status of the SGs with Alloy 600 HTMA tube in Korea (1).

Table 1. Status of Steam Generators with Alloy 600HTMA tube in Korea

	Comm. Ops	Recent Refueling Outage	Reactor Type	Manufacturer / Model	Tube Material	# of Tubes /SG	Expansion Method	Tube Support Type
Hanbit 3	‘95.03	16th('16.7)	PWR	KHIC / CE S-80	Alloy-600 HTMA	8,214	Explosive Expansion	EGGCRATE
Hanbit 4	‘96.01	15th('15.8)	PWR	KHIC / CE S-80	Alloy-600 HTMA	8,214	Explosive Expansion	EGGCRATE

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Hanbit 5	‘02.05	10th('15.9)	PWR	KHIC / CE S-80	Alloy-600 HTMA	8,214	Explosive Expansion	EGGCRATE
Hanbit 6	‘02.12	10^{th}('15.12)	PWR	KHIC / CE S-80	Alloy-600 HTMA	8,214	Explosive Expansion	EGGCRATE

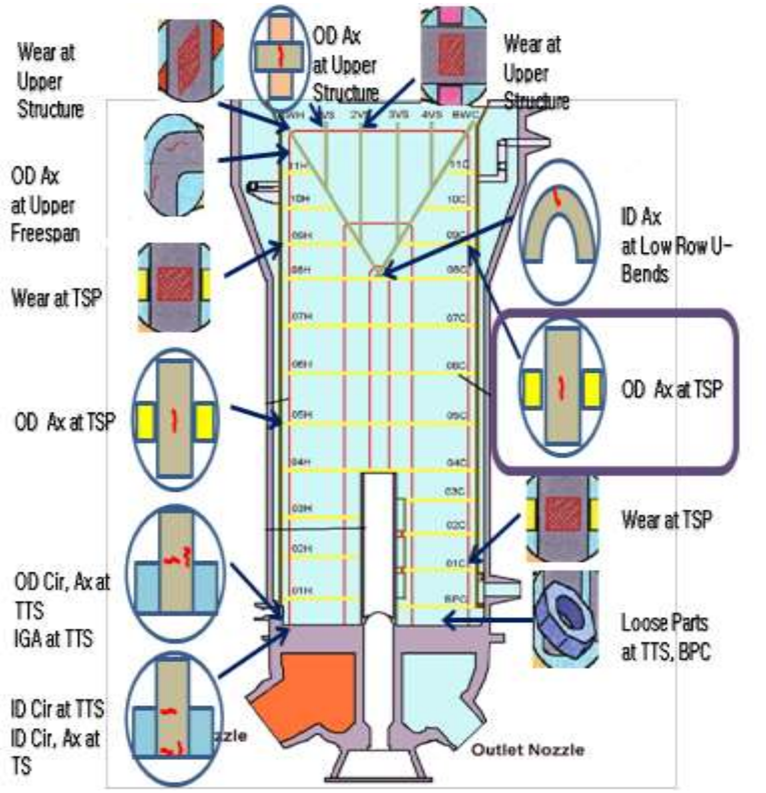

Figure 1. Type of degradation occurred in the 600HTMA tube

Hanbit Station Units 3, 4, 5, and 6 have CE-type recirculating steam generators. Each steam generator has approximately 8,214 tubes fabricated from high temperature mill annealed Alloy 600. During fabrication of the steam generators, some of the U-shaped tubes are inserted into a thick plate called a tubesheet. The tubesheet is approximately 21 inches thick and has two holes for each tube, the hotleg side and coldleg side tubes that are separated by the reactor coolant inlet and outlet. The ends of the tubes were welded to the primary side of the tubesheet. The tubes are explosively expanded for the full depth of the tubesheet. Tube support plates of eggcrate type that are assembled with a combination of 2 inch bar and 1 inch bar are installed to suppress fluid vibration. Figure 1shows the type of degradation that occurs in the SG Alloy 600HTMA tube.

The types of degradation that occurred in the tube are largely classified into cracks and volume defects. Cracks typically occur in a high a residual stress region, sludge piles, and high temperature environments. The main occurrence locations are the top of the tubesheet, tubesheet, and the support plate. The location where the crack first occurs during operation is the top of the tubesheet. This is because residual stress by expansion is present and a corrosive environment is created by the sludge pile (2) (3). The location of the cracks is then extended to the whole area of the steam generator. In particular, the number of cracks generated at the tube support plate continuously increases and the growth rate of the cracks is fast. This is because it is difficult to remove the sludge pile that affects crack generation (4). Table 1 shows refuelling outage (RFO) in which cracks were first detected depending on area in the steam generator using an alloy 600HTMA tube. Various types of cracks were detected in Hanbit 4 plant. Figure 2 shows the distribution of cracks by area as a result of the 15th inspection of Hanbit 4 unit (5). More than 80% of the detected cracks are detected on the tube support plate.

Table 1. The RFO in which cracks were first detected in Korea.

Location of Detection		Damage Mechanisms	Hanbit 3	Hanbit 4	Hanbit 5	Hanbit 6
Top of Tubesheet (TTS/Exp. Trans.)		PWSCC Ax.	12th RFO	-	-	-
		PWSCC Cir.	6th RFO	6th RFO	-	-
		ODSCC Ax.	14th RFO	6th RFO	8th RFO	1th RFO
		ODSCC Cir.	6th RFO	5th RFO	1th RFO	1th RFO
Tube Support Plant (TSP)	Eggcrate	ODSCC Ax	14th RFO	12th RFO	10th RFO	-
	BW, VS	ODSCC Ax	-	14th RFO	10th RFO	-
	Upper Freespan	ODSCC Ax	-	14th RFO	-	-
	freespan	ODSCC Ax	-	14th RFO	10th RFO	-
Inner Tube Sheet (TS)		PWSCC Ax.	14th RFO	13th RFO	9th RFO	-
		PWSCC Cir.	14th RFO	13th RFO	9th RFO	9th RFO
		ODSCC Cir.	-	-	-	9th RFO

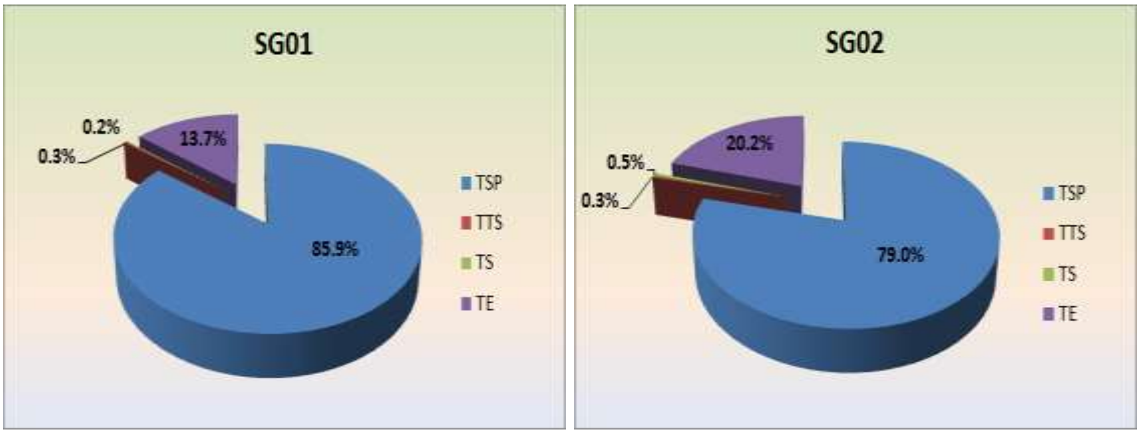

Figure 2. The distribution of cracks by area as a result of 15th inspection of Hanbit 4 unit

2. Eddy current data review of ODSCC at TSP

2.1 Examination technique guidelines for detecting axial ODSCC

In-service inspection of steam generator tubes is carried out via an eddy current test. Two different probes used for the inspection are bobbin and MRPC probes. The bobbin probe rapidly performs a full-length examination of the tubing. If an abnormal indication is detected as a result of the bobbin evaluation, the MRPC probe is applied to perform a diagnostic inspection. It is possible to confirm the presence of defects and the types of defects as well as the direction of the cracks.

Table 2 shows the specific examination technique guidelines for detecting the axial ODSCC with a bobbin coil in the tube support plate. The main channels used for the evaluation are P1 (550-150Khz), Ch3 (300Khz), and Ch5 (150Khz), and the evaluation screen size is set to 0.125 voltage per division. The evaluation screen of the left and right long strips is P1 and Ch6, respectively. The main lissajous screen is P1 and additionally Ch3 and Ch5. The P1 channel is created by combining the prime and low frequencies to remove the tube support plate signal. There are various types of noise such as the residual signal of the support structure generated when the P1 channel is created, the pilgering signal that occurs when the tube is manufactured, and the sludge on the outer surface of the tube (1) (6) (7).

Table 2 Examination technique guidelines for detecting axial ODSCC

<table>
<tr><th colspan="4">DATA ANALYSIS</th></tr>
<tr><td colspan="4">Tubing</td></tr>
<tr><td>Material</td><td colspan="2">Outside Diameter</td><td>Wall</td></tr>
<tr><td>Inconel 600HTMA</td><td colspan="2">19.05mm</td><td>1.07mm, 1.22mm</td></tr>
<tr><td colspan="3">Examination scope</td><td>Acquisition technique</td></tr>
<tr><td colspan="3">Detection of the axial ODSCC within the freespan except for the U-Bend, tube support plate region, and sludge pile region of the SG tube</td><td>Bobbin coil</td></tr>
<tr><td colspan="4">Flaw Specific Guidance</td></tr>
<tr><td colspan="4">○ Signals attributable to ODSCC can be identified using raw or process channels
○ Raw channel Ch3 typically provides sufficient data screening except for TSP and Sludge Pile at the top of the tubesheet region.
○ Confirmation trends (i.e., phase rotation) between channels may be observed, but they are not required for reporting.
○ Flaw-like indications that provide a 0% TW response (signals forming outside the typical flaw-plane) should also be reported.</td></tr>
<tr><td colspan="4">Data Screening</td></tr>
<tr><td>Left Strip Chart</td><td>Right Strip Chart</td><td>Lissajous (span)</td><td>Add. Chart (span)</td></tr>
<tr><td>P1</td><td>Ch6</td><td>P1 (0.125 v/d)</td><td>Ch3, Ch5 (0125 v/d)</td></tr>
<tr><td colspan="4">Reporting Requirements</td></tr>
<tr><td>Region</td><td colspan="2">Report</td><td>Channel</td></tr>
<tr><td>TSP</td><td colspan="2">DSI (Distorted Support Indication)</td><td>P1 Vmx</td></tr>
</table>

2.2 Defect signal depending on region where crack occurs in the tube support plate

The tube support plate is divided into edge and inner zones. The edge region is the upper and lower end of the tube support plate and the middle part. The inner zone refers to the rest of the region. Figure 3 shows the bobbin signal where there is no defect at the tube support plate. The area marked with a blue box is the edge region of the tube support plate, and the purple area between the edge regions is the inner region.

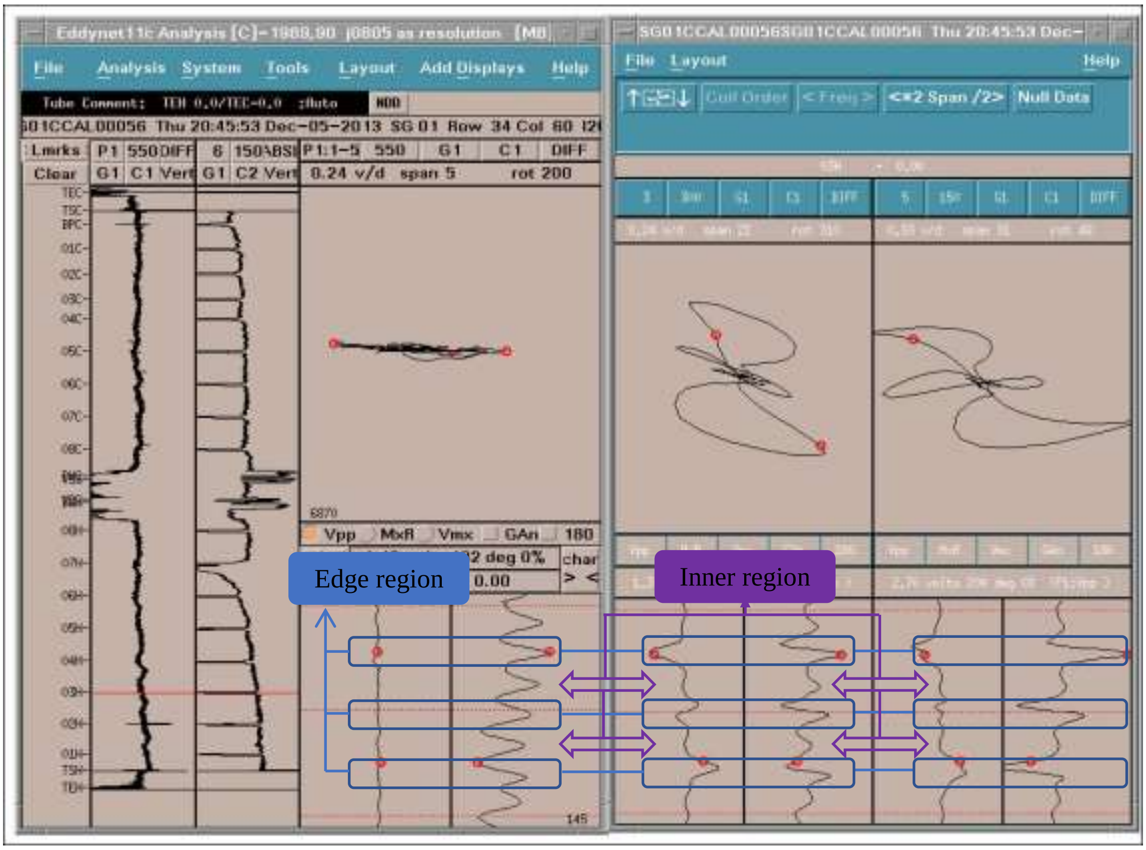

Figure 3. The bobbin signal of defect-free tube on tube support plate area

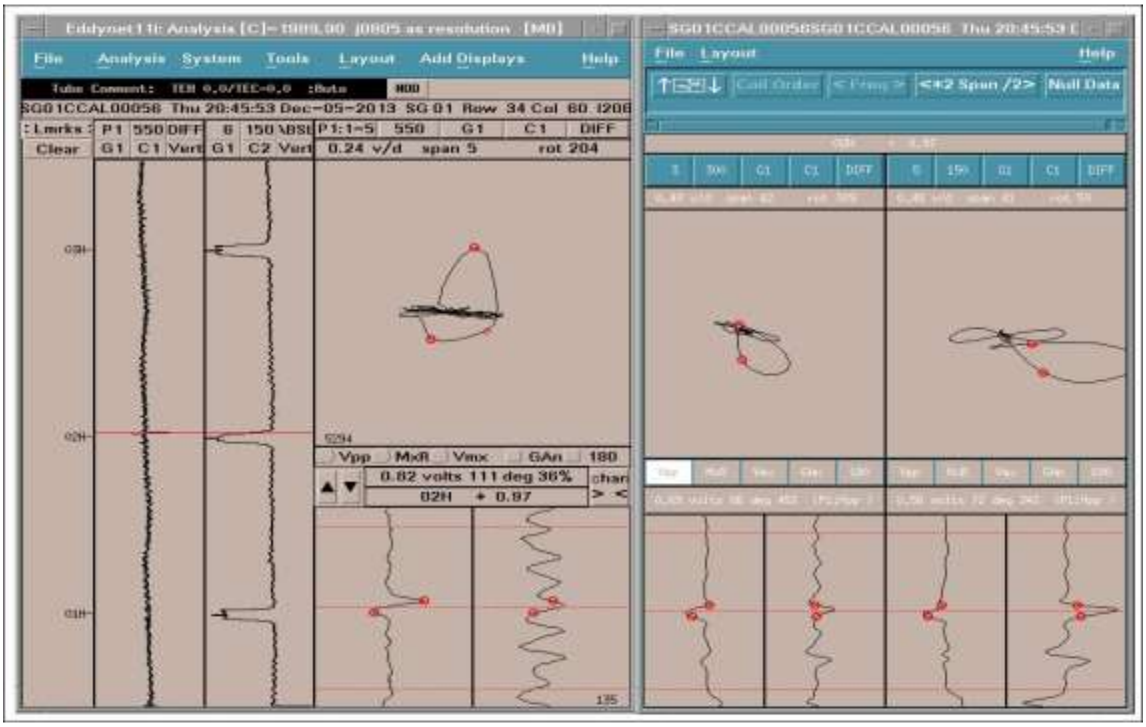

Figure 4. Crack signal in edge region of tube support plate

Figure 4 shows the bobbin signal of ODSCC occurring in the edge region of the tube support plate. The bobbin signal in the edge region is distorted due to the influence of the tube support plate. Therefore, it is difficult to evaluate and requires careful attention. In the case of the edge zone, the evaluation method shall monitor the defect with the P1 channel that removed the structure signal, and report DSI code to the MRPC confirmation test if an abnormal indication is found. When moving from a high frequency channel to a low frequency channel, the phase angle of the defect moves counterclockwise. This evaluation method is called the phase angle analysis technique. If the phase angle analysis technique is used to evaluate defects at the edge region, the probability of missing defects increases. This is because the raw channel cannot show the phase angle of the defect due to the influence of the tube support plate more than the defect. This should be evaluated carefully. The evaluation of the edge region requires a conservative approach. Eventually, the number of false calls can increase but the probability of missing defects is reduced. However, evaluation of the cracks in the inner region is easier because the influence of the tube support is relatively less than in the edge region. The final decision on the defect determination should be made using the phase angle analysis technique with the P1 channel and the raw channels 300 kHz and 150 kHz. It is possible to reduce the over call rate and to increase the probability of detection. Figure 5 shows the crack signal generated inside the tube support plate.
As a result, the bobbin signal can be effectively detected by applying different evaluation methods according to the tube support plate region.

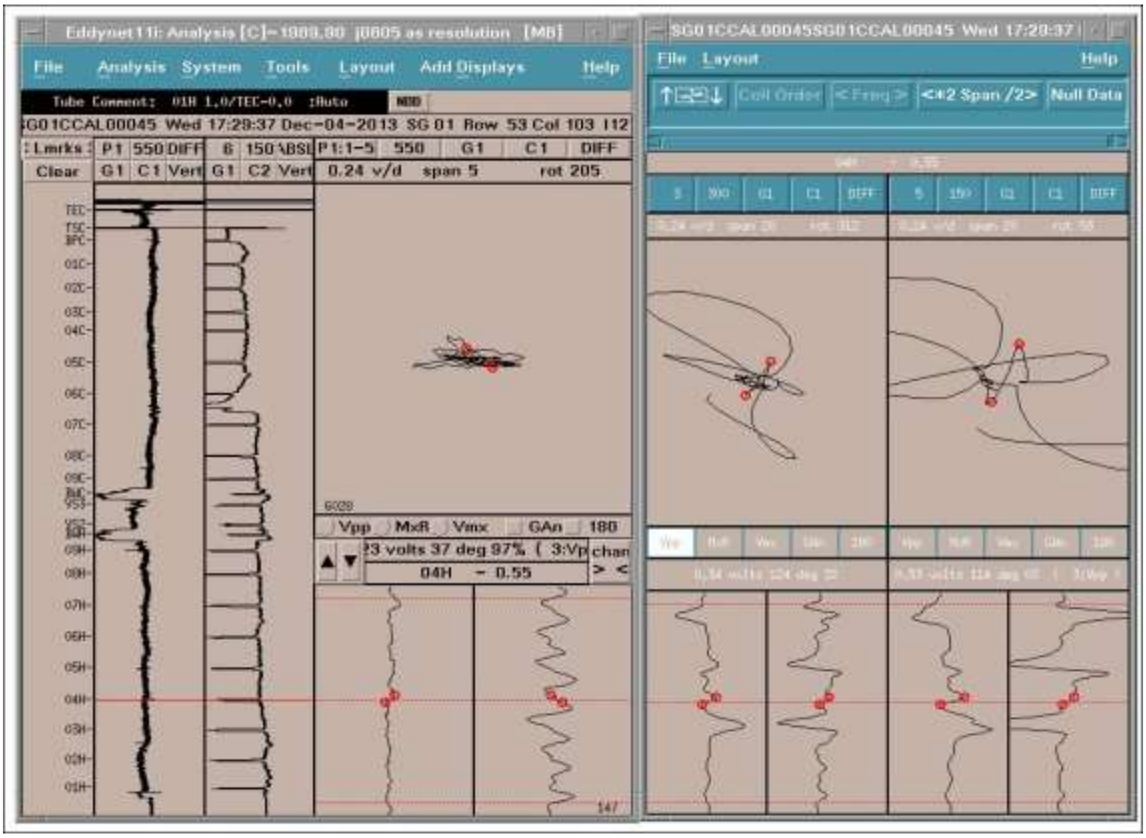

Figure 5. Crack signal in inner region of tube support plate

3. Conclusions

ODSCC that occur in tube support plates of SGs with alloy 600HTMA pose the greatest threat to SG integrity and are increasing in Korean nuclear power plants (NPPs). As a result, SGs with Alloy 600 HTMA tubes have been replaced early or are scheduled to be replaced before their designed lifetime. Above all, it is likely that unexpected SG operating limits will be met. Therefore, there is a possibility of long-term shutdown of nuclear power plants, which would cause huge economic loss. In order to prevent this, the reliability of ECT evaluation results is extremely important. In order to accurately detect the ODSCC generated in the tube support plate, the bobbin evaluation technique should be applied differently depending on the region where the crack occurs. In the case of the edge zone, the evaluation method shall monitor the defect using the P1 channel without applying the phase angle analysis technique. The evaluation requires a conservative approach. However, the final decision on the defect determination on the inner region is made by using the phase angle analysis technique. It is possible to reduce the over call rate and to increase the probability of detection.

References and footnotes

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