Steam Generator Tube Inspection I

The Degradation Experience of Steam Generator Tubing in Tomari Unit 1
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ABSTRACT

This paper introduces Eddy Current-Testing result, the cause and the countermeasure of stress corrosion cracking of Steam Generator tubing in Tomari unit 1.

During the 15th outage of Tomari unit 1 in August 2008, 100% full length inspection by an array typed Intelligent ECT probe was carried out to check the soundness of two Steam Generator tubes. As a result, one circumferential indication was found in Steam Generator #A and the location was the portion of 1-step mechanical roll of hot side tubesheet. Then, some cause investigations such as replica and manufacturing record investigation etc. were performed and it was specified that the indication was stress corrosion crack from the tube inside. Moreover, it was assessed that the cause was local residual stress in the tube inside due to tube expansion with a local minute foreign material during the manufacturing of Steam Generator and combined effect of residual stress and the stress by the internal pressure during the plant operation. As a countermeasure, the concerned tube was plugged and 100% full length inspection by Intelligent ECT probe will be performed continuously every outage.

INTRODUCTION

The Pressurized Water Reactors (PWRs) in Japan have two to four Steam Generators (SGs) which have approximately 3000 tubes of about 20m in full length and about 22mm in diameter. These tubes are made of Alloy 600 or 690 thermal treated (TT600 or TT690). All the steam generators with TT600 have been inspected since 2003 using Intelligent ECT developed by MHI, because TT600 has potential occurring Primary Water Stress Corrosion Crack (PWSCC). Intelligent ECT is used an array typed probe and has the features of high speed inspection equivalent to conventional Bobbin probe and the high detectability equivalent to conventional Rotating probe (see Fig. 1). After applying Intelligent ECT, PWSCC and wear by anti vibration bar before replacement were found in one pass inspection. Recently, Intelligent ECT has been applied to Alloy 690 tubes during pre-service inspection of new and replacement SG since 2008.

In Tomari unit 1 of Hokkaido Electric Power Co., Inc., the inspection of SG tubing by Intelligent ECT during the outage has been implemented every outage since 2004. During the 15th outage held in August 2008, 100% full length inspection of two SGs by Intelligent ECT was carried out. As a result, one circumferential indication was found in SG #A and the location was the portion of 1-step mechanical roll of Hot side tubesheet. Finally, it was specified that this ECT indication was PWSCC from the tube inside based on further investigations. PWRs in Japan had experiences with indications such as axial PWSCC at tubesheet region. However, it was first time occurring circumferential PWSCC at 1-step mechanical roll of TT 600 in Japan.

In this paper, Intelligent ECT result, additional investigation results, the cause and the countermeasure of this PWSCC of SG tubing in Tomari unit 1 were described.
INTELLIGENT ECT RESULT

Firstly, Intelligent ECT system is introduced, and then ECT result is described.

**Intelligent ECT System**

*Features of Intelligent ECT probe*

Fig. 2 shows the appearance of Intelligent ECT probe. The Intelligent ECT probe is mainly composed of a probe head with 24 coils, electronic circuits and connectors etc. In order to achieve the high speed and high detectability inspection, the unique specific of the probe head is described as follows:

- 24ch multi array probe arranged the coil circumferentially
- Mutual induction and self-comparison method, in which one coil is composed of one inclined drive coil and two thin-film pick-up coils (See Fig. 3)
- Inclined drive coils are effective for both axial and cir. Oriented flaw detection
- Thin-film pick-up coil enhances the flaw detectability

![Figure 2 – Appearance of the Intelligent ECT Probe](image-url)
**Intelligent ECT Analysis System**

The data analysis system is extremely important to analyze array typed ECT probe data because array typed ECT probe has a lot of information. In order to achieve fast, reliable and efficient analysis, Mitsubishi Intelligent Data Analysis System (MIDAS) developed by MHI has been applied for analysis of Intelligent ECT. The Intelligent ECT Analysis process is mainly consisted of three phases as shown in Fig. 4.

Phase 1: The acquired raw inspection data is calibrated and prepared for analysis.
Phase 2: The calibration data is automatically processed to extract TSP(Tube Support Plate), TTS(Top of Tubesheet), & TS(Tubesheet) data segments, as well as, any other signals of interest. Using advanced signal processing algorithms, the data segments are then automatically analyzed and any potential degradation indications are flagged for final disposition.
Phase 3: The analyst reviews each segment and the flagged indications from the Auto-Analysis. Then, the analyst categorizes and reports each valid indication as appropriate. When it is necessary to evaluate the depth of indication, original sizing method by a heavy regression analysis using the signal features of plural frequencies is applied.

![Figure 3 – Sensor Type of Intelligent ECT](image)

![Figure 4 – Intelligent Analysis Process](image)
Intelligent ECT Result

100% full length inspection of two SGs by Intelligent ECT was implemented. As a result, one indication was found in SG #A and the tube address of indication was X 76, Y33. No indication was found in SG #B. Intelligent ECT signal and the location of indication are shown in Fig. 5 and Fig. 6 respectively. As shown in these figures, it was found that the indication was a circumferential indication that is located in the portion of 1-step mechanical roll of hot side tube sheet.

Figure 5 – ECT signal by Intelligent ECT (Example of manual analysis screen of MIDAS)

Figure 6 – The Location of Indication by Intelligent ECT
CAUSE INVESTIGATION RESULT

Some cause investigations such as replica, manufacturing record investigation and stress analysis etc. were performed.

Replica Result

Replica for inner surface observation and measurement of inner diameter change around ECT indication was performed. Inner surface investigation result and measurement result of inner diameter are shown in Fig. 7 and Fig. 8 respectively.

As shown in Fig. 7, four crack patterns with 1.3 mm to 3.1 mm length were found at the about 23 mm position from tube. All cracks showed zigzag pattern with partial branch, which is one of typical features of PWSCC. No indication was found except for these four indications.

Moreover, as shown in Figure 8, a minute convex inner diameter change from outside to inside of tube was observed around ECT indication. The amount of this configuration change was about 20 μm and the range of the change was approx. 5 mm x 5 mm. 1 step mechanical roll was implemented well.

Figure 7 – Inner Surface Observation Result by Replica
Additional investigation result

Additional investigations such as manufacturing record investigation, operation record investigation, material investigation, previous damage experience and stress analysis etc were performed. Investigation results were summarized as follows;

- PWSCC at tubesheet region was occurred in the previous domestic and oversea PWR plant. In that case, it was specified that one of main causes was high residual stress due to tube expansion to discontinuity portion of tube hole and inappropriate 1-step mechanical roll.
- Based on measurement result of inner diameter change, it was considered that a possibility of interposing a minute foreign material such as tube bari generated during tube hole drilling process in the between tube hole and tube cannot be completely denied in the tube insertion process.
- As a result of stress analysis, it was evaluated that high tensile stress with axial direction was induced on the local area when tube expansion was implemented with a minute foreign material between tube hole and tube. Moreover, adding to the stress by the internal pressure during operation, it was confirmed that tensile residual stress over approx. 340Mpa which may occur PWSCC.

ESTIMATED CAUSE AND COUNTERMEASURE

From these investigation results, it was finally specified that this indication detected by Intelligent ECT was circumferential PWSCC from tube inside. Moreover, it was assessed that the cause was local residual stress in the tube inside due to tube expansion with a local minute foreign material during the manufacturing of Steam Generator and combined effect of residual stress and the stress by the internal pressure during the plant operation (see Fig. 9).
As for countermeasures, the following items were performed.
- The concerned tube was plugged. Mechanical plug with sleeve was applied to Hot side and mechanical plug was applied to Cold side.
- 100% full length inspection by Intelligent ECT probe will be performed continuously every outage.

CONCLUSION

Intelligent ECT developed by MHI has been applied to alloy 600 tubes as In-Service Inspection since 2003 in Japan. During the 15th outage of Tomari unit 1 in August 2008, Intelligent ECT found circumferential PWSCC that was located in the portion of 1-step mechanical roll of Hot side tubesheet. This indication was for the first time in Japanese PWR plant. From this finding, two following things are found.
- Tube expansion with a local minute foreign material during the manufacturing of SG has a possibility of circumferential PWSCC occurrence by combined with the stress by the internal pressure during the plant operation.
- Intelligent ECT is very effective method to detect small indication such as this circumferential PWSCC regardless of the indication location and 100% full length inspection by Intelligent ECT is important to keep the integrity of SG tubing.