Simulation of a Bow and Deposit Bridging between Steam Generator Tubes

Do Haeng Hur*, Myung Sik Choi, Kyung Mo Kim, Jung Ho Han, Deok Hyun Lee
Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: dhhur@kaeri.re.kr*

1. Introduction

Corrosion products formed from the secondary side system are accumulated not only on the top of the tubesheet but also on the tube support intersections and the outside diameter surfaces of nuclear steam generator tubes. Intergranular stress corrosion cracking (IGSCC) in the tube support plate intersection zone was found in several foreign plants. Especially, a tube rupture occurred under a free span crevice formed by deposits bridging bowed tubes in Palo Verde Unit 2. Surface analysis results on the corrosion deposits removed from the cracked tubes of these plants suggested a highly alkaline pH [1].

Several domestic plants have also had indications of IGSCC in the eggcrate tube support intersections and bow in free span region. Eddy current testing (ECT) signals by a motorized rotating pancake coil (MRPC) probe showed that flow holes around the eggcrate were covered and blocked with deposit. In addition, bowed tubes form a tube-to-tube crevice. The crevice together with the consequential heat flux provides an aggressive local environment under a tenacious bridge deposit. Therefore detection and sizing technology to these degradation susceptible areas should be improved.

In this work, a change of bowed tube signal with tube-to-tube gap and the effect of deposit on the bow signal are presented. A simulation result for 3 pairs of bowed tubes with deposit bridging observed in Palo Verde Unit 2 [2] is also given.

2. Experimental Methods

High temperature mill-annealed Alloy 600 steam generator tubes with a nominal outside diameter of 19.05 mm and a nominal wall thickness of 1.07 mm were used in all the tests.

A straight tube and a U shape-bended tube with a radius of 279.4 mm were fixed in a tubesheet instead of an eggcrate support to maintain a nominal tube spacing of 6.35 mm. The tangent point starting the bend from the straight section was 630 mm apart from the top of the tubesheet. The bow signals were acquired by ECT, varying the gap between the two tubes at the tangent point.

In order to simulate and fabricate plant deposit, magnetite powder with an average size of 1 ㎛ and a purity of 99% was used. Magnetite powder of 90% and a glue of 10% in weight percent were mixed to reach a complete wetting condition. The mixture was pressed to a 0.40~0.45 mm thickness, cut into a rectangular shape and then attached on the tube.

The ECT signals of the deposit tube specimen were obtained by the Zetec MIZ-70 digital data acquisition system with a bobbin probe (M/A-610-ULC/MR) and a 3-coil motorized rotating probe (M/+Point-610). In the case of the bobbin probe, the pulling rate was 304.8 mm/sec and the test frequencies were 35, 100, 300, 550 and 700 kHz. In the case of the rotating probe, the specimens were inspected at a pulling speed of 5.08 mm/sec and at a rotating rate of 600 rpm. The test frequencies were 20, 35, 100, 300, 400 and 700 kHz. The obtained signals were calibrated using the ASME calibration standard for bobbin and the EDM notch standard with tube expansion for MRPC, respectively.

3. Results and Discussion

3.1 Bow signals between two tubes

The amplitude of the two bowed tubes increased with decreasing the gap between the tubes. Fig. 1 shows the relationship between the relative signal amplitude and the gap. The relative signal amplitude means a value which the amplitude at a certain gap was divided by the amplitude at a gap of zero. The MRPC signals showed a higher resolution to tube approximation within a gap of 3 mm, but no more sensitive at a gap lager than 3 mm. The bobbin detected even the neighboring tube with a nominal tube spacing of 6.34 mm at both frequencies of 35 and 100 kHz.

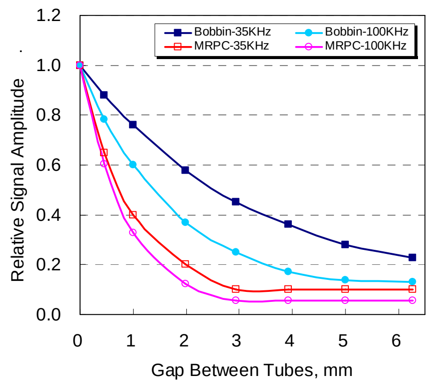

Fig. 1. Relationship between the relative signal amplitude and the bowed tube gap.

3.2 Effect of deposit

To have a better knowledge of the effect of deposit on the bow signal characteristics, a deposit with a dimension of 0.45 mm thick, 50 mm wide and 500 mm long was attached on the U-tube at an elevation of below 10 mm from the tangent point. Fig. 2 shows a bobbin signal change by the deposit, which clearly indicates that the magnetite deposition under the bowed tube area can offset the bow signal. This is because the difference between the phase angle of deposit signal and that of the bow signal is about 140°. If the thickness of the magnetite deposit increases under a fixed tube-to tube gap, the magnitude of the bow signal would decrease. Consequently, even bridged tubes with deposit may not be detected by bobbin probe. Therefore it is suggested that the expected deposit area should be reviewed and compared with pre-service inspection data.

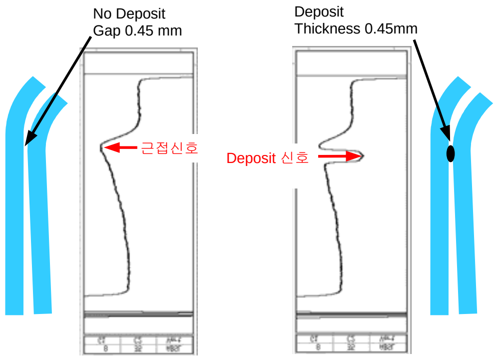

Fig. 2. Effect of the deposit on the bowed signal by bobbin probe at a frequency of 35 kHz.

3.3 Simulation of deposit bridged tubes

It was successful to simulate 3 pairs of bowed tubes with deposit bridging observed in Palo Verde Unit 2 in 1993 when the tube rupture was occurred. Three tubes moved closely each other, which resulted in the sludge deposition under the tube-to-tube crevice. It was also found that MRPC probe discriminated the bow signal and the deposit signal without interference under a deposit bridged condition.

3. Conclusions

Because the magnetite deposit under the bowed tube area offset the bow signal by bobbin probe, it was suggested that the expected deposit area should be reviewed and compared with pre-service inspection data. Furthermore, MRPC discriminated the bow signal and the deposit signal without interference under a deposit bridged condition.

ACKNOWLEDGEMENT

This work was carried out as a part of the Nuclear R&D Programs supported by the Ministry of Science and Technology in Korea.

REFERENCES

[1] A. McIlree, Oxide-Film Compositions on Alloy 600 Tubes from Steam Generators, EPRI Report, TR-104066, 1998.

[2] D.B. Hansen, Steam Generator Eddy Current Program, Analysts Guidelines Training Manual, Rev. 19, 2002.