Analysis of Noise Signal with Simulation by Cross Sectional Area Distortion of Steam Generator Tube

Se-Beom Oh [a*], Deok-Hyun Lee [a], Kyung-Mo Kim [a] and Sung-Woo Kim [a]
[a] *Korea Atomic Energy Research institute, 111, Daedeok daero 989 beon gil , Yuseong gu , Daejeon, 34057, Korea*
[*] *Corresponding author: osb1216@kaeri.re.kr*

1. Introduction

The steam generator (SG) tube of the nuclear power plant (NPP) has a U bending area. The free span areas generate noise signals primarily by external structures, while U-bend regions generate noise due to feature distortion. Figure 1 shows that the magnitude of the straight region noise signal is constant while the curved region produces a high-level noise signal. The curvature area of the heat transfer tube varies in thickness and ovality due to residual stress during the manufacturing process. This will affect the eddy current test for evaluating integrity. The coil probe is tilted by cross sectional changes inside the pipe and has a similar effect to the coil being tilt. When the coil probe is tilted, the Lissajous curve may be distorted and the noise signal may increase as the proximity current density region is finely altered. However, there is no technology that can accurately measure cross-sectional changes in piping, and it is practically difficult to measure the effect of the signal. Therefore, cross-sectional area change areas were modeled through COMSOL Multiphysics, a commercial numerical analysis program based on finite element method (FEM) using hypothetical conditions, and electromagnetic analysis was performed to analyze noise caused by structural problems in curved tubes. [1-5]

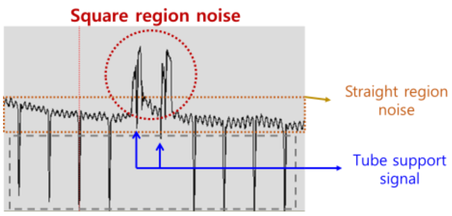


Fig. 1. The steam generator tubes curvature noise signal

2. Methods and Results

2.1 Computed Tomography (CT)

CT analysis is used in the industry to detect empty spaces or defects, perform particle analysis of materials, and measure external and internal geometry of complex parts. CT analysis was conducted to accurately measure the cross-sectional area, as the shape of the U-bending tube deformed by residual stress can cause another change if cut. If the heat pipe of the steam generator is U-shaped through the manufacturing process, the residual stress is the most affected. Therefore, it was measured using the pipe with the lowest row number. Figure 2 shows the results of piping measurements including both straight and curved parts. Analysis was conducted using high-power CT equipment (TVX-IL450, Korea Tech Valley). The color is differentiated by the density of the material and the measurement error is ±0.3 mm.

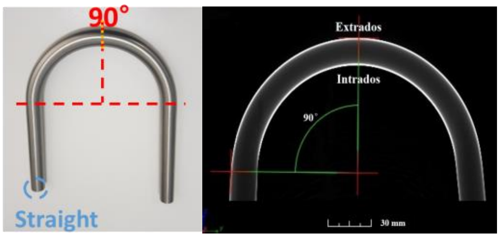


Fig. 2. The cross-sectional areas(row 1 tube) from the CT analysis.

2.2 Coil probe Design

For simulation solution, all structures should be designed to be of the same size as the real size, and the other conditions should be set to the maximum suitable possible. Figure 3 shows an overview of the probes used for the Steam Generator Tube ECT inspection. The bobbin coil is modeled to center the tube by default. Tube material (alloy 690) and dimension (19mm) outer diameter 0.11mm wall thickness are the same as those used in domestic nuclear power plants. Table 1 shows the boundary conditions used for interpretation: relative permeability, relative permittivity, and electrical conductivity.

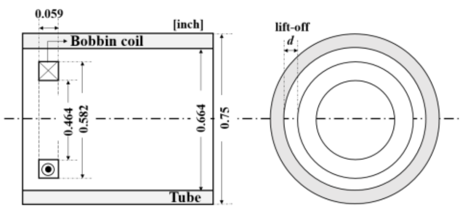


Fig. 3. The schematic diagram of the ECT bobbin coil probe

Table I: The material properties used in the simulation

	Relative Permeability	Relative Permittivity	Electrical Conductivity (S/m)
Air	1.00000037	1.000536	3×10^{-15}
Coil (Copper)	0.999994	0.9999996	5.96×10^{7}
Tube (Inconel 690)	1.01	1	6.7567×10^{6}

2.3 Simulation Results

CT analysis confirmed the cross-sectional area at the location of the straight position and 45-degree position, as shown at the top ofr Figure 4. In the case of curved tubes, it was confirmed that there was more distortion on the outer side than the straight. Based on this data, the current density analysis showed that the closer the coil probe by COMSOL, the more concentrated the current.

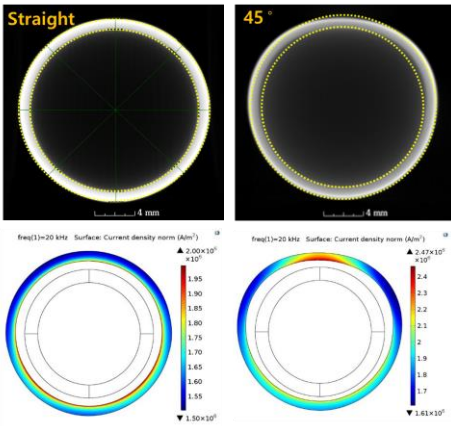
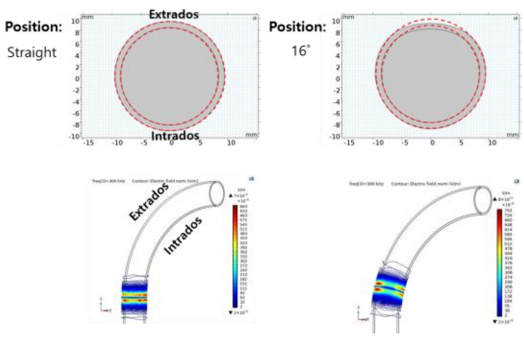


Fig. 4. The cross-sectional areas from the CT analysis and current density.

Additional two regions were randomly selected to determine the distribution of current density according to geometry at various locations other than 45 degrees. The analysis was conducted through 3D modeling to determine the effect of current density in the circumference and longitudinal direction of the pipe at each location. In the straight section, it was confirmed that the concentration of the current density was evenly concentrated along the coil and concentrated on the inside/outside of the pipe at the location where the cross-sectional distortion occurred.



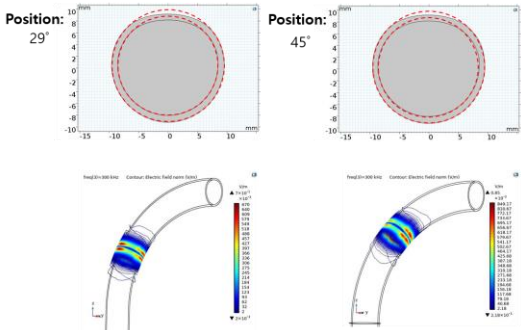


Fig. 5. The current density distribution with 3D modeling simulation

3. Conclusions

A residual stress causes distortion of the cross-sectional area of the pipe during the manufacturing process of the steam generator tube. This affects the eddy current test and raises the noise level of the signal. The distortion was determined through CT analysis because it is difficult to know exactly by mock-up. The distortion of the cross-sectional area was confirmed to vary the physical distance between the coil probe and the inside of the pipe, and the simulation analysis was performed using COMSOL. It was verified that current density was concentrated when the pipe was adjacent to the coil probe due to distortion of the pipe, and it was possible to additionally verified that changes slightly depending on the position of the curved pipe. This effect is also considered to be associated with the effect of tilting the coil in integrity piping, and is considered useful for analyzing the noise signal-causing factors of ECT testing due to various effects.

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