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Analysis of Impedance Signal on Eddy Current Testing using FEM Simulation

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1. Introduction

Steam generator (SG) tubes in nuclear power plants (NPPs) have U bend regions. However, the defect detection in the U bend region is difficult due to a large background noise signal from geometric distortions. Specially, the curvature region has different wall thickness and ovality according to residual stress during the manufacturing process. As the coil probe tilts inside the pipe, it has a similar effect as the cross-sectional area changes. It has been confirmed that the tilt of the coil probe can cause distortion of the Lissajous curve and increase in noise signal. [1-3]

Using COMSOL Multiphysics, a commercial numerical analysis program based on the finite element method (FEM), the curvature was modeled in three dimensions, and the electromagnetic analysis was performed at each frequency at each location to analyze the noise caused by structural problems in the curved pipe. [4]

2. Methods and Results

This section describes the non-destructive measurement and analysis of the detailed information of the steam generator pipes. It includes methods using CT and simulation design using COMSOL S/W and analysis of eddy current data.

2.1 Computed Tomography (CT)

CT is used in industry to detect flaws such as voids and cracks, and to perform a particle analysis of a material. CT allows measurements of the external and internal geometry of complex parts. CT analysis was performed to more accurately measure the dimensions and shapes of the U-bend tube used in this study. The tubes manufactured by the bending process have residual stress, it is difficult to measure the exact dimensions due to deformation of the pipe during cutting. The analysis was performed using high-power CT equipment (TVX-IL450, Techvalley, Korea).

When the steam generator heat pipe is U-shaped through the bending process, residual stress may exist, or the shape of the cross section may change during the bending process. Fig. 1 shows the cross-sectional geometry of the U-Bend tube at its most distortion-prone position.

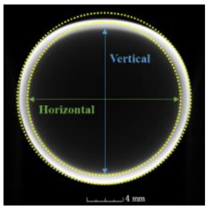


Fig. 1. The cross-sectional areas from the CT analysis for the U-bend tube.

2.2 Simulation Modeling

Fig. 2 shows a cross-sectional view of the bobbin coil used in the simulation design and a probe used for the inspection of the steam generator tube used in the analysis. The bobbin coil is modeled to be centered on the tube by default. Tube materials (Inconel 690) and dimensions (19 mm) outer diameter 0.11 mm wall thickness) are the same as those used in nuclear power plants in Korea. Table 1 shows the properties of each substance, including relative permeability, relative acceptability, and electrical conductivity.

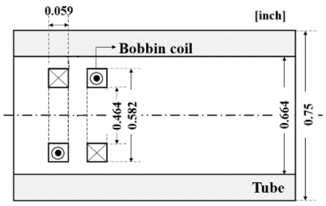


Fig. 2. The schematic diagram of the simulation analysis model

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}

Based on the conceptual plot in Fig. 2, the design conditions were set as boundary conditions for the intervals directly affected by the coil (copper). Frequencies ranging from 20 to 300 kHz are mainly used for inspection of the steam generator at nuclear power plants. To simulate the curved part of the steam generator tube, modeled by extruding a curvature (Fig. 3). To analyze the current density and electric field at each location, the coil probe was placed in the center position and shifted and tilt to confirm the change.

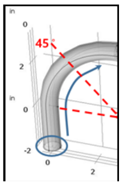
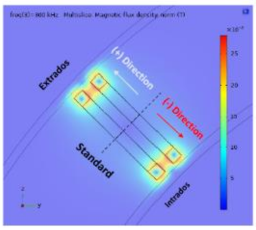


Fig. 3. A simulation modeling concept of a U-bend tube.

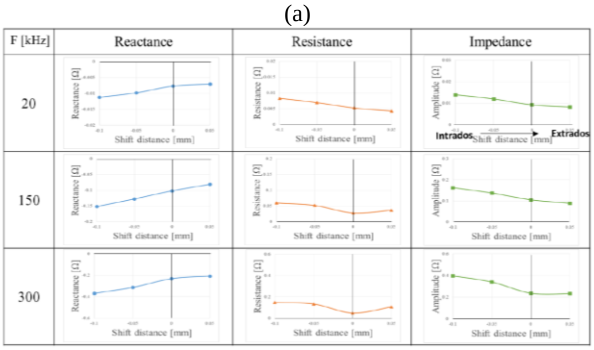
2.3 Simulation Results

Fig. 4 and 5 are the results of analyzing the current density by positioning and interpreting the coil at the 45° point with the highest cross sectional area distortion rate of the electric tube. The coil was analyzed using the method of providing lift-off distance(spacing between coil and specimen) from the center in both directions (Fig. 4(a)) and the method of tilting the coil in the center (Fig. 5(a)). Fig. 4 shows the direction (+) of the coil approaching the extrados from the center and (-) of the intrados. Fig. 5 is analyzed in accordance with the direction of tilt to the intrados/extrados relative to the center between the two measurement coils.

Each (b) of Fig. 4 and 5 is the result of an interpretation at a typical experimental frequency. The simulation analysis signal uses the coil's reactance and resistance values to calculate the impedance, which in interpretation shows the same tendency as the rise of the noise signal in the actual eddy current testing. The coil impedance changed as the coil approached or tilted the intrados of the pipe. These results indicate to possible analysis of the eddy current test signal through simulation.

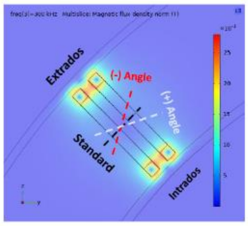


(a)

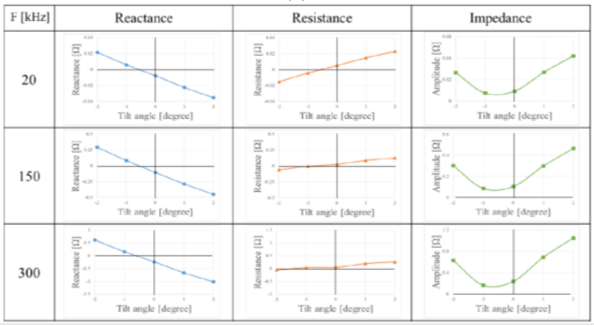


(b)

Fig. 4. (a) The current density according to the coil lift off, (b) coil impedance results according to frequency.



(a)



(b)

Fig. 5. (a) The current density according to the coil tilt, (b) coil impedance results according to frequency.

3. Conclusions

The noise signal is generated during eddy current inspection due to the effect of the change in the ovality of the steam generator heat pipe. It is expected that the noise level will rise due to the tilting of the coil in the process of manufacturing the bent part, and verified using simulation. Using CT analysis, a cross sectional view of the curved pipe according to the location was secured and a modeling method was secured. At a position with high ovality, the effect of lift off and tilt the coil inside the pipe on an ECT signal was applied to analysis the noise signal level. The Tilted the coil signal inside the pipe was confirmed that the noise signal level variation was larger than the lift-off.

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