Simulation Analysis of Eddy Current Inspection Signal by Steam Generator Heat Transfer Tube Loose Parts

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1. Introduction

The steam generator tube(SG) of the nuclear power plant (NPP) is conducting an in-service inspection using an eddy current detection test. With the recent discovery of suspicious signals due to loose parts, signal evaluation in the 20 kHz that can detect the outside of the pipe is required in addition to the frequency that detects defects directly below the pipe surface. The signal caused by loose parts can be measured only at low frequencies, and it is difficult to evaluate when mixed with structural signals. The types of loose parts are not limited and can exist in various materials and forms, it is necessary to secure analysis technique for this problem. For this reason, three types of loose parts that may exist inside the steam generator were manufactured, attached to the steam generator heat transfer tube, and then measurement signal was evaluated. Since the production and demonstration evaluation of various loose parts actually requires a lot of cost and time, it is necessary to develop an analysis method that can replace them. Therefore, it is necessary to predict the signal through the finite element method using COMSOL. In previous studies, the signal effect between the heat transfer tube and the probe coil was evaluated. And based on the result of evaluating the effect of the signal due to the generation of the defect the loose parts were hypothetical designed and the signal was evaluated. [1-5]

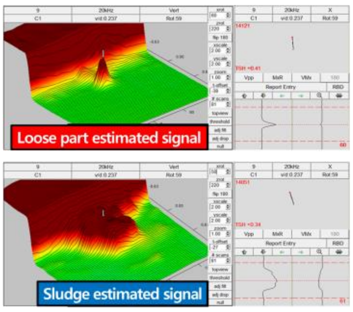


Fig. 1. A signal for estimation of loose part/sludge in nuclear power plants.

2. Methods and Results

2.1Eddy current testing simulation

Finite Element Analysis is a method of approximating the laws governing physical motion by assuming that they are composed of finite nodes and using differential equations at each node. The eddy current test method is a method of generating eddy current in a conductor materials using a coil through which current flows and measuring the eddy current generated in a test specimen. By combining the two methods, the probe coil and the test specimen can be designed in a virtual space and the signal received from the test specimen can be evaluated using conductivity, relative permitivity, and permeability used in eddy currents as boundary conditions. The eddy current test probe (bobbin coil type) used for in-service inspection of the steam generator heat transfer tube exists in a winding form, as shown in Figure 2. The specifications of the probes used in the actual inspection were assumed and applied to the simulation design (table. 1). [6]

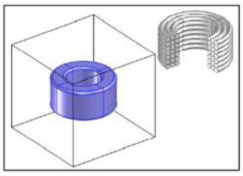


Fig. 2. Eddy current inspection probe coil schematic diagram.

Table I: Coil dimension for the experiment and the model

Coil length	10 [mm]
Number of turns	100
Coil wire conductivity	6 x 10^{7} [S/m]
Wire cross-section	3.14 x 10^{-9} [m^2]

2.2 Experimental and analytical conditions

For simulation analysis, all structures were designed to be the same size as the actual size, and the boundary conditions were also set similarly. The bobbin coil was modeled to be in the center of the tube, and the analysis frequency was set to 20 kHz, which can be measured outside the tube. The tube material (alloy 690TT), outer diameter (19 mm) and thickness (1.09 mm) are designed to be the same as those used in Korean nuclear power plants. A total of two materials are made of carbon steel, one of the structural materials, and a deposit that is generated and attached to the outside of the heat transfer tube. There are two types of deposits, one of which is separated from the outer surface of the heat transfer tube, named it flake deposit, and the outer shape is made similar to carbon steel. The other was manufactured in a form attached to around the pipe and named it adhesive deposit, and the trend of the signal was compared. Using COMSOL program, a simulation design was completed as shown in Figure 4. Similar to the actual test, it was designed in the form of attaching loose parts to the center of the heat transfer tube. The probe coil is designed to measure signals while moving the inside of the pipe at 0.5 mm steps.

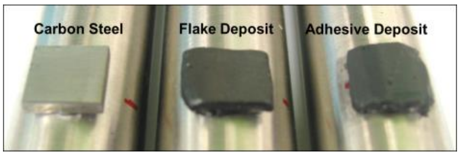


Fig. 3. Three types of loose parts attached to heat transfer tubes for testing.

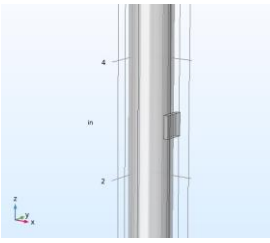
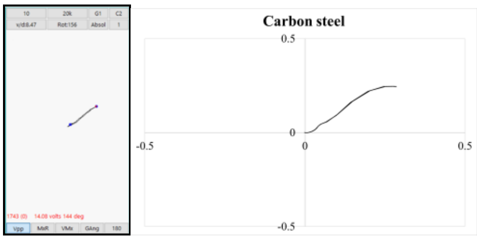
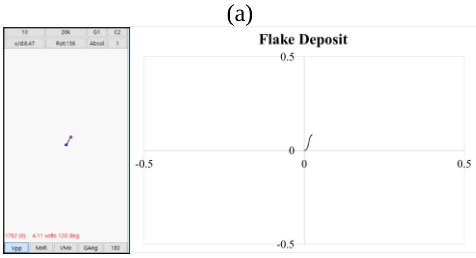


Fig. 4. Simulation design concept similar to the actual test conditions.

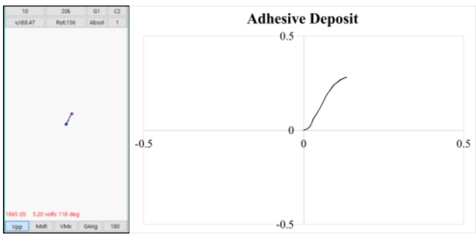
2.3 Experiment & Simulation Results



(a)



(b)



(c)

Fig. 5. Results of actual measurement (left) and simulation analysis (right) at loose parts on heat transfer tube, (a) carbon steel, (b) Flake deposit, (c)Adhesive deposit

Figure 5 shows the actual measurement results and simulation analysis results for each object. The phase angle of the signal due to the loose part and the Lissajous' curves were generally similar to the simulation results, and it was confirmed that the signal of carbon steel had an amplitude greater than that of deposition. The phase angles according to the actual test were 144 degrees of carbon steel, 120 degrees of flake deposit, and 118 degrees of adhesive deposit, and the simulation analysis results were 130 degrees of carbon steel, 163 degrees of flake deposit, and 154 degrees of adhesive deposit. Additional correction of the analysis signal seems necessary for accurate comparison with the actual measurement. On the other hand, in the simulation, it was confirmed that the carbon steel signal had the largest amplitude similar to the experimental results. In the case of deposit, in the actual test, it was confirmed that the amplitude increased as the area where the signal was attached to the pipe increased. This is very similar to the simulation result, and the simulation analysis result shows that it has a high amplitude in the form of adhesion attached to a large area. Overall, it is judged that precise signal correction of the analysis signal is additionally necessary to accurately compare the actual measurement results.

3. Conclusions

In order to evaluate the signal trend of the steam generator heat transfer tube due to loose parts, the actual test results and the finite element analysis using simulation were compared. A signal was compared by arbitrarily manufacturing three different loose parts using a low frequency, and an actual test showed that same material had the same phase angle, and the amplitude changed depending on the materials. Similarly, it was confirmed that similar signal trends were shown in the simulation analysis results that produced a virtual analysis environment. Although the signal amplitudes of different types of loose parts of the same material were large differently from the actual measurement results because the simulation analysis results did not simulate the actual environment perfectly, the reliability of the simulation was confirmed by the coincidence of phase angles.

ACKNOWLEDGEMENTS

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