Finite Element Modeling for Inspection of CANDU® Steam Generators

S. G. Mokros[1], P. R. Underhill[2], J. Morelli[1], T. W. Krause[2]

[1]Department of Physics, Engineering Physics & Astronomy, Queen's University, Kingston, ON, Canada
[2]Department of Physics, Royal Military College of Canada, Kingston, ON, Canada

Abstract

Introduction

Steam generators (SGs) are used in nuclear power plants as heat exchangers to convert water to steam using heat transferred from the reactor core. The thousands of tubes used in CANDU® SGs are supported by ferrous broach supports, which have a trefoil shaped hole to hold the tube and prevent tube vibration, while allowing water to flow past the tubes, as shown in Figure 1. Degradation of the broach support structures can cause a decrease in fluid flow and, consequently, reactor efficiency. SG tubes must be regularly inspected to assess corrosion by-products or degradation that may occur.

An inspection method using a pulsed eddy current (PEC) technique has been developed [1] to determine the condition of broach support structures. A square pulse excitation is used to induce eddy currents in the surrounding materials from within the SG tube. The square pulse effectively generates a large number of discrete frequencies, unlike a sinusoidal excitation that typically uses only a few frequencies. Previous research on aircraft structures [2] has shown that PEC provides flaw detection capabilities even at remote distances of 20 mm.

Use of COMSOL Multiphysics® Software

COMSOL Multiphysics® was used to optimize a PEC probe design that could effectively inspect the trefoil shape of broach support structures from within a SG tube. The probe design includes a single excitation coil wound coaxially with the SG tube, and six surface pick-up coils aligned at 120° intervals above and below the excitation coil, as shown in Figure 2.

COMSOL Multiphysics was used to simulate PEC signals from the broach support structures, and responses from the surface pick-up coils were evaluated. Simulated flaws were added to the support structures to determine if changes in the coil response could be detected.

Results

Flaws were simulated in COMSOL, as shown in Figure 3, to represent flow assisted corrosion

that results in material loss from broach support ligaments.

When the probe was used to investigate the broach support structure with no flaws, the surface pick-up coil responses were found to be equivalent. Figure 4 shows that in the presence of the flaw, as shown in Figure 3, the pick-up coil response was different at longer times. This change in coil response can be attributed to the material loss in the broach support ligament. Probe responses will be validated experimentally.

Conclusions

Inspection of SGs in CANDU® nuclear reactors is critical to maintaining reactor efficiency. Thousands of SG tubes pass through ferrous broach support structures with trefoil shaped holes that prevent SG tubes from vibrating while allowing water to flow across the tubes.

COMSOL was used to further optimize a PEC probe designed for inspection of broach support structures. The probe was designed with coils placed above and below the excitation coil at 120° intervals, in order for the probe to be consistent with the trefoil shape. Modelled results demonstrate the potential to detect flaws by PEC in the surrounding structure ligaments.

Reference

[1] T. W. Krause, V. K. Babbar, and P. R. Underhill, "A Pulsed Eddy Current Probe for Inspection of Support Plates from within Alloy-800 Steam Generator Tubes," in AIP Conference Proceedings, 2014, vol. 1352, pp. 1352–1358.
[2] P. F. Horan, P. R. Underhill, and T. W. Krause, "Real Time Pulsed Eddy Current Detection of Cracks in F/A-18 Inner Wing Spar Using Discriminant Separation of Modified Principal Components Analysis Scores," IEEE Sens. J., vol. 14, no. 1, pp. 171–177, Jan. 2014.
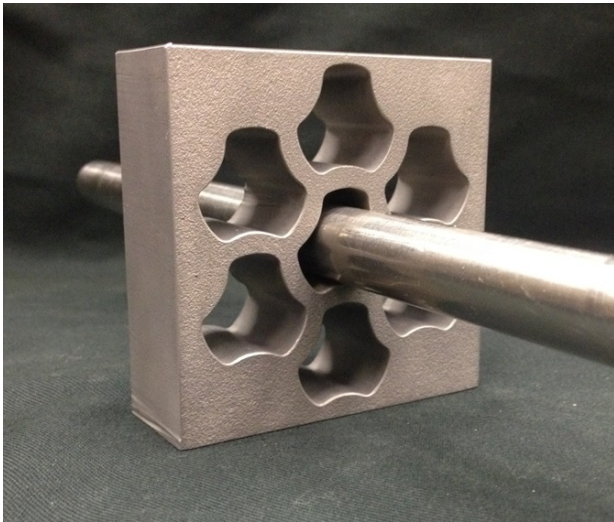
Figures used in the abstract

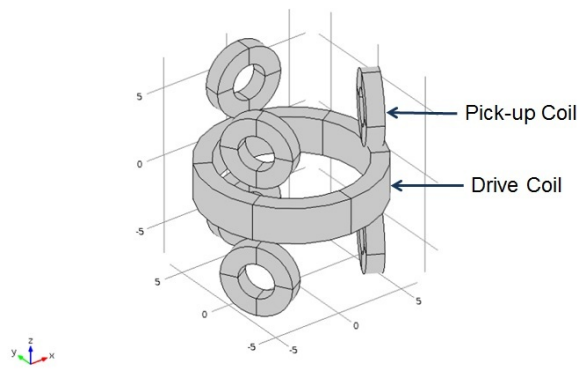**Figure 1**: Sample broach support structure for 16 mm tube.

Pick-up Coil

Drive Coil

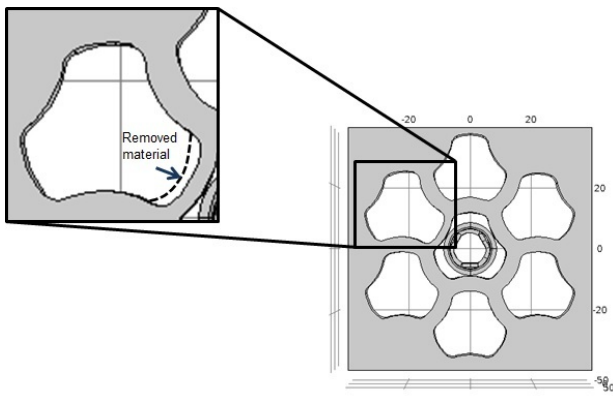**Figure 2**: PEC robe design modelled in COMSOL.

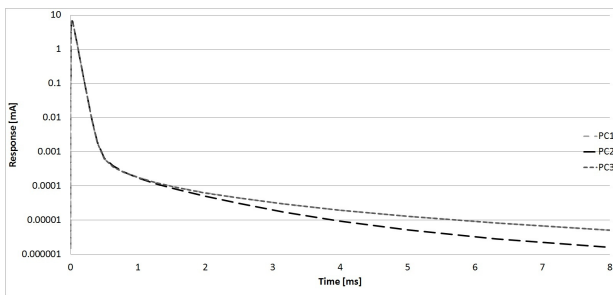**Figure 3**: Simulated 50% flaw in broach support structure.

Figure 4: Pick-up coil responses in the presence of a flaw. PC1 and PC3 responses overlap.