Finite Element Modeling of Conventional and Pulsed Eddy Current Probes for CANDU® Fuel Channel Inspection

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Abstract

As shown in Figure 1, CANDU® reactor fuel bundles are immersed in a heat transport coolant within a Pressure Tube (PT). Surrounding the PT is a gas-filled Calandria Tube (CT), which thermally isolates the PT from the moderator surrounding the fuel channels. Four annulus spacers separate the PT from the CT to prevent hydride blistering of the PT, which could occur under contact conditions. The reactor's fission reaction rate may be controlled from a Liquid Injection Shutdown System (LISS), which injects neutron poison into the moderator surrounding the fuel channels. The injection nozzles are just exterior to the calandria tubes. For inspection purposes, a non-destructive probe is necessary to evaluate the following:

- The PT-to-CT gap;
- The position of annulus spacers;
- The axial location and proximity of the LISS nozzles to the CT;

A Pulsed Eddy Current (PEC) probe, which uses the transient response to a step function voltage to detect and measure the proximity of LISS nozzles, is being developed for in-reactor inspection. PEC has the intrinsic advantage of generating a spectrum of discrete frequencies, which allows the simultaneous collection of data from a range of depths (i.e. takes advantage of multiple skin depths) that is unachievable from conventional eddy current, which can only use a limited number of frequencies obtained from separate time harmonic excitations.

As shown in Figure 2, the prototype PEC probe consists of the drive and pickup coil as well as a copper slab to shield the probe from other electromagnetic field interactions. The drive coil is excited by a pulsed voltage power supply, while the pickup coil is electromagnetically coupled to the drive coil via the magnetic field in the test-piece. A 2D COMSOL Multiphysics® model was created using the Magnetic Fields (mf) interface in the AC/DC Module. Although the coils, CT and PT have circular geometry, the 2D model is a good approximation due to the relative coil size and its proximity to the PT. A "stack of calandria tubes" were used with each "calandria tube" consisting of either air or metal to change the PT/CT gap without altering the mesh for each simulation. An electric circuit to power the drive coil was created using the Electrical Circuit (cir)

interface. Conventional and PEC technologies will be compared to evaluate their relative strengths and weaknesses.

As shown in Figure 3, the voltage responses of the pickup coil are heavily dependent on the frequency of excitation in the drive coil (and hence the skin depth within the material) and as expected, asymptotically approach a steady state value as the PT/CT gap increases. Furthermore, this model predicts that conventional eddy current will be sensitive up to the maximum ~16mm PT/CT gap. Results will be validated against analytical model results and experimental data. The transient response using PEC as well as 3D models of the same problem are currently under development and will be compared with the conventional eddy current results.

Reference

[1] S.T. Craig, T.W. Krause, B.V Luloff and J.J. Schankula, “Eddy current measurements of remote tube positions in CANDU reactors,” in 16th World Conference on Nondestructive Testing, Palais des Congrès, Montreal, Canada, 2004, Aug. 30-Sept. 3.

[2] S. Shokralla, T. W. Krause and J. Morelli, “Surface profiling with high density eddy current non-destructive examination of data,” NDT&E International, vol. 62, March 2014.

Figures used in the abstract

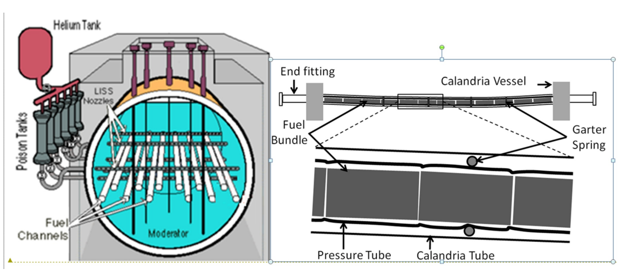

Figure 1: Figure 1: A schematic of a CANDU® fuel channel assembly (left) [1] and a schematic of an individual fuel channel (right) [2].

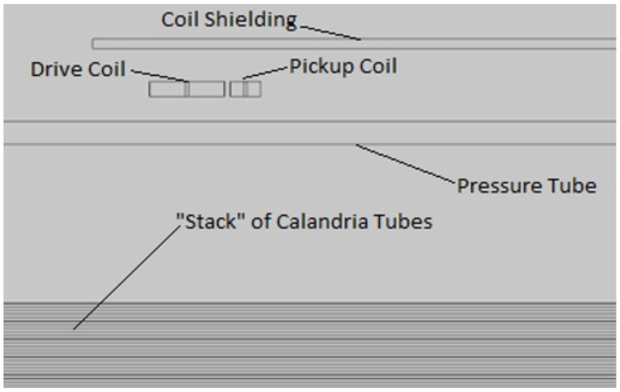

Figure 2: Figure 2: A 2D COMSOL model to simulate pulsed and conventional eddy current probes.

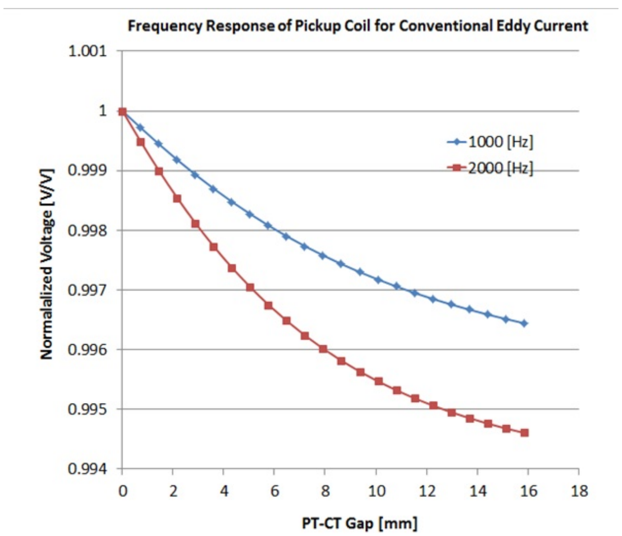

Figure 3: Figure 3: A plot of the pickup coil response due to a 1V amplitude time-harmonic voltage in the drive coil of varying frequencies to simulate the frequency response of a conventional EC probe.