Comparison of 2D and 3D FEM Models of Eddy Current Pressure Tube to Calandria Tube Gap Measurement

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Abstract

The pressure tubes (PTs) in CANDU® nuclear reactors are contained within calandria tubes (CTs) [1]. The PTs sag over time and therefore, may come in contact with the CT. This contact can cause subsequent delayed hydride cracking and failure of the PT. Therefore, contact must be avoided. The separation between the PT and CT is currently measured using eddy current (EC) based technology. A model of the EC measurement could be used to evaluate the accuracy of the measurement under variable in-reactor conditions [2]. Currently no three-dimensional (3D) model of the eddy current probe response for a curved geometry is available, only a 2D flat plate geometry [3]. Figure 1 defines the parameters examined in this work including PT-CT gap, distance of the probe from the PT surface (liftoff) and PT wall thickness. This work compares the flat plate and curved model predicted response for far and close receive coils. The validity of the results is supported by comparison of the model with experimental measurements for the close receive coil.

Based on the complexities of the real geometry of the EC measurement system, a Finite Element Method (FEM) model was required. The FEM model was designed using the AC/DC Module in the COMSOL Multiphysics® software by defining three cylinders as numeric coils through the Magnetic Fields physics option. The current through each coil was modeled using the Electrical Circuit physics option and applying a constant amplitude sinusoidal voltage to the drive coil. Using the Parametric Sweep, Coil Geometry Analysis, and Frequency Domain study options the voltage in each coil was calculated for different in-reactor parameters.

To determine if a flat plate model is an appropriate approximation, both a curved and flat-plate model were constructed. The flat plate model was shown to diverge from the solutions of the curved model for both the close and far receive coils, as shown in Figures 2 and 3, respectively. This demonstrated that a curved model is necessary to accurately reproduce the measurement conditions. The results from a curved FEM model designed in the COMSOL® software were compared with experimental probe measurements. It was shown that the curved model can accurately reproduce experimental probe responses to variation in the PT wall thickness, after the model results were calibrated to the experimental results for amplitude and phase, as seen in Figure 4.

An evaluation of how the EC based PT-CT gap measurement response varies due to changes in parameters such as PT resistivity, curvature and wall thickness, and liftoff is

required for establishing the accuracy of in-reactor measurements. Both a flat plate model and curved model were constructed to determine if the flat-plate approximation is suitable for the responses in both the close and far receive coils. The divergence between the responses in these models, as seen in Figures 2 and 3, show that the curved model must be used to accurately reproduce the PT-CT gap measurements. Good agreement between 3D FEM model and experimental results for the close receive coil provides support for the validity of the model.

Reference

[1] E. G. Price, "Highlights of the Metallurgical Behaviour of CANDU® Pressure Tubes," AECL, Chalk River, accessed May 2016 http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/16/042/16042645.pdf

[2] S. Shokralla, T. W. Krause and J. Morelli, "Surface profiling with high density eddy current non-destructive examination data," NDT&E International, 62, 153-159(2013).

[3] S. Shokralla, S. Sullivan, J. Morelli and T. W. Krause, "Modelling and validation of Eddy current response to changes in factors affecting pressure tube to calandria tube gap meansurement," NDT&E International , 73, 15-21(2015)

Figures used in the abstract

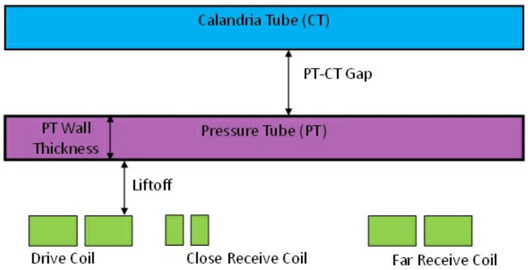

Figure 1: Flat-plate representation of the eddy current based measurement system showing the eddy current coils, PT and CT, as well as liftoff, PT-CT gaps, and PT wall thickness parameters.

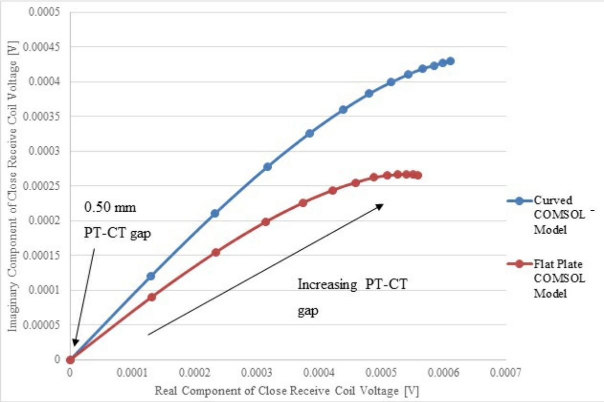

Figure 2: Real and imaginary voltage calculated in the close receive coil as PT-CT gap was varied for both flat plate and curved COMSOL models. The close receive coil voltage was induced by a 1 V, 4 kHz sinusoidal excitation. The PT-CT gap ranged from 0.5 mm to 17 mm.

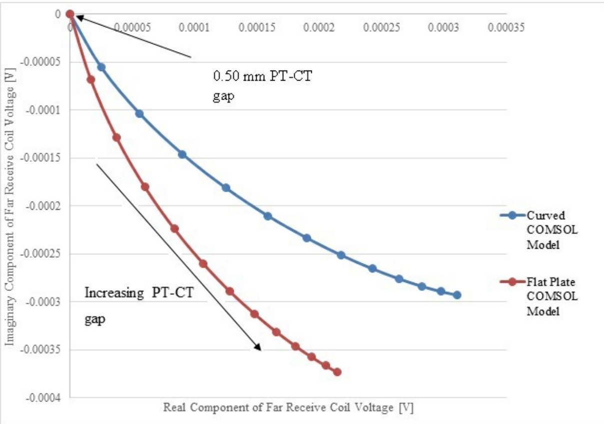

Figure 3: Real and imaginary voltage calculated in the far receive coil as PT-CT gap was varied for both flat plate and curved COMSOL models. The far receive coil voltage was induced by a 1 V, 4 kHz sinusoidal excitation. The PT-CT gap ranged from 0.50 mm to 17 mm.

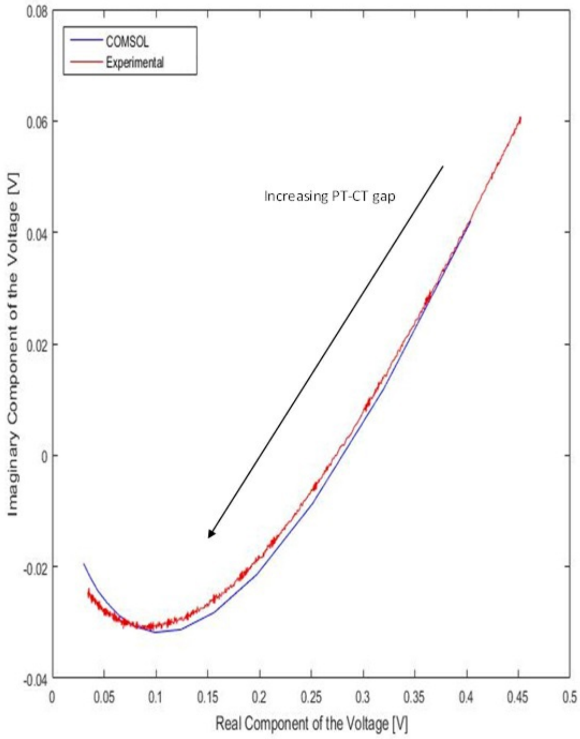

Figure 4: Comparison between FEM model and experimental PT-CT gap measurements for PT sample having a 4.38 mm wall thickness and an electrical resistivity of 50.8 μΩ⋅cm. The drive coil was excited by a 1 V, 4 kHz sinusoidal voltage.