Finite Element Modeling of a Pulsed Eddy Current Probe for Steam Generator Tube Inspection

S. G. Mokros[1], V. K. Babbar[2], T. W. Krause[2], J. Morelli[3]

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

[2]Department of Physics, Royal Military College of Canada, Kingston, ON, Canada

[3]Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, ON, Canada

Abstract

Introduction

The purpose of this work was to design a Pulsed Eddy Current (PEC) probe for inspection of support plate structures in the steam generators (SG) of CANDU® nuclear reactors. Current inspection methods have limited capability to examine the condition of support plates with regards to corrosion and build up of corrosion products. PEC technology has been proposed as a means of non-destructively determining the corrosion condition of the steel structures from within the SG tubes. A prototype PEC probe was designed with an excitation coil coaxial to the SG tube and four pick-up coils perpendicular to the tube axis. Two pick-up coils were positioned above the excitation coil and two below, shown in Figure 1.

The design of this probe was optimized for sensitivity to off-center shift of the SG tube within the support plate and tilt of the tube relative to the support plate center. Shift and tilt occur when 1) the support plate corrodes, 2) the SG tube shifts relative to the center of the support plate, or 3) a combination of both conditions occur. The differential signal from opposing coils, mounted 180° apart, was used to sense shift (PC1 and PC3 in Figure 1). Differential signals from the matched coil pair above and below the excitation coil were used to monitor tilt (PC1 and PC2 in Figure 1).

Use of COMSOL Multiphysics®

Finite element (FE) modelling was used to optimize the location of the driver and pick-up coils for sensitivity to shift and tilt. The optimized coil configuration is shown in Figure 1. A simulation of the effect of shift was performed in COMSOL and the differential current in the pick-up coil was determined as shown in Figure 2. The peak differential response, when the probe is shifted, was fit using a polynomial function. A simulation of tilting of the SG tube with respect to the center of the support plate was also performed and the peak differential response demonstrated a linear dependence. The observed change in signal caused by shift or tilt of the tube as well as

the probe can provide useful information about the severity of support plate degradation.

Validation

COMSOL models were validated against two analytical expressions for the excitation coil in air. The first expression [1], neglected the small mutual inductance between the excitation and the pick-up coils, and the second, included a mutual inductance [2]. The modeled and analytical results were found to be in good agreement, as shown in Figure 3. The mutual inductance was found empirically by using a least squares minimization technique, confirming the small value obtained theoretically [3].

The response of the pick-up coils in air was also matched with an analytical circuit model result [3]. The curves generated for both the COMSOL results and the mathematical model, shown in Figure 4, were found to be in agreement.

The results presented above will also be compared to experimental measurements in order to determine the validity of both the analytical and COMSOL models.

Reference

[1] Griffiths, David J. Introduction to Electrodynamics 3rd Ed., pp. 315, Upper Saddle River: Prentice-Hall, 1999.

[2] Goldman, S. Transformation Calculus and Electrical Transients. pp. 90-91, New York: Prentice Hall inc. 1949.

[3] S. I. Babic, F. Sirois, and C. Akyel, "Validity check of mutual inductance formulas for circular filaments with lateral and angular misalignments," Progress In Electromagnetics Research M, Vol. 8, pp. 15-26, 2009. doi:10.2528/PIERM09060105

Figures used in the abstract

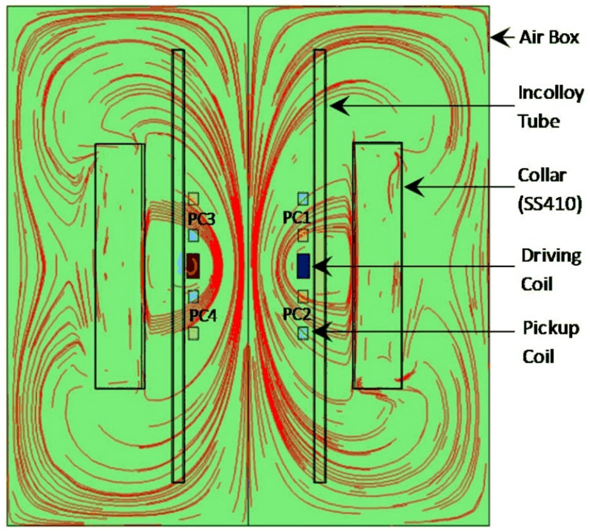

Figure 1: Finite Element model showing pulsed eddy current probe design within a steam generator tube and steel collar. Current density (Jx) and magnetic flux density (streamlines) presented at 5×10-5 s.

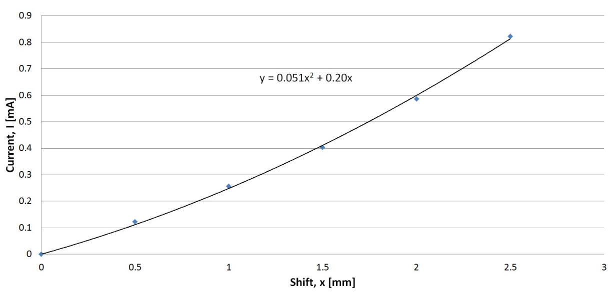

Figure 2: Peak values of differential current in the pick-up coil as the tube is shifted with respect to the center of the support plate. Solid curve is a quadratic best fit to the data.

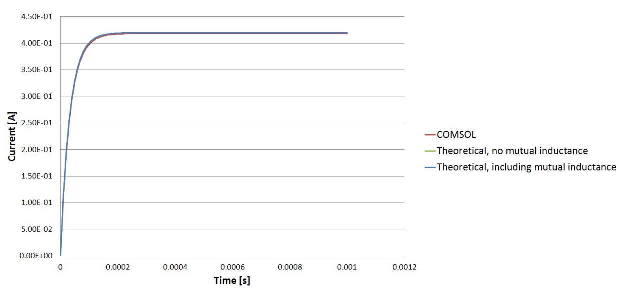

Figure 3: Response of the excitation coil for COMSOL model and theoretical models.

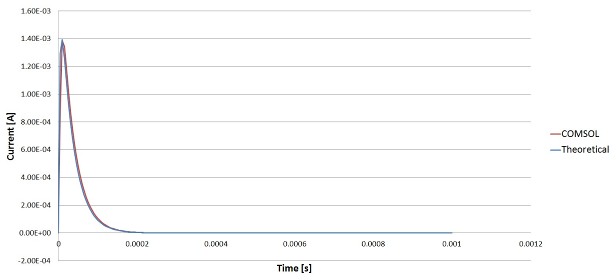

Figure 4: Response of pick-up coil in the COMSOL and theoretical models.