Evaluation of Robustness of Inverse Methods for Pit Characterization

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Accurate characterization of corrosion in tubing is critical for evaluating the integrity of the heat exchanger and making the correct decisions on maintenance actions. To truly advance the existing capability of conventional eddy-current inspection methods, model-based inversion of the measured data is presented here for local corrosion characterization. Model-based inversion is defined as a process of solving a physics-based model for parameters associated with the material state in an iterative fashion until agreement between the model and measured data for a sample under test is achieved.

Significant research into inverse methods for flaw characterization using eddy current data has been explored. To date, most efforts have primarily addressed the sizing of surface breaking cracks, with limited work on the problem of sizing corrosion pits. Prior work has demonstrated the potential to characterize surface and sub-surface pitting corrosion in both aircraft structures and tubing through the application of model-based inversion schemes to eddy current inspection data [1-2]. However, there has been limited progress to transition such technologies to application due in part to questions about the robustness of the inverse method schemes to the expected variability with in-field NDE measurements.

In this paper, a sensitivity analysis is performed for the case study problem of characterizing pits in heat exchanger tubing to quantify the impact of potential sources for variation on the performance of NDE procedures incorporating inverse methods. Laboratory data for heat-exchanger tubes was obtained from the Electric Power Research Institute (EPRI), and the Naval Surface Warfare Center, Carderock Division. The EPRI data are from round-bottom ID pit standards, and are acquired using a standard eddy-current instrument. Model-based standards for the inversion of these data were developed using a proprietary volume-integral code, VIC-3D(C) [3]. Under standard conditions, inversion algorithms performed well where the average percent error in estimated pit diameter was 12%, and average percent error in estimated pit depth was 11% across 11 different pit sizes.

In the sensitivity analysis study, the impact of changes to the NDE model, the inversion algorithm design, and experiment conditions was explored with respect to the accuracy and repeatability of the inversion results. Concerning the inversion process, the calibration of simulated impedance calculations with voltage measurement data, the use of noise filters, the feature extraction algorithm design, and the model-based inversion scheme were also evaluated. Certain data processing steps, including careful feature extraction, background clutter removal and compensation for variation in the scan step size through the tubing, were found to be critical to achieve good estimates of the pit depth and diameter. Repeated runs were found to be one of the greatest sources of variation in the inverse results, although this sensitivity was not considered excessive. Also of note, variance studied in model probe dimensions did not adversely affect inversion performance.

Model-based inversion method incorporating virtual standards and sophisticated algorithms were shown to be accurate, robust, and efficient. However, for their success, robust inverse method design practices are critical. A general design process is proposed to mitigate the impact of uncontrolled variation in NDE measurements on inverse method performance. In particular, preprocessing is important to maintain a quality fit between the simulated and experimental data. For this application where traditional eddy current NDE hardware was used, care must also be taken in calibrating the simulated impedance response and experimental voltage data. In addition, all varying conditions in the NDE measurement including scan step size and liftoff must be inverted along with the estimation parameters associated with damage. Future work will explore the challenges of validating the quality of NDE techniques using model-based inversion.

References

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