46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-1234

CRACKS DETECTION IN HEAT EXCHANGER TUBES BY EDDY CURRENT TESTING USING COMPUTATIONAL SIMULATION

Joaquim S. Côrte[1], João M.A. Rebello[1], Monica P. Arenas[1]
[1] Department of Metallurgical and Materials Engineering, Federal University of Rio de Janeiro, Brazil

Gabriela R. Pereira[1,2]
[2] Non-destructive Testing, Corrosion and Welding Laboratory. COPPE/UFRJ, Rio de Janeiro, Brazil

ABSTRACT

Eddy Current Testing (ECT) has been the most used technique for damages detection in heat exchanger equipment. This inspection aims to detect defects in the tubular bundle and to assess the integrity of a shell and tube. However, in several situations the reliability of the inspection has not been satisfactory due to the complexity of signal interpretation. The analysis of the EC signals inside the tubesheet is complex, due to the influence of the crevice region (CR) and transition region (TR), being important to develop methodologies, which allow to separate the spurious signals coming from those regions and from the real defects. Another difficulty is the evaluation of the detection limits of the probe, which depends on defects geometry and probe location. In order to simulate real inspections this study used the finite element software OPERA Cobham, in which virtual solids were constructed simulating a tube removed from operation with real cracks in the crevice and TR. Results showed that the methodology developed is quite promising. An accurate diagnosis was obtained in the differentiation between the geometric signals and the crack signals, allowing to predict probes detectability limits according to the size, orientation and vicinity of the defects.

Keywords: Eddy current testing, Heat exchangers tubes, Finite element model, OPERA-3D

1. INTRODUCTION

Heat exchangers are devices with high relevance in petrochemical plants, refining units and oil & gas platforms. For in service inspection, the nondestructive ECT has been the most used technique for damages detection in a tubular bundle and to assess integrity of the shell and tube heat exchanger (STHE) equipment [1]. However, this technique is sensitive to several variables, such as variation of electrical conductivity, magnetic permeability, location and orientation of defects, presence of magnetic deposits, dents, etc. Hence, signals obtained by ECT can be misinterpreted as defects indications, named as false indications. Thus, a careful analysis is necessary before concluding that a signal may represent a defect.

For this reason, in several situations inspection reliability has not been satisfactory due to complex interpretation of signals, especially when coming from the tubesheet region. This region presents geometric shapes related to the expanded region (ER) in the grooves, the TR at the end of the expansion and the CR between the unexpanded tube and the tubesheet hole, resulting in spurious and undesirable signals, making it difficult to distinguish signals coming from defects and from geometric signals [2-3]. Both signals are generated simultaneously during inspection. Figure 1 shows the all the mentioned regions inside the tubesheet after tube expansion.

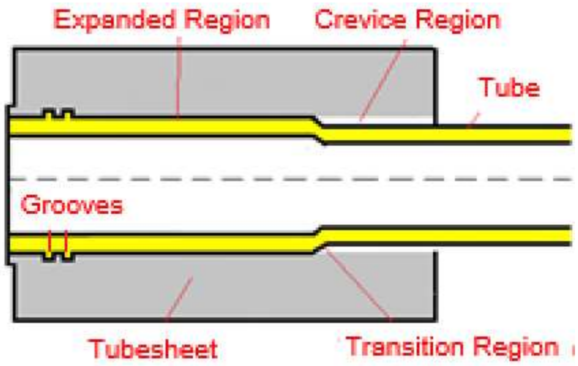

FIGURE 1: REGIONS INSIDE A TUBESHEET

A typical case of study is the inspection of tubular bundle of austenitic stainless steel (ASS) ASTM A213 TP321, in which the defects detection reliability is low because the presence of pits and chloride stress corrosion cracks (CLSCC) are located inside the tubesheet [4].

A promising alternative for the correct EC signal evaluation is to use of computational simulation. In this study, the finite

[1] Contact author: *corte.js@gmail.com*

element software OPERA 3D was used, in which virtual solids are created for simulating any geometry, such as tubular bundle, tube and tube sheet region, etc.

2. MATERIALS AND METHODS

This study proposed a methodology that compare the experimental and simulated results. Experimentally, the ECT shows a relationship between variation of the impedance plane and presence of defects. While the finite element simulation, performed in OPERA Cobham allows correlating the current density to the presence of defects. Thus, once understood the signals origin, it is possible to perform real-time measurement by filtering those signals coming from undesirable effects.

A tube made in ASTM A213 TP321, removed from operation with indication of leakage, presenting two external cracks caused by CLSCC, one longitudinal orientation in the CR and other circumferential located on the side of TR was used (figure 2). Its external diameter, thickness and length are 19.05mm, 2.11mm and 100mm, respectively. A prototype tubesheet made in A240 TP321 with holes with external diameter and length of 100mm and 90mm, respectively (figure1). The region of the tube with the cracks was inserted into the tubesheet holes for the tests.

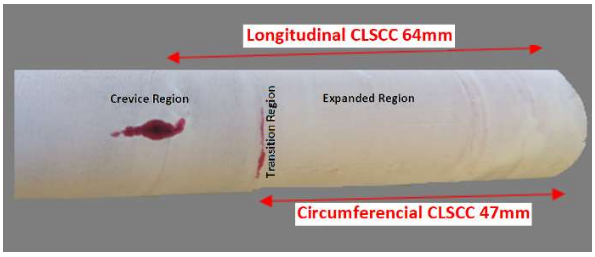

FIGURE 2: TWO CLCSS DETECTED BY LIQUID PENETRANT TECHNIQUE: LONGITUDINAL IN THE CR AT X=64mm AND CIRCUMFERENTIAL LOCATED ON THE SIDE OF TR AT X=47mm

The relative magnetic permeability (μ_r) and electrical conductivity (σ) properties of the samples are, respectively, 1.00 and 1.35[MS/m].

2.1 Finite element model

Simulation of the induced eddy currents in heat-exchanger tubes was performed using the OPERA Cobham software. This software supports evaluation of static electromagnetic fields and time-varying electromagnetic fields at low and high frequencies.

Virtual solids were created to simulate the typical assembly of a tube inserted in the tubesheet. The virtual solid of the heat exchanger system were composed of the tubesheet, the tube and the differential probe. In the tube, virtual solid notches were inserted with the same dimensions, location and orientation of the cracks of CLSCC of the tube removed from operation (Figure 3).

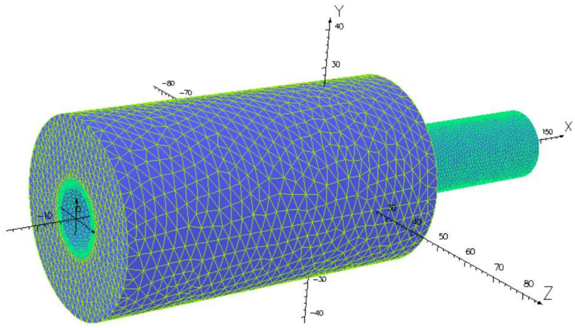

FIGURE 3: VIRTUAL SOLID OF THE HEAT-EXCHANGER TUBE. TUBE INSERTED IN THE TUBESHEET PLATE.

3. RESULTS AND DISCUSSION

3.1 Effect of the transition region

Figure 4 shows the heat-exchanger virtual solid overlapped with R and XL signals. The displacement of the probe was 1mm, generating 40 simulated points in the region of interest Two prominent signals are observed, one of them revealing longitudinal notches in CR and the other one corresponding to the TR, with the high amplitude. The TR signal camouflaged circumferential notched signal in TR. being important to suppress it during inspection in order to increase detection accuracy.

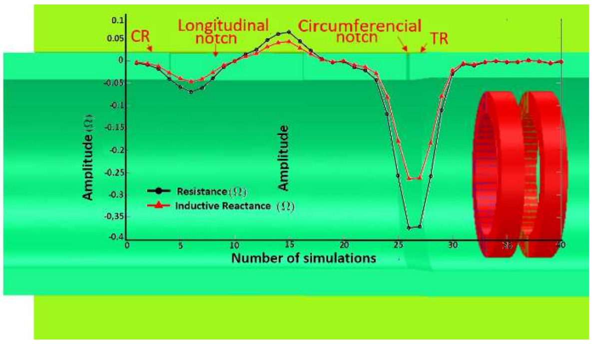

FIGURE 4: R AND XL OF SIGNALS ALONG THE HEAT EXCHANGER SYSTEM.

Figure 5 (a) shows the variation of R and XL signals in the region of the longitudinal notch in the CR. Figure 5 (b) shows the variation of R and XL in the TR, revealing no characteristic signal of the near circumferential notch in the TR.

[1] Contact author: *corte.js@gmail.com*

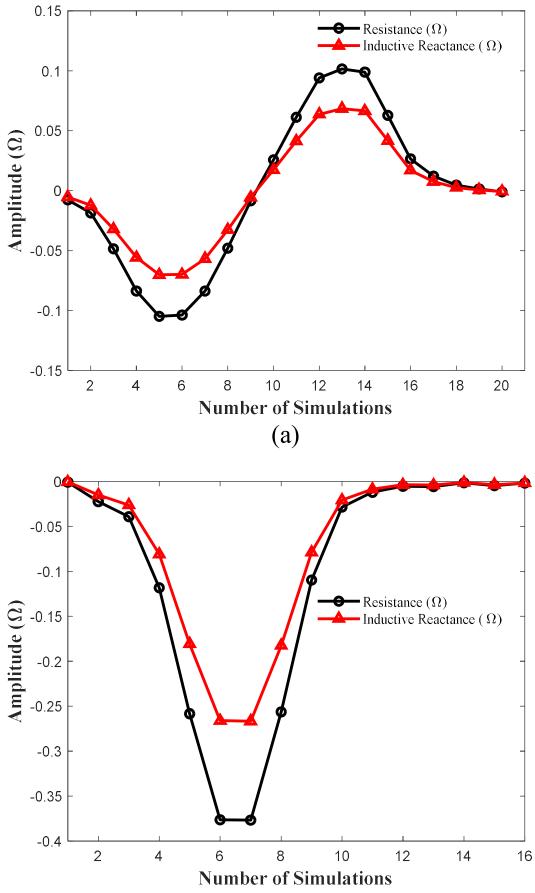

FIGURE 5: R AND XL SIGNALS (a) IN LONGITUDINAL NOTCH IN THE CR AND (b) IN CIRCUMFERENTIAL NOTCHED AND TR .

Figure 6 shows the variation of R signals along the heat exchanger system inside and outside tubesheet, revealing that the presence of the tubesheet reduced the signal amplitude variation of the longitudinal notch, but did not alter the of the TR signal amplitude variation.

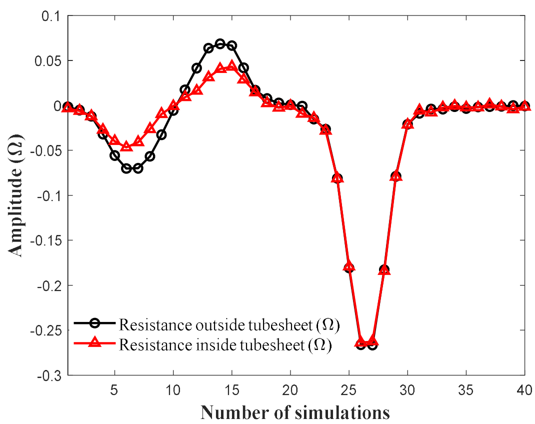

FIGURE 6: R SIGNALS ALONG THE HEAT EXCHANGER SYSTEM INSIDE AND OUTSIDE TUBESHEET

[1] Contact author: *corte.js@gmail.com*

Figure 7 shows the region of circumferential notch near TR the current density (J) does not indicate a significant increase because the differential probes generate circumferential currents along the tubes, which explains their less detectability. However, J increases in longitudinal notch in the CR because they are perpendicular to the magnetic field of the differential probe.

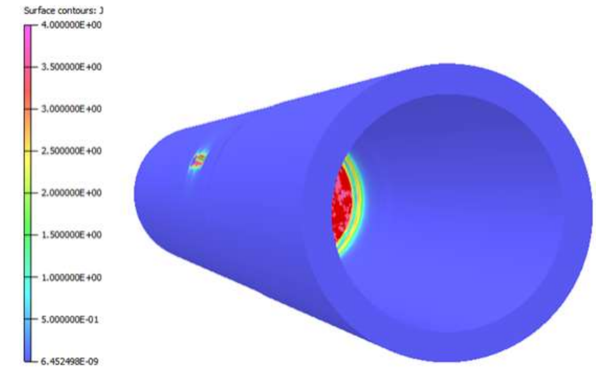

FIGURE 7: CURRENT DENSITY AROUND LONGITUDINAL NOTCH OBTAINED IN OPERA COBHAM.

4. CONCLUSION

The developed methodology showed that the computational simulation is a powerful tool for understanding the interaction between an eddy current probe and defects in a heat-exchanger system.

It has advantages such as verifying that ECT procedures detect small defects accurately when they are close to one another, or even when they have different morphology, orientation, and location. Thus, inspection in a virtual environment allows prediction of the influence and effect of each variable on induced current signals.

ACKNOWLEDGEMENTS

Acknowledgements are due to CNPq, FAPERJ, CAPES and PETROBRAS

REFERENCES

[1] Birring, Anmol. "Selection of NDT techniques for inspection of Heat Exchanger tubing." *The ASNT International Conference of Petroleum Industry Inspection,* Houston, Texas 1999.

[2]Corte, Joaquim. "Analysis of Eddy Current signals for discontinuities identification in austenitic stainless steel tubes within the Heat Exchanger Tubesheet." Master's thesis, Federal University of Rio de Janeiro, RJ, Brazil, 2013

[3] Corte, Joaquim, Areiza, Maria, Rebello, João, and Pereira, Gabriela. "Inspection of the crevice region on heat exchanger tubesheet using the mixing of eddy current signals." *21st International Workshop on Electromagnetic Nondestructive Evaluation,* Lisbon 2016.

[4]Roubi, Emar, Kermani, Bijan, Nacif, Mahmoud. "The Impact of Chloride Contamination From Leaking Heat-Exchanger Tubes on Plant Materials of Construction." *In The Abu Dhabi International Petroleum Exhibition and Conference*, November 5-8, Abu Dhabi, UAE, 2006.

