Development of a corrosion detection system using Pulsed Eddy Current

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Abstract. The industrial process equipment are mostly made of steel and these can suffer from corrosive processes, which may reduce their structural integrity. Corrosion is a mechanism that requires constant monitoring because it can occur without warning on pipes mainly containing insulation in its structure. Nondestructive evaluation techniques has been increasingly enhanced to detect and monitor effectively these discontinuities. The pulsed eddy current (PEC) technique proves to be quite effective in the inspection of these kind of equipment. This work shows the development of a system for inspecting pipes using pulsed eddy current information. A probe based on a differential GMR sensor and a scanner were used to scan carbon steel tube samples with defects in the outer surface. Different distances from lift-off were applied to evaluate the system performance.

Keywords: Pulsed eddy currents, corrosion under insulation, nondestructive testing, GMR sensors.

Introduction

Corrosion under insulation (CUI) is a dangerous damage mechanism which can lead to tubing failure. This type of corrosion occurs in pipes, tanks or equipment, which are thermally insulated. The process is simple, the interface between the tube and the insulation has a temperature differential causing moisture condensation. As they are inaccessible due to the presence of insulation this type of corrosion is a challenge for inspection services. Among the non-destructive methods employed for CUI detection, Pulsed Eddy Current (PEC), Guided Waves, Digital Radiography, Fluoroscopy Inspection and Visual Inspection are used [1].

When compared to other methods of individual components inspection, the PEC technique has the advantage of not requiring to remove the protective insulation. By employing a coil, the generated magnetic field is capable to pass through the insulation, inducing eddy currents in the metal. The secondary magnetic field generated by eddy currents interact with the field coil. The
PEC technique consists of detecting changes in the magnetic field of the coil caused by the presence of a discontinuity. By applying a current or voltage pulse to the coil drive, a broad frequency spectrum eddy current is generated, allowing deeper penetration than the conventional technique. Higher frequencies induce eddy currents closer to the surface, and thus produce a shorter time response. Deeper currents generated by lower frequencies appear with longer times [2, 3]. The PEC signal is obtained from the difference between the measured signal and a reference one, see Fig. 1. The reference signal can be obtained in a region free from defects, or from a second exclusive sensor for this purpose [4, 5]. Several different arrangements of differential probes have been used to detect cracks and corrosion in a variety of materials [6]. The most common features used to determine the flaw characteristics are the peak amplitude, the time to peak and the time to zero cross [7], although signal analysis in frequency domain can also be used [8]. Recently researches showed that PEC technique associated to automated scanners improve the capability of discontinuities detection, with the use of C-scans maps [9,10].

![Fig.1. PEC signal and common feature used for discontinuities analysis.](image)

This paper describes a system that uses a differential probe, based on Giant MagnetoResistive (GMR) sensors, and a tube scanner. The tests results are shown as C-scans maps for peak amplitude and time to peak features. To evaluate the probe performance, different lift-off distances were used.

1. System description

**Sinal de PEC e característica comum usados para análise de descontinuidades**

The system consists of a probe constructed based on two GMR sensors and a scanning table adapted for pipe inspection. The acquired signals are digitized and processed to extract parameters that were used to form images.

1.1 The differential probe
The developed probe consists of a coil with an external diameter of 33mm, an internal diameter of 17mm, a height of 20mm, and 500 turns of wire 0.25mm in diameter, see Fig. 2. Inside the coil, two GMR sensors AAH002 were installed, so that the responses are as similar as possible when the probe is positioned away from a metallic conductor. A small magnet was placed near the sensors in order to polarize them, taking the operating point to the center of a linear region of its response curve. The sensor positioned on the top of the coil has the function of providing the reference signal, while the bottom sensor (also referred to as the measurement sensor) is within a region that is strongly affected by the eddy currents magnetic field.

A Tektronix AFG 3022 B waveform generator and a FET IRF630 provided a pulse amplitude of 12V, 1kHz frequency and duty cycle of 30% for the coil excitation. For the digitization of signals from the GMR sensors it was used a Tektronix oscilloscope TDS 2024 C. To increase the signal-/noise ratio, the acquisition was made using the average of 128 signals. Fig. 3 shows the schematic of the used PEC system.

For scanner control, it was developed a program that synchronizes the movement of the probe with the transfer of the oscilloscope signals to a PC using Labview. The filtering, parameter extraction and the thickness maps were performed using Matlab.

1.2 Feature Extraction
Fig. 4 shows the differential signal obtained from the measurement and reference signals. The maximum peak amplitude and time to peak were used as parameters for detection of discontinuities. All measured points were grouped forming c-scan maps showing the probe performance as the lift-off distance increase.

![Fig. 4](image)

**Fig. 4.** Reference, measuring and differential signals.

1.3 Specimen

A carbon steel tube 702 mm long, internal diameter 239 mm and 7.50 mm wall thickness was used as a test piece. One hole was introduced in order to simulate wall thickness loss, Fig. 5.

![Fig. 5](image)

**Fig. 5.** Schematic of the test tube.

1.4 Simulation by finite elements

A finite element simulation was made for evaluating the experimental results. The model was created with the same experimental parameters to perform an additional analysis (see Fig. 6), simulations were performed using the finite element software COMSOL® Multiphysics.

The model consists of a discontinuity with same dimensions employed in the experimental work, inserted in metal (1020 steel) and a copper coil. The excitation signal from the coil used in the model was collected from experimental tests. Different lift-off distances were simulated in order
to provide a reading of the variations of magnetic field density in time. The maximum intensity times were compared for each lift-off.

![Axisymmetric finite element simulation of coil above a hole.](image)

**Fig. 6.** Axisymmetric finite element simulation of coil above a hole.

### 2. Results

The Fig. 7 shows the differential signals for three lift-off distances obtained under the same conditions of the experimental set-up. It can be observed a decrease in amplitude and peak time as the lift-off increases. The detection limit was 15mm of lift-off, considering the amplitude of the obtained signal.

![Lift-off influence on differentials signs of PEC.](image)

**Fig. 7** Lift-off influence on differentials signs of PEC.
Using the finite element model it can be seen the lines of magnetic flux density for the different heights of lift-off, see Fig. 8. The images are of the peak time of each condition Fig. 8-(a) 0.1ms; Fig. 8-(b) 0.5ms e Fig. 8-(c) 0.4ms. The peak times coincide to the experimentally obtained ones. Both the intensity and the penetration of the magnetic flux decreases with increasing lift-off.

![Fig. 8. Magnetic flux density for different heights of lift-off.](image)

The results of the tests are shown as c-scans images, Figs. 9-11. Due to the increased lift-off, in the defect region the peak amplitude values are smaller. Considering the peak amplitude of the differential signal, it can be observed that for a lift-off of 5mm the defect region can be seen in the center of Fig. 9-(a). However, several points outside the defect region presented values very close to the ones obtained for the discontinuity. For the lift-off distance of 10mm and 15mm, the color at hole is different from outside, Figs. 10-(a) and 11-(b) respectively. The scans based on time of peak show that increasing the lift-off results in loss of defect sharpness, Figs. 9-(b), 10-(b) and 11-(b) respectively. The reduction of the time of peak is represented by the transition from dark red to blue.
Fig. 9. C-scan map for 5mm lift-off. (a) Peak amplitude. (b) Time to peak.

Fig. 10. C-scan map for 10mm lift-off. (a) Peak amplitude. (b) Time to peak.

Fig. 11. C-scan map for 15mm lift-off. (a) Peak amplitude. (b) Time to peak.
3. Conclusions

In this work it was used a differential probe for wall thickness loss detection using the PEC technique. The amplitude and time of the peak of the differential signal were evaluated for detection of the discontinuity and formation of C-scans images. In both cases it was possible to visualize the discontinuity. Tests with increasing distance of lift-off proved that it is possible to make images of the defect in a distance of 15mm with good quality. The finite element simulations confirm the experimental results. The results demonstrate the potential of the technique for detecting corrosion under insulation in materials associated to the use of an automatic scanning equipment.

Acknowledgments

The authors thank FAPESB and IFBA for funding this research.

References


