High Precision Corrosion Monitoring Using Ultrasonic Techniques

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ABSTRACT

Corrosion is associated with material deterioration because of a chemical reaction between the metal and its environment. Moreover, galvanic corrosion happens when two different metals are in contact with an electrolyte. However, there are many techniques to ensure the part integrity. In the last decade, phased array ultrasonic testing (PAUT) has become a common approach to achieve such assessments. Lately, the full matrix capture (FMC) and total focusing matrix (TFM) open the door to a new potential. Indeed, it has been known for high-profiling accuracy and sizing capabilities. On the other hand, PAUT is generally faster and code compliant. This article compares corrosion mapping using the PAUT and TFM techniques on galvanic a corroded sample over time. Furthermore, it demonstrates the benefits of each technique. Both data sets are obtained during the same acquisition, applying the same apparatus through time for a reliable comparison.

Keyword: ultrasonic testing (UT), phased array ultrasonic testing (PAUT), full matrix capture (FMC), total focusing matrix (TFM), linear scan, accuracy, pulse-echo technique, amplitude analysis, non-amplitude technique, corrosion, precision.

INTRODUCTION

Corrosion is one of the main damages affecting today's infrastructure. If the assessment of sporadic corroded area is now a common application, the estimation of corrosion through time using preventive actions through ultrasonic techniques is not yet easy to achieve. This paper compares phased array ultrasonic testing (PAUT) and total focusing matrix (TFM) technic assessments of galvanic corrosion progression over time. Multiple data acquisitions of the same plate, based on the methodology describe in the second section of this document, have been acquired over on a period of 45 days.

Corrosion Overview

Corrosion is the degradation of materials by chemical or electro-chemical reactions because of its environment. In fact, once the metal corrodes, it returns to its oxide state. This means that the metal goes from its metallic state to its corroded one. It should be noted that although there are physical and mechanical degradations, corrosion is not due to mechanical action. However, mechanical action combined with corrosion can lead to corrosion types such as fatigue corrosion or friction corrosion.

Galvanic Corrosion

Galvanic corrosion occurs when two metals with different potential are in contact with each other and an electrolyte is involved. Indeed, the potential difference between the two metals will cause corrosion. The noble metal, known as a cathode, stays in is metallic state. The anode, which is a metal in its oxide state, will corrode. Otherwise, the electrolyte allows the passage of the electrons between the two metals. The electrons go from the anode to the cathode. In brief, an anode losses electron and the cathode gains electrons. This electrons exchange is the basis of an electro-chemical reaction. In fact, the particle come and come to an electrode (cathode and anode) thanks to an electrolyte.

Full Matrix Capture and Total Focusing Matrix

Full matrix capture (FMC) is an acquisition technique where every element of a phased-array transducer is individually pulsed to generate sound that is received on every element, including the transmitters. Thus, a matrix signal is generated with data files made of real A-scan information.

TFM is an imaging and post-acquisition technique applied to FMC dataset. So, this imaging algorithm uses the A-scan data from all elements to an image which is focused at every specified point in the image.

Methodology

A 12-mm thick carbon steel plate, having 12 drill holes of different diameters, has been corroded by a galvanic corrosion process. A copper plate was placed over the cavities of the carbon steel plate to act as a cathode. Various brine concentration was used as an electrolyte, starting by a low concentration (about 5 g/100 ml) and ending up with a high concentration (about 50 g/100 mm). The concentration has been changed in order to the galvanic corrosion process to increase, as seen in
Figure 1.

Figure 1: The top picture is the initial carbon steel plate and the one below is the same part at the end of the galvanic corrosion test.

The same Veo+ 32:128, with Full Matrix Capture (FMC) recording capability, probe, and accessories have been used for each acquisition. The Sonatest probe model was an X3-10M-64E-0.6P for both phased-array and TFM acquisitions. This means that the probe has a 10 MHz-frequency, 64 element and the element pitch is 0.6 mm.The data was analysed using the UTmap software. This software has an automatic defect dimension sizing tool called "annotation" for both phased array and TFM data sets. All defect dimensions in this paper have been taken using this feature. The same material velocity for all acquisitions has been used to increase the repetitiveness of measurements.

Phased Array Linear Scan Acquisition

Corrosion is well measured using a perpendicular to the surface ultrasonic beam approached. At first, corrosion was assessed using a single ultrasonic signal A-scan. Within the electronic improvement, new ways of representing the information have appeared based on dimensions, with the use of an encoder, such as the B-scan (1 axis) and the C-scan (2 axes). While the B-scan represents a cross section of the part thickness, the C-scan represents a top view of the two-dimensional encoded area; where, time-of-flight or amplitude values are represented using a colour-based palette. The data was taken with a linear scan and all the defect dimensions were extracted directly from the C-scan.

Depth Assessment Method

To increase repeatability among data acquisitions, the discontinuity dimensions have been measured using an automatic sizing tool based on a time-of-flight approach. The residual thickness of the plate was automatically extracted from this tool. The algorithm, within a given range of criteria, would give the remaining thickness value of the drill holes. Because of the amplitude nature of the ultrasonic technique, to be consistent from measurement to measurement, prior to all measurements, the back-wall echo (BWE) near the measured defect was brought to the same reference amplitude level (80%). The amplitude parameter was managed at the analysis step by setting the level of the extracting gate. For all measurements, the extracting gate position was slightly over the noise level to discard the noise impact.

RESULTS

Depth Evolution through Time

The following compares phased array and TFM over remaining thickness of a drill hole based on the depth assessment method described in the previous section. The control sample has been inspected every 7 days, except for one 14-day period, for an overall period of two months. All the curves represent one individual drill hole progression through time.

Both techniques have extracted the C-scan information using only the first gate. The dome-shaped holes make it impossible to extract the information using two gates. This limitation affects the repetitiveness of results over time because of the thickness error generated by the coupling layer. The wavelength of this inspection had a value of 0.59 mm. According to the theory, this configuration has a theoretical time-of-flight accuracy limit of lambda $\frac{\lambda}{4}$which is 0.14 mm long.

Analysis of the Phased Array Results

Figure 2 shows an overview of the residual thickness progression through time for the phased array data.

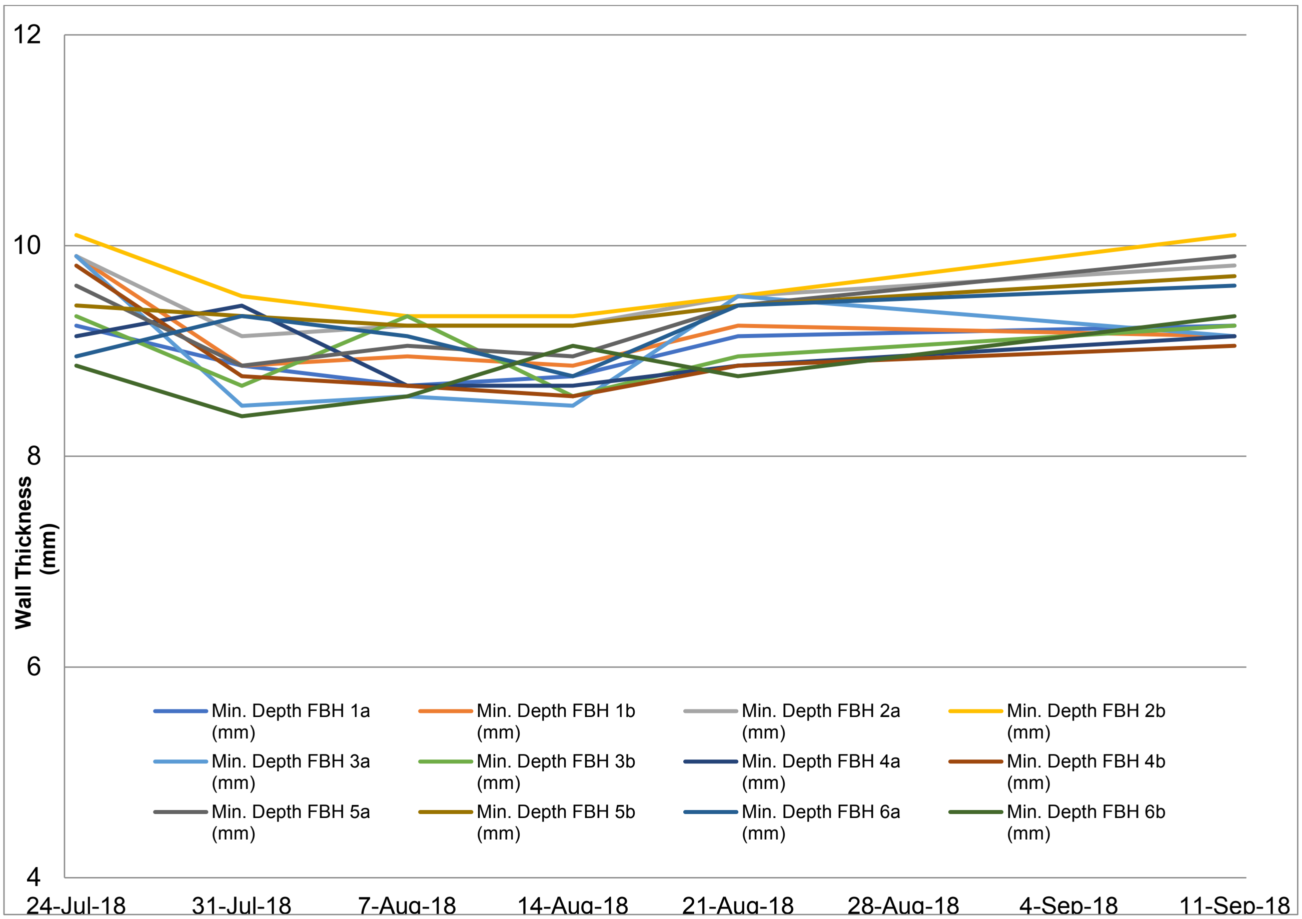

Figure 2: Remaining thickness evolution over 2 months of inducing galvanic corrosion to one drill hole sample measured with a linear phased array scan.

The expected behaviour for this study was to have small thickness variations from one acquisition to another with a thickness decreasing tendency. In this figure, the residual thickness does have small thickness variations from one acquisition to another; however, if it has a decreasing tendency at first, it is gaining some thickness within the latest acquisition.

This behaviour could be interpreted by many factors. First, the corrosion rate produced by the galvanic corrosion process might have been overestimated before starting the experiment. Furthermore, the bottom of the hole was not in direct contact with the cathode during the galvanic corrosion process and might have been less affected compared to the rest of the plate. This limited corrosion rate paired with the error generated by the acquisition would explain the lack of meaningful tendency in this graph. Indeed, because of the dome shape of the hole, the data had to be extracted using only one gate, which makes the overall measurement comparison sensitive to the couplant thickness variation. Note that the probe-to-echo considers the couplant time-of-flight.

Also, Figure 2 highlights the fact that the phased array thickness calculation for one acquisition of the 12 holes does not point toward one precise corrosion rate.

Analysis of the TFM Result

Figure 3 shows an overview of the residual thickness progression over time for the TFM data set.

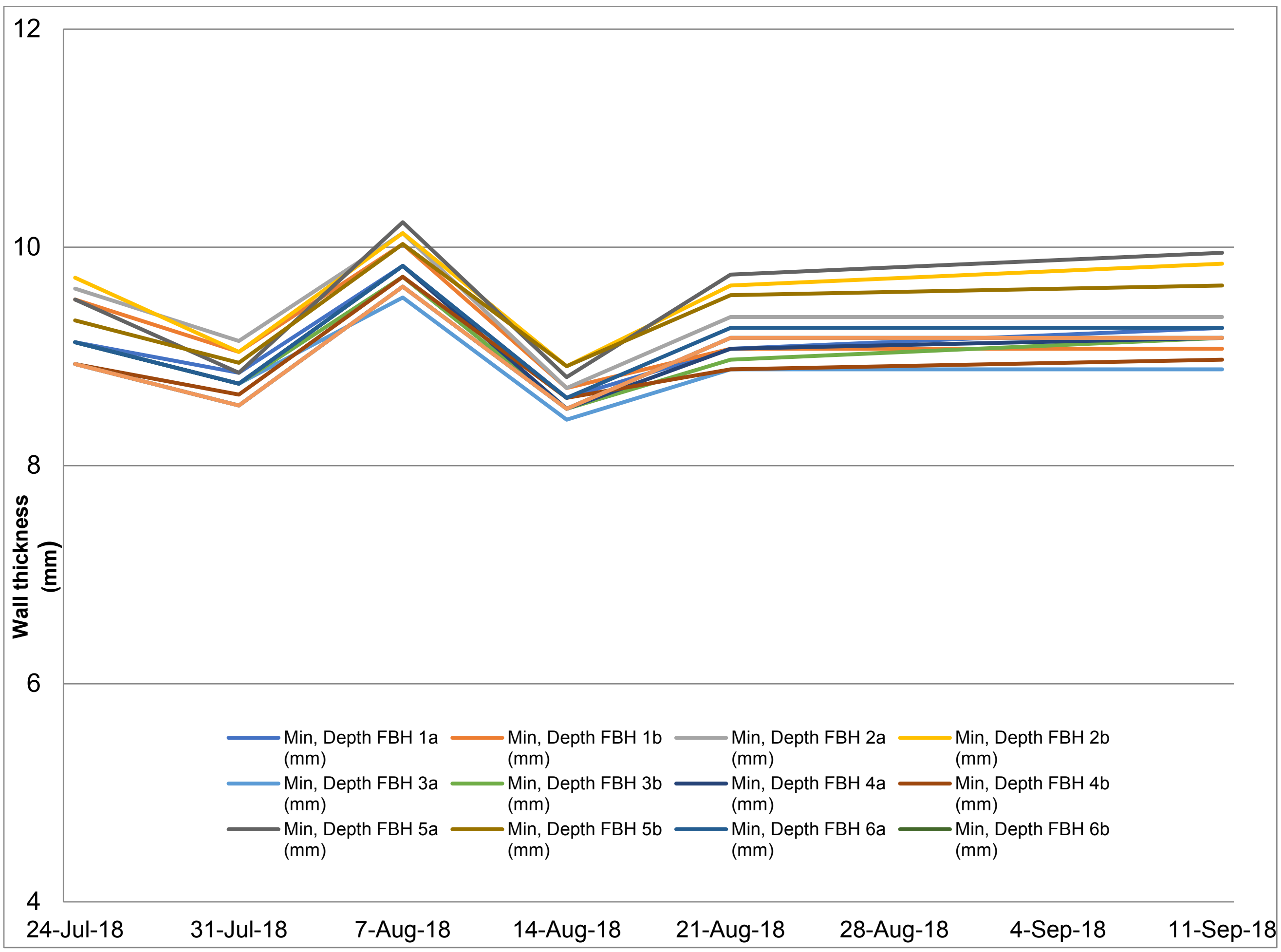

Figure 3: Minimum depth found over time; TFM scan

The expected behaviour for the TFM results for this experiment was to be more consistent compared to phased array, when it comes to small thickness variation assessment. If alike the phased array values, there is no clear thickness evolution tendency, the TFM results are surprisingly repetitive from one hole to another for a given acquisition. Those results are explained by the fact that the TFM technique is focused at every pixel which gets rid of the beam size and divergence assessment errors that reduce consistency between measurements. Specifically, while using automatic sizing tools.

This benefit gives the TFM technique a simple advantage when it comes to precisely assess small thickness variations through time.

Technique Imagery Comparison through Time

The next section compares residual thickness variation measurements in the C-scan view using automatic sizing tools. The then following section is going to compare the defect imagery difference between both techniques to improve the understanding of the corroded defect evolution.

Corrosion Progress Presentation of an L-scan View for a Specific Hole

An L-scan, also known as a linear scan, is a type of ultrasonic testing (UT) technique. It is all based on the use of a linear probe that has many piezoelectric elements in an individual housing. Indeed, each group of elements pulses a single straight beam, at 0 degree. This means that the beams are perpendicular to the inspected surface.

Figure 4, Figure 6 and Figure 5 display phased array and TFM images of the same drill hole within the trial duration. To brighten up the comparison, the reference gain has been adjusted at the same level for all the images. On the TFM image, the resolution improvement and focalisation at every pixel, highlight the creation of a smaller echo and the internal surface finish irregularity created by the corrosion process. The amplitude level is as well less affected compared to the phased array image. On the other hand, for the phased array image, this roughness could be seen by an amplitude drop of the reflector.

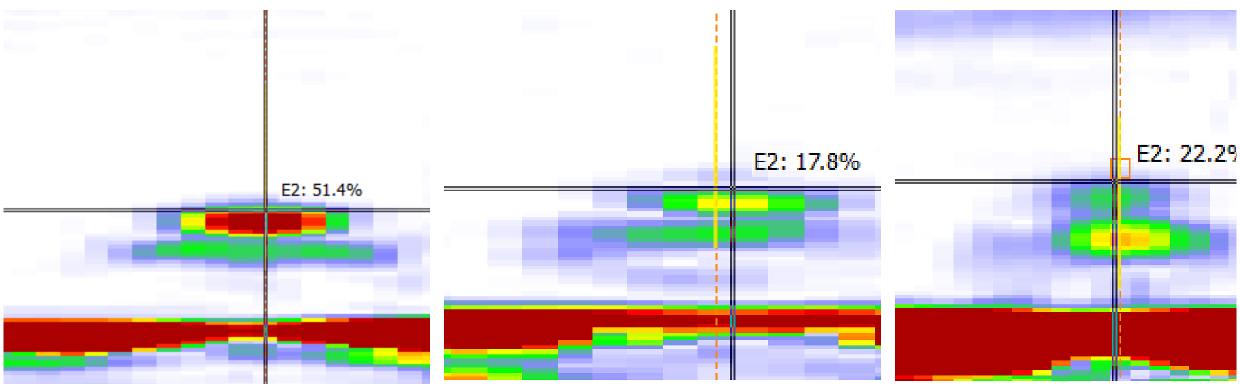

Figure 4: Phased array echo profile on July 31st and on the right on September 11th

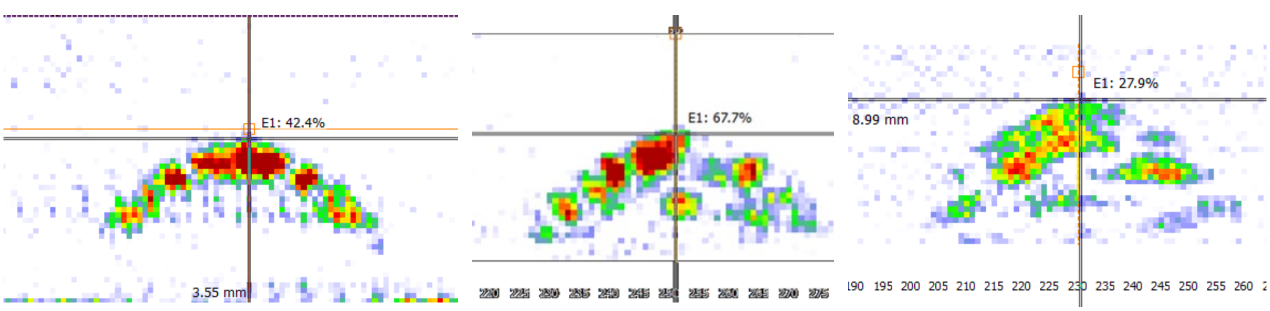

Figure 5: TFM echo profile on July 31st, then September 11th and October 24th on the right

Furthermore, TFM provides a better profile scan and improves echo accuracy through time.

Indeed, the drill hole had generated a dome bottom cavity. On the TFM image the bevelled bottom holes are clearly seen.

Top Visualisation of a Specific Hole

When it comes to corrosion mapping, it is generally recommended to use a symmetrical aperture. By doing so, the energy distribution is balanced equally for both C-scan axes, and the defect visualisation is improved. Indeed, the left phased array view appears to be slightly rounder compared to the TFM one. This difference is explained by an unbalanced resolution between the passive and active apertures for the 64-element TFM scan. To counter such visualisation, it is always possible to record an FMC scan in both directions. For this view, the phased-array may generate better flaw representation since an irregular shaped echo will appear the same way regardless of the scan direction.

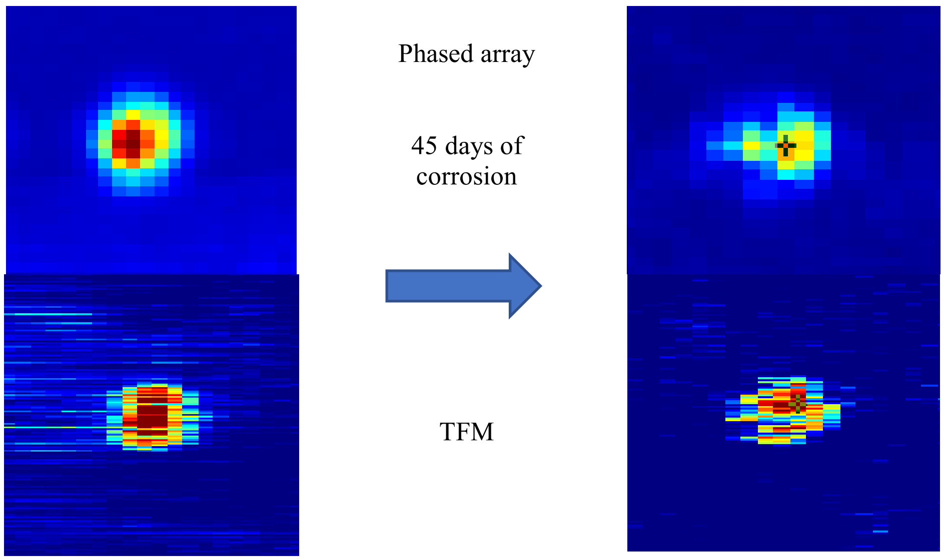

Figure 6: Phased array C-scan and TFM C-scan comparison

Also, for an equivalent amplitude level, the phased array scan has a better SNR compared to the TFM scan. Indeed, the measured SNR for phased array and TFM are respectively 25 dB and 12 dB. Both scans were recorded at the exact same time. This SNR difference is explained by a drop of energy level [1]. Pulsing in phased array technique generates more focused energy compared to only one transmitter element. Fortunately, TFM uses many receiving elements and averages random signals.

CONCLUSIONS

The lack of thickness decreasing tendency in this study was caused by an insufficient corrosion rate for the bottom of the hole and too many errors occurred during the acquisition step of the experiment. It could be interesting to extend the experiment duration in order to see this tendency. Indeed, the corrosion effects occur over a long period of time. Moreover, due to result analysis, the experiment could not be continued. One way to increase the corrosion kinetic is to have a cathode with an area larger than the anode. Nevertheless, the sensitivity and repetitiveness of the TFM measurements for small thickness variations have been demonstrated.

Additionally, we have seen that phased array offers a better defect representation for 2D mapping compared to TFM. The symmetrical aperture of the phased array configuration grants this technique a more accurate defect representation of the reality. Also, from an acquisition speed point of view, the phased array technique remains faster compared to the FMC technique.

When comparing an echo cross section between phased array and TFM it shows a difference in size dimensions and precision. The TFM images are pixels that contain highly focused energy information while the phased array gives an average profile of the echo.

Finally, both techniques have their pros and cons; once again they have shown that they are complementary technique according to specific application requirements.

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