Corrosion detection and measurement improvement using advanced ultrasonic tools

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Abstract. Accurate and reliable ultrasonic measurements on corroded areas still remain a challenge. In some cases, the accurate residual thickness measurement can be very difficult to achieve: strong corrosion, fast variation of thicknesses, shallow pits... Total Focusing Method (TFM) has been recently made available in portable Phased-Array Ultrasonic Instrument. Portable industrial equipment with full-parallel capabilities allows handling of matrix-array probes, 3D imaging and advanced techniques for optimal focusing. In the case of 2D corrosion mapping, the Total Focusing Method presents some advantages in comparison with standard Electronic scanning: limitation of the dead zone, improvement of the accuracy, detection and visualization of slopes between areas parallel to the surface. Advantages and drawback of the methods are discussed, and performances are shown on strongly corroded pipes.

Introduction

Corrosion measurements represent a major application of ultrasonic inspections. In addition to the usual thickness measurement with single or dual element probes, full corrosion mapping is more and more demanded by end-users to ensure that an eventual corrosion degradation process is not missed by a point like measurement technique. Corrosion mapping has led to significant improvements in this topic where proof of coverage, always the biggest issue with thickness testing, can be easily demonstrated through a Cscan image.

Phased array techniques have been extensively used for several years demonstrating its capability to cover large corroded area and providing a good mapping resolution (typical resolution is mm).

Recently, advanced processors and advanced computation capabilities made possible techniques such as Full Matrix Captures and Total Focusing Methods in real time and within portable equipments. These new techniques are now available in the corrosion mapping market and the advantages of these technics are discussed in this paper.
1. Phased array and corrosion mapping

Phased arrays have been extensively associated to corrosion mapping since it has the capability of full coverage thanks to their electronic scanning capabilities.

Thickness gages are providing punctual measurements. They are providing an idea on the corrosion but make unrealistic the extension to a 100% full coverage. For example a rather small area of 100mm by 100mm with a grid of 1mm measurement step (10 000 measurements) requires 2.7 hours to be fully covered assuming one second per measurement. In phased array corrosion mapping, the same area can be covered in a few seconds [1].

Nowadays, most of the corrosion mapping inspections are performed using electronic scanning and few are combining electronic scanning and angular scanning as described later in this paper.

1.1 Electronic scanning and corrosion mapping

In electronic scanning mode, a group of elements of a phased array is activated and electronically moved along the phased array probe. The probe is then, mechanically moved perpendicularly to the electronic scanning direction and a C-scan view can be produced at a high inspection speed.

A typical configuration corrosion mapping configuration managed with a 5MHz phased array probe, 64 elements, with a pitch of 0.6mm placed on a 10mm Rexolite® wedge. For a typical 10 kHz pulse repetition frequency (PRF), the electronic scanning speed is 6m/s (21 km/h). Replacing this electronic displacement by hand probe motion is in the field not feasible. This explains the success of corrosion mapping with phased array. In addition, at a single probe position, this inspection provides a high resolution description of the back wall as thickness measurements can be provided by the phased-array at 57 positions assuming an aperture of 8 elements without moving the probe. A result of a simulated corroded area case study of is shown in the following figure.

![Fig. 1. Electronic Bscan of a corroded area at one specific position (simulation through CIVA software)](image)

Another advantage of corrosion mapping with phased array is their capability to provide Cscan pictures in real time. Again, proof of coverage can be easily demonstrated through a Cscan image:
1.2 Electronic and sector scan merged for a better mapping

The previous Electronic scanning method is widely used but can sometimes missed measurement spots. This is typically the case for important corrosion where back wall slopes are presents. The next figure presents a simulated electronic scanning image superimposed with the back wall (represented by the black line). The important slope relatively to the surface echo tends to decrease the level of the back wall echo to an extent where some thickness can barely be extracted from these pictures. Safety considerations could assume the worst case scenario (i.e. through all corrosion) and lead to drastically anticipated shut down of still operational components [2].
In some heavy corroded applications, electronic scanning and sector scan are sometimes merged to decrease the sensitivity to sloped back walls. Even if missed thickness measurement spots can still be observed, this technique greatly decrease missed measurement spots. In the next example, an electronic scanning is performed and for each aperture, a sector scan of -20°, 0° and 20° is performed.

The combination (or merge) of these Electronic scanning and Sector scanning creates a better description of the back wall. Of course, as 3 shots are performed for each aperture, the inspection speed is divided by 3 compared to a simple electronic scanning.
2. Total focusing Method and corrosion mapping

The relatively new Total Focusing Technique has been recently made available in real time in the Gekko field portable equipment. TFM is applied to a dataset recorded from a FMC (Full Matrix Capture) acquisition to produce an image in a region of the component [3]. The FMC presents the advantage of maximizing the information available from a given array composed of N elements by sending ultrasonic energy everywhere in the component; this way potential defects can be seen from multiple directions and, in particular, is able to improve the detection of sloped back wall [4].

The FMC acquisition consists in firing each element of the array in turn and recording the information reflected/diffracted in the component on all the elements. The result of the FMC is a NxN dataset composed of every emitter-receiver pair combination of elements in the array. The TFM algorithm consists in coherently summing all the signals \( s_{ij}(t) \) from the dataset to focus at every points of a Region Of Interest (ROI) in a specimen.

TFM is performed in the Gekko equipment at a rate of 27 pictures per second. This is a bit slower than an electronic scanning inspection but still consistent with a manual inspection. Despite this slight speed decrease, the ROI size is at the moment a 256x256 pixel zone providing an extremely better resolution than Electronic scanning (cf. Figure 2 where only 57 pixels are available). An example of TFM picture is provided below on the same corroded area showing a great improvement for heavily corroded areas.

![Fig. 6. Merge Electronic and Sector scanning (simulation)](image)

Potential advantages of TFM versus electronic scanning and electronic + sector scan are discussed in the next paragraphs.

3. Discussion on the advantages of TFM with simulated data

In the next example, a back wall containing a triangular shape is taken as a synthetic example of corrosion. CIVA simulation software has been used to compute and accurately compare the different techniques (electronic scanning, electronic and merged sector scan, TFM).

The simulated mock-up is a 9mm thick pipe with a corroded area which has the shape of a triangle.
3.1 Linear scan

When the corrosion mapping is operated through a linear scan, the diffraction from the top of the triangle can barely be seen. The 35° slopes are not visible as it can be observed in the figure below:

![Fig. 8. Electronic scanning of triangular shaped corrosion (simulation)](image)

3.2 Linear scan and merged sector scan (-20°, 0°, 20°):

When the corrosion mapping is operated through a merge of linear and sector scan, the slopes can be detected thanks to the -20°, 20° shots and the top of the triangle as well thanks to diffraction effect. But the detection is still extremely weak as one can see the relatively small amplitude of the defected areas compared to the back wall echo.

![Fig. 9. Merged Electronic and Sector scan of triangle shaped corrosion (simulation)](image)
3.3 TFM reconstruction of FMC

The next example shows the results of corrosion mapping operated through FMC and TFM process. The advantage of TFM is clearly visible in the B-scan view (see figure below), as slopes are very well reconstructed.

![TFM reconstruction (simulation)](image)

This can be explained by the FMC acquisition scheme where the elements are fired one by one. Phased array elements are usually very small (pitch of 0.6mm in this example). Thus, the acoustic energy they radiate is very divergent: the almost spherical wave propagation increases the slopes reflectivity and enhances the TFM reconstruction. The same FMC acquisition scheme can explain a better sub-surface resolution of TFM compared to electronic scanning. In Electronic scanning, the group of emitting elements are producing a planar wave on the surface and thus, a very large surface echo, when the very divergent wave fronts created by small elements are weakening the surface echo and reduce its length.

3.4 Experimental results

The next table shows some experimental TFM examples which are compared to Electronic scanning on heavily corroded pipe (nominal thickness is 9mm but, for position 2 below, the remaining thickness is less than 1.5mm). Left column are the TFM results, right column are the electronic scanning. Each line of the table represents the two methods (TFM and Escan) shown at the same position of the probe for comparison.

<table>
<thead>
<tr>
<th>TFM : position 1</th>
<th>Electronic scanning : position 1</th>
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<tbody>
<tr>
<td>TFM : position 2</td>
<td>Electronic scanning : position 2</td>
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![TFM : position 1](image)

![Electronic scanning : position 1](image)

![TFM : position 2](image)

![Electronic scanning : position 2](image)
The TFM results show a great amelioration of the back wall detection thanks to a greatly enhanced resolution (from 57 to 256 horizontal pixels). By sending energy everywhere it is possible to detect the various orientations of the back wall and thus reconstruct the corroded surface more accurately. Moreover, the dead zone is also reduced from 1.5 to 0.5 mm thanks to the FMC acquisition (see position 2).

**Conclusions**

Recently, portable phased-array systems with TFM capabilities have been made available. The few results presented lead to the fact that Cscan imaging is enhanced by real time TFM processing. The improvements deal with higher resolution and sensitivity to shallow pit, reduction of dead zone, and visualisation of misoriented corrosion profiles.

Implementing Total Focusing Method on the field for corrosion mapping is even simpler than operating a conventional linear scan from the NDT technician point of view. The ultrasound settings are easier; the acquisition speed is compatible with hand scanning speed. In addition the results obtained with TFM that reveals more realistically the corrosion profiles, avoid sometime additional work. The quality of the corrosion profiles reconstruction could be enough to take the right decision from an engineering or inspection point of view without involving other UT techniques like TOFD, phased-array shear waves sectorial scan…

**References**


