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Corrosion Mapping Solution Using dB-UT and Phased Array Transducers

Full Paper

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Abstract

To improve the accuracy and efficiency of corrosion detection, decibel ultrasonic testing (dB-UT) and phased array techniques provide a significant solution for corrosion mapping. These techniques take advantage of dB-UT's transducer capacity to evaluate corrosion severity using decibel drop measurements, whereas phased array transducers provide detailed imaging of the internal structure, allowing for the exact localisation of corrosion flaws. This study demonstrated the corrosion mapping on a steel pipe through a series of controlled experiments where corrosion patterns were accurately mapped across various scan plans. The results significantly improve detection limits, outperforming existing approaches and offering a high resolution of corroded images via a phased array transducer.

Keywords: - Ultrasonic corrosion scanning, dB-UT, phased array, corrosion mapping

1. Introduction

Ultrasonic corrosion scanning (UCS) system is a state-of-the-art solution that produces high-frequency sound waves to detect, measure and map corrosion in metal structures and materials. By employing ultrasonic testing (UT), UCS systems offer a non-destructive method for monitoring the thickness of materials and detecting corrosion rates with high precision (Zou & Cegla, 2018). The UCS system operates by sending ultrasonic pulses through the material being inspected. Upon encountering any discontinuities, such as corrosion or material loss, these pulses are reflected to the transducer. The time it takes for the echo to return is then used to calculate the thickness of the material, allowing for the identification of areas where corrosion has thinned the material (Ber et al., 2016). One of the advantages of UCS is its ability to provide accurate measurements in real-time which is crucial for maintaining the integrity of critical structures. Advanced UCS systems incorporate techniques such as the total focusing method (TFM), which enhances corrosion detection accuracy and improves the visualisation of corroded areas (Ber et al., 2016). This method is particularly beneficial for assessing complex geometries and detecting subtle changes in thickness that may indicate the early stages of corrosion. The promising results from recent studies highlight the potential of using an artificial neural network (ANN)-based tool for real-time prediction of remaining wall thickness in stainless steel elbows (Memon et al., 2023). These findings encourage further research and development of such tools, which could significantly enhance the maintenance and integrity of industrial assets by providing accurate, real-time data on corrosion and wear. The decibel ultrasonic testing (dB-UT) system is another method that employs high-frequency sound waves to detect and measure corrosion in metal structures. This system utilises ultrasonic transducers that emit sound waves into the material being inspected. These waves are reflected to the transducer when they encounter a boundary, such as the interface between metal and a corroded area. The system can determine the presence and extent of corrosion by measuring the time it takes for the echoes to return and the intensity of the received signals (measured in decibels, dB). Despite the advantages of UCS systems, the difficulty in accurately measuring the residual thickness in areas with corrosion and the fast variation of thicknesses or shallow pits limits the capability of UCS in detecting corrosion. Therefore, corrosion solutions using phased array ultrasonic testing (PAUT), which employs an array of transducers to send ultrasonic waves into the material at multiple angles, have been proposed to overcome these problems. This technique allows for a more extensive data collection over a specific area, creating a grid that maps out the thickness variations due to corrosion. The resolution of the mapping is highly dependent on the phased array providing a typical resolution between 1-5 mm (Carte, 2011; Turcotte et al., 2016; Turcu et al., 2018; Jamil & Yahya, 2019). Phased array corrosion mapping hasn't been widely adopted in on-stream inspections, which could be mainly due to the absence of clear codes, standards, specifications and guidelines. A study by Tai et al. (2023) has provided end users and maintenance vendors with a novel approach for corrosion mapping in petrochemical plants, specifically at temperatures below 250°C. To the best of the author's knowledge, reports on corrosion mapping using dB-UT and phased array techniques are still limited. Therefore, this paper compares corrosion mapping solutions using dB-UT and phased array transducers on a steel pipe.

1.1 Decibel Ultrasonic Testing and Phased Array Corrosion Mapping

dB-UT is an automated pulse-echo inspection technology designed to store wall thickness measurements and their precise locations, all managed seamlessly by a computer. dB-UT can capture and store the real-time radio frequency (RF), A, B, C, and D-scan displays, whereas a phased array generates multiple ultrasonic beams simultaneously. By adjusting the timing of the pulses sent to each element in the array, the system can focus the beam at different angles and depths, creating a high-resolution image of the material's internal structure (Turcotte et al., 2016; Holloway & Ginzel, 2020; Tai et al., 2023). Table 1 summarises the calibration, inspection planning, scanning and data analysis of dB-UT and phased array corrosion mapping.

Table 1. Summary of the calibration, inspection planning, scanning and data analysis of dB-UT and phased array corrosion mapping

	dB-UT	**Phased Array**
Calibration	dB-UT and phased array are calibrated using reference standards to ensure accurate measurements.	
Inspection Planning	A plan is created detailing the areas to be inspected and the approach to be taken.	Multiple ultrasonic beams are used to scan the material, creating a high-resolution image of the internal structure.
Scanning	A transducer sends ultrasonic pulses through the material, and the reflected waves are received and converted into electrical signals.	A grid of data points is collected over the inspection area, providing detailed information about wall thickness and corrosion extent.
Data Analysis	The time it takes for the echoes to return and their amplitude are analysed to determine the material's thickness or to locate flaws.	The data is analysed using sophisticated software to compare current results with previous inspections to monitor corrosion progression.

2. Materials and Methods

Fig. 1(a) shows the ultrasonic flaw detector model of Olympus OmniScan MX. The dB-UT and phased array transducers were placed in the inspection areas, as shown in Fig. 1(b). The material specifications and probe selection for both dB-UT and phased array corrosion mapping were described in the following section.

2.1 dB-UT Corrosion Mapping

2.1.1 Material Specifications

Velocity and thickness tolerance are critical information for building a proper inspection plan in the material specifications. While the velocity can be calibrated, the thickness tolerance is defined by both a high and a low limit. The thickness values measured outside the boundary delimited by the said limits are flagged for rejection. For example, the thickness tolerance for a 15 mm sample, where a high alarm starts at 16 mm and a low alarm at 10 mm with a tolerance of about 2 mm (see Fig. 2).

2.1.2 Probe Selection

The performance of a transducer is determined by the thickness and material qualities when choosing probes. A lower frequency transducer that offers less attenuation of the ultrasound in the material and a higher frequency that produces a thinner and more consistent peak must be chosen. Another important component is the probe's dampening. Low damping provides greater sensitivity, while highly damped probes have a wide bandwidth and a narrow peak response. Since corrosion inspection in this work does not necessitate the use of a far field, a pitch and catch configuration of a twin crystal probe, as depicted in Fig. 3, was chosen for the near-field scanning. This dual-element arrangement eliminated the primary echo, improving the near-surface resolution detection capacity.

(a) (b)

Fig. 1 (a). Ultrasonic flaw detector, and (b) the scan plan set up on a steel pipe

									Tolerance Low							Tolerance High					
mm	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	…

Fig. 2. Thickness tolerance (Turcotte et al., 2016)

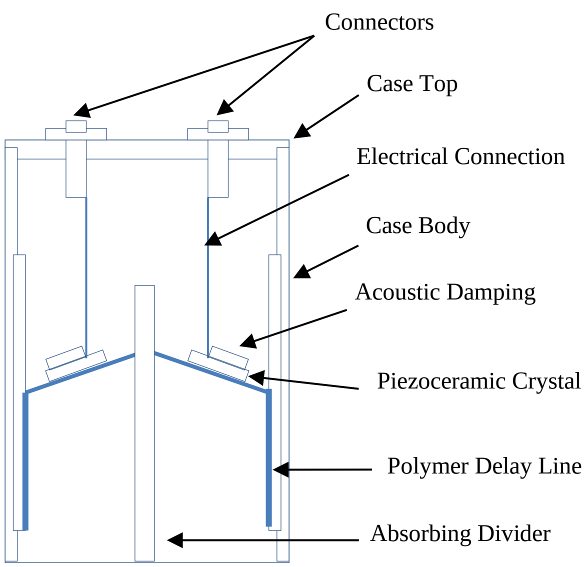


Fig. 3. Schematic diagram of twin crystal probe

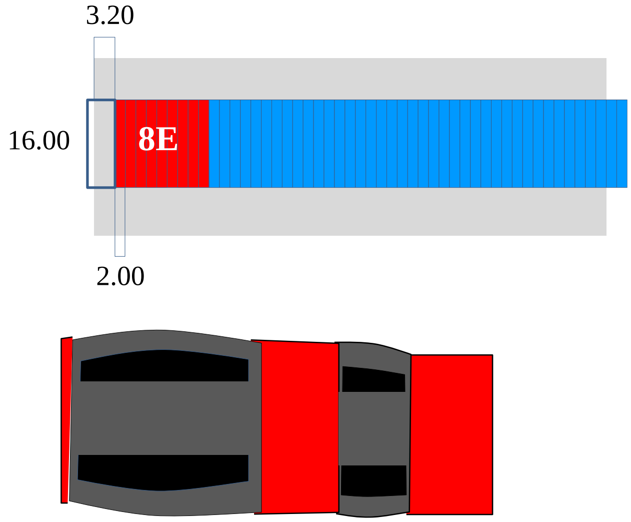


Fig. 4. Schematic diagram of phased array probes

2.2 Phased Array Corrosion Mapping

2.2.1 Material Specifications

The user must provide the part parameters to represent the physical properties of the targeted inspection while generating a configuration file. The main data to collect for corrosion mapping are the material's thickness and velocity as well as the probe delay line.

2.2.2 Probe Selection

Phased array probe selection depends more on space constraints, signal resolution and coverage because phased array probes are typically highly damped for a sharp signal and focusing technology offers more flexibility for the sensitivity unless it is for a special attenuative alloy. Therefore, the size and quantity of the probe elements are the main factors in addition to frequency. The resolution along this axis will be finer the smaller the element pitch. The probe's overall coverage capabilities will grow with the addition of more parts. Maintaining a square aperture ratio to the greatest extent feasible to provide a symmetrical beam that ensures flaws always seem the same regardless of probe orientation. The signal was placed encoded with a delay line that suits the material thickness in order to produce an exact high-resolution mapping. As seen in Fig. 4, this was conducted with a probe equipped with a typical 0° irrigated wedge and a manual encoder.

3. Result and Discussion

The corrosion mapping results from the dB-UT and phased array transducers were collected and interpreted by software. dB-UT transducer provides thickness readings with a typical resolution ranging from 25-250 mm while the phased array transducer provides a 1-10 mm resolution. The advantage of these techniques is that different depths can be referenced by colour codes for direct visual comparison (see Fig. 5).

Fig. 6 shows the indication of minimum depth at approximately 5 mm to the nominal thickness of material at 10 mm using (a) dB-UT transducer and (b) phased array transducer, respectively. dB-UT used ultrasonic waves to detect changes in steel pipe thickness due to corrosion. The reflected sound waves were measured in decibels, and the intensity of the reflection indicated the degree of corrosion (i.e., reduced thickness). A phased array transducer uses multiple beams to create high-resolution thickness measurements with a colour palette indicating corrosion severity: green for nominal thickness with no significant corrosion, yellow for moderate and red for severe corrosion. This technique provided higher resolution, resulting in detailed corroded density inspection. It is clearly shown that the phased array transducer exhibits a more detailed image of the corrosion density and colour palette, as shown in Fig. 6 (b). Fig. 7 shows the indication of minimum depth at approximately 20 mm to the nominal thickness of material at 25 mm using (a) dB-UT transducer and (b) phased array transducer, respectively. The dB-UT transducer's lower resolution capability restricted the steel pipe's corroded density (Fig. 7 (a)). The indication at 20 mm depth suggests that there is a defect or boundary within the material at that depth. The presence of an indication at this depth shows the possibility of a defect (such as a crack, void, or inclusion) or a material boundary (e.g., weld interface). In contrast, the simultaneous measurement produced by multiple beams in a phased array transducer resulted in high-resolution corrosion mapping with higher precision (Fig. 7 (b)). The indication at the same depth (20 mm) using the phased array transducer indicates a possibility of a defect (such as a crack, void, or inclusion) or a material boundary (i.e., weld interface) within the material. While dB-UT provides primary thickness data, phased array offers superior resolution and advanced features. Both dB-UT and phased array transducers effectively detect and measure corrosion, with the phased array transducer providing higher resolution and more detailed analysis capabilities. The colour palette used in both methods represents a specific range of thicknesses, visually representing the corrosion's severity and distribution. The choice between dB-UT and phased array depends on inspection requirements, material properties and accessibility. Phased array offers advantages in terms of beam steering, but it requires specialised equipment and expertise. Further analysis, including sizing and characterisation of the indication, would be necessary to determine the severity and impact on material integrity.

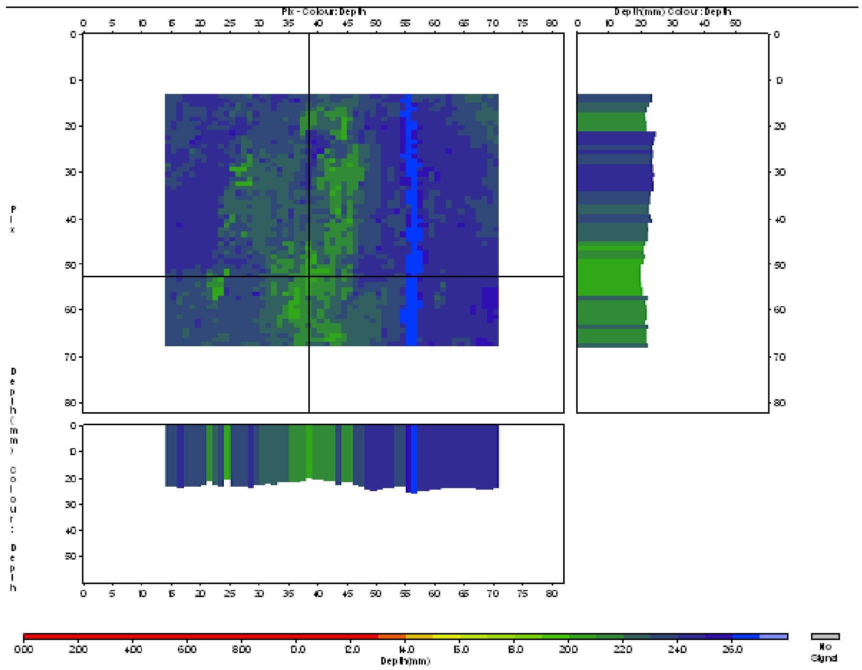
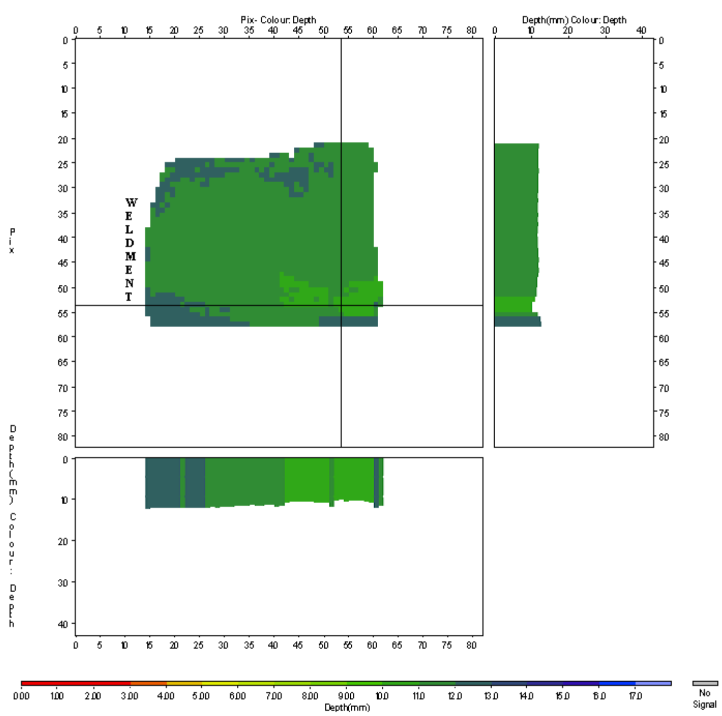
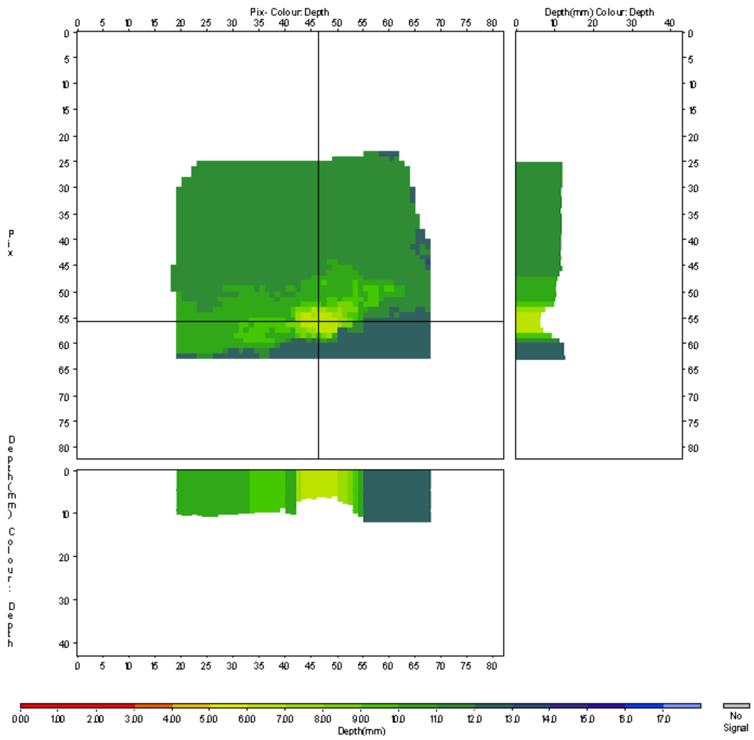


Fig. 5. Thickness value displayed using the colour palette

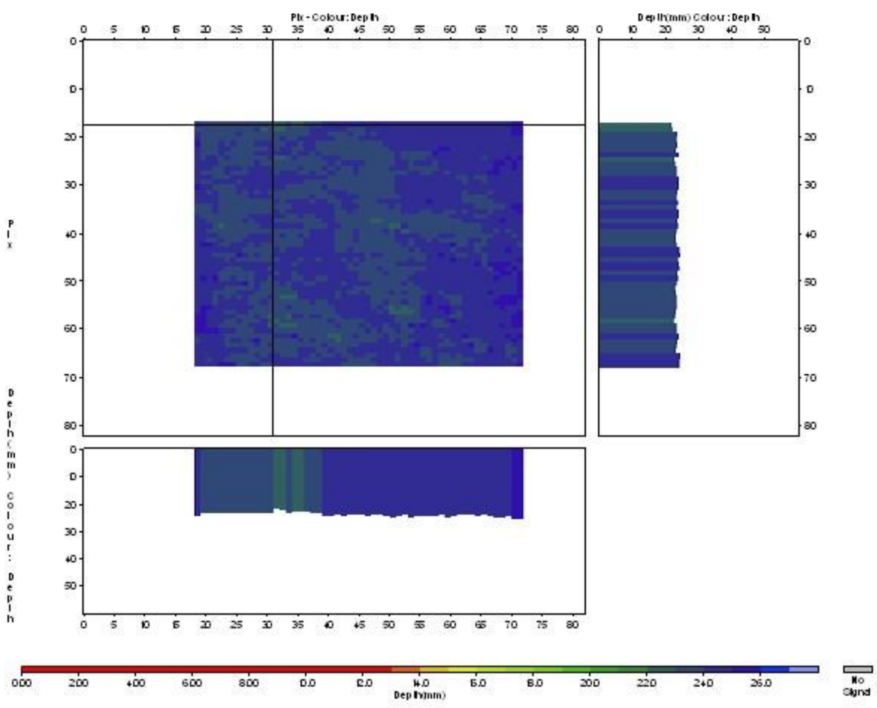


(a)

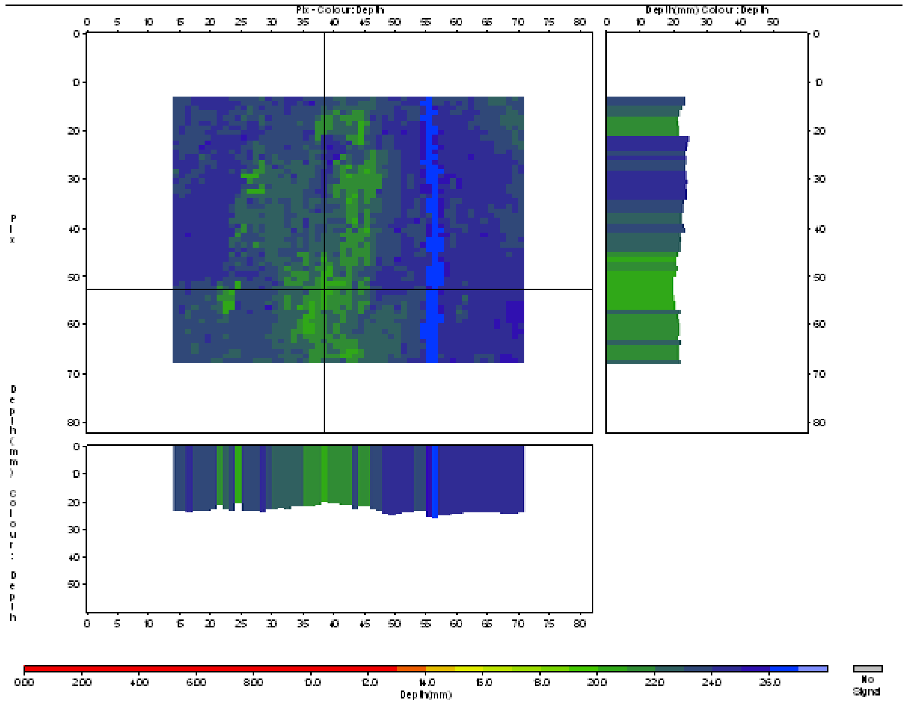


(b)

Fig. 6. Indication of minimum depth at approximately 5 mm to the nominal thickness of material at 10 mm using (a) dB-UT transducer and (b) phased array transducer, respectively



(a)



(b)

Fig. 7. Indication of minimum depth at approximately 20 mm to the nominal thickness of material at 25 mm using (a) dB-UT transducer and (b) phased array transducer, respectively

4. Conclusion

Projected multiple scan plans to improve corrosion detection, locating, and characterising, which is essential for assessing engineering products. Colour mapping in corrosion inspection provides a clear and intuitive way to understand the material's condition. While dB-UT transducer is a widely used and established technique, phased array transducer offers superior resolution and advanced analysis capabilities. The corrosion size and depth can be effectively quantified using multi-frequency local wave-number estimation obtained from a phased array transducer. Extensive coverage and high probability of detection and imaging are the most apparent advantages of phased array ultrasound for corrosion mapping.

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