DRILLING RISER INTEGRITY INSPECTION: AN APPROACH USING ADVANCED ULTRASOUND TECHNIQUES

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ABSTRACT

Integrity inspection is essential for ensuring drilling risers' safe operation in the offshore industry. The present article explores the application of cutting-edge ultrasound technologies for drilling riser inspection. Conventional inspection techniques like visual, magnetic particle testing and ultrasound are limited in accurately identifying and describing defects. In contrast, Phased Array, Time-of-Flight Diffraction, and conventional ultrasound associated with Phased Array equipment provide enhanced sensitivity, accuracy, and coverage capabilities. This article explores the principles and mechanisms of Phased Array and Time-of-Flight Diffraction techniques, shedding light on their superior attributes when combined with traditional ultrasound methods to overcome the challenges of inspecting fully assembled risers onboard by checking through the inner diameter. In addition, the article showcases examples where Phased Array and Time-of-Flight Diffraction, in tandem with traditional ultrasound, have proven to be effective in detecting critical flaws such as wall thinning and fatigue cracks. The article underlines the significance of a thorough inspection approach that integrates various methods to evaluate the overall integrity of drilling risers. The results demonstrate the efficacy of the innovative inspection arrangement, emphasizing substantial strides in ensuring the integrity of drilling risers using cutting-edge ultrasound technologies. This underscores the potential for reduced inspection time, improved safety and logistics, and upgraded operational effectiveness in offshore drilling.

KEYWORDS: *Phased Array, Ultrasound, Riser, Inspection, Time-of-Flight Diffraction.*

I. INTRODUCTION

Brazil's pre-salt reserves located in deep waters have established the nation as a dominant force in global energy [1]. However, deepwater offshore drilling presents significant challenges due to the harsh high pressure at ocean depths and environmental conditions, as specified by Da Costa Silva [2]. Equipment such as risers is crucial to ensure an efficient and safe operation. Drilling risers are vital in connecting the rig to subsea wells, facilitating fluid transfer, and providing stability and support to the drill string [3]. The integrity inspection of this equipment is essential to detect damages or potential failures that may compromise operational continuity and worker safety.

The DNV-RP-F206 (Riser Integrity Management) [4] provides practical guidelines for riser integrity inspections and their frequency. The standard ensures that the equipment is in good operational condition and that the risk to safety, the environment, or the asset's value is minimized to an acceptable level. To maintain the riser's integrity, it is necessary to perform periodic inspections, continuous monitoring, or testing to investigate degradation in the riser system's performance [6]. The following actions aim to prevent further degradation and repair or replace the damaged components if the level or rate of degradation is unacceptable. The practical recommendation mandates the completion of in-service integrity process steps and the performance of periodic assessments to document the riser integrity status, record corrosion management, and conduct integrity assessments. [4-5].

Traditional riser inspections involve the costly process of disembarking the equipment for onshore inspection, which requires logistics, disassembly, and reassembly once it is impossible to strip the equipment off onboard due to the vessel's limited deck space. Disassembly involves removing the flotation elements and dismounting the individual pipes to check the welds and identify thickness reductions using conventional ultrasound techniques [7]. However, advanced ultrasound methods provide a more efficient solution by allowing inspections within the riser's ID (inner diameter), eliminating the need to dismantle and disembark the equipment. This streamlines the inspection process and reduces associated costs. This method effectively assesses the integrity of risers, improving efficiency and safety in deepwater offshore operations. [7-8].

The article is organized into different sections. Section II provides a detailed account of the research process, including the calibration blocks and case studies used during the inspection evaluation. Section III presents the inspection findings on the calibration blocks and the field studies. Section IV thoroughly discusses these results, highlighting the effectiveness of advanced ultrasound techniques, addressing limitations, and comparing outcomes with conventional methods. Finally, section V presents the final considerations.

II. Materials and Methods

This study tried to categorize the integrity examination of drilling risers by comparing the primary differences between the classic and advanced techniques and their corresponding outcomes in each inspection method, comparing blocks with previously known thickness reductions and notches. The research process employed in this study uses a qualitative perspective to describe and explore the utilization of advanced ultrasound methods combined with a classic ultrasonic test (UT) to inspect the drilling riser's integrity. TOFD (Time-of-Flight Diffraction) and Phased Array (PA) techniques were integrated with UT to allow the internal examination of the pipes, consequently avoiding disassembling the buoyancy and offloading the equipment. A current bibliographical survey was performed to achieve these goals, using diverse data collection instruments, such as scientific articles, books, congress annals, websites, and technical reports. This literature review was centered on examining pertinent publications on the research topic.

Additionally, two case studies compared calibration blocks replicating thickness reductions and equipment failures in compliance with ASME V article 4 [12] requirements and two risers previously inspected only by conventional ultrasound. In the first scenario, a comparison was carried out with one approved equipment with no discontinuities. In contrast, a rejected riser with known defects was utilized in the second scenario. The objective of these comparisons was to check that advanced ultrasound techniques could identify all flaws in the standard blocks and, if a satisfactory outcome was obtained, repeat the examination on intact equipment to obtain data of an approved inspection and another with defects to confirm whether these inspection methods could be utilized and identify all the previously known defects.

To inspect the girth welds of the main tube, a half-round pipe of the exact dimensions and material as the main pipe was utilized, where four notches were created, one on the ID and one in the OD (outer diameter), to simulate 34mm defects for the calibration confirmation and two transverse notches for the Time Corrected Gain calibration. To check the wall thickness loss, a block with the exact dimensions and material as the main pipe was used, where reductions in thickness were created to simulate the corrosion existence, that is, a step block that allows the use of the PIG (pipeline inspection gauge) in the same manner as it would be done during the inspection. In summary, the methodology adopted in this article combines a case study with a literature review to describe and explore the use of advanced ultrasound techniques with classic UT to inspect the drilling riser integrity [9-10].

2.1 Advanced ultrasound equipment

The inspections were performed using a Phased Array flaw detector equipped with a 32:128 module, which served as the equipment for both procedures. A magnetic base scanner with two PA probes, two TOFD probes, and two 45-degree conventional probes were used to examine the circumferential welds. The probe specifications can be seen in Table 1, and the setup for each technique can be seen in Figure 1.

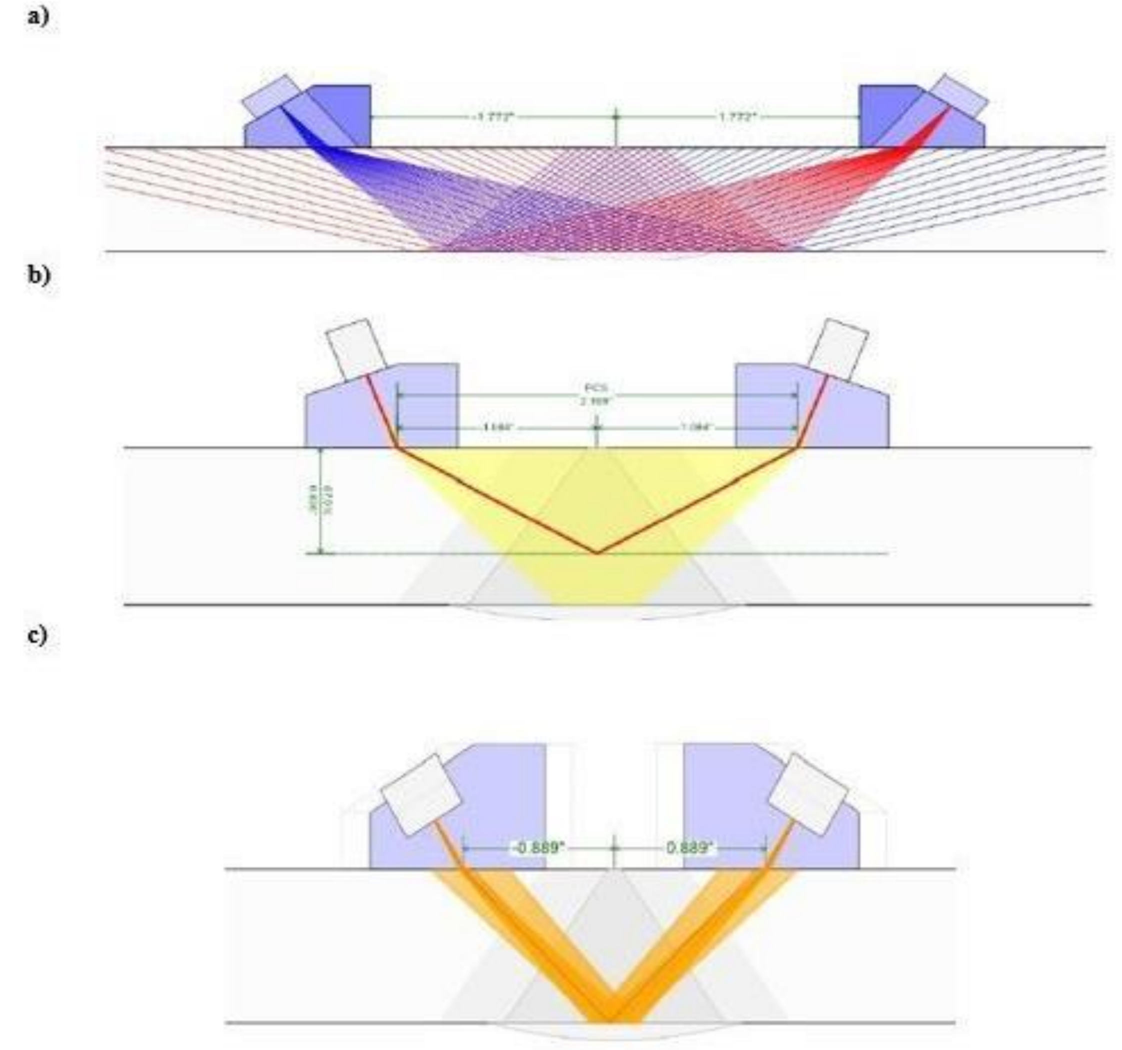


Figure 1. Probes setup: a) PA, b) TOFD, c) UT

Table 1. Scanner probes and wedge details

Process	Wedge details		Probe details				
	Type	Special considerations	Type	Frequency (MHz)	Angle	Diameter	Special considerations
UT	AT	AT	ASSW 4/45 transverse wave	4 MHz	45°	10mm	Irrigated
PA	WPA-A10-55S-IMW-AID18.5	A10 cylinder head shoe for 18.5" ID in the axial direction	5L16-9.6X10-A10-P-5-OM A10	5 MHz	0°	9.6mm x 10mm	16 elements
TOFD	60 deg ToFD Wedge	Stainless steel sprinkler for 18.5” ID	CDTOF 05/01 ToFD	5 MHz	0°	3 mm	AT

A PIG equipped with eight straight-beam probes was used for the corrosion mapping inspection, adhering to the specifications described in Table 2. The inspection method employed an immersion technique, utilizing classic UT probes combined with Phased Array equipment for the inspection and data collection, allowing the simultaneous use of eight channels, with A-scan and B-scan views and an encoder [11].

The movement of the PIG within the main pipe was enabled by an aluminum structure, which consisted of a frame equipped with a pneumatic winch and a system integrated with two cylinders. Every millimeter of displacement of the PIG was accurately recorded by the interaction of the encoder with the cylinders, which occurred when the cable was pulled.

Table 2. PIG probe details

Process	Probes details				
	Type	Frequency	Angle	Diameter	Comments
UT	Longitudinal Wave Single Crystal	5 MHz	0°	6mm	Immersion

2.2 Methodology for Analysis of Results

Two calibration blocks were employed for the result analysis, each serving a specific inspection purpose per ASME V standards [12]. The calibration blocks resembled the dimensions and material of the 15/16" main line. Initially, inspections were executed on these calibration blocks to document the scanner's configuration and capability to identify potential discontinuities in the welds and wall thickness loss throughout the main line's entire length.

After identifying these shortcomings, further inspections were conducted on two circumferential welds. One of the welds was previously scanned using conventional UT and was deemed acceptable with no flaws, while the second was declined because of recognized flaws. Scans were also carried out on a pipe that showed visible corrosion, aiming to detect and outline the extent of the corrosion throughout the surface.

2.2.1 Calibrations block

A calibration block compliant with Figure T-434.3 of code ASME V reproduced defects [12] commonly found in the main pipe circumferential welds. The calibration block (Figure 2) has four notches, two simulating defects on the pipe's ID and OD girth weld, and two transverses for the TCG (time-corrected gain) calibration.

Figure 2. Girth weld calibration block

To conduct the corrosion mapping, a pipe section with the same thickness, material, and diameter was used (Figure 3). Machined areas were created to simulate thickness losses, resulting in a step block with dimensions outlined in Table 3. This allowed the application of the same examination method during the subsequent inspections, qualifying for comparable and consistent results.

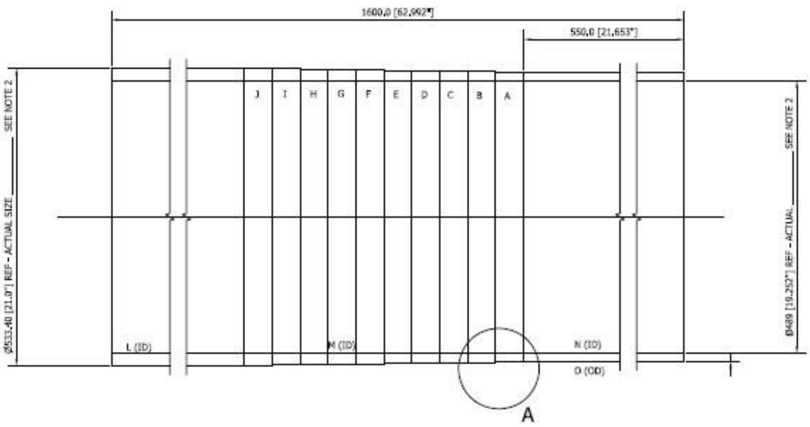


Figure 3. Corrosion mapping calibration block

Table 3. Corrosion mapping calibration block dimensions

Measure	Thickness (mm)
L	23.8
J	21.6
I	20.9
H	20.2
G	19.5
F	18.5
E	17.5
D	16.6
C	15.9
B	15.2
A	14.5

III. Results

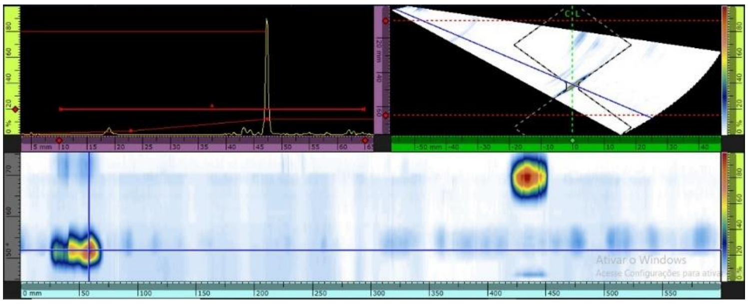
3.1 Inspection of the Main Pipe Weld Calibration Block

Following the requirements specified in the ASME V article 4 standard [12], all probes were calibrated and had their curves traced. The main pipe weld calibration block was then scanned, and all notches were successfully identified, as shown in Figure 4 (a, b, c, d, e) and Table 4. It is essential to highlight that each technique worked according to the scan plan, where The PA technique swiftly identified the notches that simulated flaws on the internal and external diameters. However, the time-of-flight diffraction technique could only detect the flaw on the exterior surface due to its restriction in detecting discontinuities close to the test surface, and the UT only caught the OD notch once its beam was focused on the weld cap.

Table 4. Inspection of the calibration block (mm)

Location	PA 1		PA 2		UT 1		UT 2		TOFD	
	Data	Cal. block	Data	Cal. Block	Data	Cal. block	Data	Cal. block	Data	Cal. block
ID notch	32	34	32	34	N/A	34	N/A	34	N/A	34
OD notch	35	34	36	34	35	34	35	34	34	34

a)



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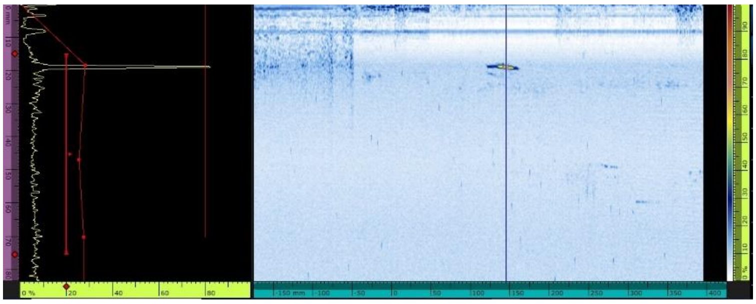

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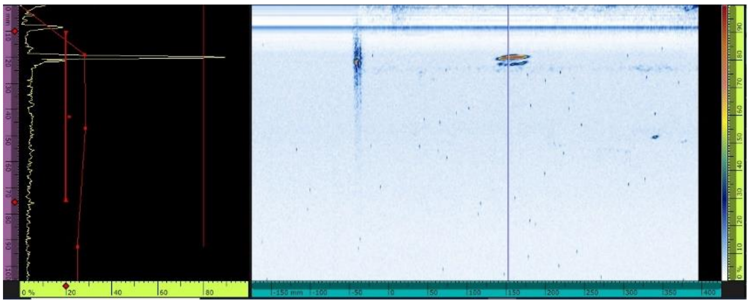
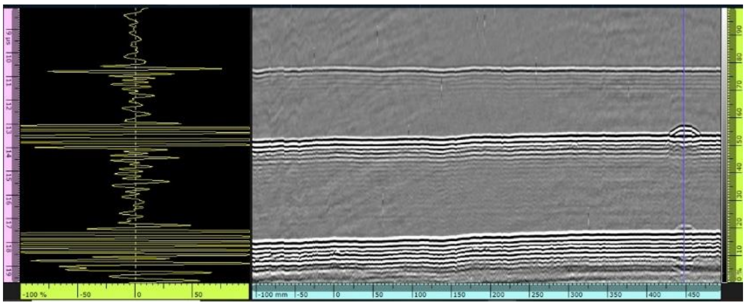


d)



e)

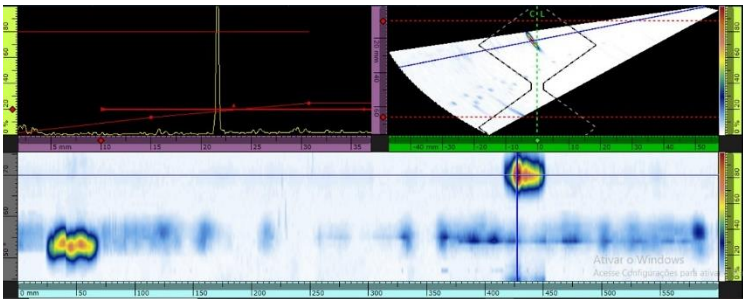


Figure 4. Data files of the girth weld calibration: a) PA1, b) UT1, c) UT2, d) TOFD, e) PA 2

3.2 Examination of an approved and a rejected main pipe circumferential weld

Pursuing the calibration of each probe and successfully confirming the location of all notches in the block scanning, an inspection was performed on the upper flange weld of RJ-03 (Figure 5). This joint was previously deemed acceptable after undergoing conventional UT inspection.

a)

b)

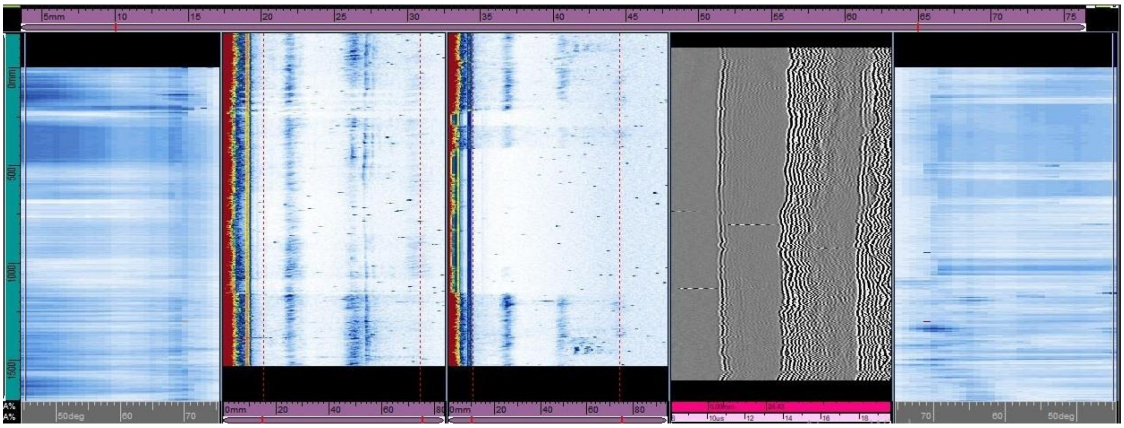


Figure 5. Girth weld inspection on RJ-03: a) Scanning direction and datum point, b) Multiple group view data file (PA1/UT1/UT2/TOFD/PA2)

To thoroughly assess the efficacy of our existing setup and inspection technique in identifying potential indications within the main line girth welds, a detailed examination was conducted on the lower flange weld of RJ-13 (Figure 6). This weld had previously failed conventional UT due to defects located in the datum point area, as outlined in Table 5.

Table 5. RJ-13 UT inspection results

Flaw	Angle	Location (mm)	Result
1	60°	0 to 267	Rejected
2	60°	1260 to 1358	Rejected
3	60°	1390 to 1480	Rejected

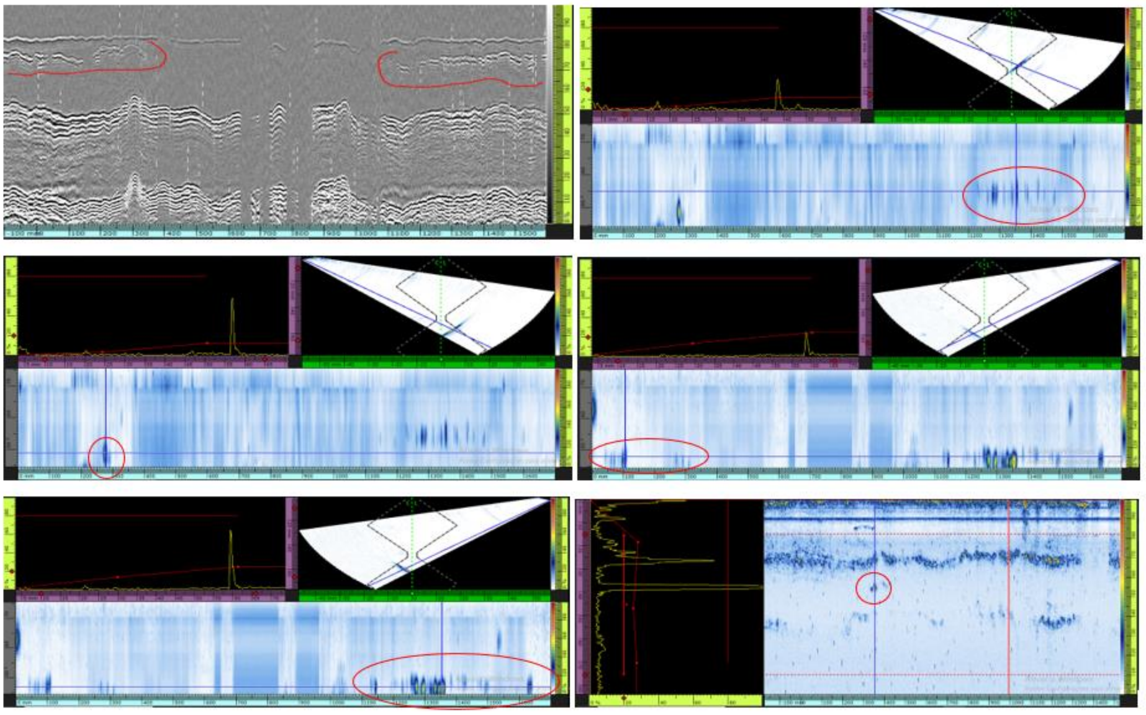


Figure. 6 Joint 13 inspection data files (multi-group)

3.3 Inspection of the calibration block for the corrosion mapping

Floating gates were used to monitor two back-wall echoes and the water column, evaluating the thickness losses of the block. The difference between gates A (red) and B (green) was used to analyze the wall thickness, as demonstrated in Figure 7 [8 - 13]

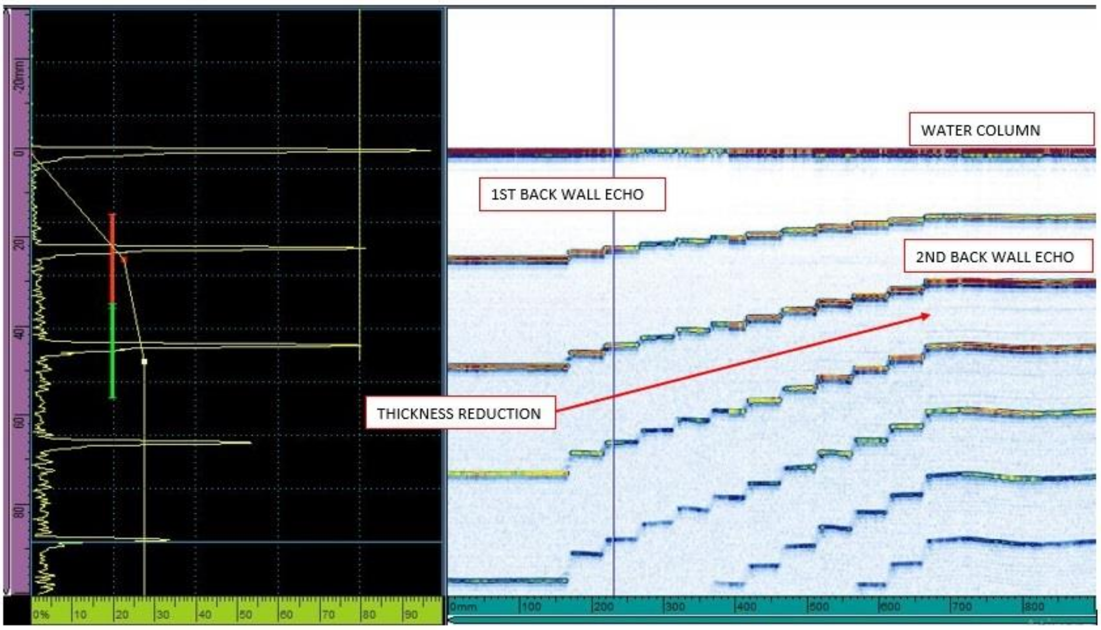


Figure 7. Corrosion mapping calibration block data file

The inspection method effectively pinpointed and cataloged all instances of reduced thickness. A detailed analysis in Table 6 showcases the specific thickness encountered per probe at various stages of the block. These findings illuminate a consistent trend, revealing a standard deviation range between

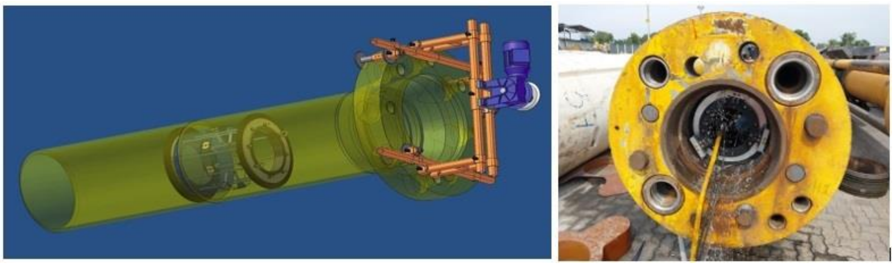
0.08 and 0.26 mm across the inspected wall. Furthermore, the method exhibited an impressive level of precision, yielding a maximum coefficient of variation of just 1.3%. This meticulous assessment ensures a comprehensive and nuanced visualization of the inspection results.

Table 6. Thickness encountered on the calibration block (mm)

Location	P1	P2	P3	P4	P5	P6	P7	P8	Average	Std Dev	Coefficient of Variation
L	23.94	24.12	24.12	24.09	24.03	24.18	24.12	24.03	24.08	0.08	0.3%
J	21.62	21.85	21.88	22.21	21.97	21.94	21.88	21.53	21.86	0.21	1.0%
I	20.76	20.82	20.97	21.35	21.23	21.12	21	20.7	20.99	0.23	1.1%
H	19.85	20	20.17	20.41	20.56	20.29	20.2	19.91	20.17	0.25	1.2%
G	19.26	19.38	19.41	19.79	19.91	19.55	19.47	19.14	19.49	0.26	1.3%
F	18.44	18.55	18.7	18.91	18.76	18.55	18.64	18.29	18.61	0.19	1.0%
E	17.55	17.73	17.82	17.96	17.88	17.76	17.76	17.55	17.75	0.14	0.8%
D	16.64	16.9	16.99	17.02	17.23	16.99	16.93	16.7	16.93	0.19	1.1%
C	16.08	16.29	16.26	16.43	16.58	16.23	16.2	16.02	16.26	0.18	1.1%
B	15.19	15.46	15.4	15.58	15.7	15.34	15.37	15.23	15.41	0.17	1.1%
A	14.34	14.43	14.37	14.28	14.51	14.64	14.28	14.22	14.38	0.14	1.0%

Following the identification of thickness reductions in the calibration block, the inspection shifted to a corroded pipe, a visual representation depicted in Figure 8b. To commence this thorough inspection process, the assembly of the winch frame onto the riser's flanges marked the initial step. Subsequently, the inspection began by delicately pulling the PIG through the ID of the tube, as visually illustrated in Figure 8a. The primary objective encompassed the corrosion mapping across the pipe's surface, aiming to rigorously evaluate the efficacy of detecting and cataloging all wall thickness loss within the pipe's infrastructure.

a)



b)

Figure 8. Corrosion mapping inspection: a) PIG going through the tube, b) Corrosion expected to be found.

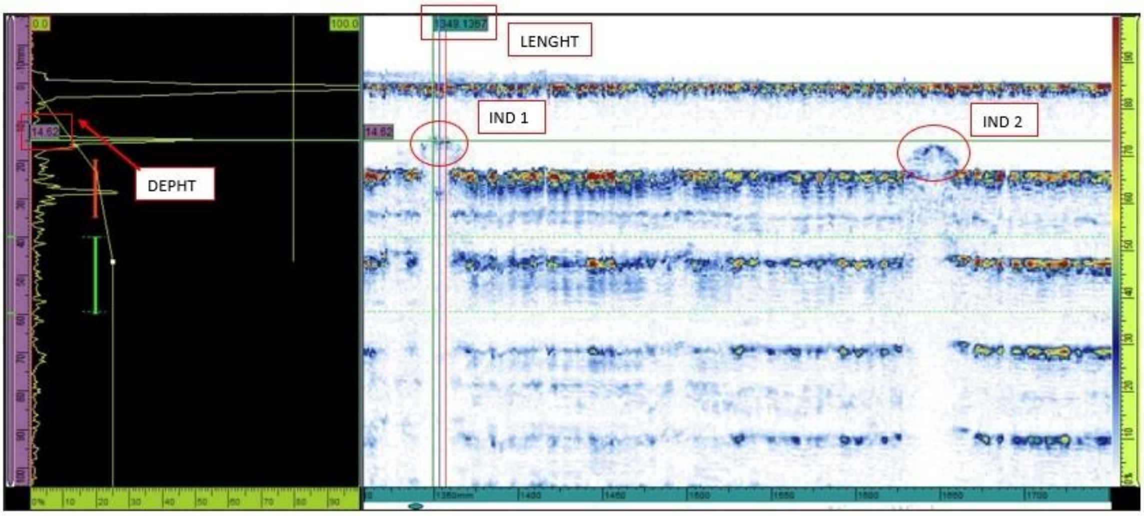


Figure 9. Zoomed view of the corrosion found.

Although the complete inspection data was recorded, the main objective of this inspection was to prove the corrosion identification. Thus, Figure 9 exhibits a zoomed-in view of this area of interest to highlight the data on corrosion detected.

IV. Discussion

4.1 Circumferential weld inspection

During the scanning of RJ-03 using the PA/TOFD/UT scanner, no irregularities or disruptions were identified, aligning perfectly with expectations. However, when turning our attention to RJ-13, the inspection yielded a wealth of information as all expected indications from Table 5 were not only detected but also with an enhanced sensitivity attributed to the amalgamation of various techniques. Figure 6 is the data registered, illustrating indications with a spatial distribution ranging from 0 to 350 mm and 1100 to 1600 mm, values corresponding to the acquisition process's initiation and termination points. The interconnection of these indications is intrinsic to the circumferential nature of the weld, with the acquisition's zero point thoughtfully set at 180° as clarified in Figure 5a.

Noteworthy is the instrumental role played by the TOFD technique, which demonstrated remarkable sensitivity, pinpointing the expected indications with a more considerable length. Furthermore, this precision was corroborated by observations in the PA1, PA2, and UT datasets, establishing a comprehensive validation of the findings across multiple inspection methodologies.

4.2 Corrosion mapping

As expected, all meticulously crafted machined reductions of the block were successfully pinpointed during the inspection. However, the configuration of the PIG, with its arrangement of eight probes equidistant at 45° angles, tempered expectations for identifying all indications in the corroded sample. Despite the widespread corrosion in the area, the inspection revealed only two distinct corrosion areas: between 1349 and 1368 mm and 1641 and 1660 mm.

A noteworthy observation emerged during numerous experiments: the PIG displayed a subtle spiral motion while being winch-pulled, altering the probe's beam trajectory responsible for that specific area. Despite concerted efforts to orient the probe towards the corrosion, the remaining indications were undetectable despite persistent attempts.

V. Conclusion

In conclusion, the evaluation of results obtained from data acquisitions conducted on calibration blocks and riser joints using state-of-the-art ultrasound methods, including Phased Array and TOFD in conjunction with traditional Ultrasonic Testing, has demonstrated their efficacy in detecting discontinuities in the circumferential weld of the main pipeline. Applying PA to cover the whole weld and TOFD to cover the weld filling enabled the 45-degree UT probes to focus precisely on the weld cap. This synergistic approach has proven invaluable for identifying potential flaws and ensuring the pipeline's structural integrity.

Adopting PA equipment emerged as an indispensable strategy in the context of corrosion mapping. Its unique configuration enables the simultaneous reading of all probes, offering integrated views such as A-scan and B-scan – features not commonly found in conventional UT equipment. Moreover, PA equipment facilitates data recording, allowing for the efficient utilization of encoders.

The nomenclature of corrosion mapping should be avoided. Instead, the examination should be comprehended as a complete thickness check at eight points through the entire pipe once it has been demonstrated that it is unattainable to detect all minor corrosion in the radial and axial directions of the line using these approaches. However, despite this restriction, the integration between classic UT and PA equipment has successfully detected corrosion and supplied a complete record of 100% of the scanned area, exceeding the capacities of manual examinations that only check four points at every 1.5-meter range.

Although both appraisals require more considerable investments in equipment, they offer significant advantages in terms of lowered logistical costs and enhanced rig performance. Substant resources and time can be saved by removing the need to offload the equipment for inspection.

Lastly, using advanced ultrasound methods in the drilling riser examinations gives a trustworthy and efficient solution for guaranteeing the integrity of the equipment when combined with classic UT. By adopting these innovative strategies, companies can minimize risks, improve safety, and enhance their operations in the long term.

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REFERENCES

[1] Velasquez, P. H. G. (2021). Wave fatigue study on a drilling riser located in ultra-deep waters.

[2] da Costa Fraga, C. T., et al. (2015). Brazilian pre-salt: An impressive journey from plans and challenges to concrete results. In Offshore Technology Conference (OTC) (p. OTC-25710-MS).

[3] Miller, C. A. (2017). Risers Introduction. Encyclopedia of Maritime and Offshore Engineering, 1-11.

[4] Veritas, D. N. (2010). Riser integrity management. DNV Recommended Practice DNV-RP-F206.

[5] Spec, A. S. M. E., et al. (2018). Specification for Marine Drilling Riser Equipment.

[6] Mabile, N. J., & Vagata, A. (2021, August). Riser Robotic Inspection-Reducing Safety Risk While Improving Efficiency and Effectiveness. In Offshore Technology Conference (p. D011S007R003). OTC.

[7] Benzecry, F. (2014). Robotic system for offshore inspection of main drilling riser lines (TCC Mechanical Engineering). Federal University of Rio de Janeiro.

[8] Neidhardt, D., Ziegler, R. F., & Lancaster, J. (2017). Drilling Riser Integrity Assurance for Deepwater Floating Drilling. In Offshore Technology Conference. OnePetro.

[9] Turcotte, J., Rioux, P., & Lavoie, J.-A. (2016). Comparison corrosion mapping solutions using phased array, conventional UT and 3D scanners. In 19th World Conference on Non-Destructive Testing.

[10] Dai, L. S., Feng, Q. S., Xiang, X. Q., Sutherland, J., Wang, T., Wang, D. P., & Wang, Z. J. (2020). Application of USCCD on girth weld defect detection of oil pipelines. Applied Sciences, 10(8), 2736.

[11] Pavan, K., Patankar, V. H., & Kulkarni, M. S. (2020). Ultrasonic gauging and imaging of metallic tubes and pipes: a review.

[12] American Society Mechanical Engineer. (2023). ASME SEC. V – Article 4 – Ultrasonic Examination Methods for Welds.

[13] Cantero-Chinchilla, S., Wilcox, P. D., & Croxford, A. J. (2022). Deep learning in automated ultrasonic NDE– developments, axioms and opportunities. NDT & E International, 102703.

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