EMAT-C Ultra Technology for Crack Inspection in Gas Pipelines

Matthias Hilvert, Felipe Freitas, Thomas Beuker
ROSEN Group

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Abstract

EMAT technology has been established as a viable method for In-Line Inspection (ILI) of pipelines. Recently, the practices in the industry for increasing sensitivity regarding axial crack detection has been connected to the emerging fuel discussion. In addition, the maintenance of existing assets can also benefit from an optimized hydrotest and dig programs thru an improved in-line inspection approach.

The presented new EMAT Ultra technology builds upon the existing technology and allows a seamless integration of existing experiences and workflows. The sensor coverage for this ILI technology has been doubled to achieve redundancy and a dual sound path approach (CW, CCW). In principle, the detection reliability for cracks with critical dimensions has been improved beyond the industry's current standards to 95% (POD). This paper will present the performance of this new technology based on industry standards and will highlight the results obtained from several pipeline inspections. This technological improvement aims to contribute positively to the pipeline industry by fostering innovation while respecting the robust foundations laid by the existing EMAT technology.

Nomenclature

AI	Artificial Intelligence
CW	Clockwise
CCW	Counterclockwise
EDM	Electrical Discharge Machine
EMAT	Electromagnetic Acoustic Transducer
EMAT-C	EMAT Technology for Axial Cracking
ILI	Inline Inspection
IMP	Integrity Management Program
MFL	Magnetic Flux Leakage
OD	Outside Diameter
POD	Probability of Detection
POI	Probability of Identification
t	Thickness
UTCD	Ultrasonic Crack Detection

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Introduction

To manage integrity threats in pipeline system, operators use a wide range of ILI technologies. The inspection tools are used to detect, identify, and size anomalies based on their performance specification, forming the backbone of the operator's IMPs.
In this context, optimized ILI approaches have become essential for improving maintenance programs, such as hydrotesting and dig scheduling, enabling operators to better manage the integrity of their pipeline networks.
The introduction of the new EMAT-C Ultra technology marks a significant advancement in pipeline inspection capabilities. Building on the robust foundation of existing EMAT-C technology, the EMAT-C Ultra seamlessly integrates with established workflows while introducing critical improvements. One example is the doubling of the sensor coverage, which provides redundancy and employs a dual sound path detection method (clockwise and counterclockwise). This innovation boosts detection reliability for cracks with critical dimensions, achieving a POD of 95%, which exceeds current industry standards.
This paper presents an analysis of the EMAT-C Ultra technology's performance, aligned with industry benchmarks, and shares results from pipeline inspections to validate its effectiveness. By combining innovation with continuity, the EMAT-C Ultra aims to set a new standard in pipeline integrity management, enhancing safety and operational efficiency across the industry.

The Electromagnetic Acoustic Transducer (EMAT) Technology

Electromagnetic Acoustic Transducer (EMAT) technology is a well-established and further growing method for detecting cracks and crack-like defects in pipelines. Since its commercially introduction in 2006, EMAT has steadily gained adoption as an essential tool in pipeline integrity management, thanks to its ability to generate and analyze ultrasonic sound waves without requiring a coupling medium.

EMAT operates using two physical phenomena: the Lorentz force and magnetostriction. These effects are produced by alternating currents interacting with a static magnetic field, allowing the system to generate ultrasonic waves [1]. When these waves encounter cracks or defects in the base material or longitudinal seam welds, they reflect back, and the tool's echo channel records these signals (Figure 1). A large number of overlapping transducers are arranged on the inspection tool in such a way that a high-resolution image of the pipeline is generated. Due to the short propagation distance of the waves between the measuring elements, this design ensures high signal quality which is the basis for accurate determination of the position and dimension of flaws [2]. Unlike traditional piezoelectric ultrasound, which captures only a single frequency, EMAT records an entire frequency spectrum. This broader dataset allows for more detailed analysis, enabling accurate identification and sizing of linear anomalies.

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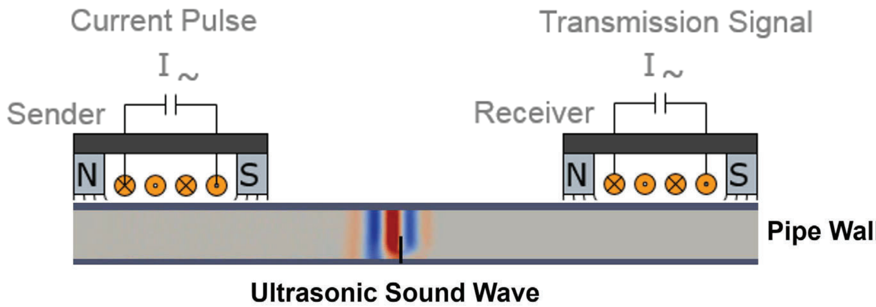

Figure 1. Schematic explanation of the EMAT soundwave propagation

The technology is highly versatile, capable of inspecting a wide range of pipelines diameters (from 10 to 48 inches), while smaller diameters (6 and 8 inches) are prepared to be commercially available. Its performance has been rigorously validated through numerous of industry pull tests and case studies, ensuring consistent and reliable results in the field.

In 2024, over 15,000 miles (~24,000 km) of pipelines were inspected by ROSEN using EMAT-C technology for crack detection. Over the past two decades, more than 125,000 miles (~200,000 km) of pipelines data have been analyzed, underscoring its critical role in pipeline integrity.
This large number of inspected pipeline miles is accompanied by a large number of field verification results, which are invaluable for the improvement and further development of the technology. ROSEN has a treasure trove of over 10,000 reported anomalies that have been verified in the field. This information is an enormously important source to be able to use modern AI (Artificial Intelligence) technologies for the continuous further development and optimization of data analysis [3].

EMAT-C Ultra

For nearly 20 years, ROSEN's EMAT-C tools have been an essential technology for pipeline integrity management. Over time, these tools have undergone continuous development, evolving from their initial designs into robust systems, addressing specifically operational challenges like data gathering (sensor design and suspension) or high gas flow (speed control).

When first introduced, EMAT tools resembled standard MFL tools with additional EMAT sensors attached. While effective for their time, these tools have transformed significantly. Nowadays EMAT-C tools are engineered to deliver low-noise data with optimized running behavior. This includes advanced electronics for efficient data storage and robust sensors capable of enduring several hundred kilometers of inspection without degradation (Figure 2).

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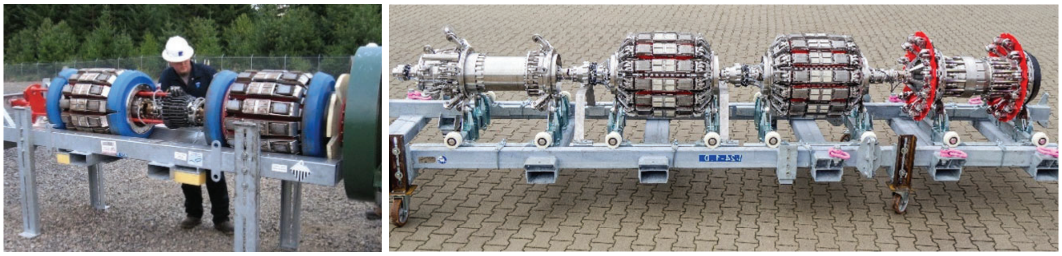

Figure 2. Comparison between EMAT-C tools from around 2006 (left) and 2023 (right).

As with earlier versions, the current EMAT-C tool employs two measurement segments, each covering a little over 50% of the pipeline's circumference. An overlap factor ensures a redundancy in coverage that varies from ~110% to ~125%, depending on the tool size. This also ensures entire circumference coverage even if the tool rotates slightly during inspection. This design guarantees comprehensive inspection results at full performance specification, leaving no area unchecked.

The latest innovation in this technology, the EMAT-C Ultra, introduces a further optimized sensor system. One of the key enhancements is the increased coverage to 200% (Figure 3).

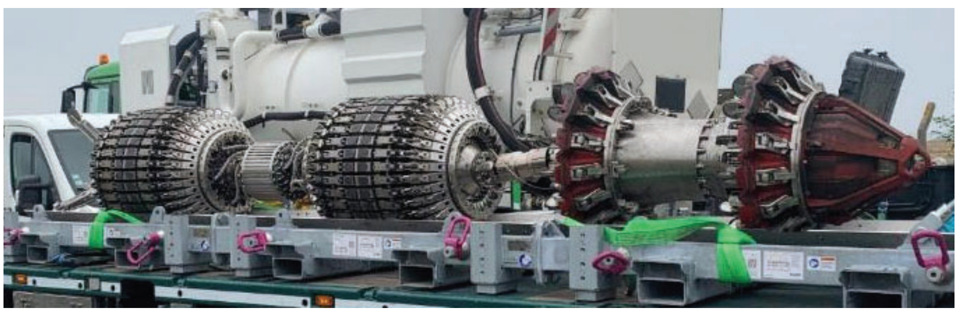

Figure 3. Picture of an EMAT-C Ultra tool at job site before launching

This is achieved through a new sensor arrangement, ensuring every point on the pipeline is inspected in both clockwise and counterclockwise directions (Figure 4).

This dual-directional inspection enhances the detection of smaller, more complex flaws that may not be detectable by other technologies.

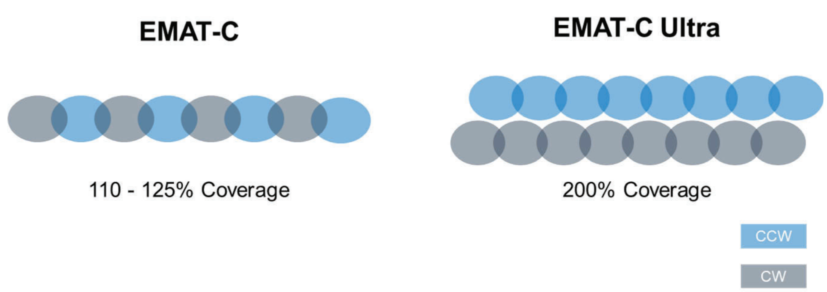

Figure 4. Comparison between EMAT-C sensor coverage (left) and EMT-C Ultra sensor coverage (right) at full performance specification.

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Another critical advancement is the separation of sender and receiver sensors onto independent carriers. This configuration allows each channel to move freely, maintaining optimal contact with the pipe wall even in challenging areas like long seam welds. This dual-sided scanning ensures that even if a sensor carrier is momentarily influenced by the geometry of the longitudinal weld, the crack-like indications are still captured by multiple sensor channels (Figure 5). This redundancy enables the detection and identification of smaller flaws in the pipe body and longitudinal welds.

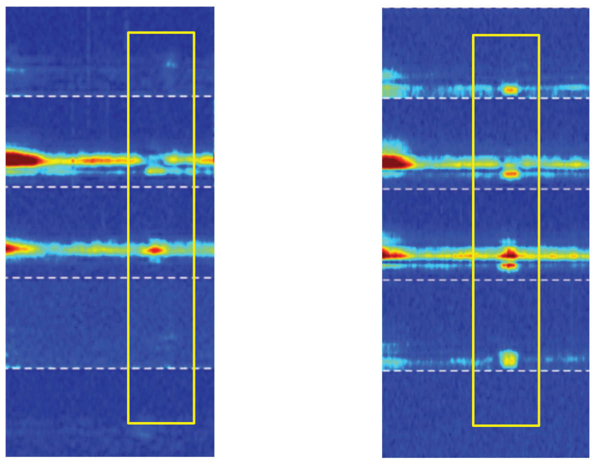

Figure 5. Comparison of EMAT-C (left) and EMAT-C Ultra (right) longitudinal weld data with a crack indication (yellow box).

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The EMAT-C Ultra service represents a significant evolution of the well-established and reliable EMAT-C service, incorporating advanced sensor technology to achieve enhanced crack detection and resolution (Figure 6). With its improved capabilities, the EMAT-C Ultra has reduced the minimum detectability (Table 1). This improvement enables the detection shorter and shallower linear indications, bringing its resolution and detection thresholds close to those offered by state-of-the-art UTCD technologies.

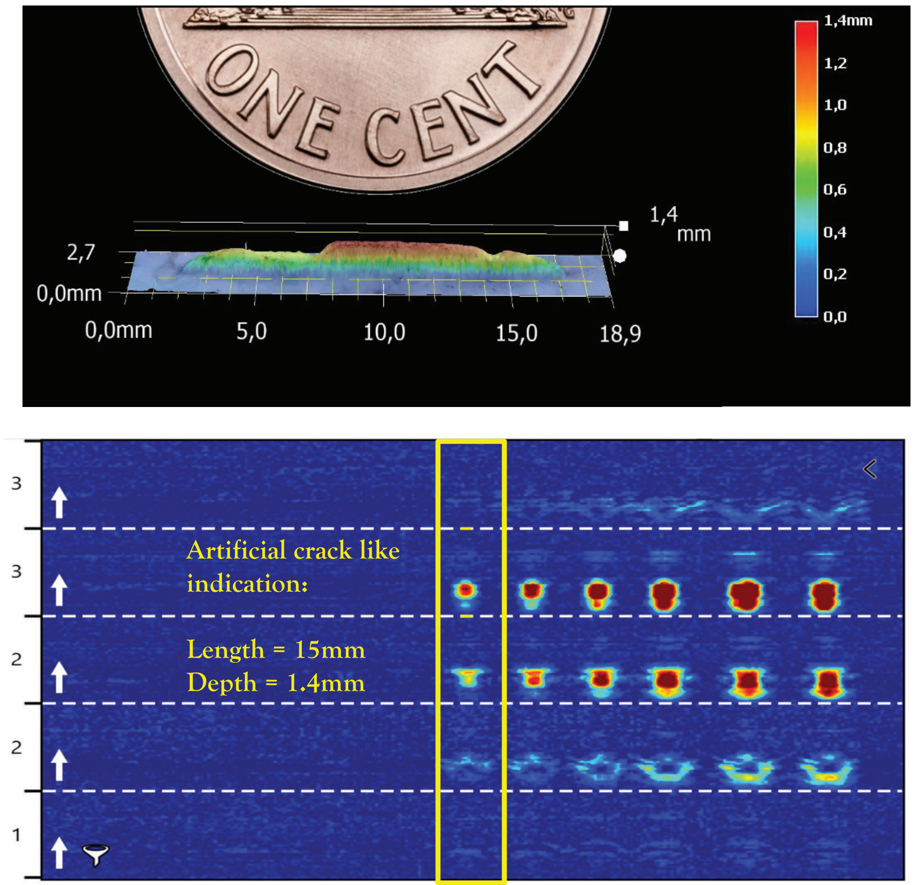

Figure 6. Example of a short and shallow feature detected by EMAT-C Ultra. The channels are alternating between cw and ccw orientation

One of the key advancements of the EMAT-C Ultra service is its enhanced detection reliability for linear indications (Figure 7). The POD has been improved to 95%, exceeding current industry standards. Additionally, the combination of higher sensitivity and dual-direction coverage, clockwise and counterclockwise, significantly increases the probability of identifying all common types of internal and external axial cracks and crack-like defects. Even for smaller anomalies, which are below the specified service performance, the probability of identification reaches up to 90%.

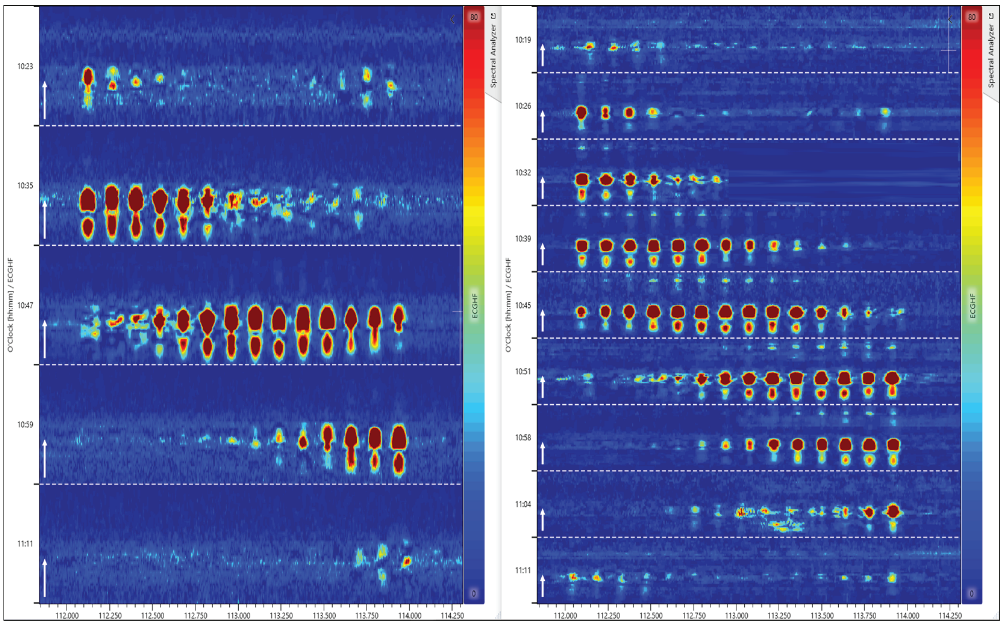

Figure 7. Comparison of EMAT-C (left) and EMAT-C Ultra (right) data of the same anomalies. The channels are alternating between cw and ccw orientation

The EMAT-C Ultra service also ensures seamless compatibility with existing EMAT-C workflows, allowing operators to integrate the enhanced capabilities without disruption. This consistent advancement of sensor technology and methodology solidifies the EMAT-C Ultra as a practical solution for pipeline crack detection, continuing the history of collected EMAT-C data for a safe and reliable pipeline assessment.

EMAT-C Ultra Performance Verification

The EMAT-C Ultra is not only a concept or prototype, but also a fully operational technology. It has already been successfully deployed in multiple pipeline inspections, demonstrating its effectiveness in real-world conditions. The current available EMAT-C Ultra tools cover pipeline diameters ranging from 10" to 42" OD. Additional tool sizes are under develop and expected to be available soon.

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Before any new ROSEN technology is deployed, it undergoes an in-depth verification process. This critical step is designed to qualify the technology in accordance with API 1163, the industry standard for in-line inspection systems.

The verification process ensures that the new technology meets all necessary requirements for safe operation and complies with the intended specifications. By adhering to this stringent protocol, the reliability and suitability for real-world applications are ensured, reinforcing a commitment to safety and performance excellence.

To comply with the requirements in API 1163, the corresponding efforts and facilities are huge. The verification process has been carried out at the ROSEN Test Centre in Lingen, Germany (Figure 8). The Test Centre extents over an expansive area of 1,162,502 ft^2 (108,000 m^2), making it a leading Centre for pipeline testing and analysis. It houses over 30,512 feet (9,300 meters) of test pipelines, comprising 6,000 pipe segments with diameters ranging from 3" to 56".

The facility is equipped to simulate a variety of pipeline anomalies, including artificial and natural corrosion, notches, natural cracks, synthetic cracks, dents, hard spots, and more, ensuring comprehensive testing scenarios.

Each year, approximately 5,000 pull tests and 800 pump tests are conducted, showcasing the required capacity to evaluate pipeline integrity under rigorous conditions.

Figure 8. Aerial view of the ROSEN Test Centre in Lingen, Germany

Verification for EMAT-C Ultra tools focus on specific parameters that significantly influence their detection and sizing capabilities, such as wall thickness and sensor platform configuration. To ensure accuracy and reliability, the verification process must cover a broad range of these parameters.

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For the EMAT-C Ultra service, ROSEN adopted a verification approach utilizing four different, fully operational EMAT-C Ultra tools for pipeline diameters of 20”, 24”, 30”, and 36”. Additional diameters, both smaller and larger, will be included as they become available.
As part of the verification process, pull tests were conducted across all diameters, covering a range of wall thicknesses from 0.193” (4.9 mm) to 0.484” (12.3 mm).

For this pull tests, planar flaws were machined in the test spools of all diameters to assess the capabilities of the EMAT-C Ultra service.
These flaws are very narrow rectangular EDM notches to mimic planar reflectors in the pipe wall. For gathering data of this test flaws, the inspection tool is pulled through the test pipe several time to ensure repeatability of the measuring technology.

In addition to the classic EDM notches, it is nowadays also possible to introduce synthetic anomalies into test spools. These anomalies can be produced with a precise morphology, size and orientation. For testing the EMAT-C Ultra, not only synthetic planar but also synthetic volumetric flaws to mimic real life pipeline defect, like sharp edged or general corrosion was used (Figure 9).

Figure 9. Example of a synthetic crack (made visible by MPI) and a synthetic sharp-edged corrosion.

In order to verify the EMAT-C Ultra, a total of 370 pull tests were carried out in the various pipeline diameters. Due to the high number of anomalies present in the pull test pipes, a considerable amount of data was generated, amounting to 78,000 anomaly signals in total, which were then used for the verification of the EMAT-C Ultra. The extensive data set yielded statistically significant insights into the tool's capabilities, confirming its reliability and robustness in a range of operational contexts.

The analysis of the 78,000 anomaly signals makes it possible to derive statistically sound parameters for the detection, identification and measurement accuracy of the system.
The data was analyzed in a workflow similar to the evaluation of a standard pipeline. The aim is to evaluate the data as it would be done for a pipeline inspection later on to obtain a result that is as realistic as possible.

As statistical approach for the calculation of the POD and the POI, the one-sided Clopper-Pearson binomial proportion confidence intervals were chosen. This to ensure to obtain statistically significant results with a guaranteed confidence level [4].

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As an example, Figure 10 shows the statistics for POD in pipe body and long seam according to Clopper-Pearson for the minimal detectable feature. The orange bar shows the number of detected features, while the blue bar shows the number of indications used for the test. If the orange bar is above the black line, the number of hits is large enough to proof the specified POD is given with 95% confidence. For both, the pipe body and the long seam, it's clearly visible that for all tested wall thicknesses the orange bar is above the black line.

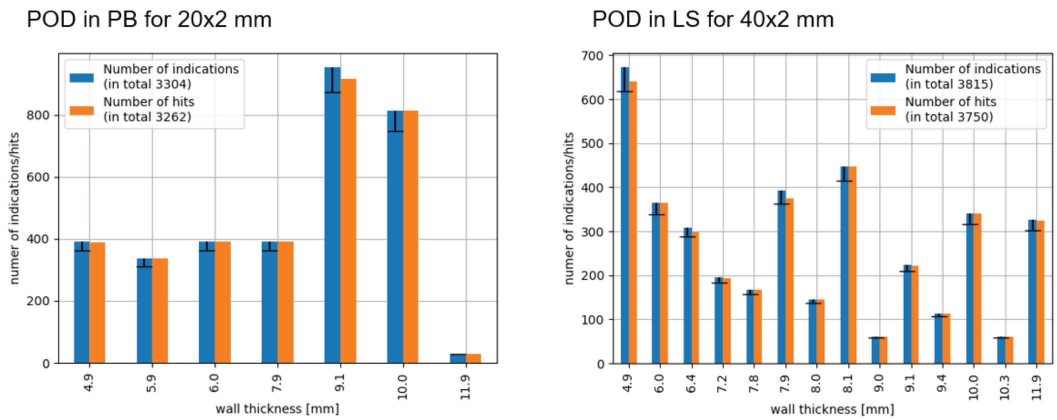


Figure 10. Statistics according to Clopper Pearson of the pull test result analysis for pipe body (PB) and long seam (LS)

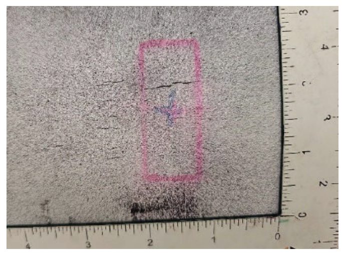
As demonstrated in the illustration of the POD (Figure 10), ROSEN has also evaluated the data for the other parameters of the specified value. From this analysis, based on a data set comprising over 78,000 anomaly signals, a conservative and reliable specification for the new EMAT-C Ultra technology can be derived (Table 1) for wall thicknesses from from 0.193" (4.9 mm) to 0.484" (12.3 mm) with a POI of 90% for all common types of radial and longitudinal cracks, with terminating on the internal or external wall surfaces, including the weld bead.

Table 1. Excerpt of the EMAT-C Ultra Specification for isolated radial cracks

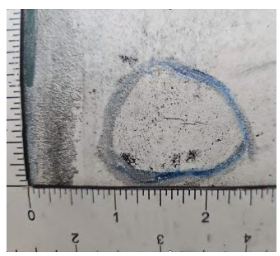
	Isolated radial cracks w/ axial orientation				
	in pipebody			in longitudinal weld area	
POD	90%	90%	95%	90%	95%
Minimum length	0.79" (20mm)	1.57" (40mm)	2.36" (60mm)	1.57" (40mm)	2.36" (60mm)
Minimum depth	0.08" (2mm)	0.04" (1mm)	0.08" (2mm)	0.08" (2mm)	0.12" (3mm)
Certainty Sizing	80%				
Depth sizing accuracy for t < 0.39" (10mm)	+/- 0.20t	+/- 0.15t			
Depth sizing accuracy for t > 0.39" (10mm)	+/- 0.25t	+/- 0.20t			
Length sizing accuracy	+/- 0.79" (20mm)				

EMAT-C Ultra Field Validation

In addition to pull tests, several in service pipelines have been inspected using the EMAT Ultra tools. The figures below (Figure 11) show cracking findings based on the EMAT-C Ultra callouts. Figure 11a shows the crack within the callout box. Figure 11 b-c, show cracking findings within the tolerance callout box. In-field sizing was in good agreement with the estimated tool sizing. All these cracking were short in length (0.4 to 0.9 inches) with depths ranging 25 to 37% of the wall thickness.



(a)



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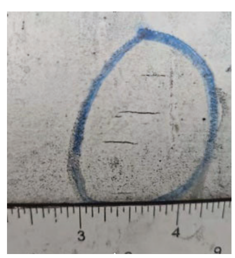

(c)

Figure 11. Cracking findings based on the EMAT-C Ultra callouts (ruler units in inches).

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Conclusion

Managing pipeline integrity is a critical aspect of ensuring safety and operational efficiency within the industry. The introduction of the EMAT-C Ultra technology represents a significant step forward, addressing the limitations of existing inspection methods through innovative features like the 200% sensor coverage and dual sound path detection. With EMAT-C Ultras higher sensitivity and by achieving a POD of up to 95% as well as the possibility to be integrated seamlessly into established integrity management workflows, EMAT-C Ultra not only meets but exceeds industry standards. This advancement underscores the importance of continuously optimizing ILI technologies to enhance pipeline maintenance programs and support the evolving demands of integrity management. The findings presented in this paper validate the EMAT-C Ultra's potential to redefine pipeline inspection practices, contributing to safer and more reliable operations in an efficient manner.

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