EMAT-C Ultra Technology for Baseline Crack Inspection in Hydrogen Pipelines

DR. M. ERDELEN-PEPPLER, M. HILVERT, M. TEWES & T. BEUKER > ROSEN GROUP

Abstract

The progressing energy transition and a fast buildup of the hydrogen pipeline backbone will play a major role in achieving net zero targets. The conversion of existing pipelines for the transport of hydrogen will play a key role in achieving the targets, which introduces new challenges for pipeline owners and operators. Pipeline repurposing projects and related in-line inspection (ILI) requirements are connected to industry practices for increasing the sensitivity of axial crack detection. EMAT technology has been established as a viable method for in-line inspections of pipelines. Built on existing EMAT technology, the new EMAT Ultra technology presented here allows for a seamless integration of existing experiences and workflows. The sensor coverage for this ILI technology has been doubled in order to achieve redundancy and a dual sound path approach (CW, CCW). The detection reliability for cracks with critical dimensions has been improved to 95% (POD), exceeding current industry standards.

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 existing EMAT technology. The paper will outline an industry best practice from a pipeline integrity standpoint and show how the new EMAT Ultra Technology for axial crack detection could support pipeline operators in de-risking the conversion process from natural gas to hydrogen transportation.

1. Introduction

Climate change and environmental degradation pose significant threats to Europe and the global community. With over 75% of the EU's greenhouse gas emissions stemming from energy production and consumption, decarbonizing the energy sector is crucial for meeting the EU's 2030 climate objectives and achieving carbon neutrality by 2050. Initiatives like the European Green Deal and Fit for 55 aim to address these challenges by transitioning the EU into a sustainable, resource-efficient, and competitive economy.

Hydrogen is anticipated to play a pivotal role in reducing greenhouse gas emissions by at least 55% by 2030 and achieving net-zero emissions by 2050. Beyond its traditional use as an industrial feedstock, hydrogen serves as a clean energy carrier and fuel, emitting no CO2 during combustion, thereby mitigating its contribution to the greenhouse effect. Clean hydrogen can decarbonize hard-to-abate sectors, including energy-intensive industries like steel, chemicals, and cement, as well as transportation (e.g., heavy-duty vehicles, rail, and maritime) and the power sector.

To enable large-scale hydrogen distribution, the injection of hydrogen into natural gas grids and the repurposing of existing natural gas pipelines for 100% hydrogen transmission are critical strategies. However, ensuring the safe and reliable operation of hydrogen pipelines requires overcoming technical challenges, particularly those associated with hydrogen embrittlement and material compatibility. Hydrogen embrittlement can degrade material properties, leading to reduced fracture toughness, accelerated fatigue crack growth, and increased risk of containment loss due to fluctuating loads, such as pressure variations in pipelines.

Worldwide, pipeline operators use a wide range of inline inspection (ILI) technologies to manage integrity threats in pipeline systems, including those integrity threats which are summarized by the term "planar anomalies." The ILI tools are used to detect, identify, and size planar anomalies based on their performance specification, forming the backbone of the operator's Integrity Management Programs.

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. As per POF 520 white paper standard, EMAT-C is a proven ILI technology for detection of planar anomalies in natural gas. (1) 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 additional redundancy and employs a dual sound path detection method (clockwise and counterclockwise).

This paper presents the EMAT-C Ultra technology performance in the context of a baseline inspection for new, purpose-built hydrogen pipelines or baseline inspection for pipeline repurposing from transportation of natural gas towards future hydrogen transportation. Following industry benchmarks and 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, supporting hydrogen pipeline conversion and commissioning projects.

2. 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 commercial 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. 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

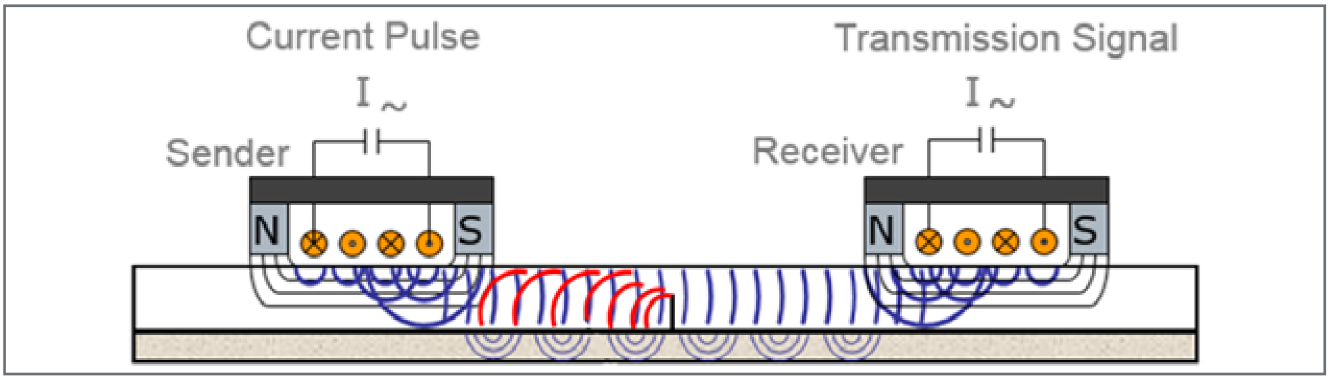


Figure 1: Schematic explanation of the EMAT soundwave propagation

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. 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 planar anomalies. (2)

The technology is highly versatile. Currently, tools are available that can inspect a wide range of pipeline diameters (from 10 to 48 inches), while smaller diameter tools (6 and 8 inches) are in development. Its performance has been rigorously validated through numerous industry pull tests and case studies, ensuring consistent and reliable results in the field.

In 2024, over 24,000 km of pipelines were inspected by ROSEN using EMAT-C technology for crack detection. Over the past two decades, more than 200,000 km of pipeline 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)

3. EMAT-C ILI Tool Development

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 guidance) or high gas flow (speed control).

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 (Figure 2).

The latest innovation in this technology, the EMAT-C Ultra, introduces a further optimized sensor system.

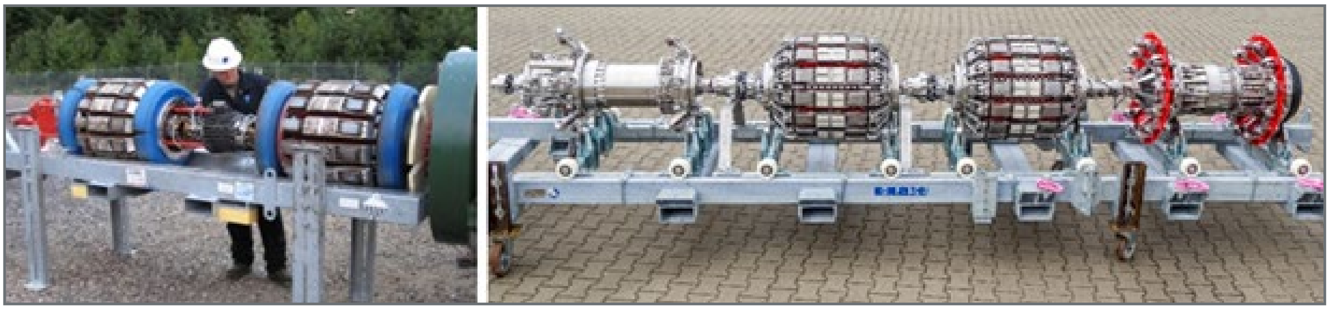


Figure 2: Comparison between EMAT-C tools from around 2006 (left) and 2023 (right)

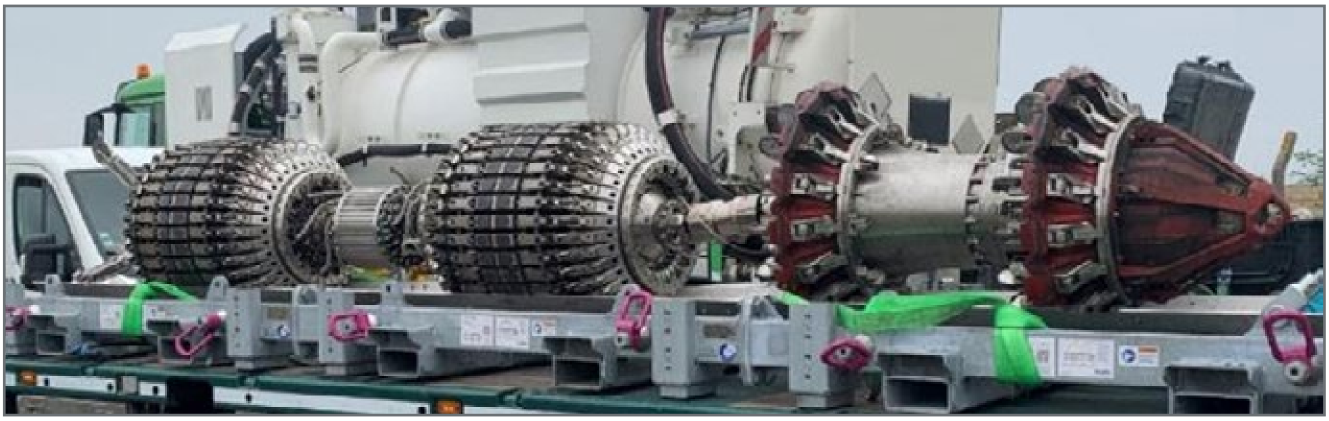


Figure 3: Picture of an EMAT-C Ultra tool at job site before launching

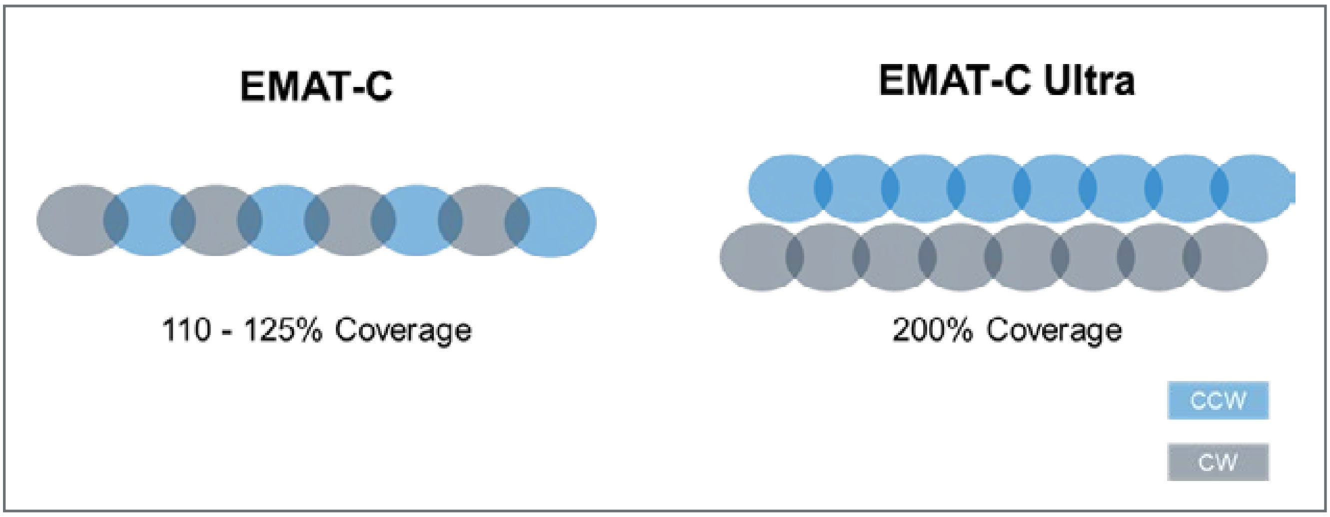


Figure 4: Comparison between EMAT-C sensor coverage (left) and EMAT-C Ultra sensor coverage (right)

One of the key enhancements is the increased coverage to 200% (Figure 3). 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.

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.

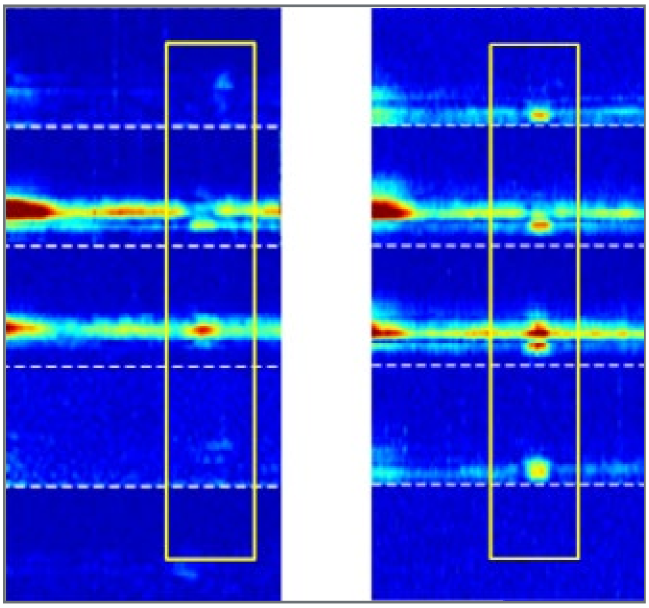


Figure 5: Comparison of EMAT-C (left) and EMAT-C Ultra (right) longitudinal weld data with a crack indication (yellow box)

The EMAT-C Ultra Service represents a significant evolution of the well-established and reliable EMAT-C Service, incorporating advanced sensor technology

Length	Depth in pipe body	Depth in longitudinal weld area	POD
20 mm	2 mm	n.a.	90%
40 mm	1 mm	2 mm	90%
60 mm	2 mm	3 mm	95%

Table 1: Excerpt of the EMAT-C Ultra Specification for isolated axial cracks

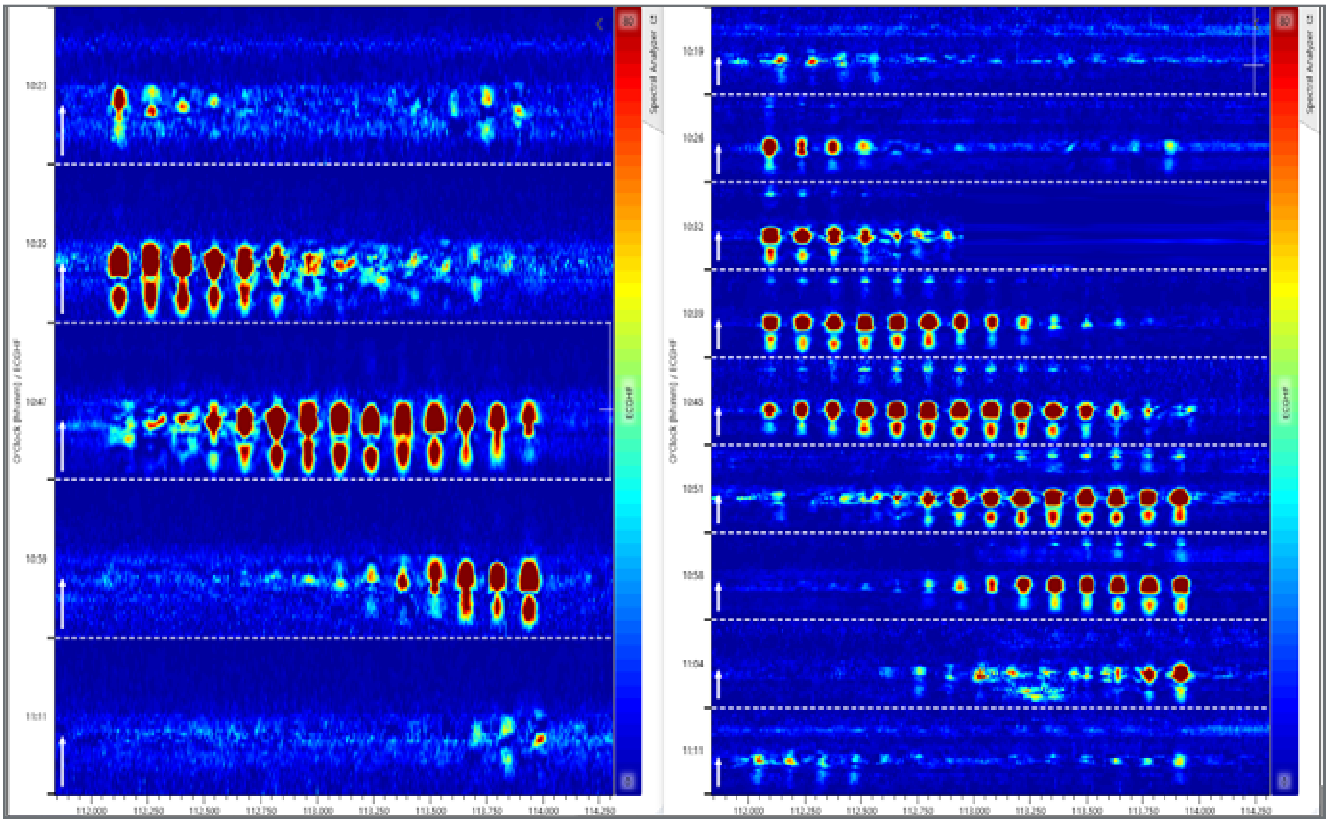


Figure 6: Comparison of EMAT-C (left) and EMAT-C Ultra (right) data of the same anomalies

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 of shorter and shallower linear indications, bringing its resolution and detection thresholds close to those offered by state-of-the-art UTCD technologies.

One of the key advancements of the EMAT-C Ultra Service is its enhanced detection reliability for linear indications. 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%. The solution is now available to cover pipeline diameters ranging from 10" to 42" OD. Additional tool sizes are under development and expected to be available soon. (4)

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.

4. EMAT-C Ultra for H_2 Baseline Crack Inspection

Gaseous hydrogen is known to influence the mechanical properties of carbon steel, primarily by reducing ductility, lowering fracture toughness, and

Length	Depth in pipe body	Depth in longitudinal weld area	POD
20 mm	1 mm	2 mm	90%

Table 2: Excerpt of the EMAT-C Ultra Specification for hydrogen pipelines for isolated axial cracks

increasing fatigue crack growth rates. (5) The presence of hydrogen in pipelines, which reduces critical defect size and accelerates fatigue crack growth, may necessitate the use of more advanced inspection techniques and/or more frequent inspections. Compared to natural gas operations, hydrogen service requires evaluating smaller critical cracks and crack-like features. Consequently, inspection tools must be capable of detecting and accurately sizing these smaller features. Operators should account for changes in critical defect dimensions when developing risk-based inspection programs and selecting appropriate inspection technologies. (6) Similar is described by POF 520 White Paper, "In-Line Inspection Tool Readiness for Hydrogen Pipelines:" Hydrogen embrittlement in combination with pressure cycling may lead to fatigue crack growth. Hence, planar anomalies are of particular concern to hydrogen pipelines. Additionally, POF considers that future hydrogen pipelines will operate with higher stresses and more fatigue loading than existing hydrogen pipelines. This, in combination with reduced fracture toughness, means that planar anomalies that are stable under current operating conditions may no longer be stable once hydrogen is introduced to the existing pipelines. (1)

Regarding ILI crack detection performance specifications, POF 520 assesses general EMAT-C crack detection sensitivity to be sufficient for cases with critical defect sizes, such as 3 mm deep by 50 mm long, as recommended by EPRG for Level 1. (1) In the context of hydrogen introduction, the new EMAT-C Ultra solution supports the industry requirements for more sensitive ILI crack detection performance specifications, as provided in (Table 1). When utilized for baseline ILI for new build hydrogen pipelines, or as baseline ILI for pipeline repurposing projects towards future transportation of hydrogen, the sensitivity of the EMAT-C Ultra performance specification can be improved even further, as provided in (Table 2). The aim of the service is the inspection of pipelines at the lower detection thresholds. This offers an important advantage for pipelines operators to monitor the full pipeline anomaly population, including potential existing shallower planar anomalies. The increased sensitivity would also support smaller ECA defect sizes, compared to the EPRG Level 1 recommended dimension of 3 mm x 50 mm, in the absence of more detailed inspection and manufacturing information. Crack-like defects with 20 mm length and 1 mm depth in the pipe body and 2 mm depth in the long seam, respectively, can be detected at a POD of 90%.

The increased sensitivity, as shown in (Table 2), is possible provided under the pre-condition of a clean pipeline, e.g., a fair absence of debris, dents, or corrosion anomalies. In general, this performance specification can be offered for new build pipelines and for pipelines to be repurposed for hydrogen transportation in good condition, with no significant defects or existing integrity threats. If the pipelines to be repurposed have already significant defects or existing integrity threats, then it is likely that any repurposing strategy would need to account for these and incorporate a lower future operating pressure and bigger ECA defect sizes. The enhanced EMAT-C Ultra hydrogen performance specification is therefore unlikely to be required in such cases, while standard EMAT-C or EMAT-C Ultra performance specifications might be solutions.

5. 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 Ultra's 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, especially for hydrogen transportation. For the energy transition and the introduction of hydrogen into pipelines, in-line inspection technologies are indispensable for pipeline integrity management. Targeting anomalies at the lower boundary of the detection threshold, supporting smaller ECA defect size determination, EMAT-C Ultra hydrogen performance specification can be considered sufficient to detect, identify, and size critical planar defects in hydrogen pipelines. By addressing these challenges through advanced inspection methods, the transition to a hydrogen-based energy system can be achieved safely and efficiently, supporting the EU's and worldwide decarbonization goals.

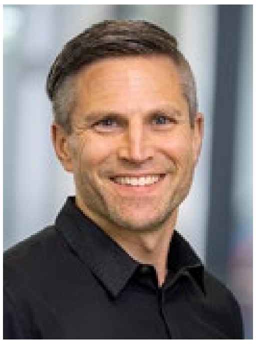
References

1. POF 520 White Paper. In-line inspection tool readiness for hydrogen pipelines. April 2024.
2. Development of an ILI Service for Heavy Wall Pipelines based on EMAT Technology. Upadhayaya, C. Garth, et al. Calgary : IPC, 2024.
3. EMAT as a basis for a comprehensive system wide crack management program. Katz, D., et al. Calgary : IPC, 2018.
4. EMAT-C Ultra Technology for Crack Inspection in Gas Pipelines. Hilvert, Matthias, Felipe, Freitas and Thomas, Beuker. Houston : PPIM, 2025.
5. Case Study: An Efficient Route to Evidence Safe Repurposing of Pipelines to Hydrogen. Burkinshaw, Ollie, et al. Berlin : PTC, 2024.
6. Management of Change when Repurposing Existing Infrastructure to Hydrogen. Shaw, Hannah, et al. Berlin : PTC, 2024.
7. Paper, EPRG White. Hydrogen Pipelines Integrity Management and Repurposing Guideline .

AUTHORS

Dr. Marion Erdelen-Peppler
ROSEN Group
Head of Group Business Line
Hydrogen and Future Fuels
merdelenpeppler@rosen-group.com

Matthias Hilvert
ROSEN Group
Global Service Manager for EMAT Crack Detection
mhilvert@rosen-group.com



Michael Tewes
ROSEN Group
Head of Business Line Hydrogen and Future Fuels
mtewes@rosen-group.com

Thomas Beuker
ROSEN Group
Head of Group Business Line
Advanced Pipeline Diagnostics
tbeuker@rosen-group.com