IBP2387_17

IN-LINE INSPECTION TECHNOLOGY FOR CRACK DETECTION IN GAS PIPELINES

David Katz[1], Steve Potts[1], Ralf Weber[2], Joerg Grillenberger[3], Thomas Beuker[3]

Abstract
The integrity of aging assets like gas pipelines are managed by a variety of inspection and validation methods. In the particular case of gas pipelines and their susceptibility to cracking, an ultrasonic inspection methodology has been developed by ROSEN, which is based on an electromagnetic acoustic transducer (EMAT). Meanwhile, a high resolution implementation of the technology has been utilized on in-line inspection tools from 10" to 48" tool size. The utilization of ultrasonic shear horizontal wave and a corresponding spectral analysis of the wave modes of higher order allows an accurate depth sizing and identification of crack anomalies present in pipelines. The high resolution approach provides redundancy in gathering reflection signals from individual cracks and crack colonies. Beside the reflection signal a so called transmission signal is recorded as well. This signal is used to normalize the ultrasonic crack response with regards to spurious artefacts. The fundamental measurement principles and the results from the inspection programs conducted so far will be discussed and re-viewed in this paper. Williams Gas Pipelines have utilized this inspection technology successfully on several pipelines. An overview of the experience gained so far will be given. Secondly a case study will be presented, in which a post hydrostatic test ILI service was used to gain additional safety and integrity relevant information from the ILI inspection and to better understand the actual capabilities of a hydrostatic test.

1. Introduction

Inline Inspection is traditionally a cornerstone for pipeline integrity. The EMAT technology was pioneered in 1972 by G. Alers and B. Thompson. They presented the first ILI prototype demonstrating that the technology can be applied in principle. It took until 2006 to have crack inspection in gas pipelines commercially available with a full ultrasonic approach using electromagnetics instead of a coupling medium. Today's tools are equipped with a central suspension system and guidance on wheels to achieve optimal run conditions during the inspection process

Figure 1: First ILI EMAT prototype developed by AGA and Rockwell in 1972

[1] WILLIAMS GAS USA
[2] ILI CONSULTING
[3] ROSEN GROUP

Figure 2: State of the art EMAT ILI tool for the detection of axial cracking in gas pipelines. On the right the pull unit with central suspension and wheel support is visible. On the left the two EMAT measurement units are shown.

2. EMAT Ultrasonic Technology – Basic Principle

EMAT technology generates ultrasonic sound waves by either of two physical phenomena resulting from alternating currents in a static magnetic field: Lorentz force and Magnetostriction. The EMAT ILI system discussed in this paper is set up to generate ultrasonic waves consisting of lower and higher mode order horizontal shear waves which propagate in the circumferential direction through the pipeline wall.

The EMAT-C inspection fleet is suitable for both the detection of cracks in the pipe wall and external pipeline coating damage. The technology described here has been implemented for pipe diameters from 10 to 48 in. For diameters below 10” the physical space requirements for generating the shear waves precludes successful implementation. Therefore, ILI tools in the size of 4” – 8” are equipped with a different EMAT technology, which is not subject of this paper. Since the first inspection in 2006 the technology described in this paper was used in pipelines totaling more than 50,000 km successfully in all areas of the world i.e. Americas, Australia, the Middle East, Europe and the CIS states.

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 dimensions of flaws.

A number of methods such as magnetic flux leakage and ultrasonic inspection with piezoelectric transducers are used in non-destructive testing of pipelines. However, the potentail of magnetic flux leakage as a method for crack detection is very limited. The ultrasonic method based on piezoelectric transducers can only be used in gas pipelines if costly and disruptive measures are taken (e.g. a liquid batch) to ensure that the transducer can couple to the pipe wall. In contrast, no liquid couplant is required if the EMAT tool is used, since EMAT technology generates an ultrasonic wave in the surface of the pipe wall solely by an electromagnetic interaction. The horizontal shear wave is propagating fully parallel to the pipe surface. Therefore a continuous depth sizing from 15% to 100% wall thickness loss is possible without running into saturation issues which are known from piezo-electric technology. Moreover, EMAT can be utilized to also assess the condition of the external coating and thus provides complementary integrity information.

Figure 3 shows a schematic representation of the EMAT arrangement. The EMAT probe inspects only a small, well-defined area between sender and receiver. This area is called the sensitive measurement area. Transmission and reflection signals are captured by means of two separate receiver sensors within the EMAT arrangement.

The waves which propagate from sender to receiver (transmission) through the pipe wall without hindrance are used for assessing the external pipeline coating. The waves are attenuated by intact coatings so that a lower signal amplitude is captured by the receiver. In case of coating disbondment or coating defects, the ultrasonic wave attenuation is reduced. If there are cracks within the EMAT sensitive measurement area running parallel to the pipe axis, as is the case, for example, with stress corrosion cracking (SCC), the ultrasonic shear waves are reflected by the crack surface. Information on frequencies, times of flight and modes are used for the analysis to identify cracks and determine crack length and depth. A comparison of an EMAT signal with the crack morphology observed from field excavation and the depth sizing capabilities of the system is illustrated in Figure 4.

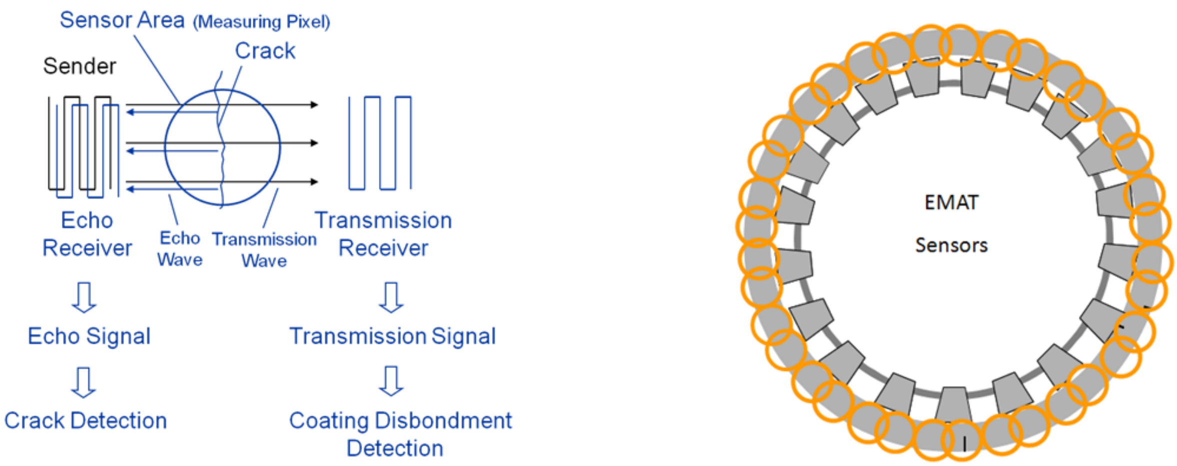

Figure 3: EMAT measurement principle and high resolution approach used by the Rosen EMAT-C ILI tools

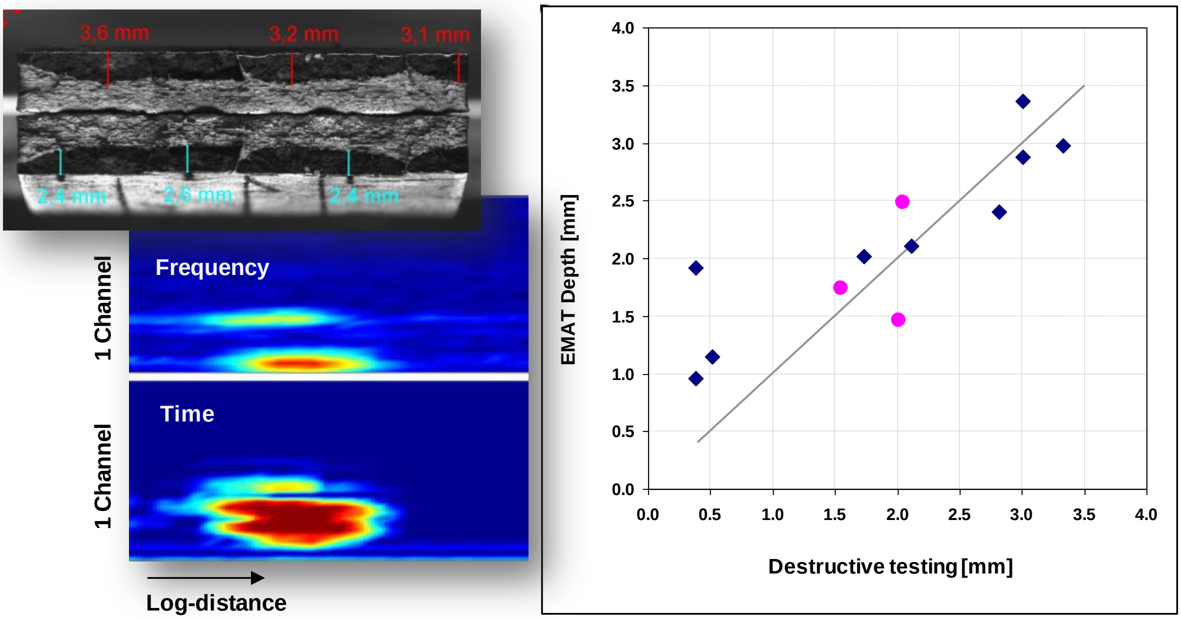

Figure 4: Depth sizing accuracy validated through destructive testing (splitting) of SCC.

Apart from the analysis of the reflected shear waves to detect cracks, the condition of the pipe coating can be determined by analyzing the signals of the transmission receiver. Impeccable adhesion of the coating material to the pipe wall results in attenuation of the acoustic waves propagating through the pipe wall. If the coating is damaged, acoustic signal attenuation is reduced. The large number of sensor heads allows for a high-resolution image of the coating condition.

Different types of external coatings have different attenuation properties. On the basis of signal dynamics of the transmission amplitudes and special pattern recognition, coatings can be classified (coating identification). Figure 5 shows the different attenuation characteristics for various types of pipe coatings. As an example, the following coating types were confirmed during one field verification: Fusion Bonded Epoxy (FBE), tape wrap coating and tar coating.

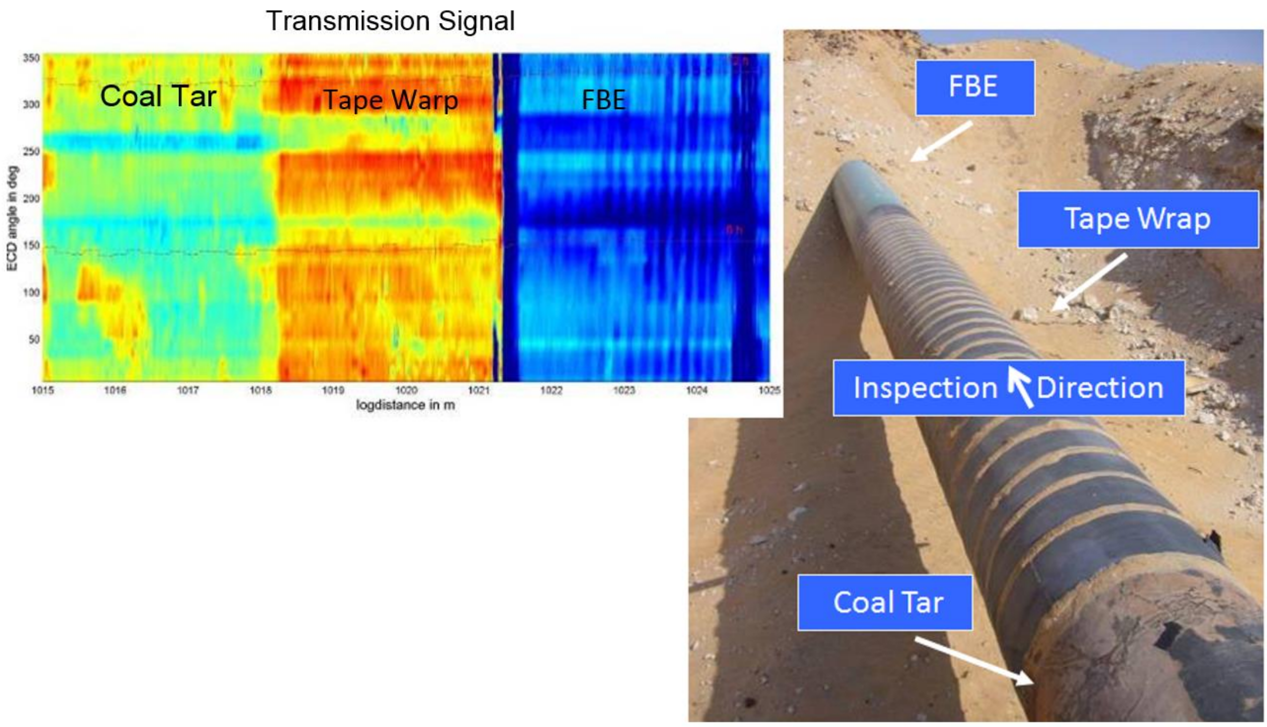

Figure 5: Different coating types and their characteristic transmission signal patterns in the EMAT data

To provide a more detailed picture of the pipeline condition the combination of an EMAT inspection run with a high resolution transverse magnetic flux inspection is recommended. This way narrow corrosion patterns can be distinguished from cracking. As shown in Figure 6, both phenomena might coincide and influence each other.

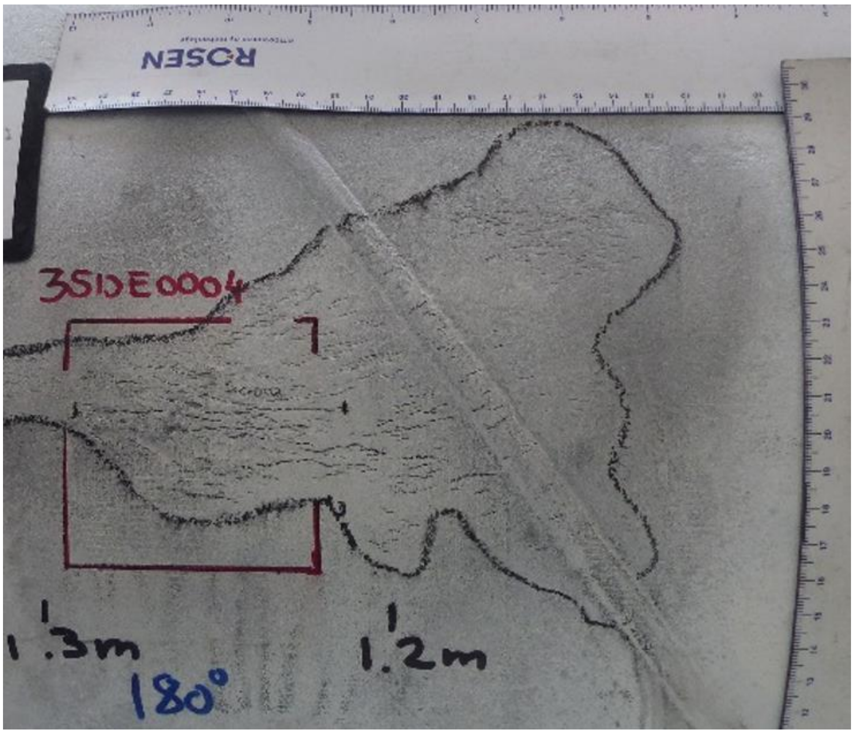

Figure 6: Corrosion and Cracking at the same location

A combined analysis of crack and corrosion data can give information on the corrosion depth and the crack depth. This allows the operator to get a better understanding of the cracking mechanisms active on the pipeline and allows the development of appropriate action plans.

3. Data Analysis

The probability of detection (POD) is typically very good for ILI. This is also true for more sophisticated challenges like crack detection. However, depending on the presence and number of other anomalies, the probability of identification (POI) for cracking features is a challenge. While cracks are identified very reliably, the identification of other anomalies can vary. Even by combining inspection technologies, this can lead to a certain number of so called false positive features. A false positive is listed as a crack-like anomaly, but found in the field to be something different.

By default the data analysis process has been designed to ensure a safe conservative approach in order to avoid missed calls or false negatives by reporting questionable anomalies as cracks or crack-like, even though the confidence in the anomaly being a crack may be low. These candidates are usually flagged in some way to inform ensure that the operator is aware of the reduced confidence. The overall crack population in most pipelines is similar to the one shown in Figure 7. A few critical defects and some close to critical, but the majority are generally minor. The main target is identifying the critical defects first. The data analysts review the automated feature search (AFS) results above a screening threshold and are usually able to report the critical defects and indicate the ones possibly requiring assessment within the Preliminary Report (PR).

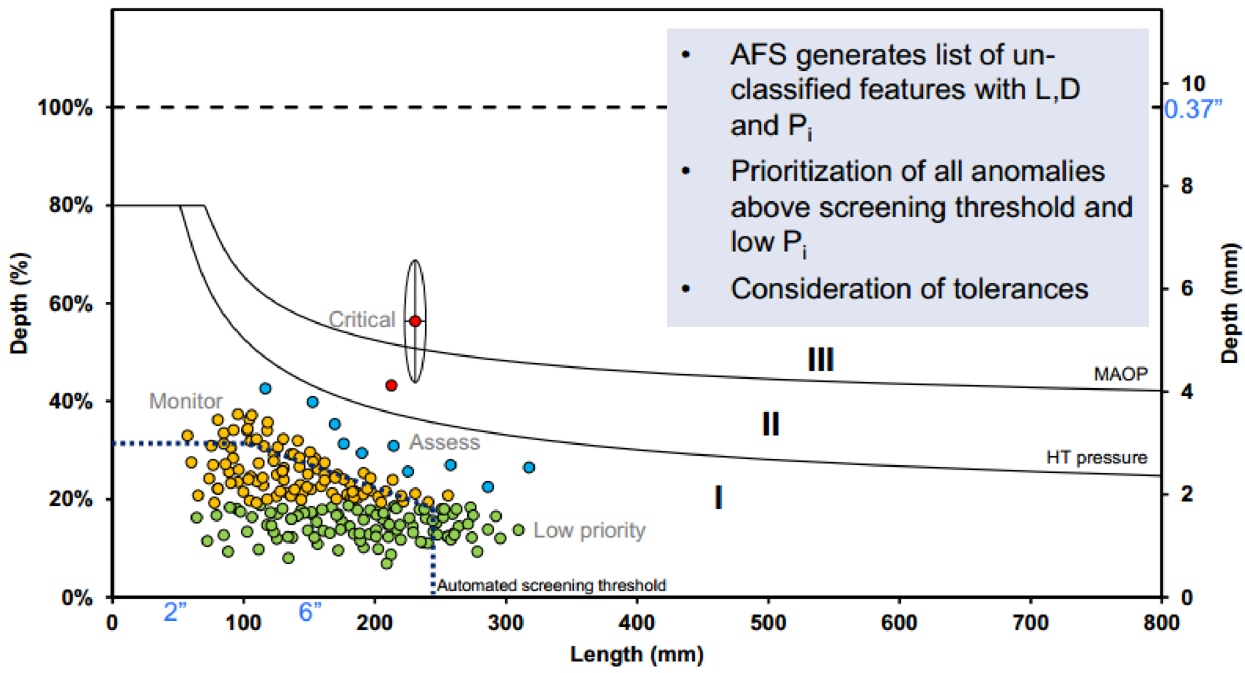

Figure 7: Exemplary crack distribution of a pipeline.

The feature can be assessed based on this PR and the operator can decide on a dig verification program. Where they are available the field verification results are fed back into the analysis procedure primarily to help improve anomaly identification to ensure a high quality Final Report (FR) containing all recorded crack-like defects above an established reporting threshold.

4. In-line Inspection and Hydro Testing

To be confident that no critical feature have been missed by the ILI tool and the performance specifications are kept, API 1163 describes three levels for validation of the performance specification values [5]. These levels are applied to gain confidence in the published performance specification and to statistically estimate the as-run performance. Earlier publications provided validation results based on API 1163 Level 3 assessment of the performance specification in terms of POD, POI and depth sizing accuracy [4]. However, these results provided estimates of POD and POI at a given reference anomaly size, i.e. length of equal or greater than 40 mm and depth of equal or greater than 1 mm based on comparison of validation data compared against EMAT predicted values derived over several years. During this time, both the technology and the data evaluation process had evolved and therefore, the results were not truly representative of the state of the art. Also, obtaining a complete POD curve as a function of the various anomaly lengths and depths would require a much larger set of data than is practically available. Therefore, a new study was conducted where POD and POI estimates were derived as a function of three broad categories of anomaly sizes [6]. A blind test with a third party auditing the process, independent from both the operating company as well as the vendor, was chosen. The data set used in the blind test originated from standard EMAT surveys in NPS 30 and NPS 36 pipelines with nominal wall thicknesses of 0.298’’ and 0.330’’. The overall distribution of the anomaly dimensions used in this blind test are shown in figure 8.

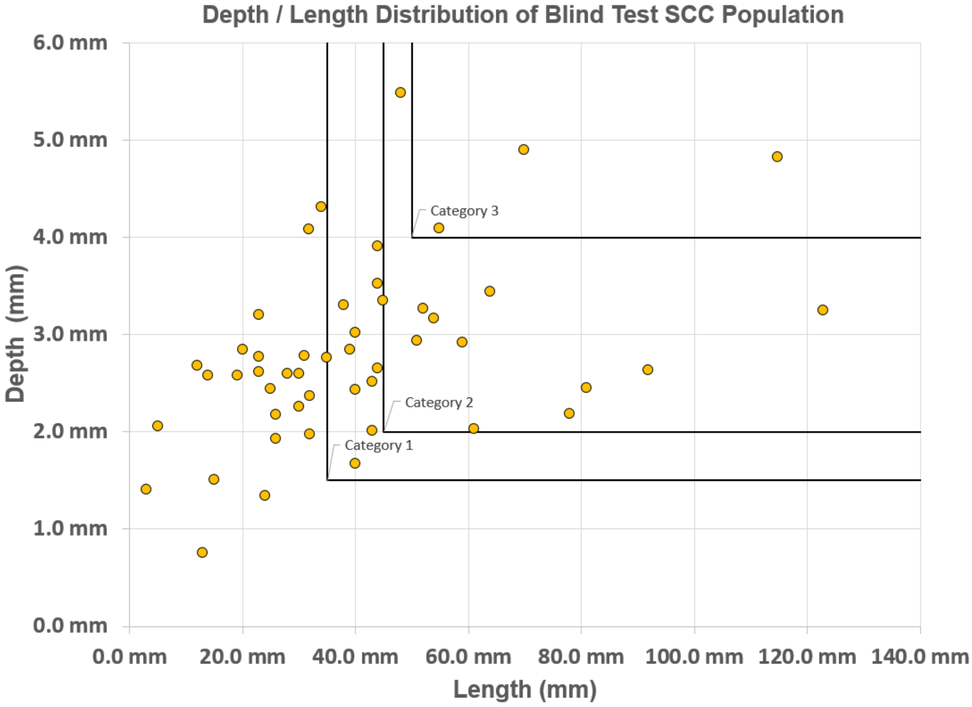

Figure 8 Anomaly distribution of all crack-like anomalies included in the blind test, including category definitions related to a graded performance specification [6].

The validation data was gathered by excavating and subsequently performing metallurgical destructive testing of the target anomalies. For the EMAT analysis, a target joint with SCC was randomly positioned within additional four joints without target SCC anomalies, however, additional anomalies such as corrosion and mill related anomalies etc. were also present in the joints. In total 51 validated SCC colonies were present in the blind test population. Ten data analysts with ILI-PQ levels 1 (in training) and level 2 (data analyst) took part in the blind test. The outcome of this blind test resulted in the graded performance specification shown in figure 9. The detection of critical anomalies showed a higher reliability. This means critical crack anomalies are detected, identified and sized with a high probability of 98%. Values of POD and POI obtained for anomaly dimension categories

Category	Min. depth			Min. length
1	≥ 1.5 mm	or	15%	≥ 20 mm
2	≥ 2.0 mm	or	20%	≥ 35 mm
3	≥ 4.0 mm	or	40%	≥ 50 mm

Category	POD	POI
POD Category 1	80%	70%
POD Category 2	95%	93%
POD Category 3	100%	100%

Figure 9 Values of POD and POI obtained for anomaly dimension categories.

Hydrostatic testing represents an established technique that has been in use for decades. During this time span standardized approaches and best practices have been developed. This has led to a broad acceptance within the community of pipeline and integrity engineers.

During hydrostatic testing, the pipeline section is filled with water and pressurized to a level well above the Maximum Allowable Operating Pressure (MAOP) providing a safety factor relative to standard operating conditions. A hydrotest has three key objectives:

- To establish a maximum operating pressure for the pipeline.
- To identify and remove large defects that could be a problem in service by forcing them to fail (burst).
- To identify leaks, for example small through wall weld flaws.

At the hydrostatic test pressure all anomalies with dimensions above a critical value assuming consistent pipe attributes are expected to fail and this failure should be detected by a pressure drop. The failed joint is found and repaired and the overall procedure is repeated until the test is completed successfully, i.e. a target pressure is achieved without a failure.

The overall process is complex, time consuming and expensive, and while hydrostatic testing provides a clear indication of the strength of the pipeline at the time of the test it is important to be aware of some significant potential drawbacks:

- Only those anomalies with dimensions above the critical dimensions will lead to a failure and therefore be detected. Large anomalies, for example 50% through wall and 2 inches long, may be present in a pipeline even after a hydrotest, as illustrated in figure 7. This is due to the inherent high toughness of most linepipe steel. Consequently a safety factor should be applied for defining subsequent maximum operating pressure, and a re-assessment interval needs to be set based on experience and standards [1, 2].
- A Hydrostatic test does not provide any information on surviving SCC anomalies. Therefore, subsequent assessments based on hydrostatic testing cannot be used to directly determine SCC growth rates or identify the development of new subcritical SCC anomalies. Information on the development of new SCC anomalies is of course valuable in evaluating the efficacy of actions taken to mitigate SCC development such as cathodic protection modifications, temperature or pressure reduction. The development of new subcritical SCC anomalies can be detected by in-line inspection [7].
- In the past it was assumed that hydrostatic testing removed critical SCC and led to a blunting of sub-critical crack tips. This was believed to passivate cracking by reducing the tension at the crack tip to a level insufficient to induce micro-plastic deformation. However, research on micro-plastic deformation shows that re-initiation of crack growth can also occur and SCC may even be initiated as a consequence of hydrostatic testing [3].
- In certain cases where there are a large number of anomalies in linepipe with moderate toughness the anomalies may be made more severe by the hydrotest due to tearing at the crack tip [8].
- An added potential issue due to very high test pressures may be the unintentional degradation of what might otherwise be good coating, although good quality coatings are generally tolerant of high strains and deformation.

Therefore hydrostatic testing may not provide a high degree of confidence in the medium to long term condition of a pipeline for planning the future safe operation. In cases where material properties are poor, wall thickness is low, and operating stress is high, even small defects could be critical and regular hydrostatic testing may be required to give the required confidence for safe operation, however prior in-line inspection may be beneficial to minimize failures during hydrostatic testing. Conversely, where material properties and wall thicknesses are reasonable, and operating stresses are lower, hydrostatic testing may leave uncertainties, whereas regular in-line inspection can be expected to identify any critical anomalies with a high degree of confidence, and provide additional valuable information on subcritical anomalies that can be used to optimize integrity management expenditure.

5. Case Study

The case study shown in the following chapters is based on an EMAT pull through tests conducted using cut outs from two previously inspected 24” pipelines, 72.2 km (44.8 mi) and 123.9 km (77 mi) long. An in service failure made a hydrostatic testing program mandatory. After the hydrostatic tests the decision to perform ILI inspection, as a basis for the integrity management program, was made. In total 118 reportable crack-like anomalies were found by ILI in both sections which did not fail the hydrostatic tests.

6. Validation of POD and POI by Pull Test

Since the ability of the EMAT ILI to identify and correctly size crack features is key to an effective assessment, an operator performed independent pull tests on segments of pipe with known SCC to validate the tool technology including limits of detection (LOD), probability of detection (POD), probability of identification (POI), probability of false call (POFC) and sizing tolerances within its operative speed window.

Three 24” joints, totaling 102’, with SCC, were combined with other pipe for a 370’ test string. The three joints with SCC were removed from a section which passed a hydrostatic spike test when SCC colonies were identified by the subsequent EMAT ILI run. The agreed upon testing protocol included EMAT ILI runs at 5 different velocities (2.2, 3.3, 4.5, 5.6 and 8mph) and the pipe was covered so that the surface of the test pipe was not visible to any attending ROSEN personnel.

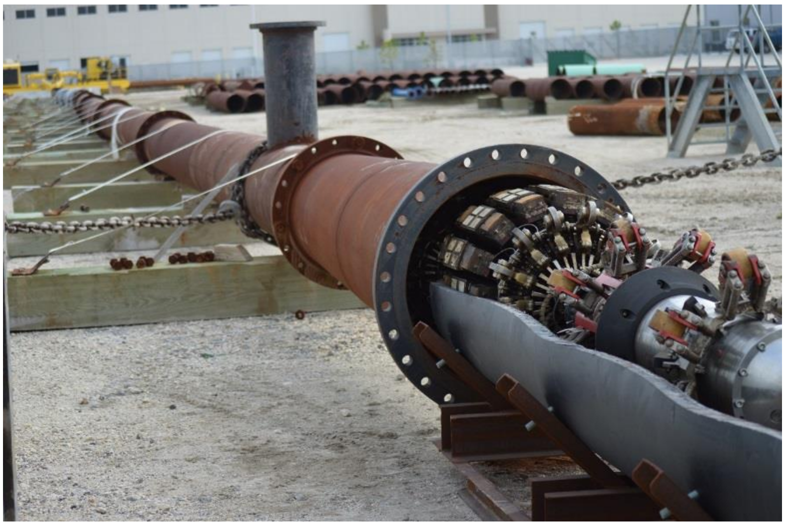

Figure 10 Launch of 24" EMAT ILI at the PRCI Pull Test Facility

The pull test string was cleaned before the runs were performed. NDE evaluations of the known SCC cracking were performed twice, in field and at the PRCI facility, to provide a comparison for the lengths and depths measured by the EMAT ILI. All SCC colonies detected with magnetic particle indications were measured for axial distance, circumferential orientation, length, width and depths. All colonies w/cracks deeper than 20% WT were also sized with phased array ultrasonic testing (PAUT). For correlation, the EMAT ILI "Significant Interlinking lengths" and the EMAT depth in %WT were compared to the lengths measured by the PAUT at 25%WT and the maximum depths of each SCC colony.

Four different analysts, including a Level 3 certified analyst, reviewed the four runs to independently identify cracking. In the 370' string of pipe, there were five (5) SCC colonies that were larger than the threshold for identification. With five runs, four analysts and five SCC colonies, there were 100 opportunities to assess the potential for False Negatives and the sizing accuracy resulting in the following:

- Length – EMAT results met ROSEN's EMAT ILI specification and were typically longer than the field measured features (Figure 11)
- Depth – EMAT results met Rosen's EMAT ILI specification (Figure 12)
- POD – There were no SCC colonies, above the threshold, that were missed by the EMAT ILI or analyst (No False Negatives) and many SCC features identified that were below the threshold.
- POI – All SCC colonies that were above the threshold were properly identified as crack features by the tool and analysts.

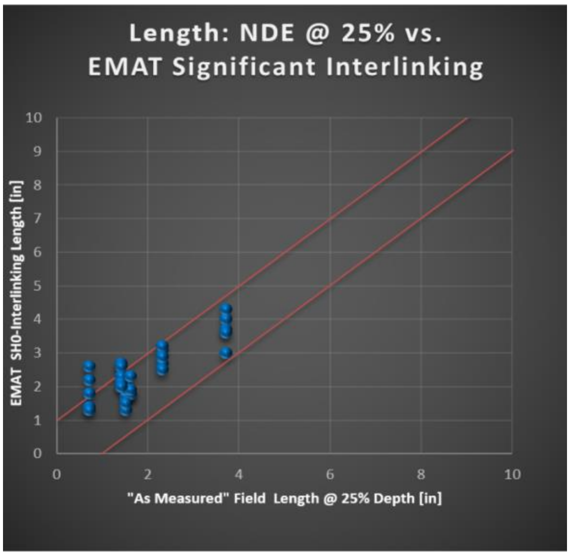

Figure 11 Length Accuracy

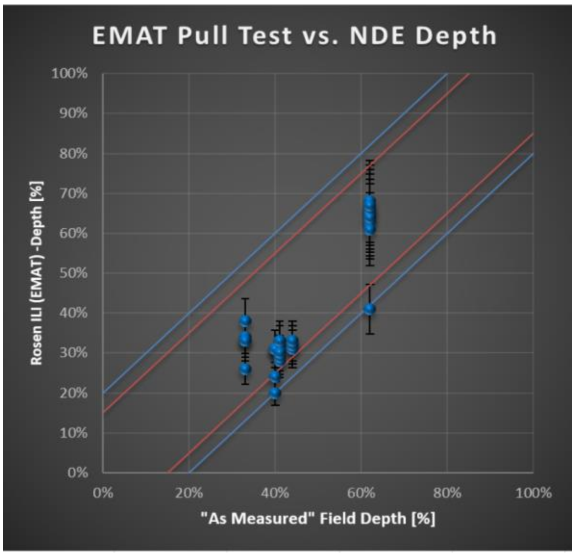

Figure 12 Depth Accuracy

Summary

Independent, blind pull testing and infield verification performed to date validated the capabilities of the ROSEN's EMAT ILI tool and therefore confirmed that EMAT ILI is an effective integrity assessment method for SCC. EMAT ILI also provides the added benefit of early identification and remediation of SCC that would not have been identified using other assessment methods. These factors combine to make EMAT ILI an integrity assessment method that meets or exceeds the margins of safety established by the SCC assessments methods currently approved.

Key to the successful utilization of EMAT ILI are the implementation of

- a rigorous EMAT ILI procedure together with an implemented SCC Management Plan
- conservative response criteria
- conservative re-assessment intervals

Today pipeline operators are in progress of implementation and are getting ready to requests approval for the utilization of EMAT ILI, as an alternative method of SCC management.

References

[1] Process Piping – ASME Code for Pressure Piping B31.3, ASME B31.1-2008, An American National Standard, The American Society of Mechanical Engineers, 2008

[2] Integrity Management of Stress Corrosion Cracking in Gas Pipeline High Consequence Areas, STP-PT-011, ASME Standards Technology, LLC, 2008

[3] Jian Li, M. Elboudjdaini, M. Gao, R. W. Revie, Investigation of plastic zones near SCC tips in a pipeline after hydrostatic testing, Materials Science and Engineering A, Volume 486, Issues 1-2, 15 July 2008, 496-502

[4] T. Fore, S. Klein, C. Yoxall, S. Cone, Validation of EMAT ILI for Management of Stress Corrosion Cracking in Natural Gas Pipelines, Proceedings of the 2014 10th International Pipeline Conference, IPC2014, September 29 - October 3, 2014, Calgary, Alberta, Canada

[5] In-Line Inspections System Qualification, API Standard 1163, Second Edition, American Petroleum Institute, April 2013

[6] M. Tomar, T. Fore, M. Baumeister, C. Yoxall, T. Beuker, Graded EMAT Performance Specification Validated in Blind Test, IPC2016-64421, Proceedings of the 2016 11th International Pipeline Conference, IPC2016, September 26-30, 2016, Calgary, Alberta, Canada

[7] M. Palmer, C. Davies, M. Ginten, Detection of Crack Initiation Based on Repeat In-Line Inspection, Pipeline Pigging and Integrity Management Conference, February 2016, Houston, Texas, USA.

[8] B. Leis, R. Galliher, Hydrotest Protocol for Applications involving Lower-Toughness Steels. IPC04-0665 Proceedings of the 2004 International Pipeline Conference, IPC2004, 2016, Calgary, Alberta, Canada