Guided Wave Quantitative Contact Corrosion Measurement

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Abstract

Contact-point corrosion, also known as corrosion under pipe supports (CUPS) presents an ongoing integrity threat and inspection challenge to operators of gas and liquid processing facilities, refineries and compressor stations globally. Contact corrosion most often occurs within difficult-to-access areas such as tightly spaced pipe racks, full encirclement supports, concrete wall or deck penetrations, and soil-to-air interfaces. The technology now exists for rapid quantitative corrosion measurement within these difficult applications utilizing axially and circumferentially transmitted guided waves [Ref 1].

This novel, low-profile scanning technique is robust and tolerant of pipe surface condition while providing reliable corrosion profile analysis in areas inaccessible by other inspection methods. This paper will discuss the advantages of guided wave quantitative short-range corrosion measurement and how it can serve to enhance existing inspection programs.

Background

In the context of pipeline corrosion and integrity management related inspection, guided wave pipe screening, also known as “long-range” ultrasonic testing (LRUT), has become a trusted method to detect and locate corrosion wall loss in piping systems. Guided wave screening has existed in commercial service for over 25 years and has served to augment corrosion assessment programs in a wide range of pipeline and facility piping applications [Ref 2,3,4,5].

While guided wave screening provides asset owners with valuable qualitative data, the demand for quantitative corrosion wall loss evaluation within inaccessible areas has remained. Guided wave screening involves the excitation and propagation of guided wave modes that are responsive to axisymmetric and non-axisymmetric changes in pipe cross-section [Ref 2,3,4,5]. The reflection amplitude, shape, axial position, circumferential position and circumferential extent of each feature are all recorded, interpreted and reported by the operator. Areas of indicated wall loss are placed into three categories of minor, medium and severe based on estimated cross-sectional loss (CSL) and circumferential extent. From this information, the asset owner must decide which indications require action, and the detailed examination method to be used for verification.

Until recently, guided wave technology did not play a part in the verification process as it was not quantitative. Research has revealed that different guided wave modes (other than those used for screening) that are sensitive to pipe wall thickness and can therefore be applied to quantify wall loss.

Pipeline facility asset owners recognize and must prioritize the evaluation of these contact points and embedded pipe sections. For pipeline facilities under state or federal safety regulation, there are code requirements to conduct atmospheric corrosion inspections and remediations where necessary [Ref

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6]. The removal of rigid concrete or steel piers, solid clamps, buried “sleeper” supports, or embedded concrete sections for inspection represent a significant operational cost. The external appearance or existence of rust staining in these contact areas typically indicate the initiation of corrosion, but not necessarily actionable pipe wall loss. Visual inspection and direct wall thickness profile measurements are extremely limited, if not impossible to collect as the main area of concern is hidden from view in most cases.

Corrosion under pipe supports

Corrosion under pipe support (CUPS), also known as contact-point corrosion is a very common challenge within refineries, pump stations, gas processing plants, compressor stations and gas measurement facilities. These are areas where pipes are in contact with supporting structures and protective coatings break down to due mechanical movement. Moisture tends to collect in the areas of damaged or degraded coating, forming a corrosion cell. The progression of corrosion further compromises the integrity of the coating, leading to significant pipe wall loss in some areas. Visual and mechanical access to these areas is limited in many cases due to the design of the structural supports, lack of space between multiple pipes, and other factors.

For many years guided wave screening has been deployed as a reliable method to evaluate and prioritize large numbers of pipe supports within facilities. Quantitative short-range (QSR) guided wave systems were developed to provide a wall thickness profiles for the pipe supports identified through screening as critical [Ref 1,4].

Figure 1. Simple pipe support examples

Other corrosion challenges

Concrete wall penetrations and soil-to-air interfaces are other areas where non-intrusive quantitative corrosion evaluation tools are needed. These areas are notorious for corrosion cell formation as the external coating has a tendency to disbond or detach from the pipe surface. Atmospheric moisture infiltrates these areas, forming corrosion cells that can go unnoticed for long periods of time. These

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areas can be difficult to access for detailed visual inspection without invasive removal of components or exposure by excavation.

Concrete penetrations

Natural gas and hazardous liquid pipeline facilities are often designed to include locations where suction, discharge, fuel and auxiliary service piping must pass through concrete structures. Over the system service life, pulsation, vibration, temperature cycles and soil movement can compromise protective coatings within the embedded pipe segments. This can be observed visually by the appearance of rust staining and concreate spalling around the interface locations. Wall loss may be noted just outside of concrete interface but in many cases, the damage occurs deep within the embedded section and beyond view.

Figure 2. Concrete wall penetration examples

Soil-to-air interfaces

As pipelines and piping systems transition from buried to above ground, the soil-to-air interface tends to be an area of susceptibility to external corrosion due to a number of factors. 1) Moisture, occasional running water and soil erosion can compromise coating integrity at the interface. 2) Transition coatings may be not be appropriate for the existing conditions, or poorly applied. 3) Cathodic protection influence subsides as the pipe transitions out of the electrolyte (soil). These factors on their own or in combination create areas of vulnerability that must be evaluated as part of the asset corrosion control program.

Quantitative Short-Range Guided Wave

The ability to effectively quantify pipe corrosion wall loss in practical applications was developed through the study of various guided wave modes and their reaction to wall thickness variation. Guided wave screening systems utilize torsional or longitudinal wave modes to evaluate cross-sectional change, but these wave modes at the optimum operating frequency range of these systems

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cannot provide reliable wall thickness measurement [Ref 1,5]. With the concept of developing a simple, practical system to quantify pipe wall thickness profile from an a short-range, offset position, it was determined that the shear horizontal guided wave modes SH0 and SH1 provide the most reliable results. The dispersive nature of SH1 makes it particularly suited for the detection and sizing of defects as a function of cut-off frequency rather than reflection amplitude.

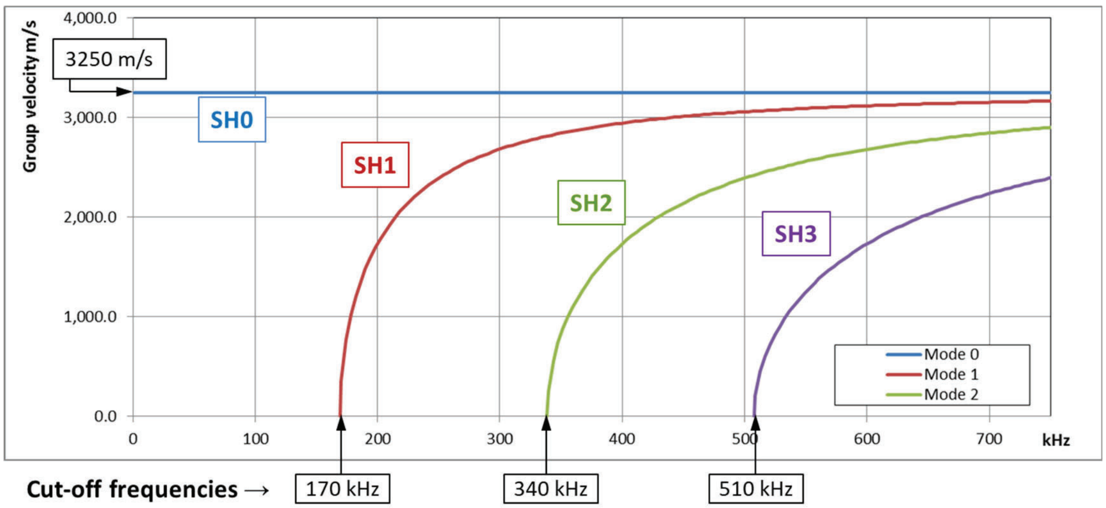

Figure 3. Dispersion curves for a mild steel 9.6mm thick plate

Figure 3 shows the group velocity dispersion curves for the SH mode family in steel plates, which are very similar to the corresponding relationships for propagation in pipe. The SH0 mode is non-dispersive, so measurement of its travel time can be used to calculate distance between transmitting and receiving transducers. The higher order mode dispersion curves follow a frequency-wall thickness form where wall thickness can be inferred from measurements of the SH1 or higher mode velocities as a function of frequency [Ref 1,4]. The SH wave mode and frequency range has proven to be much more tolerant of rough pipe surface condition as compared to conventional UT thickness measurement, which operates at a much higher frequency range.

Figure 4. QSR1 and QSR Axial scanning systems at concrete wall penetration

SH wave modes are excited by electromatic acoustic transducers (EMATs) arranged in a transmitter-receiver (also known as pitch-catch) configuration for either circumferential or axial scan direction. The circumferential scanning system (QSR1) excites SH waves that travel in two paths around the top and bottom of the horizontal pipe circumference as the scanner physically travels axially over the area of interest [Ref 1]. The EMAT transducers are not in contact with the pipe surface, which allows for minor pipe surface and coating irregularities. Each system is capable of providing accurate wall thickness data under coatings up to 1mm (0.039") thick.

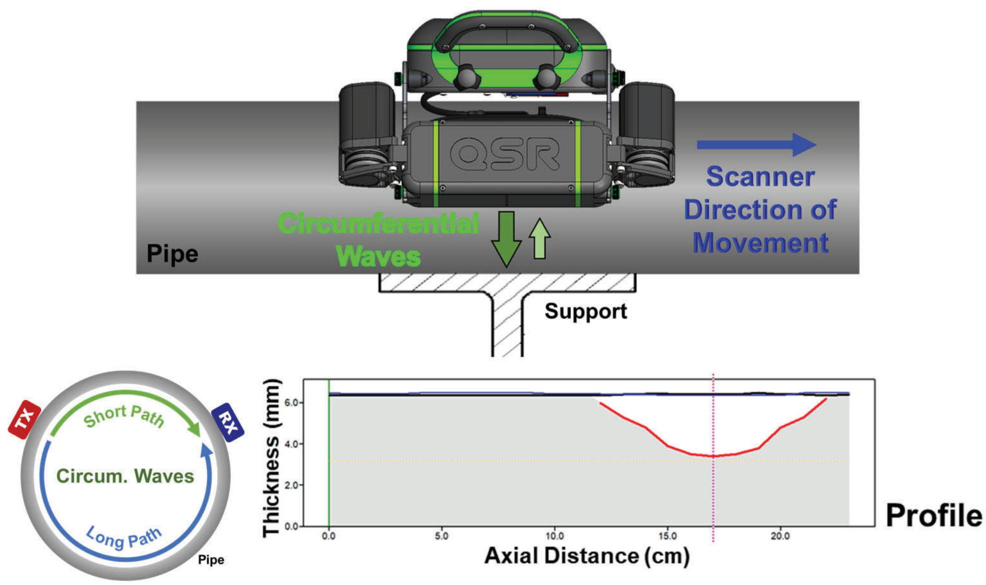

Figure 5. Circumferential scan movement and example profile result

Circumferential Quantitative Scanning – QSR1

The QSR1 system as illustrated in Figure 5 is tuned to profile the wall thickness from essentially the 5 o'clock to 7 o'clock sector of the pipe circumference (bottom path), where pipe simple support corrosion typically resides. This requires an unobstructed mechanical patch for the scanner to travel above the support area of interest along the 9 o'clock to 3 o'clock position. As the scanner travels forward (axially), it collects circumferential data within an optimum frequency range selected by the system for the specific pipe diameter and nominal wall thickness. Test frequency is varied by the magnet spacing within each EMAT sensor. The magnet spacing is adjusted by servomotors within the transmitter & receiver. The scanner pauses in 1 cm increments over the area of interest to collect and then interpolate the wall thickness profile over the total distance scanned. With the circular wave propagation path, the system is able to evaluate both the transmitted and reflected signals as they travel past the receiving sensor [Ref 1].

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Axial Quantitative Scanning – QSR Axial

The QSR Axial scanning system excites SH waves that travel down the pipe axially as the offset scanner physically travels circumferentially adjacent to the area of interest. The system is tuned to focus on an area 5 cm to 50 cm [2" to 20"] from the sensor edge. This allows the operator to place the scanner in very close proximity to the support, wall penetration or soil-to-air interface for the most accurate result. As with QSR1, test frequencies are dictated by EMAT magnet spacing. The key difference with QSR Axial is that the magnets are pre-spaced in a stationary arrangement within the sensor array. The SH waves propagate through the pipe and reflection frequencies (cut-off) are detected and correlated to wall thickness. The thinnest ligament of material at each circumferential position is indicated by the reflected signal and plotted as a profile for analysis.

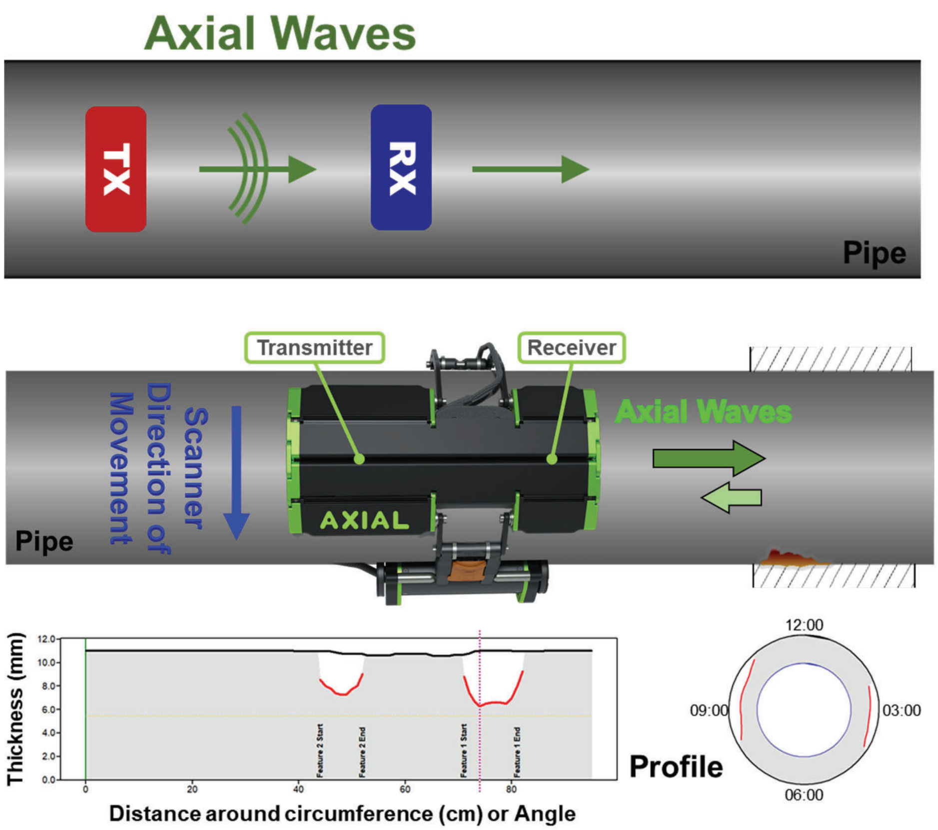

Figure 6. Axial scan movement and example profile result

Data Interpretation and Analysis

The QSR system software provides a visual interface for the operator as well as scanner health status, pipe design parameters, calibration, raw reflection visual display, as well as live pipe wall profile image (similar to UT thickness B-Scan). The interface allows the operator to select an automatic configuration function whereby the scanner excites SH waves in an area of representative, full wall thickness pipe material. Through this process of transmitting a range of SH frequencies, the system determines the optimal test frequencies for the pipe under examination. The operator has the option to proceed with the recommended test strategy or manually select the test frequencies for special scenarios.

Once a scan cycle is completed, the data is automatically processed and an initial wall thickness profile is presented to the operator for review. The operator then steps through each collection point along the scan range data plot and analyses the transmitted SH signal traces, presence of reflections, identified split frequencies of each reflection, signal decay, and overall signal-to-noise ratio for the entire scan. The operator can manually adjust the split frequency position based on a comparison between the transmitted and reflected dispersive SH signals. The correct positioning of the split frequency dictates the accuracy of the wall thickness profile plot [Ref 1]. It is important to note that the measurements of wall loss are quantitative up to 50% loss and qualitative for greater loss. As the pipe wall loss increases, the cut-off split frequency shifts outside of the current operating range and an accurate wall thickness value cannot be measured. The reflection data will qualitatively indicate the presence of wall loss exceeding 50%.

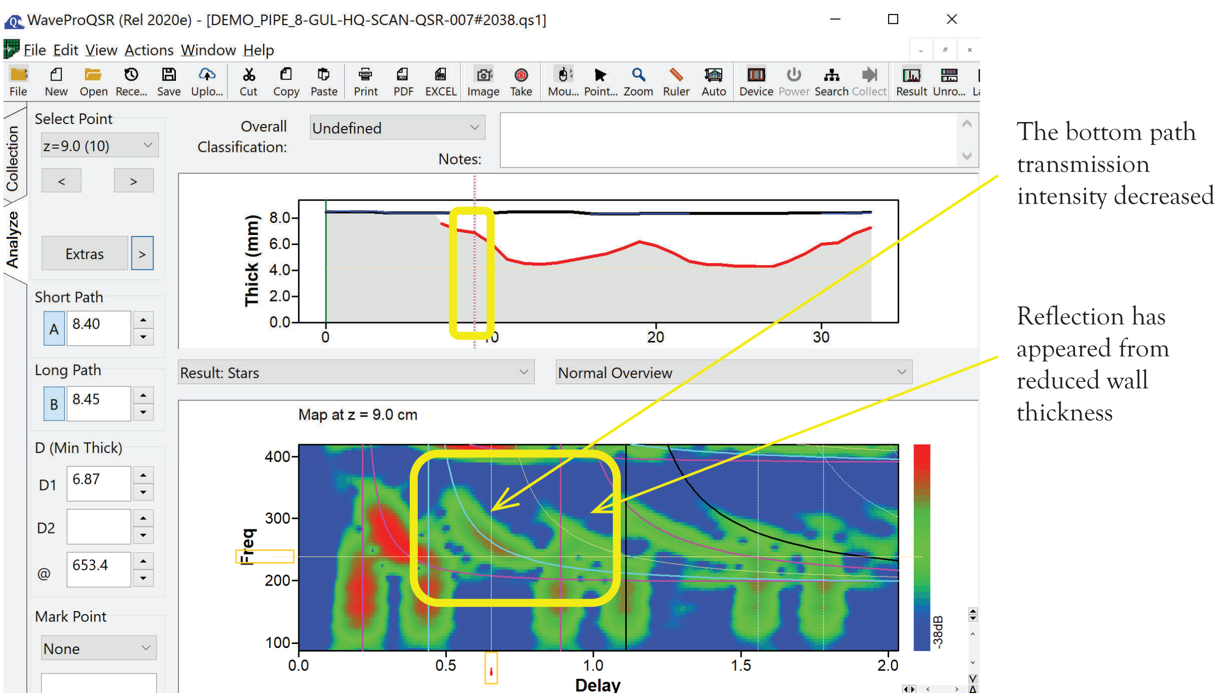

Figure 7. Manual analysis of transmission and reflection traces

Machine learning assisted advanced data interpretation

The QSR1 system is supported by a machine learning (ML) algorithm that can provide an independent evaluation of each data file. The current database includes more than 2 million data points from ex-service pipes as well as a library of manmade defects that were used to train the system.

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Access is provided by a cloud-based interface with a drag & drop processing function. The quality of each processed data file is assessed and feedback provided to the user. If the data file meets the minimum quality threshold, it processes the contents and provides a comparative wall thickness profile to the manually interpreted version. All collected thickness values can be exported into PDF or CSV file formats for integration with existing report templates or for additional analysis. ML assisted interpretation provides the operator with an unbiased evaluation they can use as a training aid, with added confidence for the asset owner. ML support for QSR Axial is currently under development.

GUL QSR Scanning Data Analysis Report

Test ID	QSR-038#1307	**Scanned**	Sep 11, 2023, 07:51:31 AM
Pipe size	10 Inch, Schd 40(STD) (9.27 mm / 0.365 in)	**Analysed**	Oct 23, 2023, 11:24:01 AM
Mag spacing	9,7 mm	**Exported**	Dec 5, 2023, 11:24:22 AM
Scan info	24 scan points, 1.0 cm step	**SNR and Averages**	42 dB (4*4 avg)
Inspector	Rhett D. O'Briant [GUL]	**Scan type**	Standard
Frame	unknown	**Signal Quality**	HIGH

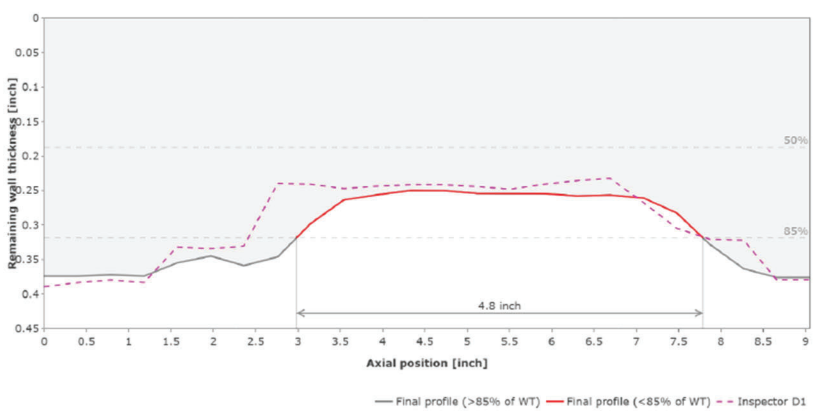

Figure 1: Remaining wall thickness

Figure 8. Example machine learning analysis export

Guided Wave Screening & Complementary QSR1 Circumferential Scanning Application Example

QSR1 scanning was deployed complementary to long range guided wave screening within a processing facility containing horizontal pipe runs supported by tack welded saddle-type supports. The subject pipe was 12” diameter with atmospheric coating.

Positive Direction　　　Negative Direction

Figure 9. 12" diameter pipe undergoing long-range screening

Initial guided wave screening indicated a significant, non-axisymmetric wall loss feature at approximately 26' downstream (positive direction) from the transducer ring location, with a circumferential extent running from approximately 4 o'clock to 8 o'clock. This area was determined to align with a saddle support contact point.

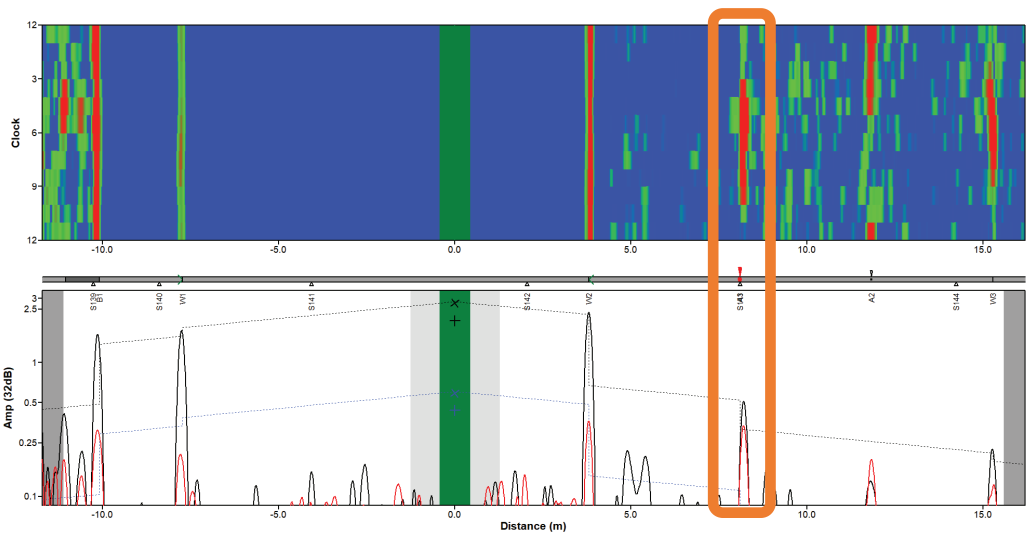

Figure 10. Guided wave screening results indicating significant wall loss

Once the guided wave screening results were fully analyzed, physical measurements were taken from the transducer ring location to accurately identify the area of concern. QSR1 was deployed to examine and size the wall loss area that had been indicated by guided wave screening. The QSR1 scan profile data confirmed the presence of significant wall loss at the support contact location. This data was fully interpreted by a qualified inspector and was then further validated by machine learning analysis.

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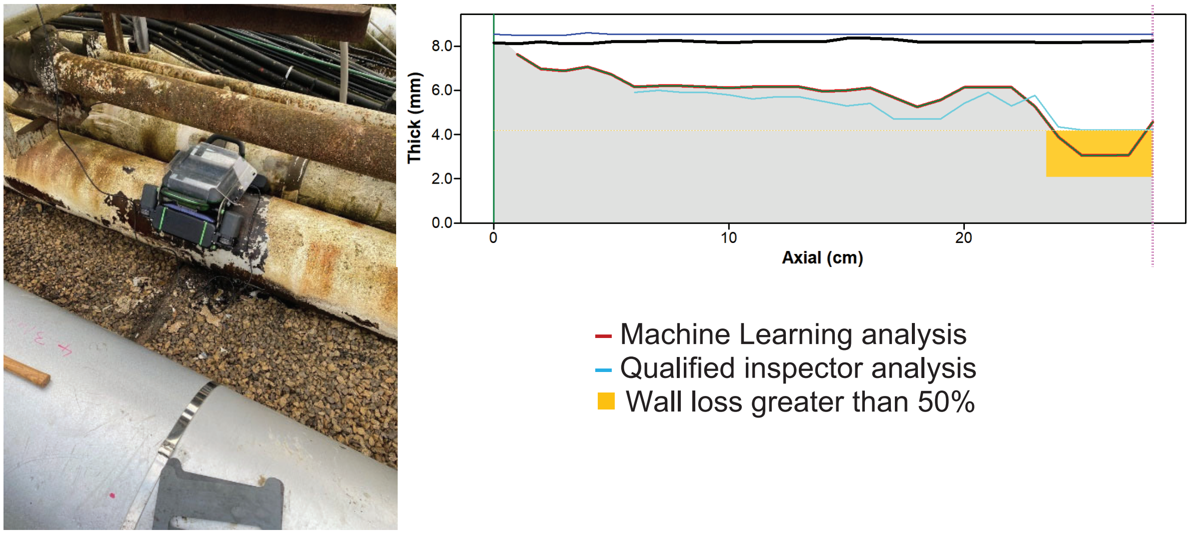

Figure 11. QSR1 scanning in-progress and profile results

While the machine learning wall thickness profile matched very closely with the qualified inspector's interpretation, it did however, show that the wall loss exceeded 50% of nominal. Based on these reported results, the asset owner elected to remove the pipe from service and cut out the affected section. Visual inspection of the removed specimen validated the guided wave screening and quantitative short range inspection data.

Figure 12. 12” pipe removed from service with significant external wall loss

QSR Axial Application & Example Results

A practical application example for QSR Axial involves pipe embedded in a concrete wall at a tank facility. The subject pipeline is 12” diameter and passes through a 12” (30cm) this concrete wall, with a horizontal shelf extension over the pipe. Figure 13 shows the Axial scanning configuration with the QSR1 electronics pod that provides control for the system.

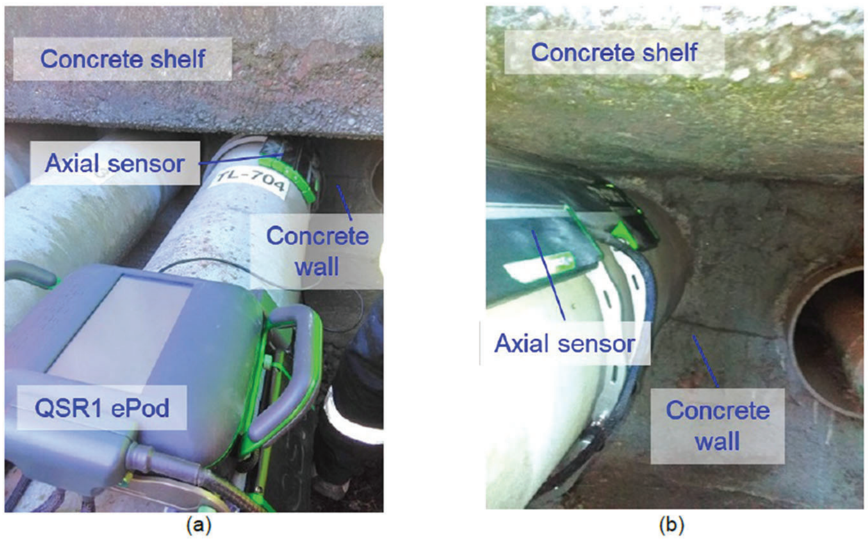

Figure 13. Scanning configuration at concrete wall penetration. (a) the QSR1 electronics pod controls the Axial sensor and traction unit (not visible). (b) the Axial sensor clearance beneath shelf extension and proximity to concrete wall.

Figure 14 illustrates the wall penetration layout. The concrete shelf extension restricted radial access around the pipe, however, there was sufficient clearance for the Axial sensor to successfully pass underneath the shelf (TP1). The scanner traction unit could not pass beneath the shelf so it was decided to only scan the upper portion (8 to 4 o’clock), though a manual scan was possible. Access to the opposite side of the wall was unrestricted so a complete circumferential scan was performed from this direction (TP2). No visual indication of corrosion was observed at either side of the penetration.

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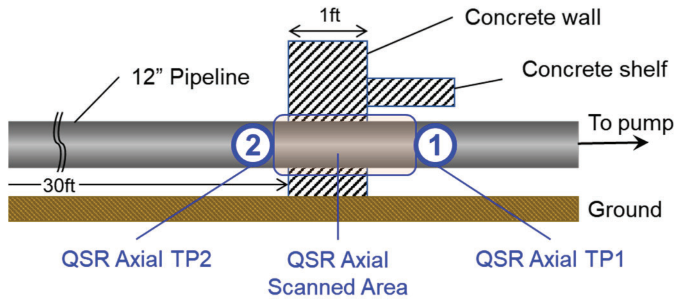

Figure 14. Side view sketch layout of 12" pipe QSR test positions

Scan results

Figure 15 illustrates the analyzed axial scan profile results from around the circumference of the pipe, from 8 o'clock to 4 o'clock at 1cm steps (Test Position 1). The results are presented as thickness referenced to the orientation angle around the pipe circumference. The black line represents the pipe wall thickness at the position of the sensor. The red line represents the measured remaining wall thickness within the embedded section. The gray area represents the pipe wall material.

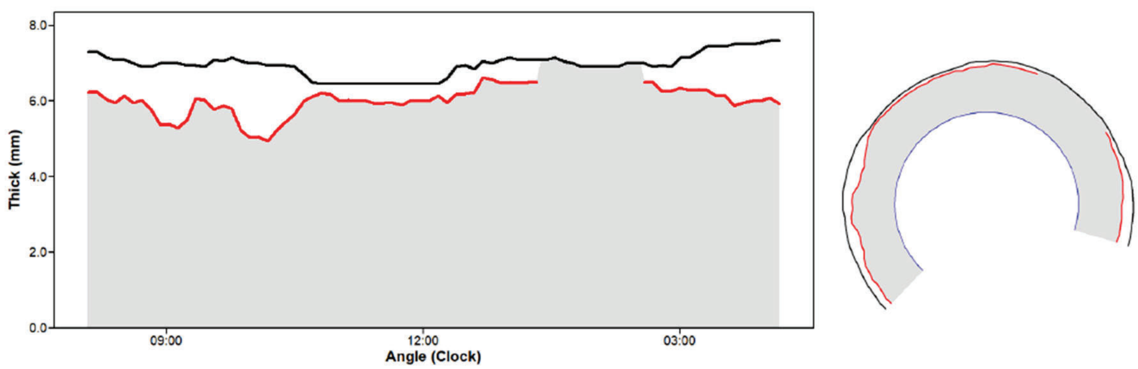

Figure 15. Axial scan results from Test Position 1 under concrete shelf

Some wall loss is evident at almost all scan positions around the pipe circumference. The measured nominal wall thickness at the position of the sensor is 0.254" to 0.299" (6.45mm to 7.60mm), and the measured remaining wall thickness at the penetration is within the range of 0.193" to 0.272" (4.90mm to 6.90mm). The deepest wall loss point was measured at 10:10 o'clock. Figure 16 represents the split frequency analysis at this scan position, which is converted into a wall thickness value.

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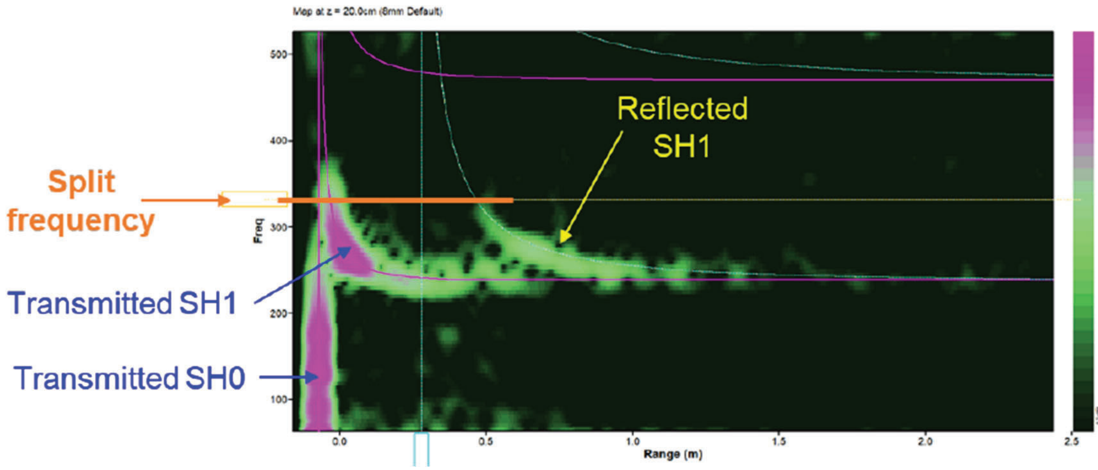

Figure 16. Axial split frequency analysis from Test Position 1

Figure 17 illustrates the analyzed profile results from the axial scans at Test Position 2. Scan (a) presents the results from 12 o'clock to 6 o'clock and scan (b) covers 7 o'clock to 12 o'clock positions. Polar views of each scan section are presented to the right of each profile.

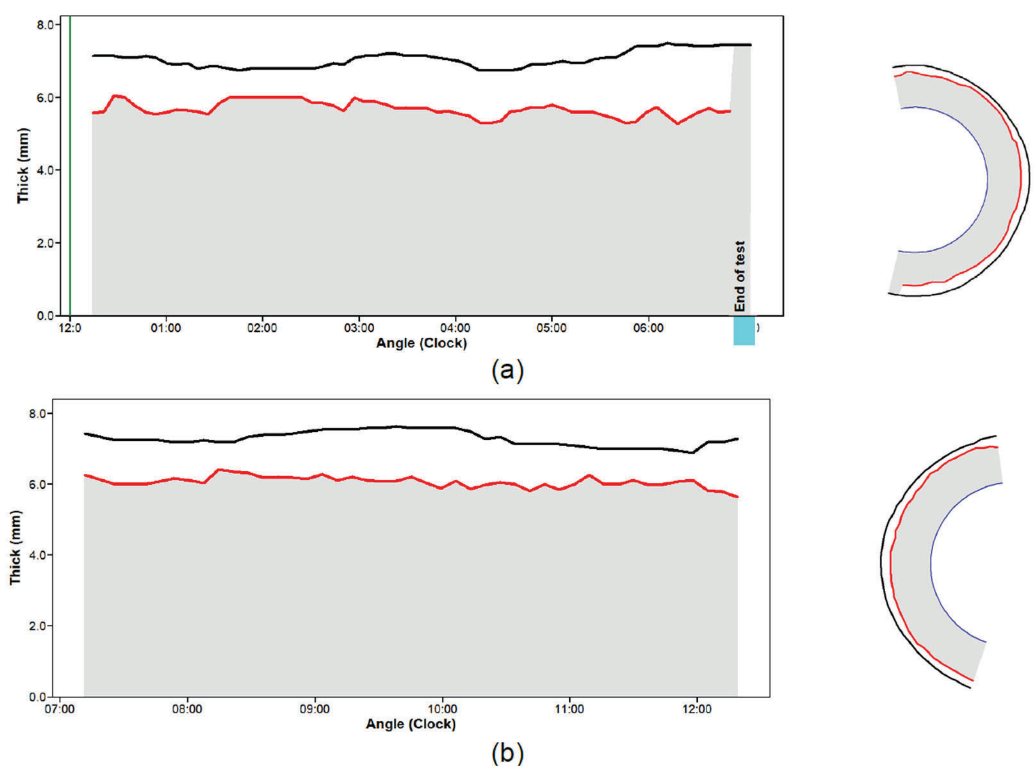

Figure 17. Axial scan results from Test Position 2

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Wall loss is evident at all scan positions around the pipe circumference. The measured nominal wall thickness range at the position of the sensor for Scan (a) is 0.266” to 0.293” (6.75mm to 7.45mm), and the measured remaining wall thickness is within the range of 0.209” to 0.272” (5.30mm to 6.90mm).

For Scan (b), the measured nominal wall thickness range at the position of the sensor is 0.272” to 0.299” (6.90mm to 7.60mm), and the measured remaining wall thickness is within the range of 0.222” to 0.252” (5.65mm to 6.40mm). The deepest wall loss points were measured at 05:45 o’clock and 12:18 o’clock respectively across both scans. Overall, areas of wall loss ranged between 0.079” and 0.118” (2-3mm) for this inspection.

Corrosion Program Implementation

For pipeline facilities containing mechanical pipe supports, concrete wall penetrations, anchors or soil-to-air interfaces, asset owners must develop robust contact point corrosion inspection programs and execute by established procedure. These programs are driven by a combination of engineering design consideration, operational history, and regulatory requirements. Federal and state safety rules are specific about the timing of inspections and areas of applicability, but may be not be detailed on how they are to be accomplished [Ref 6].

As previously stated, true visual inspections are limited in these areas so asset owners must evaluate the effectiveness of their existing inspection program and determine if improvements are needed. Gaps within the program may come to light by way of observation during ongoing operations, piping system failures, regulatory program inspections, or through structured internal audits. In the case of contact point corrosion, the ability to “visualize” the pipe’s condition where it cannot be seen by the human eye is the most significant challenge. Access for true visual inspection may require excavation or other significant facility modification. These modifications are in many cases very costly and carry their own risks.

Asset owners must continuously risk rank and prioritize their annual corrosion control and integrity management initiatives to best ensure the safety of the public, protection of the environment, and regulatory compliance (where applicable) [Ref 6]. For those pipeline systems containing large numbers of supports or concrete interfaces, operation and maintenance records must be reviewed to determine if problematic design factors or operating conditions exist that increase risk of contact corrosion.

Once this population is identified, a feasibility study must be conducted to determine which inspection methods are applicable and provide the most representative results. The following feasibility factors may be considered:

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- Pipe orientation
- Pipe support design (clamped, welded, saddle)
- Coating type and general condition
- Pipe operating temperature
- Environment (humid vs. dry)
- Access restrictions/excavation
- Inspection history and results
- Failure history

Technology continues to reside at the forefront of the pipeline safety industry and asset owners are challenged to evaluate the numerous offerings available. This evaluation process is driven by the need to solve a problem, reduce risk, reduce cost, and hopefully all of these collectively. Quantitative contact corrosion scanning may serve to enhance existing “visual” pipe inspection protocols by providing insight into areas not previously accessible. This added insight may prevent the removal of support structures or alteration of concrete barriers that might not otherwise have been in critical condition.

Complementary guided wave inspection

As previously stated, guided wave screening has been in wide use for the evaluation of contact points for many years. Quantitative guided wave scanning is considered complementary to screening in that areas of interest can be quickly categorized in terms of severity using screening, then quantified with scanning. This combined approach can add efficiencies with NDT inspection service companies who provide both services. This reduces mobilization costs and greater continuity in data reporting. Data interpretation and defect calls can be more accurate and presented with greater confidence where a combined dataset (qualitative/quantitative) is available [Ref 1,2,4,5].

Summary

Contact point corrosion presents an ongoing threat to our pipeline and process facility infrastructure. Visual inspection methods are only effective where access permits the human eye to see. The most significant atmospheric corrosion tends to occur where it is least visible and accessible. Regulatory requirements, where applicable, drive asset owners to locate, inspect and remediate at-risk areas.

The costs associated with removing support structures, excavating transitions, and carving out concrete wall penetrations are considerable and consume resources that could be allocated to other risk mitigation efforts.

Corrosion inspection technology continues to progress through research, testing and the availability of more robust hardware, computer processing capability, and sophisticated algorithms. Guided

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wave technology in general has been integral to corrosion control and integrity management programs for over two decades and now provides greater capabilities than ever before.

The methodical deployment of quantitative short range guided wave technology in difficult access areas can provide insights beyond conventional inspection techniques, allowing asset owners to extend integrity assessment resources beyond current expectations.

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