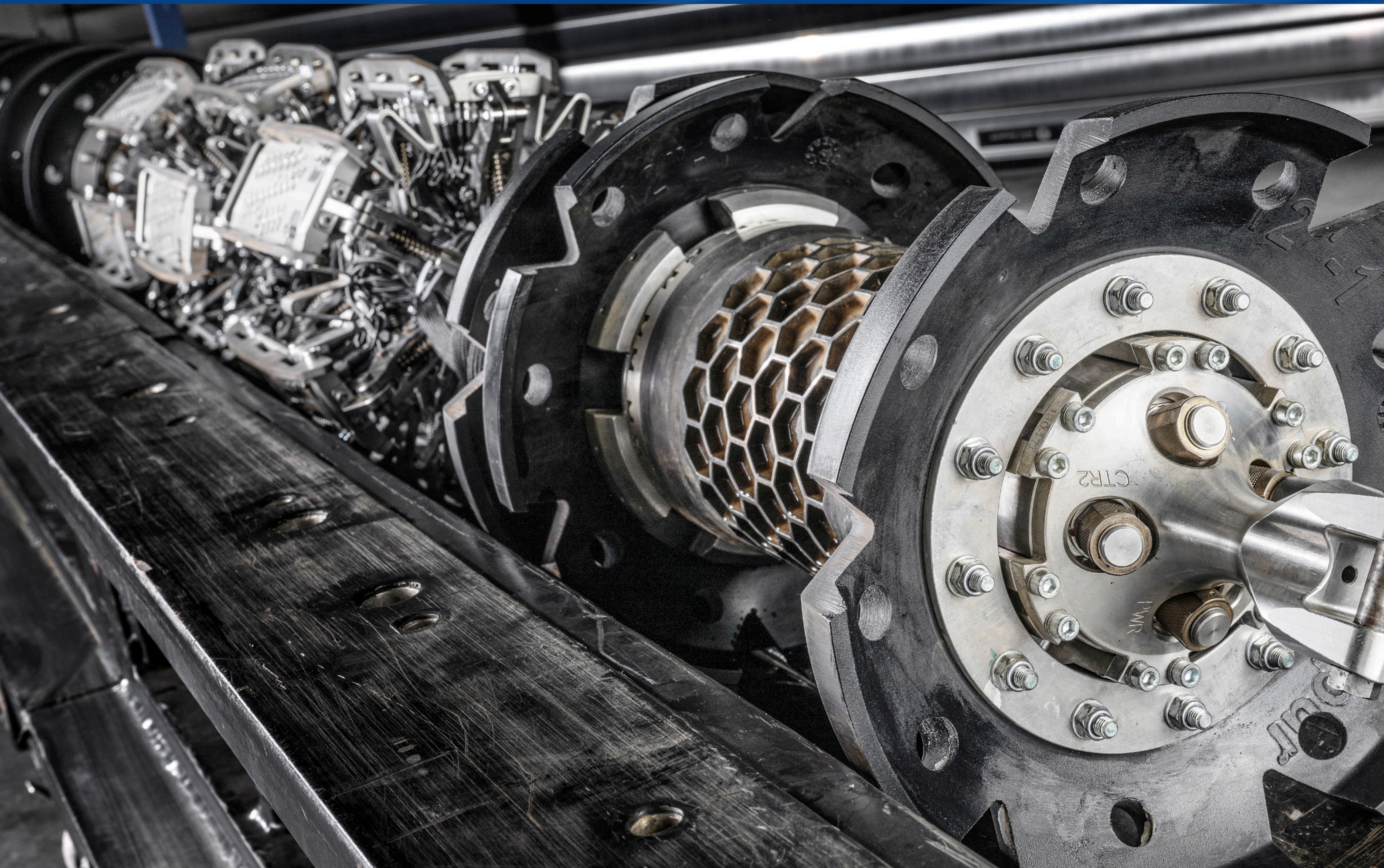
White Paper

UT and MFL Inspection Comparison for Pipeline Integrity Enhancement



White Paper

A Comparative Study of UT and MFL Inspection Technologies

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Abstract

Inline inspection (ILI) plays a pivotal role in pipeline integrity management programs. While ultrasonic technologies (UT) have been a part of ILI vendor portfolios for decades, many operators exclusively rely on magnetic flux leakage (MFL) technology for metal loss inspection. This paper explores real-world experiences highlighting the integrity advantages gained from using UT alone or in combination with MFL, emphasizing the importance of incorporating an off-cycle technology during re-inspections that utilizes a different measurement principle.

The choice of ILI technology depends on factors such as anticipated threats, pipeline conditions, and parameters, which ultimately shape the desired outcome. Additionally, this paper elucidates the distinctions between UT and MFL ILI technologies concerning operational constraints, anomaly detection, sizing, and associated analytical differences. These insights are substantiated by extensive collaboration with a pipeline operator across multiple liquid pipeline assets.

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Introduction

Saudi Aramco is the largest integrated Oil and Gas company in the world with assets encompassing all aspects of the Oil and Gas eco-system both onshore and offshore. This vast pipeline network ranges in diameter from very small diameter flow pipelines to large 56" cross-country lines with different pipe types and pipe vintages. These assets are considered critical as they transport refined and unrefined products to facilities for both domestic and international usage.

Historically, Saudi Aramco has performed primarily Magnetic Flux Leakage (MFL) ILI to detect metal loss in its 'piggable' pipelines but in the last few years, has started to also use other ILI technologies, one of which is ultrasonic testing (UT). UT was introduced to detect, identify, and size cracks in liquid pipelines, the advantages were soon recognized for metal loss and runs have subsequently been performed purely for this purpose.

In addition to the advantages of using UT for metal loss, the important additional benefit of detecting, identifying, and sizing laminations has also increased the overall utilization of UT tools, providing considerable additional value for pipeline asset integrity. While metal loss, lamination detection, and sizing typically use a series of 0-degree transducers (compression wave) and crack detection and sizing use a 45-degree shear wave principle, having the combination of the two can help detect, identify, and size combined and complex features.

However, each inspection technique has its advantages and disadvantages and in the case of Saudi Aramco, a suite of technologies will continue to be used either standalone or in combination. An example of this is where a pipeline can suffer from both very small internal pits and larger external general corrosion. In some cases, using a strategy of alternating UT and MFL can give the best of both worlds hence providing optimum data for decision making. This approach has been used to add real value to critical pipelines in high-consequence areas such as road crossings where the impact of disruption caused by severe metal loss can be significant.

This paper will expand on the extensive collaboration between Saudi Aramco and NDT Global to enhance the current Integrity Management Program (IMP) by leveraging UT and MFL technologies.

Metal Loss Inspection: UT and MFL

The most common measurement principles for ILI metal loss inspection tools are UT and MFL. Each technology delivers the depth and size of a metal loss feature by using a different physical principle. As a result, one of the technologies may be better suited to detect certain metal loss or feature morphologies due to the way the technology works. Successful application of one of these technologies starts with understanding the history and feature morphologies that exist in the pipeline. If this cannot be known in advance, either by cut-out or non-destructive examination (NDE), both technologies should be run in a pipeline to gain a better understanding. This enables a more accurate and confident IMP to be conducted moving forward.

The two different principles of metal loss detection

Ultrasonic inspection tools for wall thickness measurement use piezoelectric sensors whose surface is a distance away from the inner pipe wall (called the "standoff") and positioned parallel to the pipe wall to send and receive sound waves (Figure 1). The sensors generate a sound wave that travels through a coupling medium, into the pipe wall, and outside the pipe wall. At the interface of each change in material (liquid to inner pipe wall, pipe wall to outer surface) part of the sound wave is reflected to the sensor, where a signal is recorded. In knowing when the sound wave was sent, when signals returned, and the speed of sound in the coupling medium and pipe wall, the pipe wall thickness can be calculated. This is a direct measurement since the distance is calculated from known or measured physical properties. The sizing accuracy is therefore independent of wall thickness and independent from length and width sizing. In addition to the pipe wall thickness, the distance between the sensor and the wall is measured as well. This distance is called the stand-off, and it is used to identify internal features.

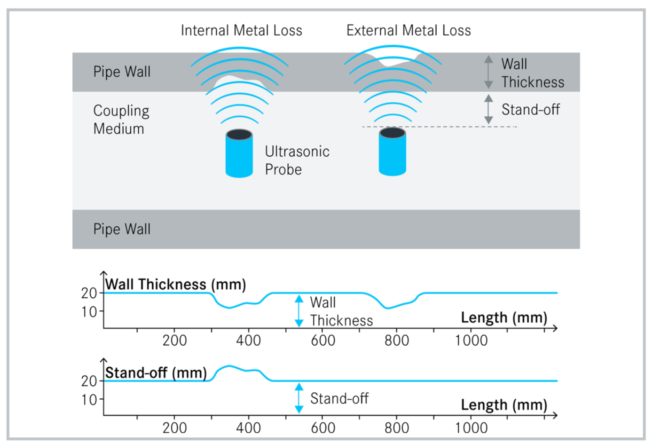

Figure 1 – Principle of ultrasonic wall thickness measurement

A drawback of the classic UT measurement principle is that a liquid coupling medium is required. UT ILI of gas pipelines therefore must be performed in a batch. For specific pipelines, the limitation of requiring a liquid couplant can be overcome using acoustic resonance technology (ART) to make direct measurements of wall thickness and stand-off providing similar insights to the asset as conventional UT.

MFL ILI tools for wall thickness measurement use a different principle to measure metal loss in a pipeline. With MFL ILI tools, magnets induce a magnetic field in the ferromagnetic pipe wall up to magnetic saturation. Volumetric metal loss, such as a corrosion anomaly, results in a leakage of the magnetic flux which can be measured by sensors on the MFL ILI tool (Figure 2, top).

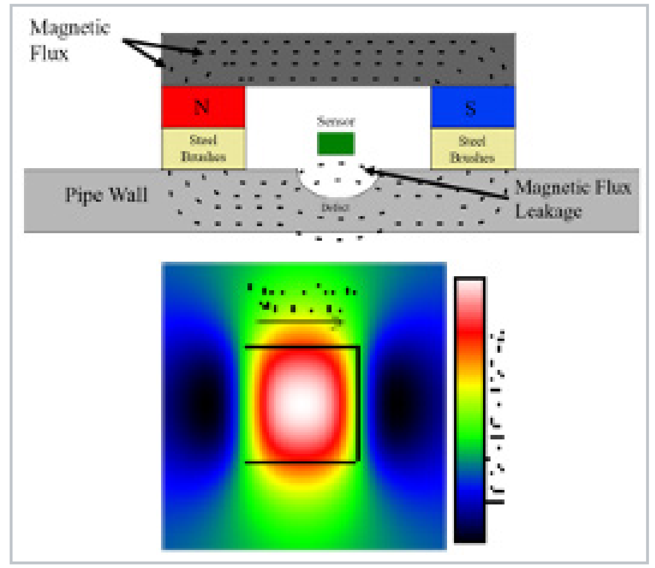

Figure 2 – Top: Principle of MFL wall measurement [2]. Bottom: example of an MFL signature used to size a feature [3].

This recorded magnetic flux leakage signal is then converted to the dimensions of the metal loss using different criteria (size) and grading algorithms (depth) (Figure 2, bottom). Since these algorithms require calibration data, the conversion of the MFL signal to metal loss depth is an indirect measurement. Additionally, multiple metal loss morphologies could correspond to the same MFL signal, so the topography of the metal loss is not precisely captured [1]. The determined feature depth is typically relative to the wall thickness and therefore the absolute depth sizing accuracy decreases with increasing wall thickness.

The direction in which the magnetic field is applied affects detection and sizing capabilities for different feature geometries as the technology functions best in detecting changes in wall thickness perpendicular to the direction of the magnetization. Sizing and detection performance are reduced for narrow features oriented parallel to the magnetic field. The most commonly applied MFL tools are axial MFL tools (hereafter referred to as conventional MFL), where the magnetic field is oriented parallel to the axial direction of the pipeline. In this case, the tool has limited capabilities to detect and size axially aligned metal loss. Other MFL tools like circumferential or spiral MFL are better suited for the detection of axially aligned metal loss.

MFL tools do not require a liquid coupling medium and can therefore be directly used to inspect gas pipelines. MFL technology can only be used for ferromagnetic pipe walls and requires a high magnetic field in the pipe wall. Limiting factors can be the wall thickness, external ferromagnetic casings and sleeves, or ferromagnetic debris.

Detection of non-metal loss features

Due to the principles of the sizing methods and the mechanics of the tools, other features like surface-breaking laminations, inclusions, geometric features, crack-likes, and their repairs, may or may not be able to be detected and/or properly identified by MFL tools.

UT metal loss tools also allow reliable detection and sizing of mid-wall anomalies such as laminations since these features act as reflectors for the UT signals. All types of laminations can be detected, like laminations parallel to the pipe surface, laminations that are embedded within the pipe wall but are sloping, and surface-breaking laminations. Sloping and surface-breaking laminations can be assessed using API 579 [4]. In this assessment, laminations are conservatively considered to be axial crack-likes, with a length equal to the lamination's length and a depth equal to the difference in wall thickness between the two sides of the lamination (Figure 3). However, as laminations block the travel of the sound path to the outer surface of the pipe wall, they could also impair the detection of external metal loss in their location.

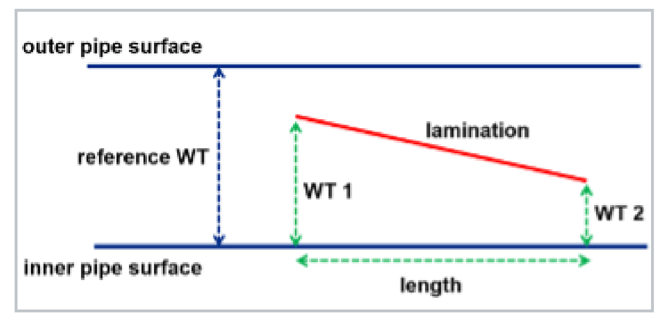

Figure 3 – Sizing of laminations in UT data

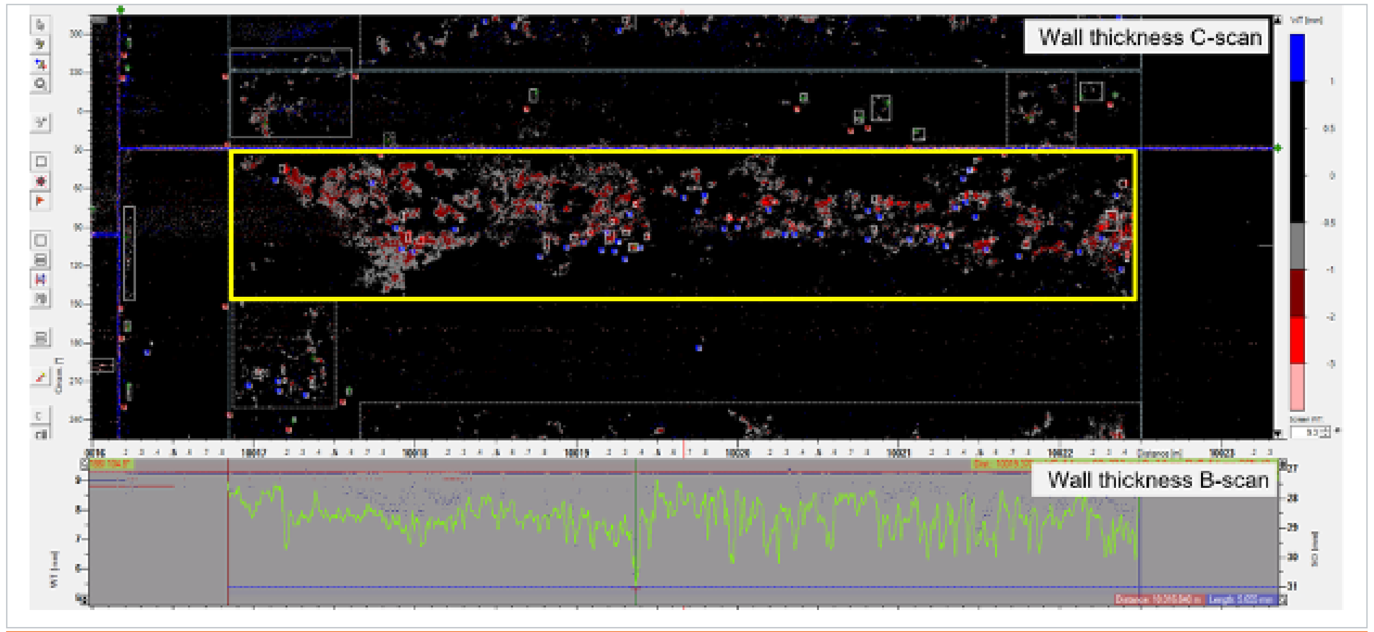

Figure 4 – UT wall thickness inspection data. The yellow box indicates one reported area of external metal loss (length = 5.65 m, width = 0.77 m) matching 42 smaller MFL boxes, seen in white with blue "u" labels. The green curve in the lower part indicates the River Bottom Profile (RBP).

As MFL relies on volumetric metal loss to detect and size features, the magnetic field is generally undisturbed by the presence of a lamination. Therefore, MFL cannot detect non-volumetric features like non-surface-breaking laminations.

Both technologies are often capable of detecting, but not sizing, geometric features that influence how the tool interacts with the inner pipe wall, for example, dents and bulging or blistering laminations. This limitation arises from how the tool records other information, such as lift-off, which enables the detection of these features.

Neither metal loss technology is well suited to detect and size cracks. For UT metal loss technology, a typical crack does not present a reflective surface and therefore cannot be detected or sized. For conventional MFL metal loss technology, a typical crack does not have volumetric metal loss associated with it and therefore cannot be reliably detected and/or sized.

Certain repairs can be detected and identified by both technologies, as a consequence of how the technology works. UT technology can detect metal welded to the pipe; therefore, Type B sleeves are visible and recognizable in the data. MFL technology can identify the effect of the repair. This means that detection is possible, but, as an example, Type A versus Type B repairs are not necessarily discriminated. Because of the additional material and a magnetization level that is tailored to the expected wall thickness, MFL is generally unable to size features located underneath ferromagnetic sleeves. In contrast, UT metal loss measurements are unaffected by the presence of sleeves. This attribute can be valuable when monitoring possible corrosion growth under sleeves.

Data analysis and reporting of anomalies

Once an ILI is performed, the results are often sent to the customer in a spreadsheet, which in its most basic form lists feature locations, sizes, depths, and orientations. It is not uncommon for an MFL inspection report to contain significantly more metal loss features compared to a UT inspection in the same pipeline. This is mainly a consequence of a different boxing algorithm during the preparation and analysis of the inspection data.

In the case of UT, a coherent area of metal loss is usually reported as one feature, described by maximum depth, total length, and total width (feature list information). This feature boxing and sizing is performed or checked by a data analyst in most cases. On the other hand, boxing, and sizing of MFL inspection data is largely an automated process, which often results in more, but smaller, anomaly boxes.

An example is shown in Figure 4 where one UT feature matches to 42 MFL features. Such significant differences in feature boxing are typically only observed for areas of extended general corrosion. In the case of localized metal loss anomalies, UT and MFL reporting results often match quite well.

Anomaly assessment for integrity management

For extended corrosion areas like in Figure 4, the small MFL boxes might not accurately represent the actual corrosion area, potentially leading to unconservative assessment results. The larger UT boxes provide a better description of the area affected by metal loss, but Level 1 assessment methods like B31G [5], which are based on the box dimensions (maximum depth, total length), might be overly conservative. Level 2 assessment methods like RSTRENG Effective Area (which uses the River Bottom Profile (RBP)) and Plausible Profile (PSQR) [5] account for the remaining wall thickness profile of metal loss anomalies and

Figure 5 – Comparison of what a remaining wall thickness profile from MFL in lower resolution (top right) versus higher resolution (bottom right) might look like [6].

should be used to calculate the safe operating pressure for extended metal loss anomalies. The remaining wall thickness profiles required for Level 2 pressure assessment methods are readily available from UT inspection data (see example in Figure 4). Furthermore, the UT data precisely traces the topography of the metal loss, which reduces conservatism. However, as discussed in the next section, tool resolution will determine how well the topography is traced. UT technology easily generates remaining wall thickness profiles because it directly measures the wall thickness.

As discussed previously, MFL data is an indirect measure of wall thickness, and there is not a 1:1 correspondence between feature size and feature morphology. Therefore, it is more difficult to generate remaining wall thickness profiles for metal loss anomalies measured using MFL. One strategy used to generate a profile for MFL data is to combine the depth and width of MFL boxes into clusters. When a higher resolution MFL tool is applied, smaller MFL boxes are generated, which when combined, lead to a more detailed profile (Figure 5) [6]. However, this is still an approximation of the shape of the metal loss profile that could be conservative. Methods to generate a 3D profile of metal loss from MFL data do exist but are not widely used in practice [1].

Overcoming challenges

Each technology has challenges that are unique to the principle of operation. For UT technology, one challenge is detecting and sizing pinholes. For MFL technology, one challenge is reproducing the metal loss topography.

Pinholes pose a challenge to UT technology because the size of the metal loss is small relative to the diameter of the sound field generated by the sensor. When this happens, a phenomenon called the edge effect could occur, where the signal associated with the metal loss is coupled to a signal associated with a healthy wall. Such signals can still be analyzed; however, their probability of detection and sizing (POD and POS) can be improved with higher resolution and tailored sound fields.

In the past, UT ILI tools typically recorded wall thickness data with 3 mm axial resolution and 8 mm circumferential resolution. Modern high-resolution UT tools can record wall thickness data on a dense grid with e.g. 0.75 mm axial resolution and 4 mm circumferential resolution or 0.75 mm axial resolution and 2.5 mm circumferential resolution in the highest resolution configuration option.

A higher resolution not only increases the POD and POS for pinholes but also facilitates the accurate sizing and assessment of metal loss anomalies, as can be seen from the remaining wall thickness profiles in Figure 6. Such wall thickness profiles are ideal input for Level 2 assessment methods like RSTRENG Effective Area and PSQR.

In contrast, the MFL signal response is larger than the actual anomaly diameter, a phenomenon called the blooming effect. This contributes to the generally good detection capabilities of MFL tools for pinholes. Examples of high-resolution (axial) MFL tools from published papers have listed resolutions of 1.0 mm axial resolution and 1.6 mm circumferential resolution [7], compared to a typical standard resolution of 2.5 mm (axial) and 5.9 mm (circumferential).

Reproducing the metal loss topography poses a challenge for MFL because as an indirect measurement, the MFL signatures do not directly reflect the topography of the metal loss. As discussed in Section 3.4, increasing the resolution of the MFL tool can aid in the generation of RBPs, but this is still not a three-dimensional view of the metal loss.

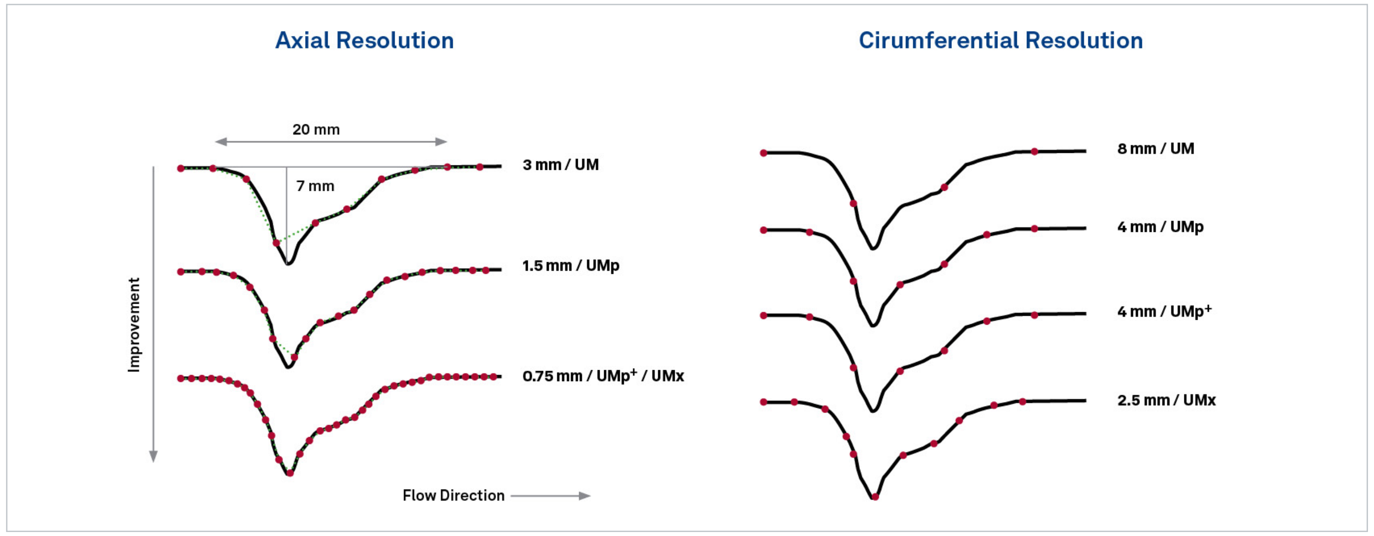

Figure 6 – Axial and circumferential remaining wall thickness profiles extracted from UT ILI data (red dots) for different resolution vs. real feature profile (black curve)

Generating the topography from MFL data can be time-consuming and require additional measurements or analysis. The field of machine learning is facilitating the generation of three-dimensional MFL profiles, this is currently an important topic for the industry which is actively being researched [7].

Pipeline Anomalies – Detection and Assessment

This section shows examples of typical pipeline anomalies and discusses the detection capabilities of UT and MFL metal loss inspection tools. NDT Global performed the review and assessment of all UT data.

Metal loss

A very common type of pipeline anomaly is internal or external corrosion. These corrosion features can vary in size from localized pits or pinholes with sub-centimeter diameters to extended general corrosion spanning over several meters.

Figure 7 shows UT inspection data of a general external corrosion area detected in a 46" pipeline. The metal loss area has a total length of 0.52 m and a circumferential extent of 1.62 m. The maximum depth is 7.5 mm (68 % of the local reference wall thickness of 11.0 mm).

Based on the total length and maximum depth, a low safe operating pressure of 29.1 bar is calculated using the Level 1 assessment method modified B31G (0.85 dL). Applying the Level 2 RSTRENG Effective Area assessment method, which accounts for the detailed remaining wall thickness profile, a significantly higher safe operating pressure of 49.2 bar is obtained which is above the local pipeline MAOP. The remaining wall thickness profile (river-bottom profile) is directly available from the UT wall thickness data and is indicated by the green curve in the lower part of Figure 7.

This area of corrosion was reported as 14 smaller metal loss areas with a maximum depth of 55 % in the previous MFL inspection. For these 14 features, the lowest modified B31G (0.85 dL) safe operating pressure is 47.4 bar which in this specific case agrees well with the RSTRENG Effective Area pressure calculated for the UT anomaly.

In addition to general external corrosion, which was detected in a short section of the pipeline, the considered pipeline is mainly affected by internal pitting corrosion. Compared to the previous MFL inspections, the applied UT metal loss tool was not able to identify all small-diameter features reported by MFL and tended to undersize the depth of pitting features compared to the MFL results. As mentioned in Chapter 3, the detection and sizing capabilities of UT metal loss tools for pits and pinholes strongly depend on the axial and circumferential resolution of the ILI tool. As a high-resolution UT metal loss tool was not available for the inspection of this pipeline, the survey was performed using a standard-resolution UT tool. After a careful review of the UT inspection results, NDT Global recommended using high-resolution UT or continuing MFL inspections in this pipeline to monitor the internal pits. UT metal loss inspections are recommended to monitor the external general corrosion.

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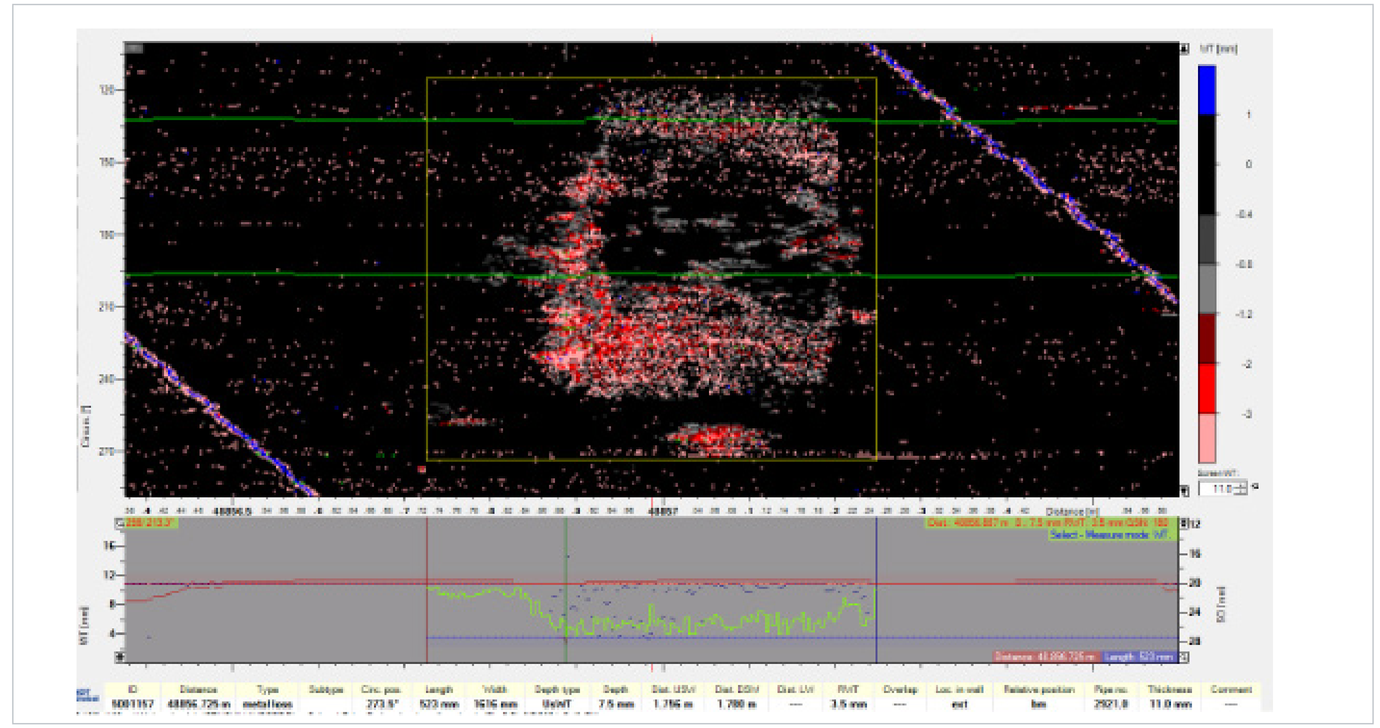

Figure 7 –UT wall thickness data of a general external corrosion area and river-bottom profile (green curve in the Wall thickness B-scan). For this and all subsequent images, the flow is from left to right.

Laminations

The UT wall thickness surveys revealed that several of the inspected Saudi Aramco pipelines are affected by laminations. As expected, these anomalies were not detected in the historic MFL inspections.

A lamination is a plane of non-fusion in the interior of the steel plate that results from the steel manufacturing process. Laminations are rare in modern pipelines but are frequently found in older pipelines. Such manufacturing-related laminations are generally not a significant defect if they are embedded, parallel to the pipe wall, and not close to structural discontinuities or welds (API 579 [4]).

Sloping and surface-breaking laminations reduce the effective thickness of the pipe and require assessment. API 579 [4] recommends evaluating such laminations as crack-like flaws based on equivalent dimensions. The input required for this lamination assessment can be directly determined from UT wall thickness inspection data: The equivalent flaw depth is the wall thickness range affected by the sloping lamination, and the equivalent flaw length is the corresponding axial extent of the sloping lamination (see Figure 3).

Most of the laminations detected in the Saudi Aramco pipelines are parallel to the pipe walls and therefore are considered insignificant in terms of pipeline integrity. An example of one of the few detected sloping laminations is shown in Figure 8. This tongue-shaped lamination starts at a girth weld and slopes towards the external surface at the downstream end of the anomaly. The assessment according to API 579 [4] showed that this lamination is acceptable at the established MAOP. However, due to the significant weld contact verification of this feature was recommended.

Laminations at welds

According to API 579, through-wall cracking may occur for laminations at or close to welds, as such laminations can propagate along the weld fusion line or in the

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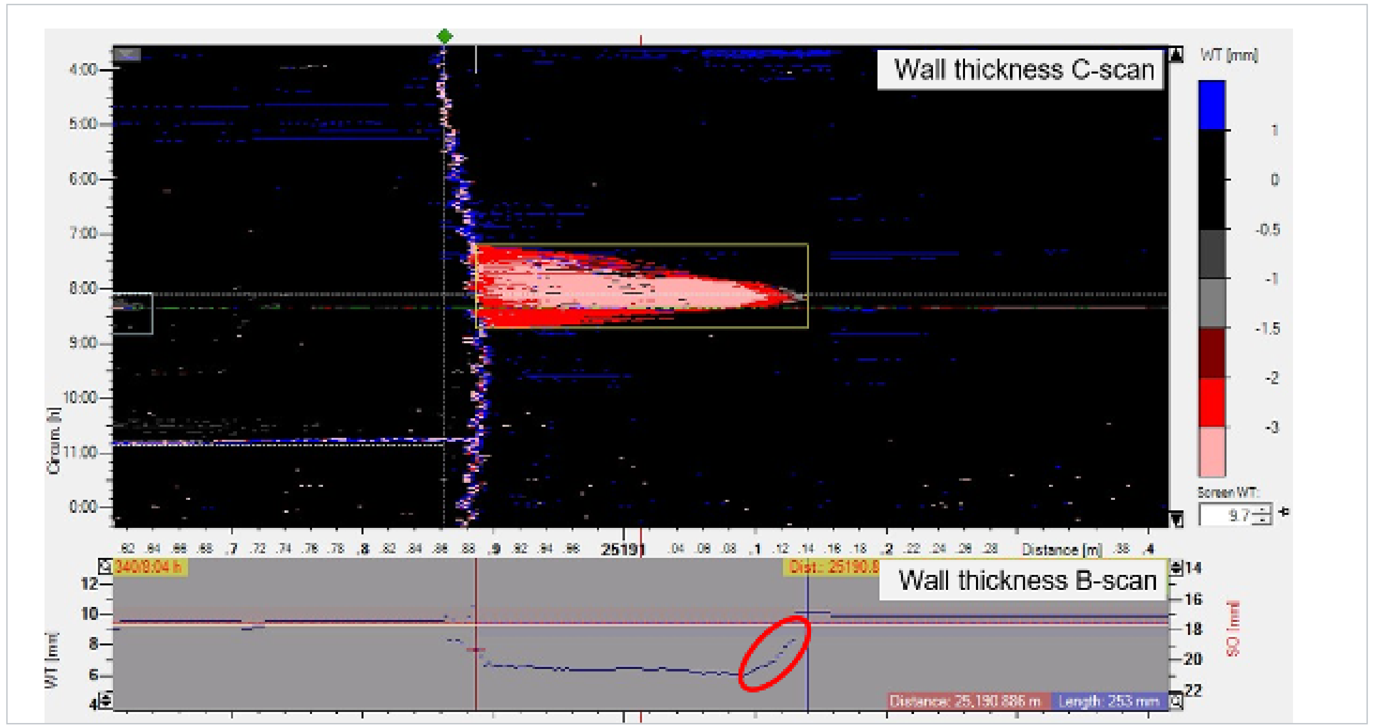

Figure 8 – UT wall thickness inspection data for a sloping lamination located at a girth weld. The sloping portion of the lamination is circled red in the B-Scan

heat-affected zone in the through-thickness direction, especially if the welds were not subject to Post-Weld Heat Treatment. API 579 therefore recommends that laminations at weld seams should be monitored in-service. API 579 states that laminations at welds are acceptable if it is determined that through-thickness cracking towards the inside or outside surface does not occur.

Based on the available UT metal loss and axial crack inspection data, it is not possible to determine whether there are indications of through-thickness cracking in the weld zone. For laminations at the long seam, axial cracking towards the outside could be shielded by the lamination, and circumferentially oriented cracking along girth welds would not be detected by the axial crack detection technology. Therefore, potential cracking originating from the lamination cannot be quantitatively assessed. Instead, all laminations reported at welds were reviewed in the UT inspection data and prioritized based on the length of the weld contact zone. The lamination in Figure 8 has significant contact with the girth weld in a zone > 400 mm length and was recommended for verification. Figure 9 shows another example of a lamination reported at a girth weld. Based on the feature list information (lamination at girth weld), this anomaly would have to be considered as a possible threat to the integrity of the pipeline. However, the detailed review of the inspection data showed that this planar mid-wall lamination is intermittent, and the weld contact was judged to be insignificant. This anomaly was therefore classified as an uncritical feature not requiring verification or repair.

Hydrogen-induced delamination and blistering

The UT metal loss and crack surveys identified pipelines affected by hydrogen-induced delamination and blistering [8]. Such anomalies are caused by atomic hydrogen combining to become hydrogen molecules at imperfections such as inclusions or laminations. The accumulation of hydrogen can result in high local pressure and stress leading to bulging or blistering. UT crack detection surveys have proved to be beneficial in revealing the existence of hydrogen-induced stepwise cracking (HIC) in some of the blistering areas.

Individual hydrogen-induced delamination often shows a typical circular shape and sometimes forms dense clusters. Due to their typical shape, hydrogen-induced delamination can be discriminated from manufacturing-related laminations based on the recorded UT wall thickness data grid. Blistering to the internal pipe surface can be detected using the UT stand-off data (however blistering on the external pipe surface is not visible in the ILI data). An example of a cluster of blistering hydrogen-induced delamination's is shown in Figure 10. While the UT data provides a good picture of this anomaly, the previous MFL inspections were not able to detect this type of mid-wall anomaly.

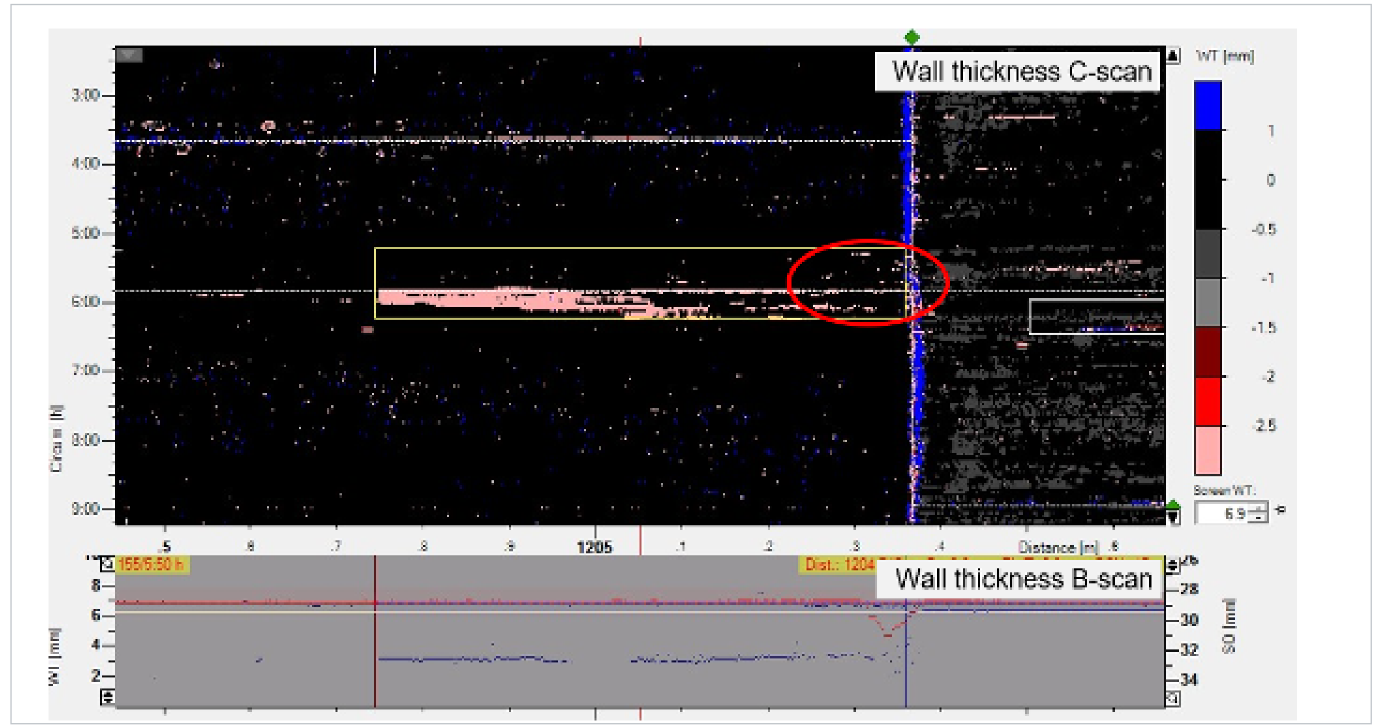

Figure 9 – UT wall thickness inspection data for a planar lamination with no significant contact to the girth weld. The weld area that could be contacting the lamination is circled in red.

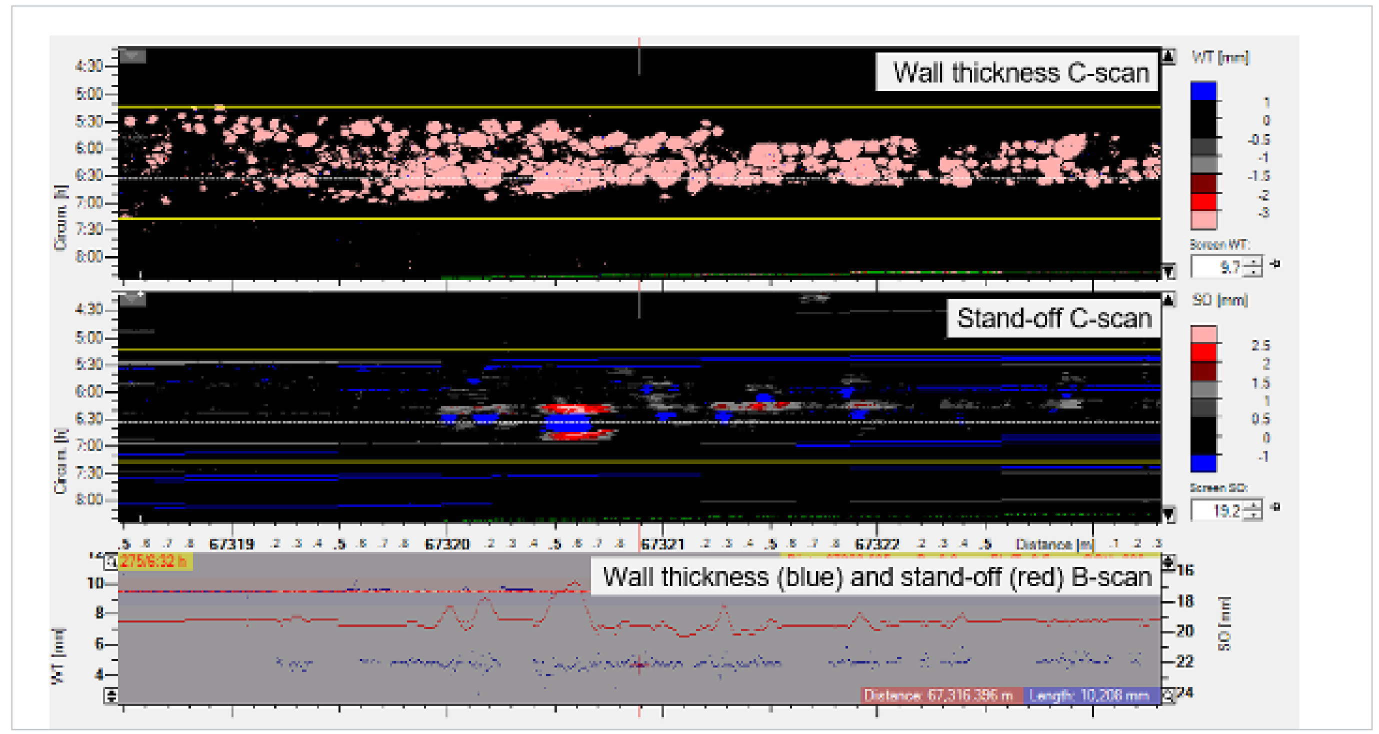

Figure 10 – UT inspection data for a cluster of hydrogen-induced delaminations. The typical circular shape is visible in the wall thickness data (top). The stand-off data (middle) shows blistering on the internal surface. The B-scan display (bottom) shows that the delamination is located in the middle of the pipe wall and also indicates blistering (decrease in stand-off).

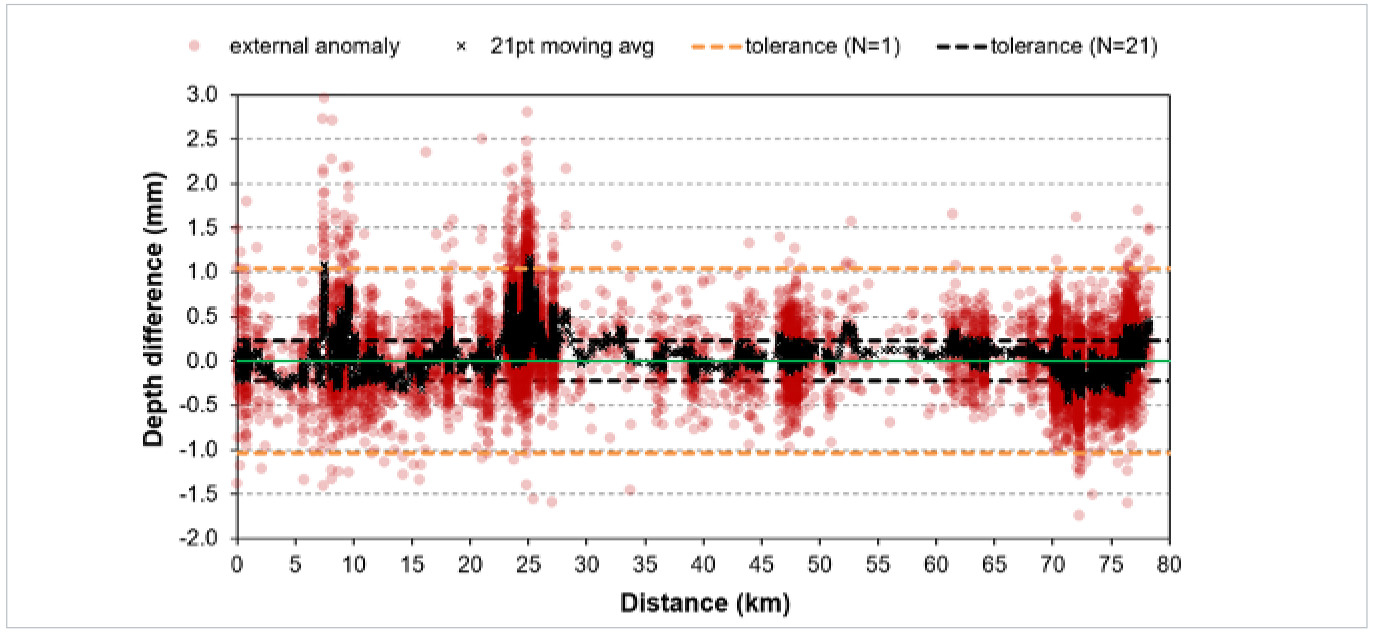

Figure 11 – Change in reported depth (UT – MFL) for external metal loss anomalies (red dots). The black crosses show the average change in depth of 21 neighbouring features. The dashed orange line indicates the comparison tolerance for the change in depth of a single anomaly. The corresponding tolerance for the average change in depth of 21 anomalies is shown as a black dashed line.

API 579 (part 7) [4] gives guidance on the assessment of hydrogen blisters and hydrogen damage associated with HIC. This assessment requires detailed information such as spacing between individual HIC features or blisters, HIC through-thickness extent, distance from HIC damage zone to internal and external pipe surface, blister diameter, blister projection (blister height), the existence of blister periphery or crown cracking. Not all of these input parameters can be (accurately) determined based on the available UT ILI data (e.g. ILI data does not provide information on blisters and potential blister cracking on the external surface). In addition, the future damage rate is uncertain. As a quantitative assessment of the delamination and blister anomalies is hardly possible, a qualitative ranking of the affected pipe joints is performed. A high priority is assigned in case of strong blistering and/or if delamination's affect large areas of the pipe joint (mechanical strength of pipes might be degraded). A lower priority is assigned to delamination's with no or minor blistering and not affecting large areas of a pipe joint.

> **Comparing consecutive metal loss ILI runs enables the assessment of corrosion growth behavior of a pipeline**

Geometric anomalies

UT and MFL metal loss ILI tools can detect geometric anomalies such as dents. However, sizing of such features is not possible with these tools. Nevertheless, a qualitative ranking of geometric anomalies is possible accounting for interacting with other anomalies or welds and location in the pipe (top or bottom). In the case of UT, the variation of stand-off (distance between the sensor and internal pipe surface) provides additional information that is useful for identifying possibly severe deformations. A quantitative assessment of geometric anomalies based on depth or strain requires geometry inspection data. Geometry inspection data can be acquired using traditional mechanical caliper tools, or UT geometry tools which can be combined with UT metal loss tools.

Corrosion growth assessment

Comparing consecutive metal loss ILI runs enables us to assess the corrosion growth behavior of a pipeline.

As part of a corrosion growth assessment (CGA), differences in reported anomaly depth are compared to the ILI depth sizing accuracy to determine if a depth difference is within the limits of the sizing accuracy or indicates actual anomaly growth. The calculated internal and external corrosion growth rates can be used to calculate the remaining life for the detected corrosion anomalies. This information is a good basis for prioritization of repairs and reinspection planning.

In the case of Saudi Aramco, previous inspections were usually performed using MFL. For the CGA based on UT and MFL ILIs the following aspects were accounted for:

- MFL reports relative feature depths referring to the pipe wall thickness. These depth values are converted to absolute feature depth using the actual wall thickness measured by UT.
- MFL depth sizing accuracy is relative to the pipe wall thickness and the absolute sizing accuracy decreases with increasing wall thickness. The absolute MFL sizing tolerance is calculated based on the actual pipe wall thickness measured by UT.
- Extended corrosion anomalies were usually reported as single features by UT but as several smaller features in the MFL results. In such cases, the deepest MFL feature was considered for the CGA.

To assess a possible systematic bias between two compared inspections, manufacturing-related anomalies such as grindings can be compared for which it can be assumed that their depth is constant in all compared inspections.

A comparison and CGA of the UT and MFL results are shown in Figure 11 and Figure 12. Figure 11 shows the change in depth of external metal loss anomalies versus the distance along the pipeline. The orange dashed lines indicate the comparison tolerance for the predominant wall thickness. For features with a depth difference above this limit, the change in depth is outside the limits of the sizing tolerances indicating a higher probability of corrosion growth. For features between the orange lines, the depth difference is within the limits of the sizing accuracy. Analyzing the moving average change in depth of 21 neighbouring features allows the identification of pipeline sections with a higher probability of growth (e.g. km 5 – 10 and around km 25).

Dividing the change in depth by the inspection interval yields the corrosion growth rates shown in Figure 12. The blue dashed line and black solid lines indicate the average and 95 % quantile corrosion growth rate calculated for different sections of the pipeline.

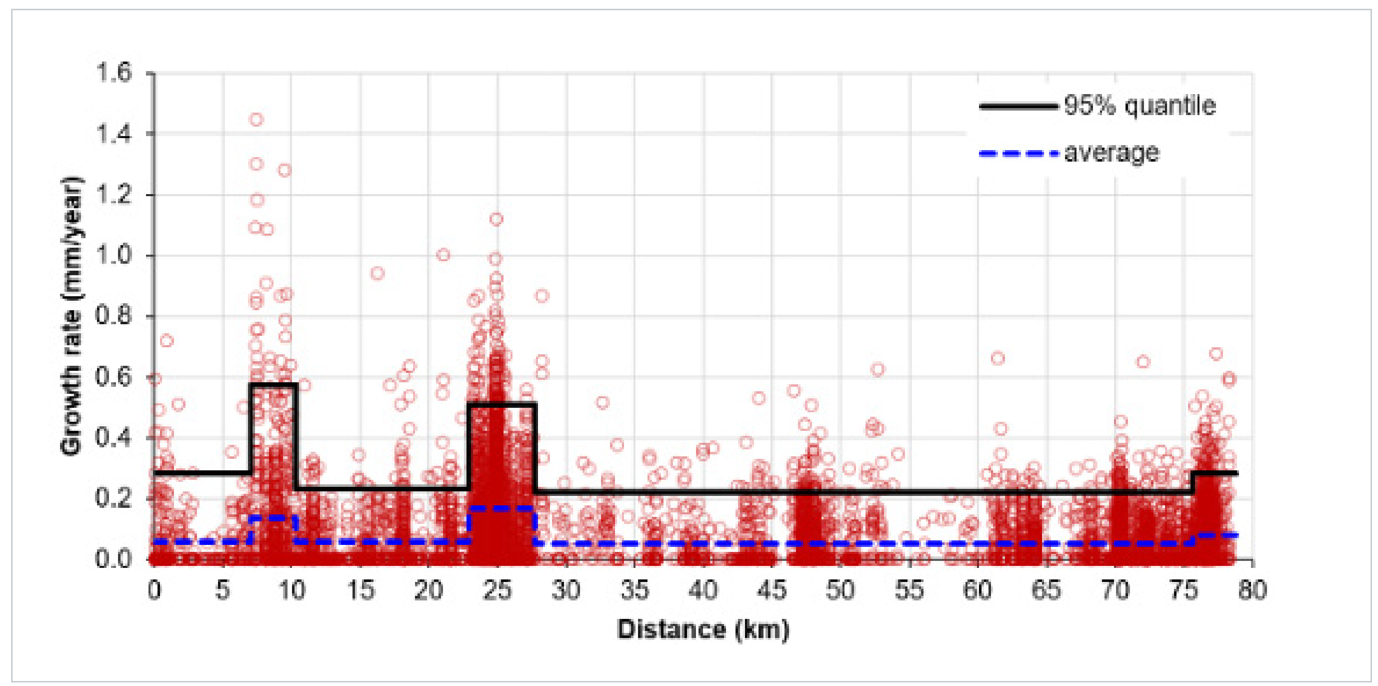

Figure 12 – External corrosion growth rates obtained by comparison of UT and MFL inspection results

Conclusions

Each pipeline has its unique attributes (anomalies, product, wall thickness, location), calling for a tailored solution in Integrity Management. Many of these attributes have been addressed in this paper regarding the selection of the correct technology to identify the features of concern. One of the most crucial decisions is determining the inline Inspection strategy throughout the pipeline's lifespan. Employing the appropriate technique or combination of techniques can significantly benefit operators' asset integrity management. However, understanding the correct selection criteria requires knowledge and experience of multiple technologies and techniques, as well as primary and secondary integrity threats, and how to utilize the provided information to yield meaningful and cost-effective outcomes.

Primary Application / Threat	UT Metal Loss	Conventional MFL	UT ML+MFL Candidate
Vintage Liquid Pipelines			
Laminations and delamination's	Yes	No	
Pinholes	High-res candidate	Yes	Yes
General metal loss	Yes	Yes	
SCC / crack fields	No	Min opening of 0.5 mm required (volumetric)	
Seam cracking	No	Min opening of 0.5 mm required (volumetric)	
Long-axial corrosion (i.e. channeling)	Yes (accurate topography)	Limited	Yes
Corrosion development under repairs	Yes	No	
Dents with stress risers	Yes (lift-off based, except cracking)	Yes (except laminations and crack-likes)	Yes
Mechanical damage	Yes	Yes	
Sour service-driven damage (i.e. blistering)	Yes	Limited	Yes
Newly Commissioned Liquid Pipelines			
Baseline	Yes	Yes	Off-cycle / alternating
Mechanical / construction damage	Yes	Yes	

Table 1 – Sample ILI technology selection matrix.

Table 1 demonstrates an ILI technology selection matrix that could be considered for an Integrity Management Program. If a baseline inspection is performed and there is no prior of knowledge of threat type, it would be valuable to run both UT and MFL technologies.

Acknowledgements

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Acronyms	
CGA	Corrosion Growth Assessment
HIC	Hydrogen Induced Cracking
ILI	Inline Inspection (tool)
IMP	Integrity Management Program
MFL	Magnetic-Flux Leakage
NDE	Non-Destructive Examination
POD	Probability of Detection
POI	Probability of Identification
POS	Probability of Sizing
PS	Performance Specification
RBP	River Bottom Profile
UT	Ultrasonic Testing

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