Complex Internal Metal Loss Pitting Corrosion in a Small-Diameter Pipeline and its Successful Detection and Sizing with UT Metal Loss – A Case Study

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Abstract

When a pipeline is inspected, recorded pipeline data is manually or automatically evaluated. Regardless of the pipeline condition (such as degree of corrosion), once the features meet the inspection system's performance specification requirements, a standardized data analysis can be carried out.

But what about inspections that, for various reasons, do not correspond to the standard and feature complexities are at the limit of, or even below, the performance specification? What if the feature is detected but not recorded correctly and the data evaluation is permanently impaired, or appears impossible at first glance? What if the position of the features, such as at or in girth welds, further increases the complexity of the analysis? Is it still possible to extract the essential information from the recorded signals?

Even under difficult conditions, detailed ultrasonic (UT) data analysis can provide highly accurate results. This was the case in a non-standard 6" project with the results being confirmed by field measurements and presented in more detail in this paper.

Introduction

What happens if the results of the data analysis are not wrong but not sufficient? This question arose three years ago when the data analysis of a complex pipeline with challenging anomaly shapes needed to be used as the basis for a run comparison and a Fitness for Purpose (FFP) assessment. Due to the complexity of the pipeline (6" diameter with a demanding curvature, uncommon feature shapes, etc.), it was clear that a standard analysis would not be sufficient to assess the true condition of this pipeline. A customized, non- standard data analysis approach was needed to identify all relevant information and all metal loss anomalies, predominantly on the inner pipe surface, within the limits of the inspection systems performance specification.

Due to short-term inspection intervals, a monitoring process was established and almost laboratory conditions were created to learn how this challenging data can be analyzed in the best manner. This process is still on-going, even after 4 inspections runs.

This paper will demonstrate how complex an analysis procedure can be, which factors are relevant, and how it is still possible to achieve excellent results. Since pipeline operators can choose UT metal loss and MFL technologies for the inspection of this 6" pipeline with extensive pitting corrosion, a short comparison of the UT metal loss and MFL technology will follow. An overview of the data analysis process will be provided, highlighting certain impacts and their consequences. A review of the data analysis results will demonstrate that despite the challenging data, reliable metal loss depths could be determined, forming the basis of sound decision making for the integrity management program.

An additional benefit of this paper is to show the importance of linked learning processes and exceptional projects to create new knowledge and promote new developments.

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The UT Metal Loss Principle

UT metal loss tools for wall thickness measurement are equipped with piezo-electronic transducers aligned perpendicular to the pipe wall. The transducers operate in the pulse- echo mode. The distance between the sensor and the internal pipe wall (stand-off) is calculated from the time of flight of the signal reflected from the internal pipe wall, considering the speed of sound of the medium. The (remaining) pipe wall thickness is calculated from the time-of-flight difference of signals reflected from the internal and external pipe wall, considering the speed of sound of the pipe steel. One single UT measurement contains the information from several time-of-flight signals in the pipe wall, so-called back wall echoes. Ideally, two different time-of flight data are available for internal material losses are available due to the stand-off and the actual wall thickness data. The principle of UT metal loss is illustrated in Figure 1.

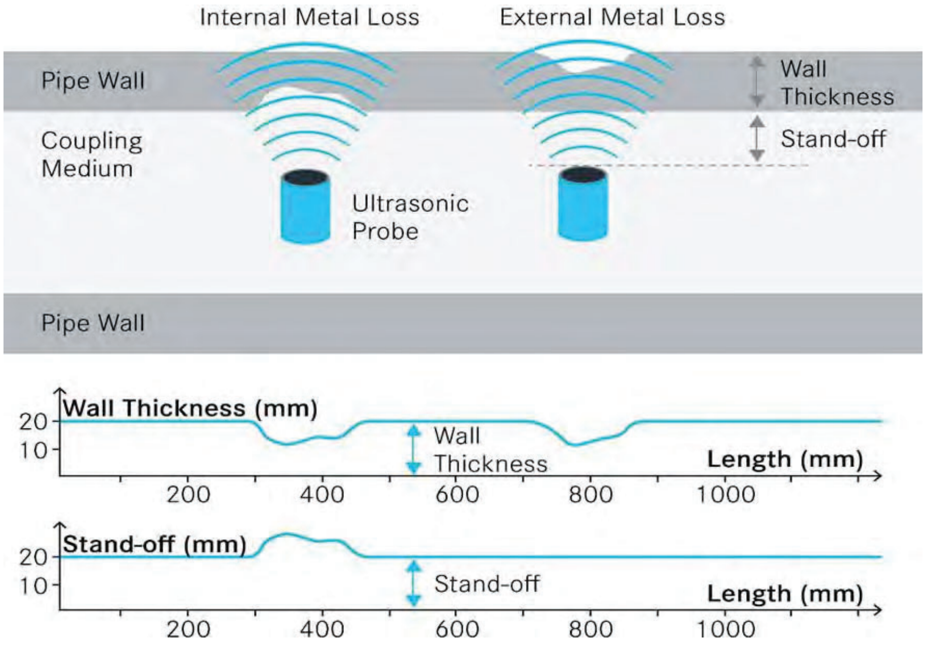

Figure 1. Principle of ultrasonic wall thickness measurement

UT metal loss differs from MFL in that it is a direct measurement of the wall thickness. This means that the true dimensions of the features are known. The UT metal loss tool used in this case can measure a minimum internal pit diameter of 0.20 in (5.0 mm), with a minimum depth of 0.03 in (0.80 mm). Additionally, to achieve the best results, especially for pits and pinholes, the cleaning and the pipe surface condition should meet the requirements for a successful inspection.

As the results in this study are compared with magnetic flux (MFL) results from a 3rd party, a quick overview about this technology shall provide the basics. MFL tools for wall thickness measurement use magnets to induce a magnetic field in the pipe wall. In unaffected pipe wall thickness, so-called sound wall, this magnetic flux does not change. Where there is metal loss present, the magnetic flux leaks outside or inside the pipe wall.

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The change in the magnetic flux is compared to the sound wall. The relative change in the magnetic flux can be correlated to a volume loss, which means that measurements are relative. Through calibration, testing, and further analysis of signal patterns, the volume loss can be calibrated to feature dimensions (API 1160).

As the MFL measurement is relative, the orientation of the magnetic field can affect the measurement. Axial or circumferential MFL is where the magnetic field is established in the corresponding direction. However, the directions cannot reliably detect, and size axial or circumferentially aligned metal losses.

Non-standard data analysis of a complex pipeline with a high complexity

Complexity factors and types of data analysis

In general, it can be said the more the stated factors shown in Figure 2 interact, the higher the complexity of the ILI feature detection and data analysis. Each factor alone can be compensated to a certain extent, but the complexity significantly increases as more factors collude with consequences for the data acquisition and analysis.

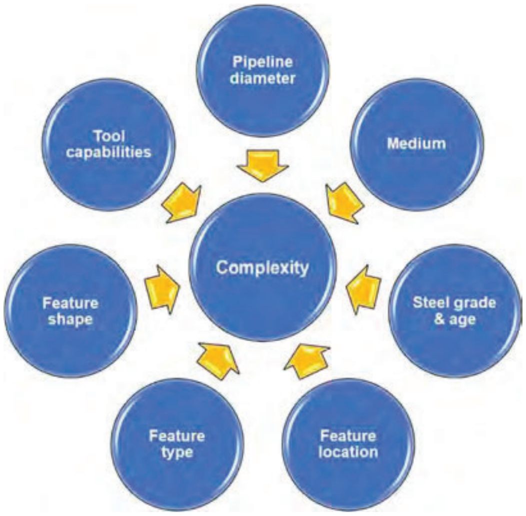

Figure 2. Complexity factors

Factor	**Impact**
Diameter	A decreasing diameter has an increasing impact on the inner curvature associated with changes to physical factors including pressure and friction for the inspection system.
Medium	Mediums have an influence on the pipeline condition and/or on data recording. For example, "dirty" mediums like diesel or volatile mediums like kerosene, have different impacts on the signal recording. Apart from that, mediums can also have impact type of the metal loss. While crude oil can shape channeling corrosion, aggressive mediums like hydrogen/condensate can cause pitting corrosion with sharp edges.

Steel grade & age	The older the pipeline and the used steel grade, the more impurities, and other irregularities (e.g., rough surface) can be seen. Additionally, older assets are often seamless which is prone to wall thickness variations.
Feature location	The feature location can make a significant difference: The base material is usually characterized by a plain surface without impacting the tool's capabilities and data recording, and a Probability of Detection (POD) ≥ 90% can be delivered. However, all locations outside of the base material, e.g., welds, heat affected zones (HAZ), or in bends, are not completely covered by the performance specification and the POD might be reduced.
Feature type	The detection of certain feature types, see Figure 8, dependent upon the technology utilized. Because of their smaller dimensions, slottings and pittings are at the edge of the UT metal loss tool capabilities and are not necessarily covered by the performance specification. A detection of features with small diameters is possible with UT metal loss but might be restricted regarding their Probability of Identification (POI).
Feature shape	Furthermore, the data acquisition also depends on the shape of feature. The performance of the inspection system is less affected with smoother transitions than compared to defects which are characterized by hard edges between the sound wall and the indications of an anomaly. This effect is well known from laminations and inclusions but can also occur with steep- side pinholes, pitting and slotting features with sharp edges.
Tool capabilities	Inspection tools are already highly complex tools in which mechanics and optical systems are precisely coordinated. The successful detection of features strongly depends on the objective of the inspections and the chosen technology systems because the tools are defined by their specific advantage and disadvantages. A limitation in one technology does not automatically mean that recording and/or analysis is not possible or can be fully covered by another technology. This is particularly true when more and more factors interact, and complexity increases. The knowledge of the limitations of a technology can be used to investigate them directly and incorporate this into the data analysis.

Depending on which factors and to what extent they interact, a change from standard data analysis to non-standard analysis might be necessary.

Standard analysis	**Non-standard analysis**
The interpretation of the inspection data can be carried out along the standard process and with the conventional tools and education. No special support is needed.	By certain reasons the inspection data need a deeper and/or special analysis which is not covered by the standard process and the tool capabilities. Advanced knowledge is required and often support by further specialist from other technical departments is needed.

The transition between both analysis types is fluid and depending on the individual case.

Background of the case study

This case study contains all ingredients for a highly complex, non-standard data analysis. The internal surface of the 6” pipeline is significantly affected by aggressive medium conditions causing thousands of steep-sided internal corrosion anomalies. Because a cut-out was never made, the real status of the surface is not documented. Therefore, the following Figure 3 and Figure 4 were chosen as representatives to give an idea of what the interface might look like.

Figure 3. Pitting corrosion by an aggressive medium (www.watertechnologies.com - December 2023)

Figure 4. Metal loss in a girth weld (NDTG 2007)

A typical example of that kind of corrosion anomalies is shown in the Figure 5 below. Besides all challenging metal loss indications due to their typical steep-sided shape, an additional challenge was that about 20 % of the internal metal loss features are located directly at girth welds which are characterized by the so-called heat affected zone (HAZ). The HAZ is an area ± 1.97 in (50 mm) around of the girth weld centerline with a restricted performance specification for the tool. A girth weld can be considered as a natural barrier that must be passed by the sensor carrier. Depending on the shape of the girth weld, the resulting lift-off effect, visible in the stand-off data, can differ strongly. In the chosen example below (Figure 5), the lift-off effect is more moderate, but nevertheless clearly existing. The lift-off effect may cause a change of the angle of incidence which is a relevant condition for an accurate UT metal loss data recording.

In addition, the depth sizing in wall thickness data for features which are directly located in or near girth welds may be impaired under certain circumstances. The reason for this is the surface of the weld as well as the weld material itself causing an irregular reflexion behavior.

The 3D view of this example shows a sharp edge which is typical for this kind of corrosion, but also a pronounced zigzag pattern. On the one hand this is related to the lift-off effect, while on the other hand the rough surface and additionally the steep-sided feature shape cause noises and unwanted outliers.

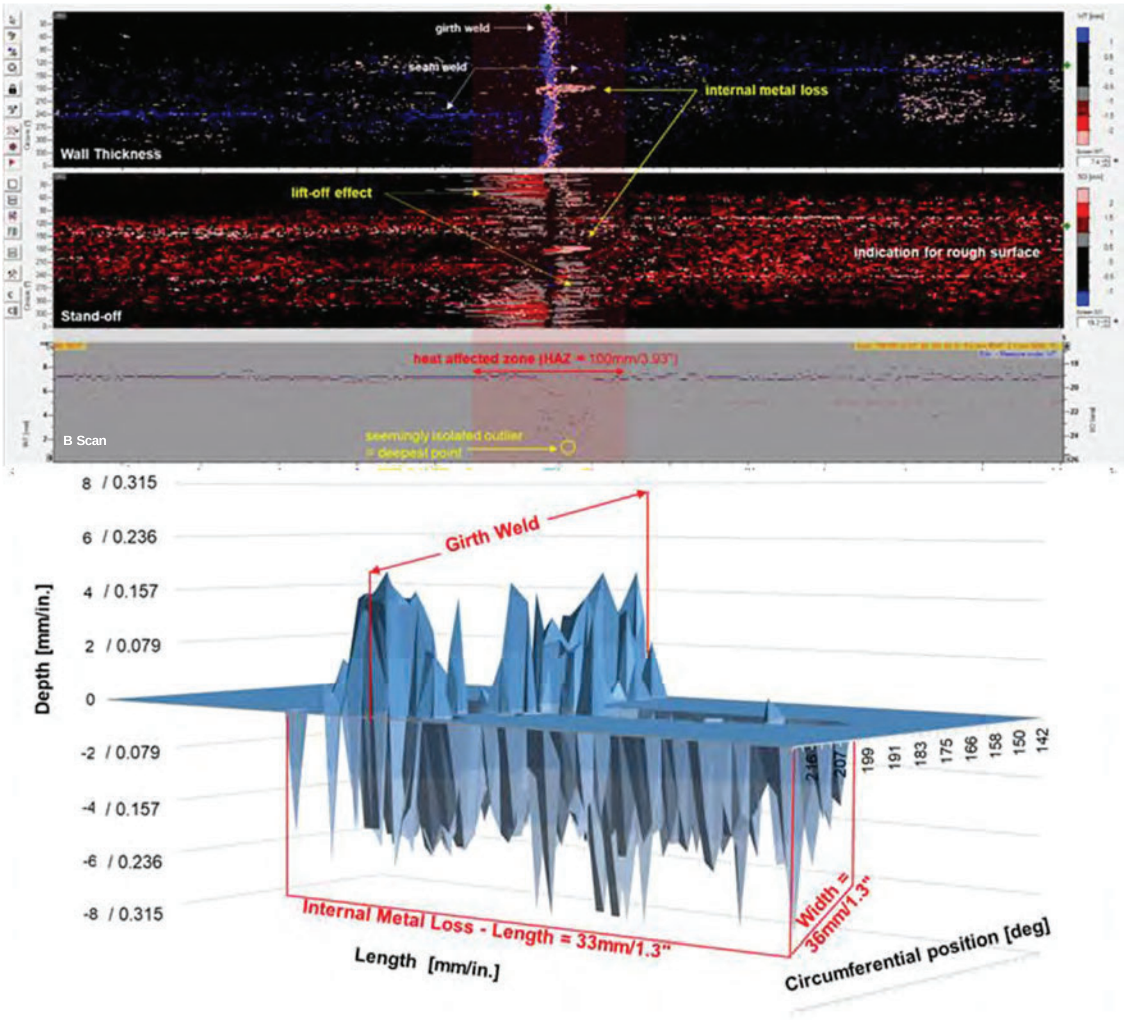

Figure 5. Example of a complex internal metal loss corrosion at a girth weld (above: 2D as displayed in the analysis software, below: 3D model created by the stand-off data; colour interpretation: black = regular sound wall, red/pink = wall loss, blue = wall increase, speckles indicate irregularities, such as rough surface)

The screenshot from the inspection data (top part of Figure 5) shows the encircled depth peak in the B-scan measurement, that could be identified as the deepest point and is visible isolated from the measurements that show a coherent contour. Helpful for that were 2 circumstances: First, the depth could be confirmed by the next following sensor track which revealed another isolated stand-off value in the same depth dimension. Second, as a very important factor for the whole project was the learning process how to interpret the data in a right manner. As it will be shown later, a significant corrosion growth could be excluded. Basing on that, a positive learning effect can be clearly seen in the number of the reported features as displayed in the following Figure 6.

The described example above is indeed one of the simpler features, because it shows at least clear stand-off information. However, there were many features which mainly show unspecific wall thickness data, which were not reliably analyzable in the beginning of the project in 2020.

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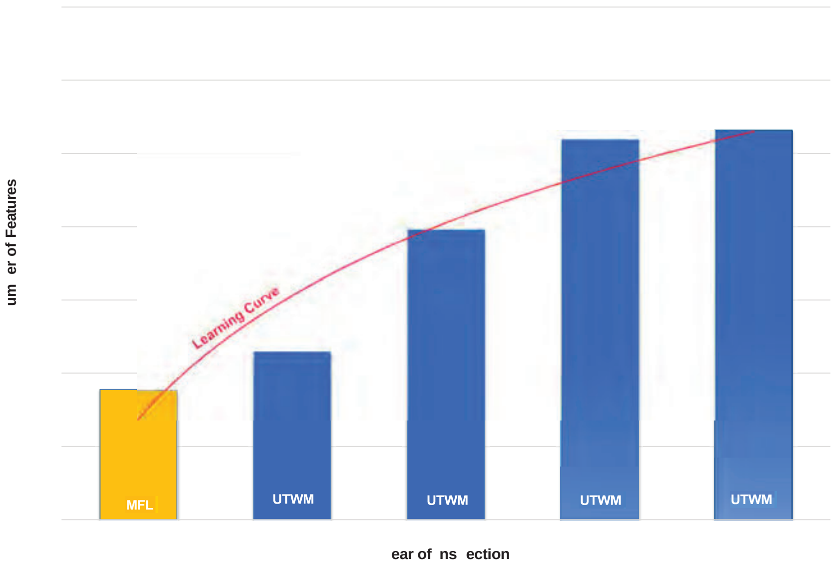

Figure 6. Number of reported features over the years

Figure 7 shows an example of this special situation: While the internal metal loss on the left (yellow circles) can be clearly identified and depth-sized via the stand-off, unveils the feature highlighted in red just an indication in the wall thickness data. However, the information about the correct wall location in the stand-off is missing and the given wall thickness data cannot be used for the depth sizing, because they were only related to stray effects, recognizable by the fact that no coherent shape can be identfied.

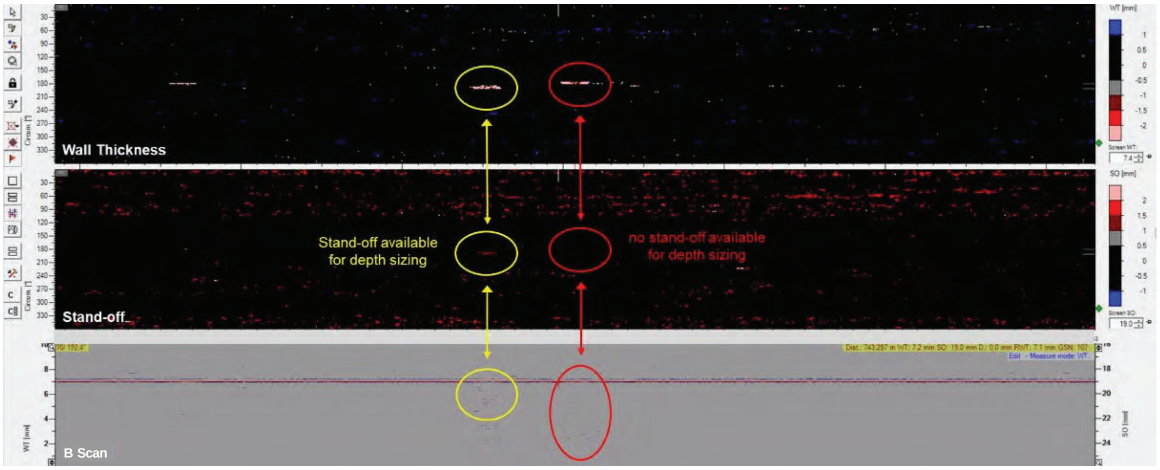

Figure 7. Display differences of internal metal loss features with a small width

This demonstrates the difficulty of this advanced analysis procedure. Under perfect conditions, internal metal loss depth-sizing works with two time of flight measurements – wall thickness and stand-off. Primarily the data analysis is performed via wall thickness data which correlate 1:1 with the stand-off information. In this case study, however, the whole pipeline is characterized by the combination of rough surface (stand-off part in), steep- sided shapes, often with small diameters, which impact the data acquisition of the wall thickness data. Due to the impaired wall thickness detection, mainly the stand-off measurement is taken into consideration for best possible data analysis. In cases where the stand-off data is not reliable, with a standard analysis the real depth cannot be identified.

Once this complex situation was understood, the analysis procedure was improved and adapted to the conditions. It has now reached a point where numbers of detected features are not varying signficantly. On basis of the improved understanding, the run comparison and FFP analysis which was a second part of the project could be carried out with reliable depths and the assessment of anomalies that do not appear clear at first glance in the inspection data was enabled.

Technical Impact

Resolution

Figure 8 shows another important challenge of this project: Besides the girth weld as one impact, the width of the features was another significant issue. Also, around 20 % of the anomalies have a width ≤ 0.315 in (8 mm). When the first inspection run was performed in 2020 (= 2020 (1)), the state of the art in the industry for UT metal loss resolutions at this time is depicted in Figure 9.

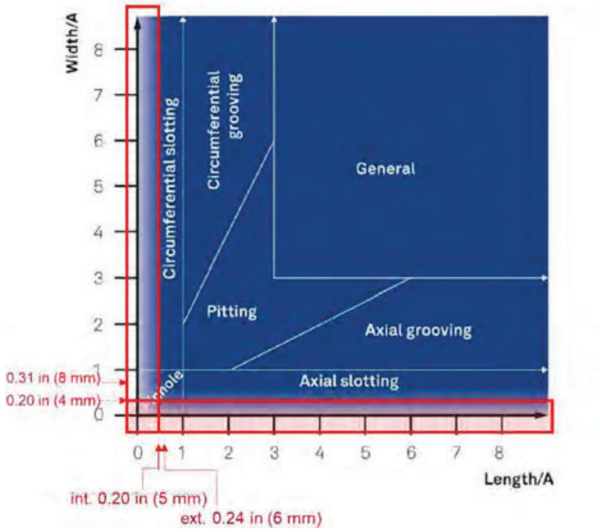

Figure 8. POF-classification with limits for the UT metal loss detection (highlighted in red)

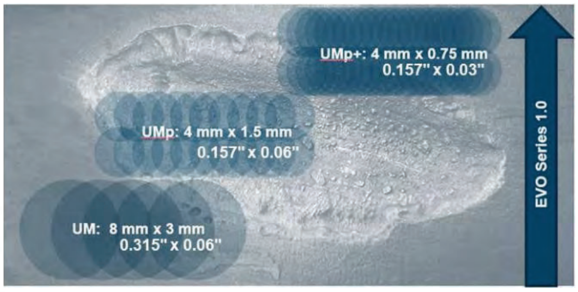

Figure 9. UT metal loss resolutions in 2020

While the axial resolution was significantly improved over the last years and in the meantime and the resolutions of 0.06 in (1.5 mm) or 0.03 in (0.75 mm), respectively, are standard, there was no improvement regarding the circumference for more than a decade. Reason is that the axial sampling rate can be technically easier adjusted than the circumferential resolution which requires a new tool design and furthermore a new sensor development. Consequently, the detection of pinholes and axial slotting features is technically limited by the sensors and the tool's current design, shown in Figure 9. This primarily affects features with a width ≤ 0.157 in (4 mm) but in worst case it can also include features with a width ≤ 0.315 in (8 mm), depending on the diameter of the UT beam. Thus, a certain feature dimension is required. In case a feature is smaller than the beam, it may not be detected reliably. However, if the feature has a width between 0.157 in (4 mm) and ≤ 0.315 in (8 mm), it can happen that the feature is not correctly recorded and/or displayed, because information of signals may be mixed from sound wall and corrosion part ("edge effect"), which cannot be selected automatically by online algorithms during the inspection.

Edge Effect

As mentioned, the edge effect had a significant impact on the data analysis of this case study and was affecting the proper analysis of the anomalies. Technically, the edge effect occurs in the edge region of steep-sided metal loss anomalies, when the UT beam hits partly the sound wall and partly the defect region.

Therefore, for features with a small width, the correct data recording strongly depends on the correct positioning of the probes in relation to the feature as depicted in Figure 10.

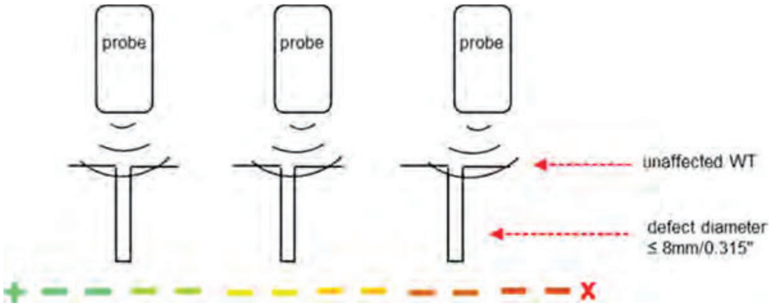

Figure 10. Interaction of feature diameter and sensor position

This is a typical side effect for very small and/or steep-sided anomalies as displayed below in the test sample with flat bottom drills and varying diameters (Figure 11). Internal metal loss features with larger diameters may be recorded with additional conspicuous measurement values in the edge area as a kind of "corona". In contrast, small internal metal loss features may only be recorded with conspicuous values that at first glance are not usable for data analysis.

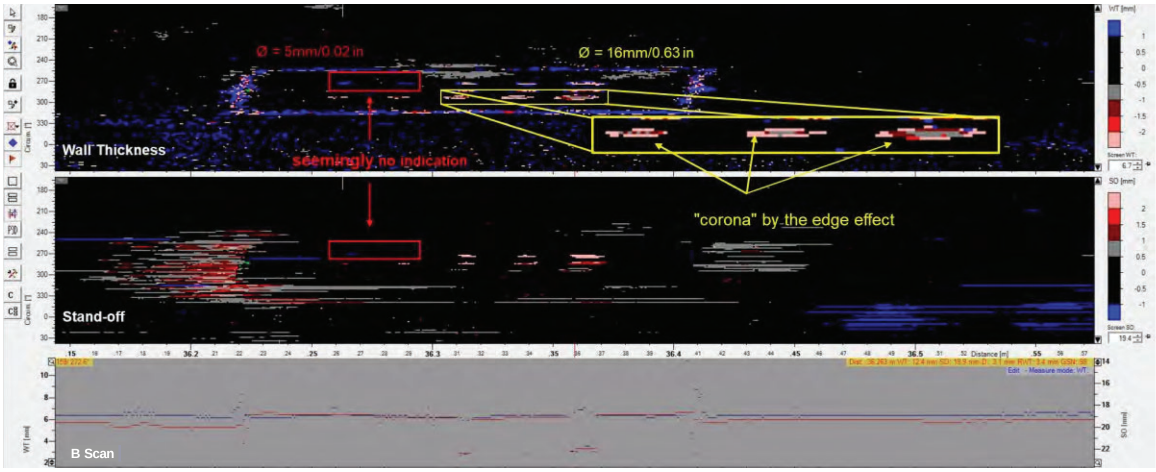

Figure 11. Occurrence of internal metal loss features in dependence of their diameters in a 10" test pipe joint

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In case there is no stand-off data available for the internal metal loss features, it seems like the feature cannot be depth-sized at all as shown in Figure 7.

However, Figure 11 reveals another effect that can be observed in this context. Features with smaller diameters and deeper depths exhibit a prominent wall thickness increase (blue spots in the red box) which seems contradictory at first sight. Here, the algorithm creates a paradox where the true time-shifted stand-off signal is considered as the real first backwall echo of the sound wall, resulting in a thickness value higher than normal. The full understanding of this phenomenon supported the identification of additional internal metal loss anomalies and thus moving the run comparison in the right direction. One of the most prominent examples found in that context is displayed in Figure 12.

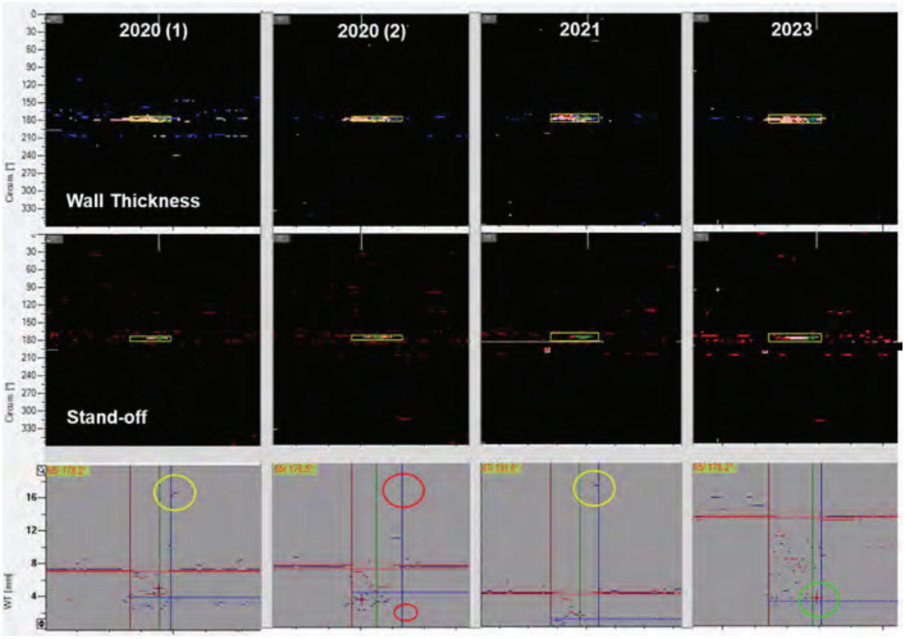

Figure 12. Different detection results during 4 inspection runs (WT scales in the lower part vary to demonstrate the different details)

This example shows for the first time the correct stand-off feature shape and the real depth by an isolated stand-off pixel (green circle) in the 2023 inspection run. The data of 2020 (1) and 2021 show a clear correlation to the position of the deepest point, however as a kind of "reversed" indications (yellow circles) because of the mixed signal information and their display of an extraordinary thicker wall thickness than in reality.

How these findings affect the data analysis and results is highlighted in the next chapter.

Results of the Data Analysis

Output of the non-standard analysis

As already demonstrated in Figure 6, despite all challenges, the first UT metal loss inspection run already delivered more features, partly with more severe depths, than the MFL inspection run. Even

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if it must be considered that corrosion growth could have been on- going and therefore, an increase of the feature number might be related to defects which did not exist in 2017 or were below the reporting threshold of 10% at this time, it is the first evidence despite the complexity and the resulting restrictions that the data analysis of this special 6" pipeline was successful.

Table 1. Overview of the reported features

Vendor	Year	Number of features	Features agw	Highest depthall	Average depthall	Standard deviation depthall
				in %		
MFL	2017	1778	331	45	14	5.1
UT metal loss	2020 (1)	2305	745	69	31	12.1
	2020 (2)	3961	801	79	29	12.9
	2021	5193	822	86	29	12.7
	2023	5318	817	83	31	12.3

However, the average of the depths shows a consistently higher level during the 4 UT metal loss inspections runs compared to the first inspection with MFL. Also, the range of the depths differs stronger than stated in 2017 (see also Figure 13).

While for the first inspection run 2020 (1) no anomaly with a depth of ≥ 70% was identified, after the learning process and the resulting non-standard analysis approach, the feature depths were now different. 25 anomalies could be sized with depth values ≥ 70% after the improvements.

More than one fifth of the 2023 features were reported as slotting or pinhole anomalies, what means that they are close or below the UT metal loss performance specification. The number of features which could be identified by their uncommon increase of the wall thickness due to the edge effect and for which the depths were calculated afterwards, is on the same level.

Although the differences in numbers may not seem large, it is noteworthy for the integrity of the pipeline that more critical depths values could be identified in the inspection data with this approach, as demonstrated in Table 2. In particular, the average values from 2021 and 2023 reveal the identification of metal loss features with higher depths than for the other features displayed in Table 1.

Table 2. Overview of the reported features with a clear edge effect

Year	Number of features	Highest depthall	Average depthall	Standard deviation depthall
		in %		
2020 (1)	-	-	-	-
2020 (2)	138	72	29	10.1
2021	101	86	46	13.1
2023	134	80	44	11.8

The following plot provides an overview of the results after the second UT metal loss inspection run 2020 (2) when the relevant issues of the pipeline had been understood. Besides the obvious increase of the features, the discrepancy between the depths by different technologies is noticeable.

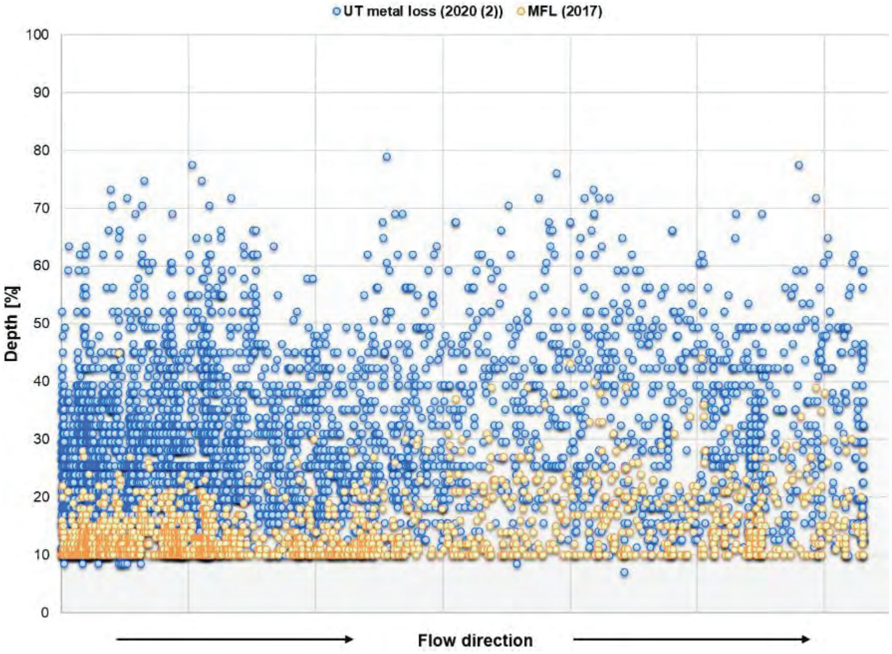

Figure 13. Plot of the MFL (2017) and UT metal loss (2020 (2)) results

The difference is even more evident when considering the circumferential welds and their vicinity. Both Table 1 and Figure 14 reveal that a large proportion of the internal metal loss features is directly located at a girth weld. The plot of the features in relation to their position in a pipe joint as illustrated in Figure 14, demonstrates the linkage of the girth welds with the disproportional accumulation of the highest depths, typically with the appearance as exemplified in Figure 5.

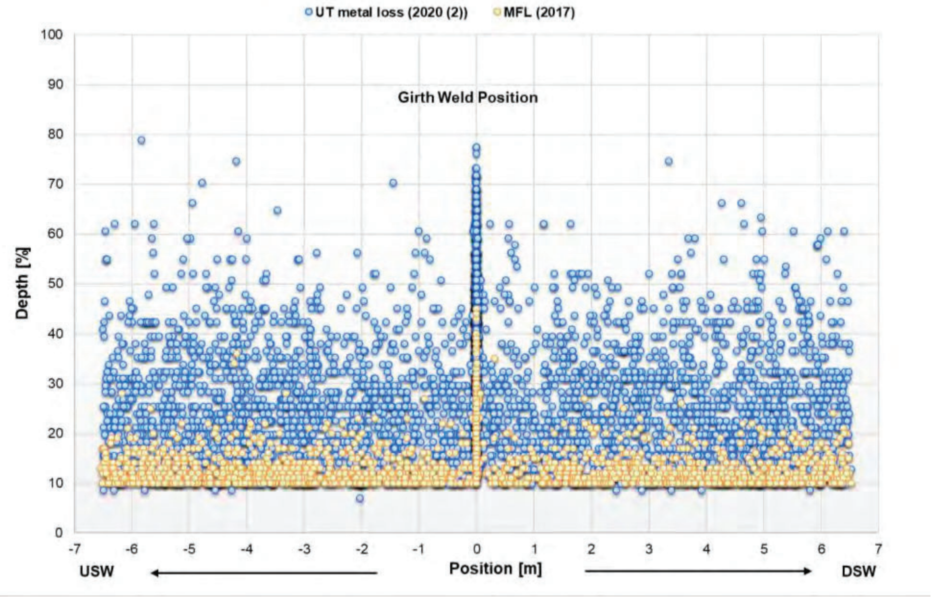

Figure 14. Plot of the MFL (2017) and UT metal loss (2020 (2)) results with focus on the location in the pipe joint

Run Comparison Results and Fitness-for-Purpose

For a solid run comparison and Fitness-for-Purpose analysis, an accurate database is essential. This statistical analysis helps operators to understand the pipeline condition and to make decisions regarding repair and re-inspection plans.

The significant increase of the feature number in Figure 6 suggests that active corrosion growth is still on-going. However, as Table 3 shows, all newly reported features could be identified in the previous inspections runs. The fact that they were not depth-sized and reported in the past is related to the circumstance that only conspicuous wall thickness values were available, but no stand-off data (see also Figure 7). Therefore, a reliable measurement was not possible at this time. However, since all additional features are indicated in the previous inspections runs, it could be concluded that the probability for an active corrosion process is quite low.

Table 3. Number of seemly new features per inspection run

Inspection run	Number	Cause
2020 (2)	11	Different reasons (learning process).
2021	1294	No metal loss anomaly was identified as possible new corrosion anomaly.
2023	190	

The critical statistic factor for this type of analysis is the tolerance window of ± 0.023 in (0.6 mm) (blue dashes in Figure 15) in which it is expected that an anomaly did not grow between 2 inspection runs with a probability of 90 %. On basis of this non-standard analysis with its strong focus on edge effects and isolated stand-off indications, for more than 90 % of all reported features a statistically relevant corrosion growth with more > 0.023 in (0.6 mm) could be excluded as depicted Figure 15 and Table 4.

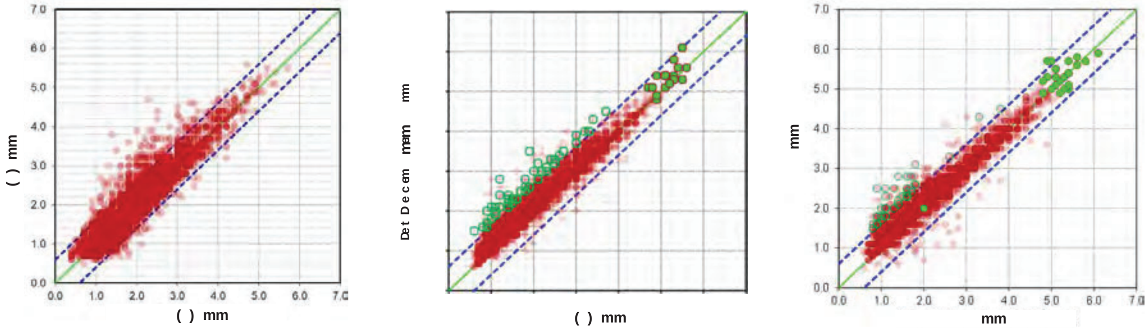

Figure 15. Comparison results between the 4 different inspection runs

The anomalies marked by green circles represent feature for which an assumed corrosion growth could be disproved, visible differences in depths are due to the improved approach. The solid filled spots in green show internal corrosion which have been repaired. Variances regarding the tolerance window can be explained by the complex interaction of location at girth welds and feature shape.

Only a low number of features indicate in each run comparison a possibly true corrosion growth as shown in Table 4.

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Table 4. Overview of selected run comparison results

Inspectio n run	Features ≤ ± 0.023 in (0.6 mm) [%]	Features with poss. corrosion growth	Growth Rates in in/year			
			Mean value	Maximum	Standard deviation	90 % quantile rate
2020 (2)	93.7	219	0.004	0.108	0.015	0.57
2021	96.4	130	0.004	0.079	0.016	0.25
2023	97.2	126	0.004	0.056	0.008	0.36

However, a run comparison is not only focused on the direct predecessor inspection. Because of the precise detection repeatability of UT metal loss technology, older inspection data are also reviewed to understand the whole context and to derive the right conclusions in case of depth divergences > 0.023 in (0.6 mm). As consequence of this deeper understanding, the range of the plotted anomalies is getting closer and closer in direction of ± 0.023 in (0.6 mm) window and the likelihood for possible corrosion growth can be more and more refined.

Field verification results and repeatability

Results of data evaluation stand or fall with confirmation through field verifications. In the meanwhile, a total of 29 features have been repaired. 18 of the NDE-results which were shared with reports and detailed numbers could be correlated with the analysis results. Hereby, except for 1, all reported features have a critical depth, partly around 80 % as visible in Figure 16. An example of these features is the corrosion anomaly in Figure 5.

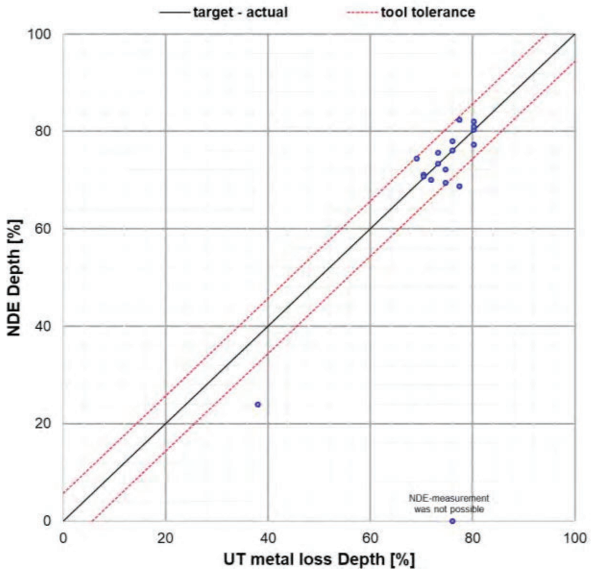

Figure 16. Unity plot NDE and UT metal loss 2023

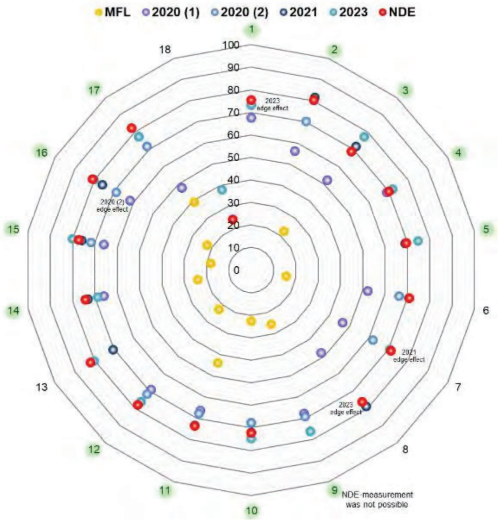

Figure 17. Unity plot of all features according to their absolute depth (overlaps of the UT metal loss results are possible)

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The comparison shows in particular for the inspections runs in 2021 and 2023 a high accuracy of the results and reveal the limited results from 2020 (1) from the original standard analysis. Thirteen of these anomalies are located at the girth welds (encircled in green), could be found in the field meeting the close tolerance range of ± 0.16 in (0.4 mm). In addition, the provided results could be also used as validation for the computed wall thicknesses of the "edge effect"-indications.

Additionally, Figure 17 demonstrates a further benefit linked to the UT metal loss measurement. Except for 1 axial slotting feature found in the last inspection run, all metal loss anomalies could be detected and confirmed several times beside all impacts, always with significantly higher depths than provided by first inspection with MFL.

As already mentioned, in most cases the depth sizing was made by usage of the stand-off which shows the true internal wall loss. While the measurement of the wall thickness data is restricted by physical limits of 0.08 in (2.0 mm) remaining wall thickness (RWT) in order to avoid a noise impact, the stand-off measurement is not affected by that. This enabled the data analysis also to provide accurate results for internal metal loss features below this critical limit. In context of the entire learning process, but also by the provided NDE results which confirm the UT metal loss measurements, the usage of stand-off turned out as successful, even if only isolated indications were depicted.

Key takeaways

As indicated at several points, this project delivered many new insights for the data analysis of small diameter pipelines and the interpretation of pitting corrosion.

Important insights for the data analysis are:

- Having more trust in isolated stand-off indications which do not seem to be part of a coherent shape. In the analysis of girth weld features, single pixels can represent the true depth.
- Identification of edge effects and extracting the relevant information for depth-sizing, especially for features with smaller widths edge effect signals can often be used for manual depth calculations.
- Development of an automatic detector to identify wall thickness data paradox created by online algorithms to use this unexpected indication for the true wall thickness calculation of the edge effect signals (see Figure 12). For internal features with unspecific wall thickness data, but no stand-off indications at all (see Figure 7), the feature depth can be assumed applying a formula which is considering the sound velocity.
  Furthermore, on this basis, for all anomalies not showing this paradox it can be assumed that a certain depth is not exceeded. First results of a different test run with known true depths delivered promising outcomes. Only 3.6 % of a sample with 55 internal anomalies of the given features exceed this criterion about a maximum of 0.01 in. (0.24 mm). One potential of this is particularly around the 180° position, where severe pitting corrosion with depth ≥ 30 % can be stated.

This project can also be considered as part for technical improvements to further expand the tool capabilities for challenging tasks and customer expectations:

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- This analysis of the edge effects has demonstrated that an improvement of the circumferential resolution is supporting the probability of an accurate data recording and a reliable data analysis. The effect that is already well-known from the refined axial resolution and with a more complete feature profile, can be observed also for an improved circumferential resolution as exhibited in Figure 18.

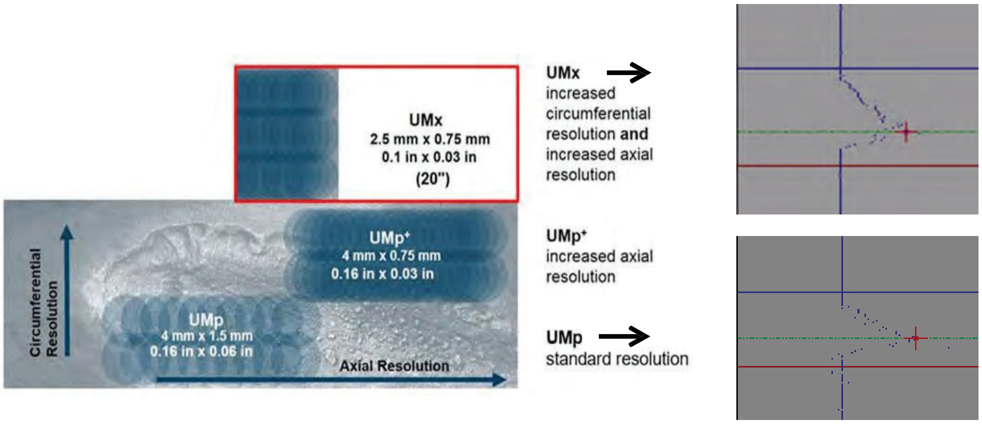

Figure 18. Enhanced circumferential resolution and their positive impact on the data quality

- In addition, the UT metal loss sensor carrier was improved to pass girth welds smoother and to reduce related lift off effects with a negative impact for the wall thickness measurement. This can enhance the possibility that both data sets of the actual wall thickness and the stand-off can be used for internal material loss features.

Summary and Conclusions

Target of this case study was to demonstrate how successful UT metal loss inspection and data analysis in a small diameter pipeline can be - even under difficult conditions. This paper gives an insight to numerous factors that may occur in parallel with significant impacts regarding the complexity and challenge both the data acquisition as well as the data analysis. A particular focus in that context was highlighting of the interaction between the small feature widths, their relative positions (e.g., at girth welds), and the resulting effects (such as strongly affected wall thickness data or the edge effect). Accompanying this case study was an intensive learning process and comprehensive understanding, how most accurate statements about the pipeline status and reliable forecasts for the future could be provided despite the challenging impacts. As important results the identification of several severe metal loss features with ≥ 70% which had been unknown before and that are now repaired, but also an extensive exclusion of active corrosion growth can be highlighted.

Helpful for this was the change from the standard to a non-standard approach with a specific analysis design, a special focus on exceptional characteristics, and their detailed investigations. In this context, the success of this project is also related to the fact that four inspection runs were performed within a short period of time and a set of historic data was shared. Since the impact of a significant corrosion growth in this pipeline could be widely neglected, conditions for the investigations were optimal and quite comparable to ideal

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testing environments. However, it must be emphasized that the resulting learning process would never have happened if the customer had not supported the development.

The resulting question is, can this case study be generalized? Although this project is unique in the described constellation and its complexity and therefore a customized analysis design was required, there is a clear yes! In comparison to an MFL-data set from 2017, UT metal loss technology is despite all challenges verifiably able to deliver highly accurate results which enabled a well-founded pipeline integrity management for the future.

Even though this is a case study, many aspects could be learnt and transferred to other projects impacted by challenging factors, such as the 6" diameter topic or features showing edge effect and the WT paradox. These new and deeper insights help to better understand other complex situations in general. This applies to analysts and operators likewise.

Internally this project also delivered a contribution to raise up new or pending open questions to continue the improvement process for the tool capabilities in the future. First steps are already done with the development of the first tools which have an improved circumferential resolution that counteract the edge effect. Finally, this project can be used for training purposes. Pitting corrosion is a standard feature type in pipelines and should be identified by each analyst also under adverse circumstances.

A side effect of this UT metal loss non-standard analysis is a prime example of the fact that exactly these exceptions are the ones of which we all can learn the most.

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