The Importance of Accurate Data Alignment for ILI Assessments

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Abstract

Within the last decade, there have been increasingly more vendors and operators looking into ways to improve the accuracy of in-line inspection (ILI) data correlations with both in-ditch validation methods as well as across consecutive ILI runs. It may seem obvious, but it is important to ensure the defects that are being correlated from one data source to the other are, in fact, the same defect. ILI data correlations can be particularly difficult when differing vendors or tool technologies are applied or if location conventions are not applied similarly from one run to the next. If there are inaccuracies in the locations and orientations provided by the vendor, or if the dig site location is not verified and reference locations are incorrect, this leads to meaningless data results. This paper will go into detail in the discussion for the guidance of ILI data correlation from both successive ILI assessments for growth rate assessments, as well as in-ditch non-destructive evaluation (NDE) data to ILI data for tool validation practices. The primary method discussed will be a pattern-matching approach, where sources of error can be reduced by aligning overall patterns of reported defects using modern software tools along with insight from experienced analysts. Applying expertise in this manner leads to more accurate outcomes for tool validation, corrosion growth rate (CGR) assessments, and probability of identification or detection (POI or POD), ultimately leading to better and more informed integrity management decisions.

Introduction

When the concept of pattern-matching data was first introduced in the context of ILI validation over a decade ago, the data was correlated on single joints of pipe to validate ILI data with the in-ditch NDE data. It proved particularly useful for wide-area corrosion, correlating hundreds of individual metal losses for ILI validation quickly and efficiently. The pattern-matching concept was then brought forward to evaluate larger swaths of data, including full ILI data sets. This concept was at a time when many operators were using Excel-based tools or macros to align and match based on absolute distances and clock orientations as reported by the ILI tools, which is cumbersome and challenging to ensure accurate alignment and correlations when the reported features are shifted or have any misalignment from one ILI run to the next. These inaccuracies can be efficiently addressed and minimized for further data evaluations by using a pattern-matching system. A comparison of successive ILI runs can be aligned and correlated to review any changes in the reported data on the pipelines. Correlating multiple technologies may provide insight into interacting defects. Statistical evaluations can be applied to analyze CGR, POD comparisons, or interaction rule assessments. The ability to assess the performance of ILI tools for the length of the entire line allows for better application of areas of growth concern, determination of reassessment intervals, and improvement of the safety of the line by responding to any potential features in a timely manner. However, as always, it is important to understand where sources of error and problems may arise when performing these types of analyses.

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Background

In-Line Inspection Technology Limitations

The most widely applied technology for ILI in the pipeline industry is magnetic flux leakage (MFL) due to its application accessibility in both liquids and gas lines. The correlation of MFL-based ILI predictions with locations of a second MFL tool run or actual metal loss can be complicated when high numbers of metal loss features are encountered or when certain shapes of metal loss are encountered, known to introduce locating and sizing errors due to the physics of magnetic flux leakage. As a result, distance-based correlation (axial and circumferential) can sometimes prevent the determination of true ILI performance.

Figure 1 illustrates how the shape of two defects with the same depth can result in different MFL signal responses and locations due to the manner in which magnetic flux behaves depending upon the orientation of the defects with respect to the principle magnetization field and metal loss shape.[i] Automated alignment and correlation processes can compensate for this behavior by employing metal loss pattern matching to provide the highest reliability for matching ILI signal events (boxes) with actual metal loss events for depth, length, width, and burst pressure correlation.[ii]

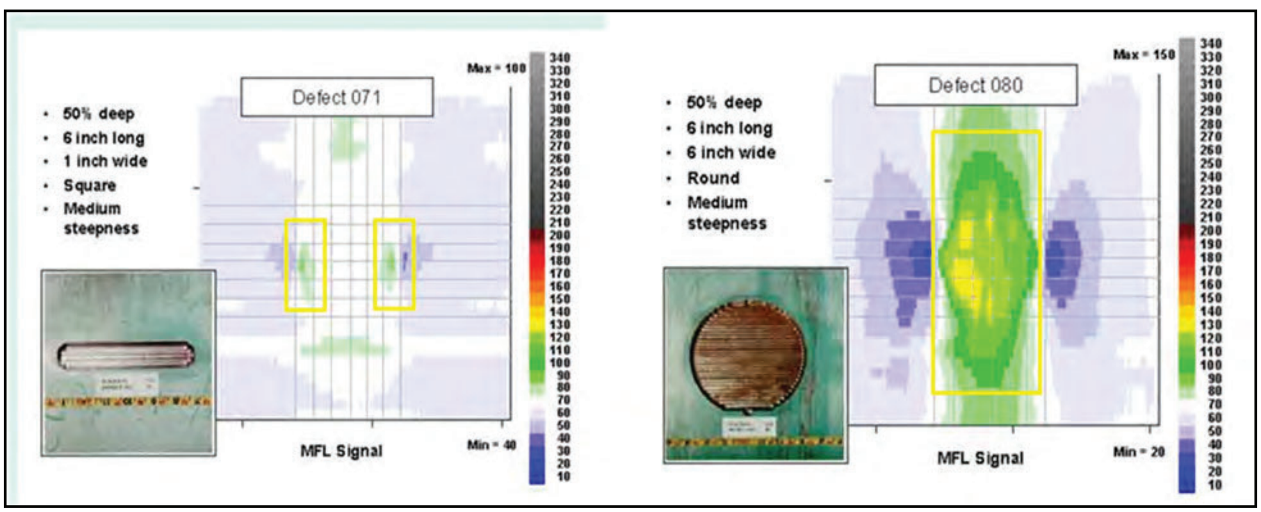

Figure 1. Two different metal loss shapes with the same depth show differences in "box" locations as well as differences in predicted depth

The basic principles and complexity of flaw identification for a pipe with a wall thickness (t) of 0.344 inches are demonstrated in Figure 2 and Figure 3.[iii] In Figure 2, the MFL color image on the left is of a pair of 3t anomalies separated circumferentially by 3t appears to be one wide anomaly. This effect is called circumferential blooming. In Figure 2, the MFL false color image of a pair of 3t anomalies separated axially by 3t appears to be two distinct anomalies. The spreading of the signal in the circumferential direction leads to a potential conclusion that the interaction criterion in the circumferential direction may not need to be as conservative as that in the axial direction. The separation of individual pits can be improved by using sensors that measure all three magnetic field

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components, referred to as tri-axial sensors. The application of interaction rules for single-component MFL sensors may have to be more conservative than results from MFL tools with tri-axial sensors.

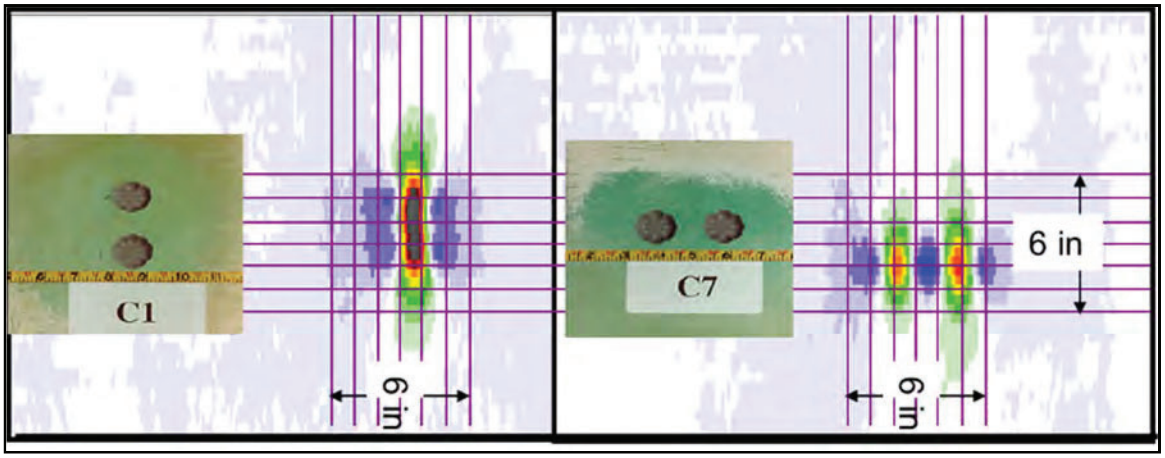

Figure 2. The complexity of MFL Flaw Characterization Dependent Upon Magnetic Field Orientation

Figure 3 shows the additional complexity of larger metal loss anomalies shadowing smaller metal loss. In the image, a pair of 3t anomalies separated axially by 3t appears to have a white area between them, which is the same appearance as the full wall thickness. However, the wall thickness is reduced by 20% in that area; this is called axial shadowing. A misinterpretation of this image could lead to an underprediction of the severity of depth and, ultimately, the assessment of a CGR if this profile technique is used. With this type of corrosion morphology, it is possible that the underreporting of depth and poor probability of overall detection of metal loss anomalies may exist.

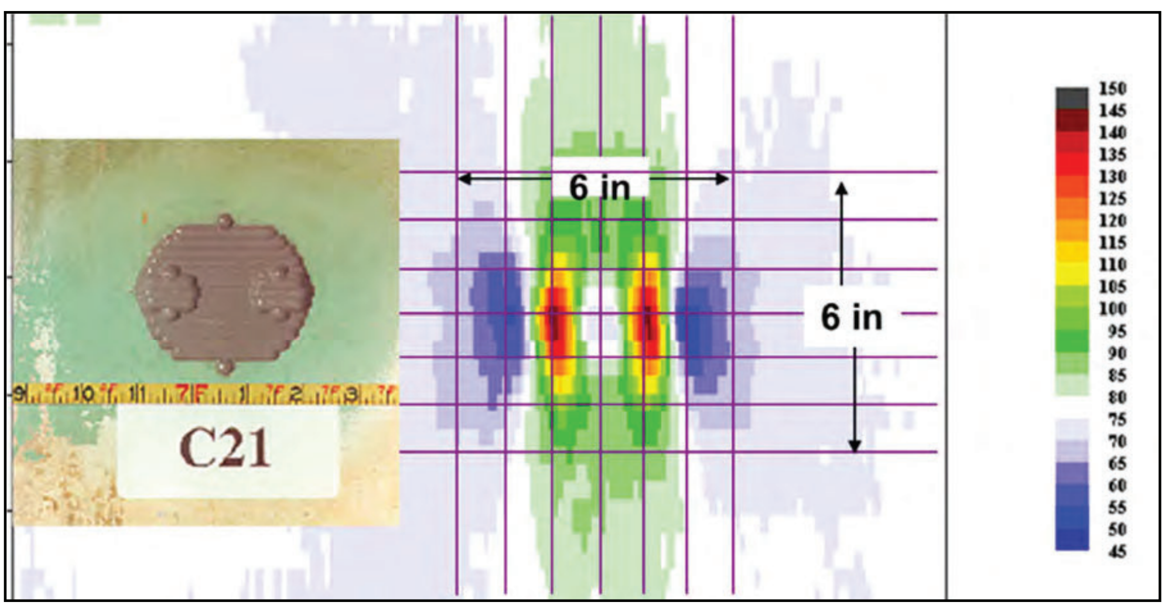

Figure 3. Complexity of Larger Metal Loss Anomalies, Pits within Pits

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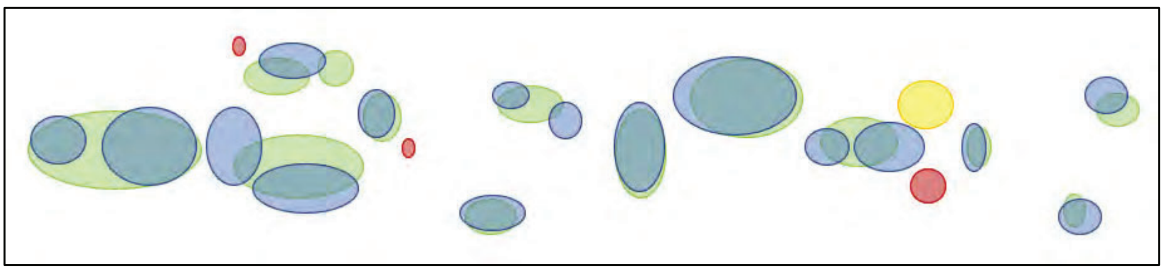
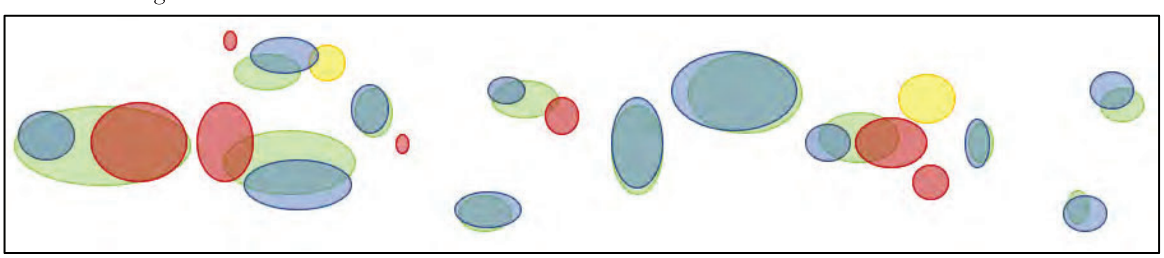
Method of Correlating Defects – What do you want to get out of your data?

For pipelines with little to no corrosion reported, the correlation method is relatively straightforward. A one-to-one basic align and correlate method should suffice. However, when dealing with wide-area, complex corrosion, pits-within-pits, or interacting threats, the process becomes more involved and requires more thought and planning prior to performing the analysis. When determining how to match features reported from one ILI data set to the next, the factors to consider depend on what you want to get out of your data. Some common options for correlation methods include:

- All Overlapping: A match of all available features if any area is overlapping. This is required for a POD or POI assessment in order to understand what the tool is capturing and reporting throughout the entirety of the ILI run and how it compares to the other run.



- Single Deepest: A one-to-one match of overlapping features correlating only the deepest pits. This is typically the data that is processed when performing a CGR assessment since the deepest pits for each ILI tool should be correlated for best accuracy of the overall depth change from one assessment to the next.



- Most Overlapping Area: A one-to-one match of overlapping features correlating the largest areas regardless of reported depth. This is typically the most appropriate for a burst pressure assessment since this is usually linked to the feature having a longer length value, which is then applied to any of the assessment methods, B31G, MB31G, or RSTRENG assessments. This is not always the case, depending on the depths reported, but it can be helpful to review to contrast with the other methods.

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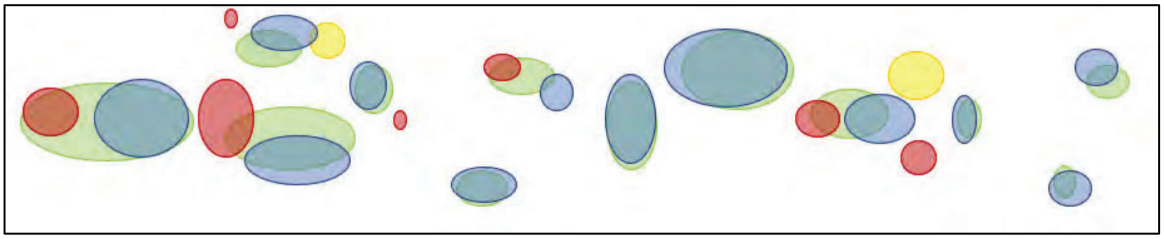

Data Alignment Considerations for Correlation of In-Ditch to ILI Data

There are no given standard practice requirements for the correlation of data when comparing one set to another. However, one could safely assume a measurement using two differing techniques for validation purposes that sizing a defect would look at the same defect for each inspection. For instance, when measurement tools such as a basic straight beam UT tool are validated, a minimum accuracy of measurement and the POD result is required to understand how well the tool is performing and whether that tool can be used in the industry it is designed for to capture the defects or flaws required. This exercise is straightforward in a laboratory test setting, where Part A is Part A, and the technician compares measured Flaw A to known Flaw A with their measurement techniques. This same procedure gets tricky when performing validation measurements in the field and even more so when defects cannot be seen visually to confirm locations, such as in the case of internal corrosion.

When performing field validation of an ILI tool, there are some important items to consider:

1) Incorrect Locationing
    a. ILI reports the location of a feature on a particular joint with a corresponding latitude and longitude. It is important to ensure that the dig location is tied in correctly from a reference point location and then ensure the dig performed references the correct upstream girth weld. There have been instances where a dig was performed on a joint upstream of the target joint. ILI predicted internal corrosion, and when nothing was found. The dig site was recoated, backfilled, and the dig crew moved along to the next site. From experience, ILI tools do not report false positives very often, i.e., if something is reported with significant length, width, or depth, an anomaly should exist to correlate and justify that feature call. Therefore, it is best standard practice to validate by verifying the physical location and examining a joint up and downstream of the target joint to ensure there was no unintentional offset in the physical positioning of that particular dig.

2) Lack of Complete Data Collection
    a. Target features selected for a dig based on ILI data are often the deepest or most severe features reported, either due to regulatory requirements or a calculated response interval deadline. If a dig program does not require all defects in an area to be captured, there might be a possibility of simply matching the deepest feature found to the target feature, even if there is an offset in the axial distance or clock orientation. This is one reason why it is essential to capture surrounding defect calls to ensure features are being correlated accurately throughout the entirety of the dig.

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Capturing more data typically also allows for improved statistical calculations. Trends may be seen for shallower defects or differing geometries. With more data collected, a better understanding of the nature of the threat mechanism can be obtained, and provide higher confidence in the location and correlation of defects from ILI to in-ditch measurements can be realized.

How Can We Address The Issues for Correlation Problems with ILI Validation?

Visual pattern-matching processes have been developed to align ILI features (pits and clusters) with actual metal loss measurements from high-resolution in-situ measurement technologies such as automated ultrasonic testing (AUT) and laser profilometry. Previous research demonstrated that for complex morphology corrosion, pattern-matching correlation techniques tend to reveal performance details (bias about unity and variance) that are not evident with manual distance-based correlation. With the increased performance resolution from pattern matching correlation, it becomes possible to identify the cause of non-conservative burst pressure performance or quantify the safety level associated with deterministic or probabilistic ILI response plans. Pattern-matching correlation and performance evaluation have allowed pipeline operators to calibrate responses to ILI indications and for ILI vendors to calibrate ILI feature predictions in accordance with API 1163 to optimize ILI response and safety.[iv]

Data Alignment Considerations for Consecutive ILI Runs

When evaluating multiple sets of ILI data, it is important to not only consider accurately correlating the metal loss features but also perform a review of the full set of line data. Without decent data quality overall, the metal losses or other features reported on the line will be difficult, if not impossible, to correlate. ILI vendors provide joint lengths, which should be reviewed and aligned to determine if there are any differences between multiple ILI assessments. This is particularly important when comparing two differing ILI vendors or technologies operated. Any differences in joint lengths due to pipe replacements or poor positioning accuracy data from the run should be addressed before aligning the features reported by the tool.

Case Study 1: Effects of Odometer Drift

In Case Study 1, two axial MFL ILI tools from the same vendor and the same technology were run on a 17.4-mile line two years apart. This line was selected for evaluation due to its propensity for accelerated corrosion growth due to likely, but unconfirmed at the time of inspection, microbiologically-induced corrosion (MIC). Run 1 reported a total of 97,926 individual metal loss features. Run 2 reported a total of 158,950 individual metal loss features. This line was prioritized for a CGR evaluation based on the increase in both the number of features reported and the depth change of the reported metal loss indications.

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The data from two successive runs were reviewed, and the overall joint lengths were found to be, on average, 0.40 ft offset in length. The maximum difference in joint length was 2.16 ft. The result of ongoing problems with locationing resulted in the final odometer length of Run 1 to Run 2 being offset by about 900 ft, as shown in Figure 4.

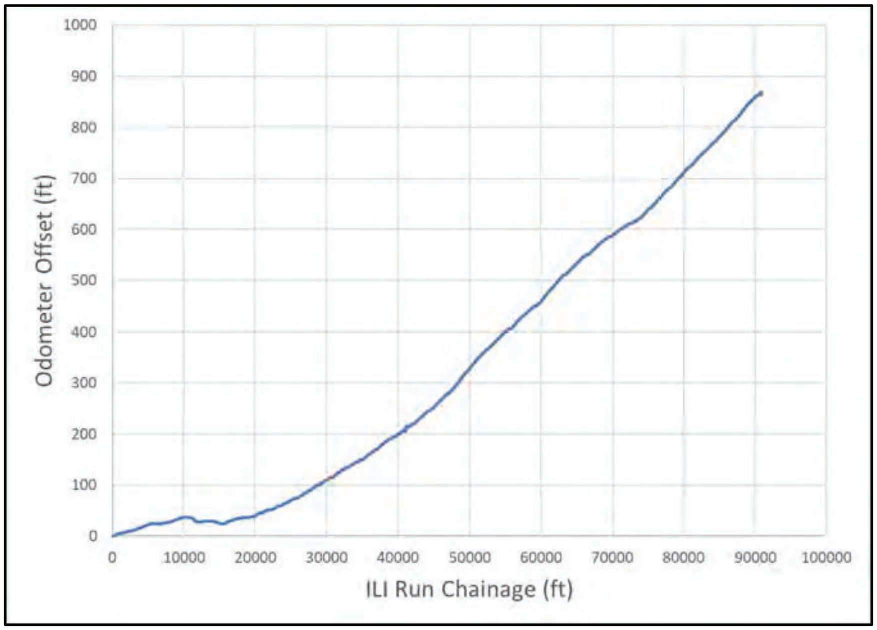

Figure 4. Odometer Offset as a result of poor positioning performance by the tool.

Generally, this problem could be fixed by normalizing the lengths of the joints from one run to the next, assuming the data from the more recent run is correct and normalizing to this data set. However, if this difference is not realized, there will be a problem when a vendor provides a position relative to the upstream girth weld. The metal loss positioning data will be elongated if the joint is overcalling the length from Run 1 to Run 2. In some cases, this difference may not be noticed by the operator if there are little to no defects reported. However, in Case Study 1, an abundance of small pitting corrosion features were the primary type of feature reported. Even a slight offset of half a foot in the length of a joint prevents straightforward alignment of metal loss feature correlation. Depending on the amount of offset in those lengths, the correlated features may be entirely incorrect, as well, since matching defects that may overlap are not truly correlating defects.

Figure 5 (a-c) are examples of the Case Study 1 correlation process, where the upstream end of the joint aligns metal loss features well, i.e., each yellow oval is matched with a red oval, and the downstream end does not. Figure 5 (a). shows a five-foot span of the upstream end of a pipe which is well correlated. Figure 5 (b) shows five feet at the downstream end of the pipe, where it appears that no corrosion correlates from one run to the other. Figure 5 (c) shows the Run 2 ILI data shifted by 0.61 feet downstream to align the data properly. Further downstream, the red ovals are aligned slightly to the left of the yellow ovals, causing these features to not appear to correlate as they do not spatially overlap. The cause of this is the vendor-provided distance to the upstream girth weld constantly being stretched further from the location as it moves downstream.

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Figure 5 (a). Five-foot span of Run 1 compared to Run 2 at the upstream end of the joint.

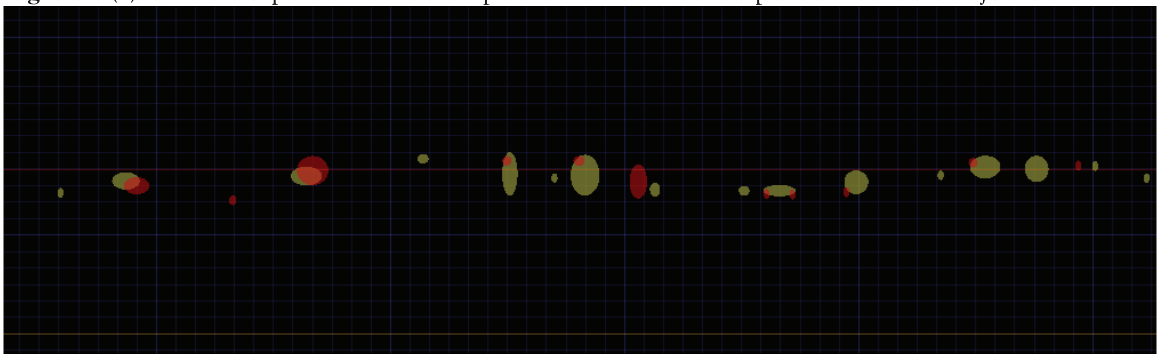

Figure 5 (b). Five-foot span of Run 1 compared to Run 2, 40 ft downstream at the end of the joint.

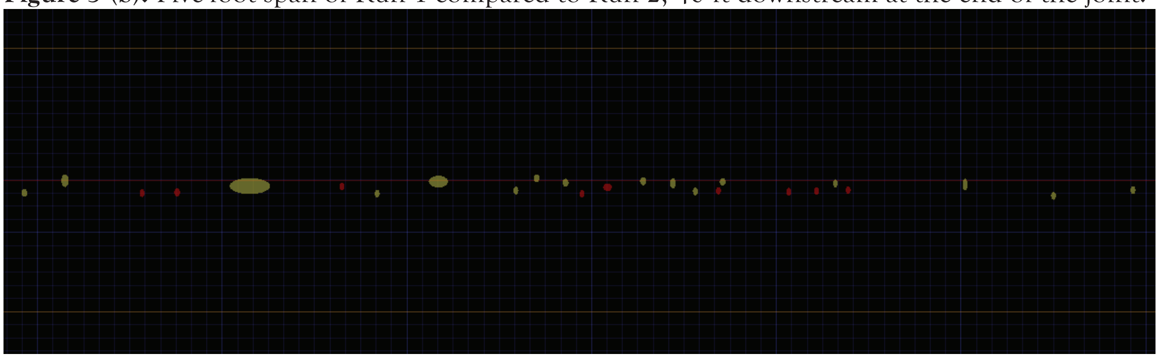

Figure 5 (c). Five-foot span of Run 1 compared to Run 2 at the downstream end of the joint after a shift in the Run 2 data of 0.61 feet axially.

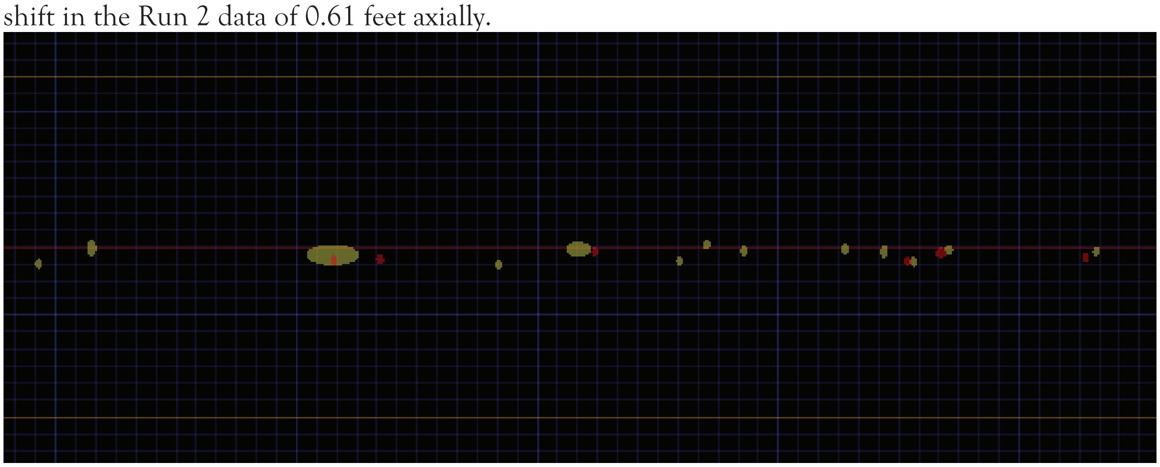

Figure 5(a-c). A screenshot of two ILI data sets overlaid, red vs yellow, shows that the upstream end aligns well while the downstream end is offset.

For Case Study 1, running a simple correlation algorithm to align the upstream girth welds without adjusting for the odometer offset error for each individual joint and each feature reported on that joint resulted in only 19 metal loss features correlated. Once the joint length was corrected and the positioning of associated metal loss features was adjusted similarly, 67 metal loss features correlated. Compounding this over the 2500 joints of this problematic odometer readings resulted in a difference of 25,357 metal loss features. Before the correction of the whole lengths, there were

47,330 metal loss features that essentially were useless data points due to the error, to a final total of 72,687 metal loss features with accurate correlations.

A recommended course of action for the operator in this case would be to take this information back to the ILI vendor to correct the data so future problems may be avoided. But, without this initial review of joint lengths and odometer issues, this went unnoticed and caused poor initial data analysis results.

Case Study 2: MFL Blooming and Shadowing Effects

In Case Study 2, a third run was performed on the same line using the same technology from the same ILI vendor, another two years later. The second and third runs were well correlated for correcting the odometer drift issues, but a new problem arose when performing this correlation. It was not immediately apparent until reviewing the ovals overlaid in the pattern-matching software, but there was a definite change in the reporting lengths of features, with the most current run identifying longer features than the previous two. This could be assumed to be corrosion growth, the features spreading in the axial direction and forming one larger defect. However, this cannot be assumed when we know that axial MFL tools have intrinsic limitations when detecting and sizing pitting and axially oriented features.

Due to the MFL tool reporting a single feature at the upstream end of the axially longer feature, it appears as though a slight axial shadowing effect has occurred. The pattern-matched images for an example joint are shown in Figure 6, Figure 7, and Figure 8. The red and blue ovals in Figure 6 indicate unmatched and matched 2021 features, respectively. The yellow and green ovals in Figure 7 indicate unmatched and matched 2023 features, respectively. The final overlay of the two data sets in Figure 8 shows a single ILI Run 2 feature correlated with two ILI Run 1 features, highlighted by a bright blue arrow in the figure. To obtain a growth rate for an individual anomaly as reported, only one anomaly was correlated to one other anomaly. In this case, the deepest features nearby were used for either run to correlate to show the highest change in depths, which is reasonable to assume given the limitations of axial MFL tools for these axial grooving type indications.

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Figure 6. Internal corrosion was reported during the first ILI run. Blue ovals indicate correlated features, and red ovals are uncorrelated.

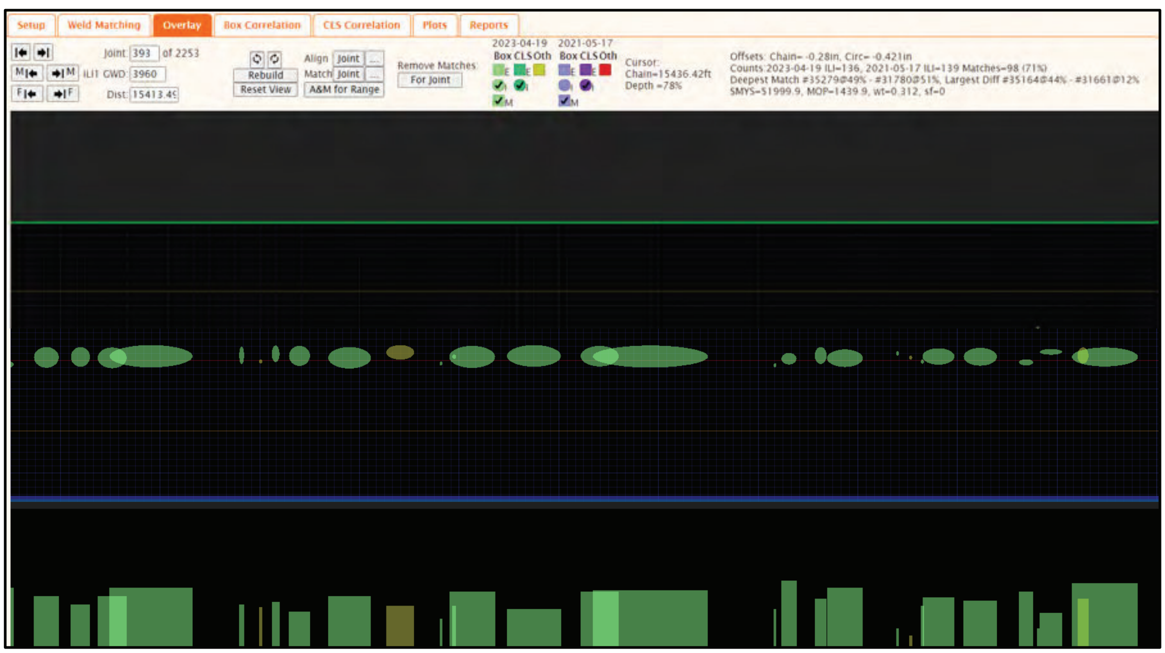

Figure 7. Internal corrosion was reported during the second ILI run. Green ovals indicate correlated features, and yellow ovals are uncorrelated.

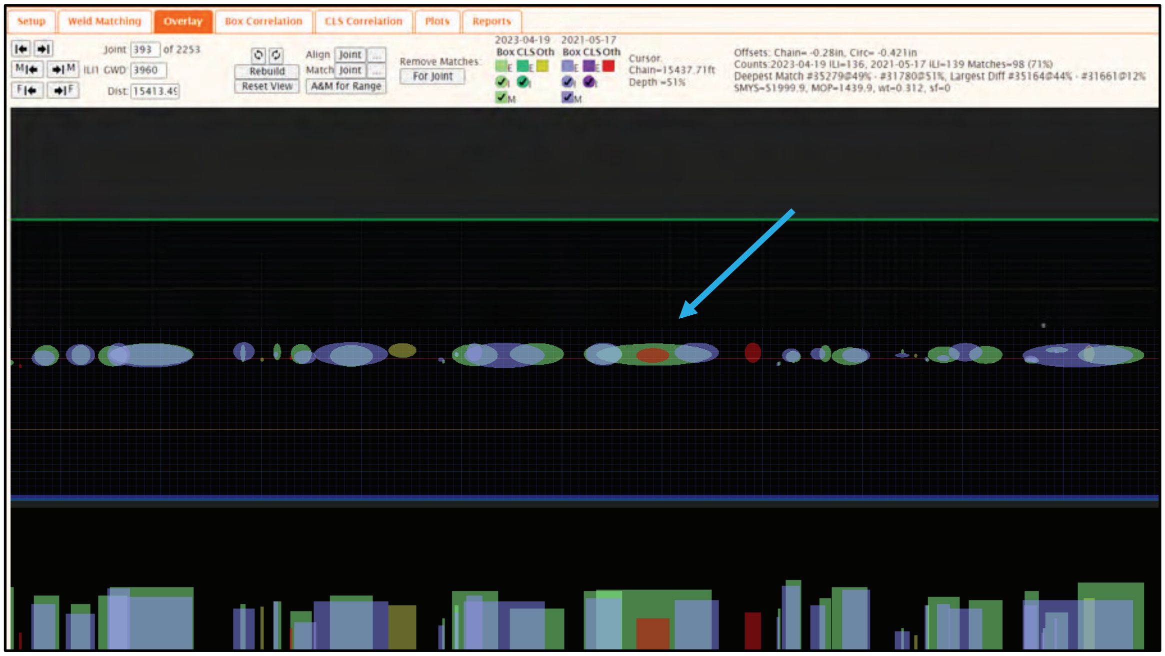

Figure 8. Internal corrosion was reported during two successive ILI runs overlaid to view the correlated defects using a single deepest matching approach.

In this case, it may be helpful to review the raw signal data to observe the boxed data in relation to the signals from the tool itself. MFL signals are converted to metal loss depth measurements by analysis software algorithms. For most MFL ILI technologies, signals from individual corrosion anomalies above a prescribed level or that are discernable by the software algorithms are approximated as rectangular "boxes" with associated depth, length, and width dimensions and delivered as such to the customer for integrity evaluation. Figure 9 shows an example of axial MFL signals reported for long, complex, bottom-side internal corrosion. When the software misses boxes, no ILI features are reported and cannot be analyzed.

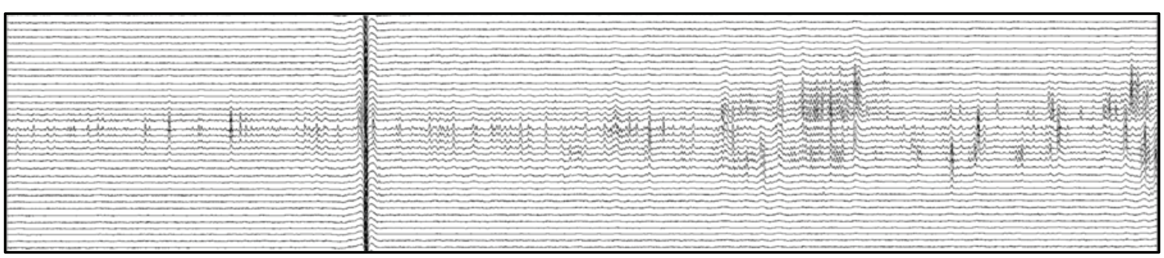

Figure 9. Bottom-side internal corrosion axial MFL signals.

Case Studies 1 and 2: What Does the Validation Data Tell Us?

For the data used in each case study, validation data was obtained for a short section of pipe where this internal corrosion was occurring. A ten-foot section of pipe was cut out where leaks had been reported. This pipe was sectioned horizontally at the 3:00 and 6:00 positions, and the internal corrosion was sized using laser profilometry in two separate scans. A five-foot laser scan image output

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is shown in Figure 10, where eleven ILI features (blue ovals) were correlated with associated laser indications.

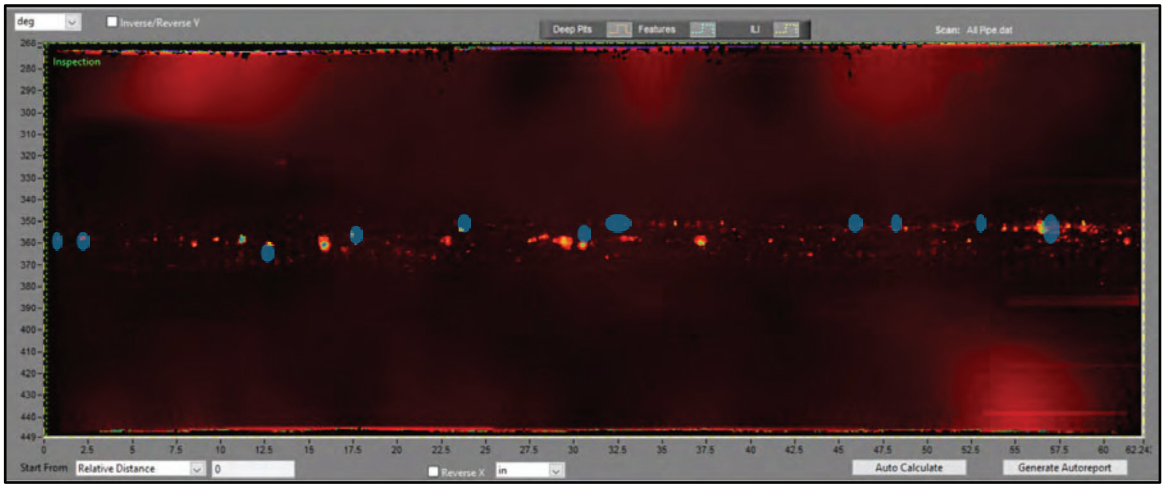

Figure 10. Laser profilometry c-scan of the internal corrosion located at the six o'clock position.

From the two scans performed, nineteen validation data points were obtained and summarized in Table 1. Ideally, a larger sample data set is preferred for as much corrosion as was seen on this line, but the data can still provide insight into the situation at hand. Of these 19 features, ILI accurately identified only one as a pitting defect. Laser identified eleven of the features as pinholes. The ILI tool utilized did not have any specifications for detecting and sizing pinhole features, a limitation that led to poor probability of identification and some of the difficulties experienced in the case study examples when performing a run-to-run comparison. While the MFL tool did detect metal loss indications, it was not able to size them accurately.

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Table 1. Reported Geometries of Features Reported by Laser and ILI

Feature Number	Distance to Upstream Ref Location (ft)	Laser POF Category	ILI POF Category	Laser Depth (% WT)	ILI Depth (% WT)
1	0.17	Pinhole	Circ Slotting	23	12
2	0.39	Axial Grooving	Pitting	20	13
3	1.32	Pinhole	Pitting	94	15
4	1.71	Pitting	Circ Slotting	13	22
5	2.30	Pitting	Pitting	35	12
6	2.77	Pinhole	Pitting	24	25
7	3.09	Pitting	Circ Slotting	48	17
8	4.20	Pinhole	Circ Slotting	10	12
9	4.36	Pitting	Circ Slotting	37	13
10	4.70	Axial Slotting	Circ Slotting	60	12
11	5.10	Pitting	Axial Grooving	28	11
12	1.94	Pinhole	Pitting	20	13
13	2.50	Pinhole	Pitting	*	12
14	2.72	Pinhole	Pitting	16	10
15	3.14	Pitting	Circ Slotting	32	12
16	3.68	Pinhole	Circ Slotting	24	13
17	3.75	Pinhole	Circ Slotting	18	10
18	4.09	Pinhole	Circ Slotting	*	13
19	4.84	Pinhole	Circ Slotting	11	12

*These features were identified as leaks prior to the joint cut-out.

But let's backtrack for a moment. Correlating the features from the cut-out section to the ILI data was not a straightforward process. Several problems were encountered along the way to attaining the final output, as shown in Figure 10.

1) No Obvious Indications from ILI

   Problem: It was not immediately apparent how the ILI data would line up since ILI reported no alarmingly deep features at the locations of the leaks. The deepest feature reported by ILI on the entire length of the joint was 62% WT, but it was 30 feet downstream of the location of the two leaks identified on site.

   Solution: It is important to always gather as much information during a dig as possible. Based on this discrepancy, three full joints, or 120 feet of pipe, were excavated, cut out, and replaced.

2) Marking up Pipe Accurately

   Problem: Once a piece of pipe is cut-out, the integrity of the data can easily be compromised. Pipe not marked up completely and thoroughly indicating the direction of flow, reference distances to upstream markers, and clock orientations can cause incorrect data assessment.

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Solution: Have a procedure in place for documentation of any excavation and/or cut-out and ensure personnel follow it and provide communication of those details to all stakeholders. What seems obvious in-the-ditch at the moment can be extremely confusing, or even lacking in necessary information when processing data days or weeks later. Proper documentation is key.

3) Processing Digital Data Accurately

Problem: Digital sources of data are an amazing wealth of information when properly captured. However, things can go awry without understanding what the data entails, how programs will interpret the data provided, and how those programs will report the data. Orientation of the data, wall loss vs remaining wall, and even basic pipe property inputs can quickly cause good data to turn to garbage.

Solution: Ensure basic checks are followed along the entire process of data assessment. Ensure data analysts are properly trained, and the software is up to date. Metadata on any data files should be accurate so steps can be retraced throughout the entire process.

Without ensuring all data at every step of the process is accurate, the data becomes frustratingly meaningless.

Conclusions

For any measurement system, it is important to understand the sources of error that can contribute to not only poor overall tool performance but also to obtaining the accurate necessary data in order to validate in the first place. For ILI data, there are challenges in how the tools may report data, both in terms of the physical limitations of the technology performed and the quality of the run data, even if the most appropriate technology is run.

Therefore, we must ensure the quality of data by thoroughly reviewing all sources of potential error. Odometer drift occurs far less frequently on modern ILI tools than in decades past, but there is still room for error. Depending on the geometry and amount of corrosion reported by an ILI tool, this can present considerable integrity management planning issues when correlating defects from one data source to another. Communication with the ILI vendor can help identify and address this issue. The correct and most applicable technology for the threats anticipated on a pipeline should be used, and validation data should be collected with this in mind, validating the type of defects reported and the tool's sizing reported. Reviewing and integrating data is vital in understanding what technologies will provide quality data for that particular pipeline.

Numerous improvements are ongoing in research and application to improve the quality of ILI data. The use of automated alignment and pattern-matching software is just the beginning. More companies are taking advantage of the computing power currently available to improve the results of

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their physical systems equipment. From neural network developments in determining girth weld locations to artificial intelligence integrated into the data processing software. The more we can integrate the broad scope knowledge of the industry from case studies such as those discussed in this paper, where odometer slippage and technological limitations are still present, the more we can ensure the safety of our pipeline infrastructure for years to come.

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i Nestleroth, B., Bubenik, T., MFL, MFL Topical Report, Battelle, GRI 1999.

ii Tomar, M., Fingerhut, M., "Qualification of ILI Performance in Accordance with API 1163 and the Potential Impact for Management of Pipeline Integrity", ASME IPC2008-64469, Calgary, AB, Canada.

iii Nestleroth, J.B. and Bubenik, T. A., February 1999. Magnetic Flux Leakage (MFL) Technology for Natural Gas Pipeline Inspection, Battelle, Report Number GRI-00/0180 to the Gas Research Institute.

iv Yu, D., Smart, L., et al, "ILI Performance- Validation Rupture Pressure Prediction Performance of In-Line Inspection Tools", NACE 2011-11301, Houston, TX, USA.

https://doi.org/10.52202/072781-0017