

ILI Validation – Overview and Case Studies

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ABSTRACT

The pipeline industry strives to keep pipelines running safely and reliably. The process involves many steps, including selecting the lines/segments to be inspected with in-line inspection (ILI); maintenance, repair, digs; ILI validation; growth predictions and risk-based programs to establish maintenance and repair practices. Most operators' programs start with in-line inspections, which generate large data sets and provide interpretations about the pipeline integrity without a validation process. Although ILI information is thorough, it is generated by non-destructive and/or indirect measurements. As with any non-destructive examination (NDE) technique, comparisons must be made to direct observations and measurements to ensure accuracy. This paper overviews validation of the ILI data through four case studies: determining whether the tool is functioning per its listed specification, discussing the applicability of validating crack tool ILI runs and presenting two examples of feature misidentification by the ILI tool. Together, these case studies demonstrate the importance of validating ILI data to ensure the integrity of the pipeline is adequately assessed.

INTRODUCTION

The pipeline industry strives to keep pipelines running safely and reliably. The process involves many steps, specialized groups, and decisions:^{1, 2, 3}

1. The group that chooses the lines or segments to be inspected with in-line inspection (ILI). This work entails choosing the ILI tools for the anticipated integrity threat.
2. The ILI tool runs to detect and identify defects.
3. Maintenance, repair, and excavation digs.
4. The ILI validation.
5. Defect growth predictions and risk-based programs to establish maintenance and repair practices.

¹ Mingjiang Xie, Zhigang Tian, A Review on Pipeline Integrity Management Utilizing In-Line Inspection Data, Engineering Failure Analysis, April 2018

² NACE SP0102-2017 (formerly RP0102), In-Line Inspection of Pipelines

³ NACE Publication 35100-2017, In-Line Inspection of Pipelines

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To date, many operators' integrity assessment programs include In-Line Inspections (ILI). Without excavating, ILI generates large data sets and provides interpretations about:

1. Pipeline integrity.
2. The presence of anomalies/features such as dents, metal loss, mill defects, girth weld cracks, etc.
3. The size of the anomalies (length, width, depth, clustering, etc.)
4. Regulatory key performance indicators (KPIs) include the ASME B31G burst pressure, the Rupture Pressure Ratio (RPR), feature density, etc.

ILI tools use conventional non-destructive examination (NDE) techniques such as magnetic flux leakage (MFL), calipers, and ultrasonics (UT), backed by powerful analytical approaches to predict the integrity of pipelines. The combination of improved technology and years of historical ILI validations has led to increased accuracy. As the accuracy of these tools has increased, integrity personnel have relied heavily on the ILI tool's results, sometimes, depending on the severity, even forgoing excavations to perform validations. However, these tools still rely on basic inspection principles and are subject to the same limitations – geometry, interference, masking, etc., of the inspection techniques. As with any NDE technique, comparisons must be made to direct observations and measurements to ensure accuracy.

This paper overviews the validation of ILI data through four case studies. Context as to the ILI information and the need for validations are addressed.

ILI DATA NEEDS VALIDATION

An objective of the ILI is to identify the most severe potential anomalies in accordance with the tool type, i.e., metal loss, cracking, etc. In general, these are the features that require remediation per the operator or regulatory requirements. An example of typical dig criteria is shown in Table 1.

However, important questions remain:

- A. Is the tool assessing features within its threshold/capabilities? Most tool vendors report tool feature sizing accuracies based upon feature classification, as shown in Table 2 and Figure 1.
 - False Positive features. The ILI may assess a feature as existent when direct assessment and/or NDE do not find it.
 - False Negative features. The ILI may not identify a relevant anomaly that meets the ILI tool detection threshold.
 - ILI Non-Reportable features. Direct assessment of the line may identify an anomaly outside of the tool's detection capabilities, but that is nevertheless an integrity concern (see Figure 2 for a deep non-reportable pinhole feature).
- B. Does the data have a conservative or non-conservative tendency? Direct observation is required to identify potential inaccuracies, as illustrated in Table 3 (prepared from a group of pipeline cut-outs).
 - Safety outliers (an ILI under call, see Table 3), e.g., corrosion features deeper than 50% wall thickness (WT) may have the depth underestimated by more than 20% based on our findings.
 - Resource outliers (an ILI over call, see Table 3), e.g., corrosion features reported as deeper than 50% WT may have the depth overestimated by more than 20%WT.
- C. Has the tool correctly identified each feature?
 - MFL tools may misidentify internal corrosion as external corrosion.
 - Cracks, ripples, wrinkles, and buckles can be misdiagnosed as corrosion features and/or dents and incorrectly sized.
 - Damage such as gouges and metal loss within dents may not be identified. See Figures 3 and 4. The dented area had a gouge.

To address the above concerns, validations are required. These validations are conducted:

- 'In-the-ditch' via NDE techniques before repair or removal of the pipe joint/segment, or
- In a shop setting on cut-outs removed from service.

While both methods have value, this paper focuses on validations in a shop setting.

VALIDATION NDE AND DESTRUCTIVE EXAMINATIONS WORKFLOW

Once a segment is received in the shop, the pipe is:

- A. Visually examined to confirm the reported chainage (the pipe joint's linear position relative to a common feature, a processing facility, and/or terminal). As well, the pipe coating condition and large or obvious defects are assessed.
- B. Abrasive media blast cleaned typically to a NACE No. 2/SSPC-SP 10⁴ finish using silica sand. If the proper grit abrasive is used, masking of stress corrosion cracking (SCC) is minimized with this cleaning.
- C. Subjected to specialized NDE to validate crack-like features or provide supplemental data, including:
 - a. Magnetic Particle Inspection (MPI, see Figure 5). MPI is typically used to assess for cracking (e.g., SCC),
 - b. Phased Array Ultrasonic Inspection (PAUT) of the electric resistance weld (ERW) seam and/or girth welds for cracking or fabrication anomalies,
 - c. Radiographic Inspection of girth welds for fabrication anomalies. The weld quality is evaluated to assess potential fabrication flaws in non-removed joints (see Figure 6).
- D. Examined for OD volumetric features such as corrosion or dents via manual metrology (calipers, dial depth gauge, etc.) or laser profilometry (see Figure 7). For ID features, automated UT scans can be performed. Alternatively, laser profilometry is performed after splitting the pipe lengthwise.
- E. Subjected to the destructive evaluation of features and/or pipeline properties, Figure 8 shows a pipe's metallographic cross-section with flaws present from fabrication. The flaws shown are laps (oxide inclusions) from rolling incorporated into the ERW seam during fabrication. Depending on their size and severity, features of this type can generate "hook cracks" during service.

⁴ CEPA Recommended Practices for Managing Near neutral pH Stress Corrosion Cracking 3rd edition, May 2015, prepared by cepa pipeline integrity working group, electronic source https://www.ceph.com/wp-content/uploads/2016/11/Stress-Corrosion-Cracking_3rdEdition_CEPA_FINAL.pdf

CASE STUDY 1: ILI VALIDATION – SIFTING THE DATA

In-line Inspection of ~50 km (~30 mi) pipeline identified nearly 8000 metal loss features and 42 dents. The pipeline had been constructed in 1967 and comprised 3.2 mm (0.125 inch) thick, 168.3 mm OD (NPS 6), API 5L Gr. X42 material. To validate the data and answer the important questions outlined in the previous section, the client had provided ~20 m (65 ft) of pipe for analysis; Table 4 summarizes the ILI and laser reported features for the pipe cut-outs provided.

The first step to determine if the tool is functioning within its tolerance is to 'group' the data, i.e., organize the features by classification (matched, false positive, false negative, non-reportable, etc.) as shown in Table 5. In this case, the laser identified:

- Thirty features that matched with the ILI.
- Twenty-two reportable features that were missed by the ILI tool (false negatives for the ILI).
- Fourteen locations of metal loss that were not present on the pipe (false positives for the ILI).

After the data has been grouped, a series of statistical tests are performed to determine if it meets the vendor listed specification for the tool run. These include:

- A. Verification of the detection threshold at the 90% confidence interval. This entails hypothesis tests on reportable features. In this case, of the 52 laser features within the reporting threshold of the ILI tool, 30 were matched to ILI features (true positives for the ILI). Following the procedure detailed in API STD 1163 Appendix C, the probability of detection for the 52 reportable features is calculated as 66% (Table 6 shows a calculation example); therefore, this tool is not detecting features per its 90% confidence interval.
- B. Verification of the sizing tolerance at the 80% confidence interval. This entails hypothesis (API STD 1163 Appendix C) and tolerance tests (which were performed per CEPA⁵ Appendix A) on matched reportable features:
 - a. Table 6 shows that the estimated probability of sizing (hypothesis test) is 74%; therefore, the tool is not sizing features per its 80% confidence interval.
 - b. Table 7 shows that the standard deviation of the difference in depth measurements between the laser and ILI (tolerance test) is 12.4 %WT; therefore, the tool does not meet the 8.6 % WT CEPA specified maximum standard deviation.
 - c. Table 7 also shows that the average difference in depth measurements (ILI – Laser) is -4.9 %WT indicating an under call by the ILI tool; this value does not have a specified acceptance limit.

In summary, the ILI tool did not meet the reported specifications for detecting or sizing these cut-outs. The ILI vendor may need to reprocess the data or verify the run parameters.

⁵ CEPA Metal Loss Inline Inspection Tool Validation Guidance Document, 1st Edition, Nov. 2014

CASE STUDY 2: CRACK TOOL ILI VALIDATION

In-line inspection of ~90 km (~56 miles) of pipeline identified around 1000 long seam anomalies; approximately half were reported on the external surface, with the other half on the internal surface. Over 40 digs were completed to remove all the features found by the ILI tool. The pipeline had been constructed in 1997 and comprised 6.35 – 8.00 mm (0.25 – 0.3 inches) thick and 324 mm (NPS 12) OD pipe. Approximately 75 m (246 ft) of pipe cut-outs with 39 ILI reported long seam anomalies were provided for further analysis and ILI validation.

The cut-outs were validated with phased array ultrasonic testing (PAUT) and with MPI as follows:

- A. Half (Dig 1) had the ERW inspected using PAUT.
- B. The other half (Dig 2) was inspected with magnetic particle inspection (MPI). See Tables 8 and 9. Some MPI identified significant features which were fractured open after immersion in liquid nitrogen. Then, the depths of the MPI detected features were measured. Other features were ground until they were not visible.

The findings were:

- A. PAUT and MPI identified short, discreet seam flaws, while the ILI reported one long seam flaw.
- B. The ILI tool overcalled the depths of the features significantly:
 - a. Figure 9 shows the ILI reported depths as being greater than those measured with PAUT.
 - b. Figure 10 shows the ILI reported depths as greater than those measured based on fractures opened after MPI.
 - c. Figure 11 shows the ILI reported length as being greater than that identified with PAUT.
 - d. Figure 12 shows the ILI reported length as being greater than that identified with MPI.
- C. PAUT identified numerous reportable flaws that were not reported by the ILI. However, the flaws were short and shallow.
- D. The average depth/length difference and resulting standard deviation for PAUT and MPI data sets were calculated; the results are summarized in Tables 10 and 11.

In addition to the ILI validation, the long seam anomalies were investigated for service growth through metallography and fractography. No sign of cracking or in-service growth was found.

The lengths and widths of the features were significantly overcalled by the ILI tool, and no sign of cracking in service was found. Subsequently, the integrity threat of the line was downgraded. The integrity plan was also updated to include ILI validation on a small portion of digs before performing more extensive digs.

CASE STUDY 3: ILI VALIDATION – CASE OF MISTAKEN IDENTITY

During an NPS 6 crude oil gathering pipeline inspection, an MFL tool with calipers called out a multi-peak deformation with metal loss. These features are commonly found to be a dent with gouging. After removal and further testing, a 1 m long crack-like feature with associated corrosion was identified - no deformation was found in the area.

Subsequently, the pipe was split, and a bulge (see Figures 13 and 14) was identified on the ID. Upon further metallurgical examination, the bulge was characterized as a scab from manufacture. During the rolling of the steel, some refractory material became embedded, and during subsequent forming of the skelp, the presence of the foreign material produced the identified OD feature.

This explains how the ILI tool had been fooled. It is assumed that the geometry tool (which is essentially a series of fingers/calipers) detected the ID bulge. In contrast, the MFL detected the embedded refractory due to the leakage field being disturbed.

In this case, the limitations of the geometry and MFL tool resulted in mistaken identification. Instead of the ILI reported dent, validation revealed a different threat that would not have been identified without further destructive testing.

CASE STUDY 4: ILI VALIDATION – TESTING THIN PIPELINES

Crack-like flaws were identified in the ERW of a 4.8 mm thick 273.1 mm diameter pipeline during ILI. Accurately assessing the depth of flaws in less than 6 mm thick pipelines with ILI and NDE is challenging. Multiple manual UT scans were made to characterize the flaw. While the ILI assessed the flaw as being 2.8 mm deep, UT assessed, after multiple trials, the depth as 1.7 mm. The assessed lengths were similar, as shown in Table 12. Metallographic examination identified the depth as 1.6 mm. See Figure 15.

In summary, the ILI oversized the flaw. The UT examinations, considering the challenges imposed by thin pipelines, gave useful information. Testing thin pipelines remains a challenge to date.

CONCLUSION

ILI is a powerful and efficient tool for keeping pipelines operating safely. Due to limitations in the ILI inspection techniques, the current processes for assessing the integrity of pipelines require ILI validation. This paper has illustrated various examples of why validations are essential to ensure the ILI data is accurate.

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