POF Your ILI System Selection and how to Comply with API STD 1163

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Abstract

In-line inspection (ILI) continues to evolve and prove to be a high-value solution for performing pipeline integrity assessments. Industry has seen ILI promoted through NTSB recommendations, Federal Pipelines Safety Statutes by Congress, and PHMSA's recent updated pipeline federal regulation. However, each ILI technology and its application by ILI service providers must be vetted to ensure it is qualified for the inspection goals and objectives. Unfortunately, some ILI technology is not properly vetted commensurate to the risk associated with the integrity assessment for a given pipeline. As governance, PHMSA has now incorporated by reference API STD 1163 In-line Inspection Systems Qualification (API 1163) into both 49 CFR 192 and 195. While API 1163 is generally understood, details can be overlooked, leading to non-compliance. This paper uses two case studies to highlight the topic of ILI System Selection within the API 1163 standard and its importance in performing a sound integrity assessment. The process for selecting an appropriate ILI system for metal loss and cracking will be reviewed and a practical four-step process will be demonstrated.

Background

Integrity assessments are fundamental to managing the risk associated with operating pipelines to transport hazardous materials. It is well understood that the data provided by ILI-based integrity assessments is advantageous in risk management programs. ILI technology's ability to provide discrete and location specific data enables opportunities to maximize risk reduction to the environment, public, and operations. Industrial momentum using ILI has provided a competitive environment resulting in significant ILI technology improvements and capacity expansion. In the United States pipeline operators reported to PHMSA an increase of over 30% in total annual mileage inspected using ILI between 2017 and 2022[1], as shown in **Figure 1**. Federal regulation governing the use of ILI are found in 49 CFR § 195.591 *In-Line inspection of pipelines* and 49 CFR § 192.493 *In-line inspection of pipelines*, both establishing the requirement to conduct ILI in compliance with API STD 1163 (reaffirmed 2018) *In-line Inspection Systems Qualification*.

Figure 1: Total Miles Inspected Reported to PHMSA

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[1] https://www.phmsa.dot.gov/data-and-statistics/pipeline/source-data

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The ever-growing demand for ILI technologies to support integrity management plans and provide solutions to address evolving operational, integrity, and risk continue to create an attractive market for technology development. Operational demands push for fewer runs and disruptions to product, flow rates, and normal operating pressure. Integrity demands better anomaly detection (POD) and characterization through classification (POI), identification and sizing accuracies. Risk management and finite resources demand improved data analysis and integration for engineering assessment techniques. ILI program managers are challenged with staying abreast of industry-wide ILI service providers' technology updates, tool developments, personnel changes, and ILI system capabilities. While ILI tools traditionally focused on single sensor technologies circa 2000, a decade of advancements brought combination tools that enabled a few technologies to be joined into one inspection train and have their data aligned for analysis. The most common example being caliper, metal loss, and mapping being mechanically joined into a combination tool. More recent developments target specific threats using some combination of increased sensor resolution, complementary sensor technology, and novel data analytics. Good examples of technology developments are mechanical damage[2], cracking[3], and hard spot[4] ILI solutions. It is important to note that as technology advances, the need to properly vet new and existing technologies remains critical. This paper will highlight several interpretations to the ILI System Selection process outlined in API 1163 to support pipeline operators in this process as technology continues to advance. Two case studies are also summarized to share recent lessons learned for two projects.

Discussion

Magnetic Flux Leakage and Shear Wave ILI Systems

Circa 2010 high resolution MFL tools were commonly equipped with an axially oriented magnetic circuit and hall effect sensors sized approximately 5 to 7 [mm]. The variations in commercially available MFL technology between ILI service providers were easily comparable through sensor resolution, single or tri-axial components, and personnel related factors. Now it is common for MFL ILI systems to come in the form of combination tools with more than one magnetizing circuit configuration and complementary sensors such as caliper, mapping, and/or eddy current. This enables multiple datasets for integration. Hall effect sensor resolutions are now commonly under 2 [mm]. Additionally, advances in data analysis have enabled greater information extraction to characterize anomalies. A secondary benefit resulted in various assessment capabilities for other pipeline threats and attributes like hard spots, material properties, and cracking. In some cases, these data-based techniques can present similar capabilities as complementary sensor technologies and potentially in lieu of higher resolutions and sensors. Machine learning techniques have become common in supporting anomaly classification and sizing. When considering the use of a services provider's application of the MFL technology it is fundamental to understand the qualification process and results that serve as the basis for the capability claims being made. Capability statements should be supported by the documented qualification process and performance specification.

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[2] Romney, M., Burden, D., "A Case Study Applying Gouge Classification to Mechanical Damage Defects", International Pipeline Conference, IPC2022-84801.

[3] Thompson, R., et all, "The use of ILI technology for the detection and measurement of elevated stress associated with CSCC", February 2022, Pipeline Pigging and Integrity Management Conference.

[4] Tran, K., et all, "Know Your Enemy – Improvements in Managing the Threat of Hard Spots", International Pipeline Conference, IPC2022-88362

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If the qualification process for an ILI technology is based on blunt or uniform flaws, then the risk associated with the ILI goals and objectives should be reviewed and considered in the ILI selection process. Different ILI systems will have different levels of maturity where the qualification process is augmented with data analysis processes which leverage algorithms, integrating signals from multiple sensors, targeted small scale testing such as pull/pump tests, and analyst experience. A small-scale test of a complex metal loss flaw is illustrated in **Figure 2**. This complex flaw has two 3t by 3t flaws axially aligned with 3t spacing between them and within a larger 20% flaw. The adjacent color pattern is a representation of the axial MFL signal data. The two red indications in the color pattern are representative of the two 3t by 3t flaws. The white patch between the two red indications is representative of nominal metal and not the 20% metal loss. This can be considered as axial shadowing when reviewing a single vector component of the magnetic flux leakage of axially oriented MFL data. This situation can be overcome with several approaches, such as hall effect sensors that capture more than one vector component of the magnetic flux leakage, commonly referred to as "tri-axial" sensors. However, the analysis of all three hall effect sensor components may require scope expansion in standard offerings. MFL data analysis is a sophisticated process with many variables which can create challenges and solutions. The capabilities and/or deficiencies of one MFL application in an ILI system does not represent the capabilities and deficiencies of another. Sensor resolution and type alone are not sufficient to rank one ILI system superior to another. The ILI system as a whole must be reviewed as a whole. API 1163 defines an ILI system as *an inspection tool and the associated hardware, software, procedures, and personnel required for performing and interpreting the results of an ILI.* The example in **Figure 2** is only to demonstrate the how one application of the MFL technology can have challenges and highlight the importance of reviewing the ILI Service provider's performance specification qualification process.

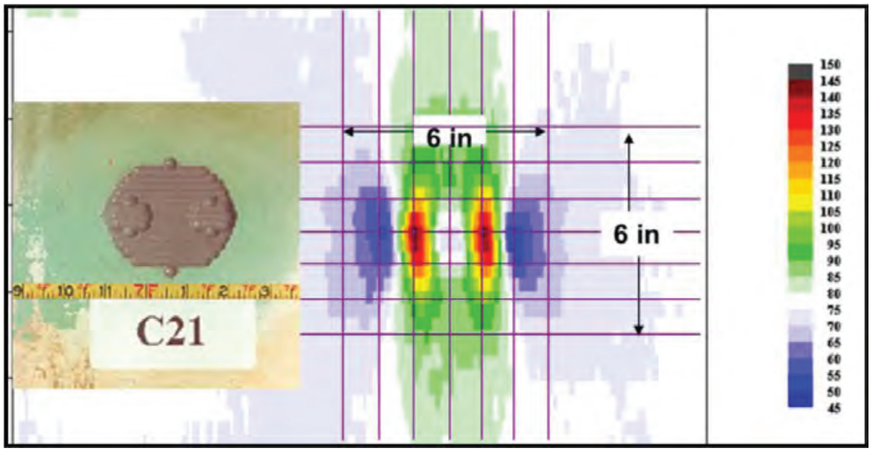

Figure 2: Axial MFL Signal of Complex Flaw[5]

ILI systems for crack type flaws have traditionally leveraged ultrasonic based applications. However, as previously mentioned, some MFL based platforms are leveraging complementary sensors and data integration to inspect for cracking. As of the writing of this paper, the two most common ILI technologies for assessing cracks in pipelines are based on Ultrasonic Transducers (UT) and Elector-Magnetic Acoustic Transducers (EMAT). UT based crack detection creates shear waves at 45 [deg] to interpret reflections of the wave to detect and characterize cracks in pipelines. A pulse-echo configuration is based on a UT sending and receiving a shear wave to detect echoes from the pipe

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Smart, L., Nestleroth, B., Li, Y., Ward, S., "Interaction Rule Guidance For Corrosion Features Reported By ILI," International Pipeline Conference, IPC2018-78284.

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material and flaws such as cracks. A pitch-catch configuration is based on a pair of UT sensors where one sensor is the transmitter, and the other is a receiver. Known limitations for this shear wave UT technology are related to reliable discrimination between crack flaw types and detecting and characterizing crack-like flaws with particular skew and tilt attributes. Skew is defined as the deviation of the crack's angle relative to the pipeline's axial orientation, and tilt is defined as the angle of the crack through the wall thickness. Circa 2013 UT crack ILI systems were commonly reporting crack-like anomalies in ranges or buckets between 1 and 4 [mm] with limited discrimination between cracking flaw types. Now it is common for absolute sizing to be provided for anomaly depths up to 4 [mm]. Technology maturation, sensor development, and data analysis techniques have also improved the ability of crack and crack-like classifications. This is particularly important when performing a long seam assessment for cracking. The ability to classify and discriminate between flaws such as lack of fusion (LOF) and hook cracks is significant. An ILI system's ability to accurately classify an anomaly is communicated in the performance specification as a Probability of Identification (POI). The example in **Table 1** demonstrates how classification accuracy may be presented. When considering the use of a services provider's crack ILI system (UT or EMAT) technology, the pipeline operator should collaborate with the ILI service provider to review the performance specification, qualification process, and quality management practices. Capability statements should be supported by a documented qualification and a performance specification. Through this process the pipeline operator may discover critical information in the definitions used and details about the limitations of the ILI system. In example, the information below in **Table 1** alone does not provide clarity in the ILI system's ability to discrimination between LOF or hook cracks.

Table 1: Example POI Performance Specification

Probability of Identification Feature	YES POI > 90%	NO POI<50%	Maybe 50 ≤ POI ≤ 90%
Anomaly			
• Corrosion	X		
• Crack	X		
• Dent with Crack			X
• Longitudinal Weld Anomaly	X		
• Longitudinal Weld Crack	X		
• Stress Corrosion Cracking (SCC)	X		

API 1163 - ILI System Selection Requirements

API 1163 provides a framework for the qualification of an ILI system, meaning it provides a standard for the process to establish a performance specification for a given ILI system. However, it does not establish a performance standard. The level of testing and performance validation will vary with no standard. It important to recognize that API 1163 also allows ILI service providers to have self-governance. It is fundamental that pipeline operators perform due diligence when selecting an ILI system for an integrity assessment. API 1163 prescribes the following responsibilities between pipeline operators and ILI service providers:

Service Providers:

- Identify ILI system capabilities

- Proper use of ILI system
- Appropriate application of ILI system

Pipeline Operators:

- Identify specific threats for investigation
- Choose the proper ILI technology
- Maintain the operating conditions within the ILI system performance specification limits
- Confirm inspection results

Since there is no industry standard for determining when an ILI system is sufficiently mature or the performance has been sufficiently validated, it is the pipeline operator's responsibility to investigate each service provider's ILI qualification process as part of choosing the proper ILI technology. Doing so will enable a better understanding of an ILI system's capabilities and maturity. This point cannot be more emphasized, independent of the service provider and technology. Today, the numerous commercially available applications of ILI technology can be overwhelming. However, the importance of a diligent review is intrinsic in establishing the ILI goals and objectives.

API 1163 Section 5 *Selection of an In-Line Inspection System* offers general guidance on choosing the proper ILI System via five subprocesses summarized below:
General:

- When selecting an ILI system, both the ILI system capabilities and the pipeline operational and physical characteristics shall be considered.

Inspection Goals and Objectives:

- The goals and objectives of an ILI shall be defined, with documents such as API 1160 and ASME B31.8S providing leadership in this regard.
- Goals and objectives shall include, but are not limited to, the detection, classification, and characterization of anomalies and features within the pipeline.

Physical and Operational Characteristics and Constraints:

- The operator shall provide information on physical characteristics and constraints of the pipeline to the service provider, which is typically done through a pipeline questionnaire.
- Characteristics of the pipeline that shall be provided for assessing the compatibility of the ILI system with the inspection goals and objectives are described in NACE SP0102.
- The service provider shall define the constraints (minimum or maximum) under which the ILI tool will operate,

Selection of an In-line Inspection System:

- Selection of an ILI system is based on the operator's goals and objectives, with evaluation including:
    a) Expected performance with regard to detection, classification, characterization, location, and coverage capabilities for the anomalies of interest and pipeline to be inspected;
    b) Physical characteristics and constraints of the ILI tool;
    c) Reporting requirements;
    d) Operational reliability of the tool (history, operational success, etc.) and vendor;
    e) Performance on other types of anomalies other than those of interest;
    f) Operational constraints and availability.

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- The operator shall select one or more appropriate ILI systems that meet the goals and objectives established.

Performance Specification:

- The service provider shall state whether the chosen ILI system can meet the written performance specification in that pipeline and under the existing operating conditions, including the specific tool configuration for the proposed run.

The result of completing the above five sub-processes should result in the qualification or dis-qualification of an ILI system for use as an integrity assessment. Pipeline operators are encouraged to establish and document a sixth and additional sub-process for "ILI System Qualifications" as part of ILI system selection. This qualification would be focused on identifying for which integrity related goals and objectives each ILI system is qualified. **Table 2** below provides an example:

Table 2: Example ILI System Qualifications

Service Provider	Technology	Class	Threat	Assessment	Note
Vendor A	MFL-A	High Res	General	B31.G and Mod B31.G	
Vendor A	MFL-A	Ultra Res	Pitting, Complex Corr.	B31.G and Mod B31.G	Complex Corr. and Possible EAM with Manual Analysis
Vendor A	MFL-A + MFL-C/S	Ultra Res	Pinhole, Complex Corr, SSWC	Effective Area (EAM), Pipe Type (Properties)	EAM with Manual Analysis, Long seam classification with Manual Analysis
Vendor B	UT	Pulse-Echo (PE)	SCC, Manufacturing, Linear Indications	Pipe Body, Limited Long Seam	Possible Hook Crack
Vendor B	UT	Pitch-Catch + PE	SCC, Manufacturing, Hood Cracks	Pipe Body, Long Seam	Possible Pressure Test Replacement

Interpretation of ILI System Selection Requirements for ILI Assessment

To satisfy the intent of *Inspection Goals and Objectives*, it is critical that the Pipeline operator recognize how the reported data will be used. The reported information must be usable in determining the pipeline's fitness for service. Therefore, the fitness for service objectives must be included in the inspection's goals and objectives. This is seen by API 1163 calling on ASME B31.8S and API 1160 as leadership. However, it is important to note that federal regulation currently does not incorporate by reference any edition of API 1160 and only recognizes the 2004 edition of ASME B31.8S, which is outdated related to ILI technology capabilities and best practice. The intent should be interpreted as the ILI system selected must be able to provide the characteristics data for specific threats that enable sound engineering assessments. The Pipeline Operators Forum (POF) published the *POF 100 Specifications and requirements for ILI*[6] (POF 100) to serve as an international standard practice for specifications and requirements for in-line inspection of pipelines. POF 100 provides additional guidance on anomaly assessment methodologies that can be reviewed to support establishing the integrity related goals and objectives for an ILI. It also provides guidance for reporting requirements associated with report structure, terminology, and abbreviations. Reporting requirements should be explicit in the documented objectives for the ILI as the information reported should be tuned to support the targeted threats and anomaly assessment methodologies. One scenario to consider is the effort to perform a run-to-run comparison for data integration. Reporting requirements play a fundamental role in this regard. POF 100 is the basis for the well-known surface dimension classes for metal loss anomalies. These classifications are widely used in ILI performance specifications.

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[6] Standard POF 100, *Specifications and requirements for in-line inspection of pipelines*, November 2021

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However, the API 1163 (reaffirmed 2018) classification uses the term “General” in place of “Extended” from an earlier version of POF 100.

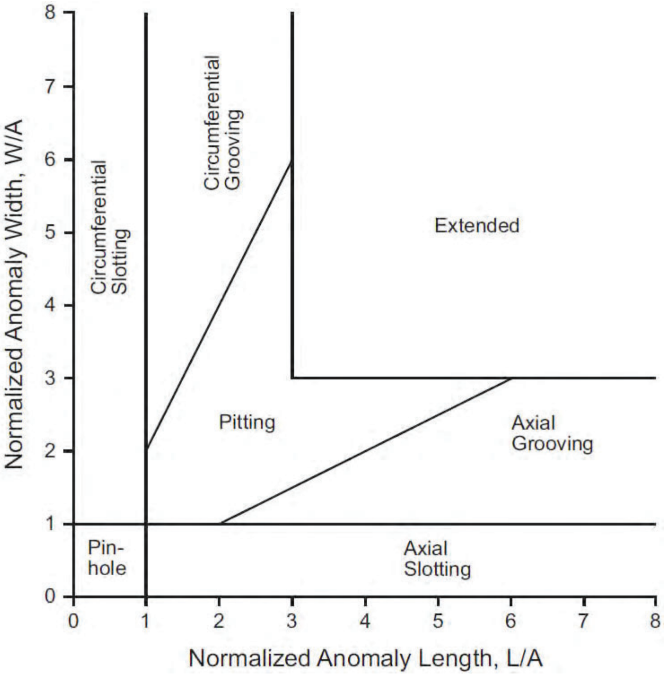

Figure 3: Surface Dimensional Classes for Metal Loss Indications per POF 100

The following four steps are recommended interpretations to support part of the requirements outlined in API 1163 ILI System Selection:

Step 1 is to define the goals and objectives of the inspection. It is recommended that the anomaly assessment methodologies to be used serve as the basis for the inspection goal. For example, if an MFL ILI system will be used to assess for the threat of corrosion, then the goal of the inspection can be presented as follows, “An MFL based ILI system will be used to provide characteristic data on Pinhole, Pitting, and General metal loss to perform Modified B31G and Effective Area Method based anomaly assessments”. Another example, “A shear wave UT based ILI system will be used to perform long seam integrity assess and shall have sufficient capabilities to detect, identify, and size critical flaw sizes for hook cracks with a POI greater than 90%”. This will provide the basis for evaluating the ILI system’s capabilities and compatibility, and ultimately the ILI objectives, such as reporting requirements. The ILI goal(s) and objectives should be documented to provide comparison to each service provider’s ILI system documentation. It is common that the pipeline operator’s use an ILI standard to establish the broader goals and objectives of an ILI. This approach is sound for ensuring a standard practice and quality of performing an ILI. However, these ILI standards may not always be sufficiently comprehensive to address the qualification of various ILI system’s capabilities to provide the data necessary to perform integrity engineering assessment with confidence. The pipeline operator should integrate previous ILI data to ensure the next ILI system used has a performance specification and maturity to reliability and accuracy provide characteristic data for active threats.

Step 2 is to review the essential variables and qualification process – Performance specifications are generally known to be initially developed based on pull tests and/or pump tests using fabricated or natural flaws. The parameters used in these development tests often determine the essential variables

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that are the basis for qualifying the performance specification. These tests may be combined with advanced modelling, such as Finite Element Analysis (FEA) to augment testing and further qualify of the ILI system's capabilities. As the ILI service provider gains experience with the ILI system, the essential variables may be modified based on documented empirical data and feedback. It is essential that the attributes of the pipeline to be inspected be compared to the documented essential variables. An example of how pull tested data can be used to qualify an MFL ILI system is presented in
Figure *4* and
Figure *5* below.

Figure *4* illustrates the target POF dimension classes for the pull test.

Figure *5* illustrates the data captured for anomalies ranging in depths from 5% to 80% of nominal wall thickness using an MFL-A ILI system.

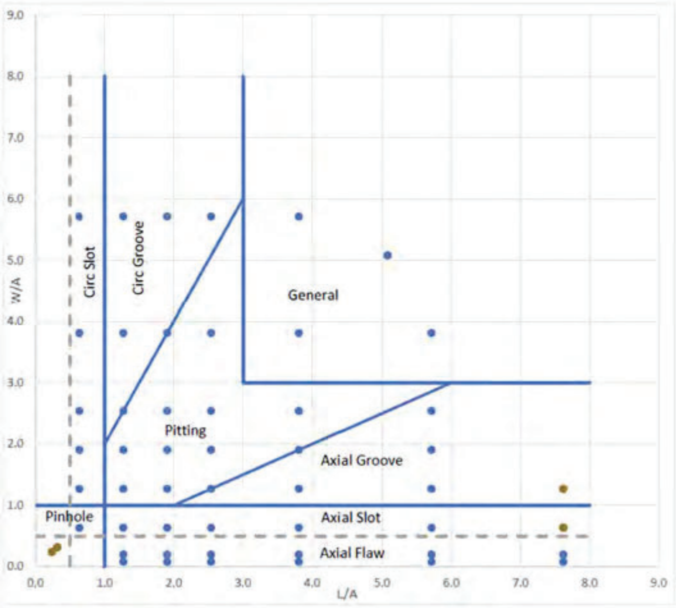

Figure 4: Pull Test Flaw Distribution

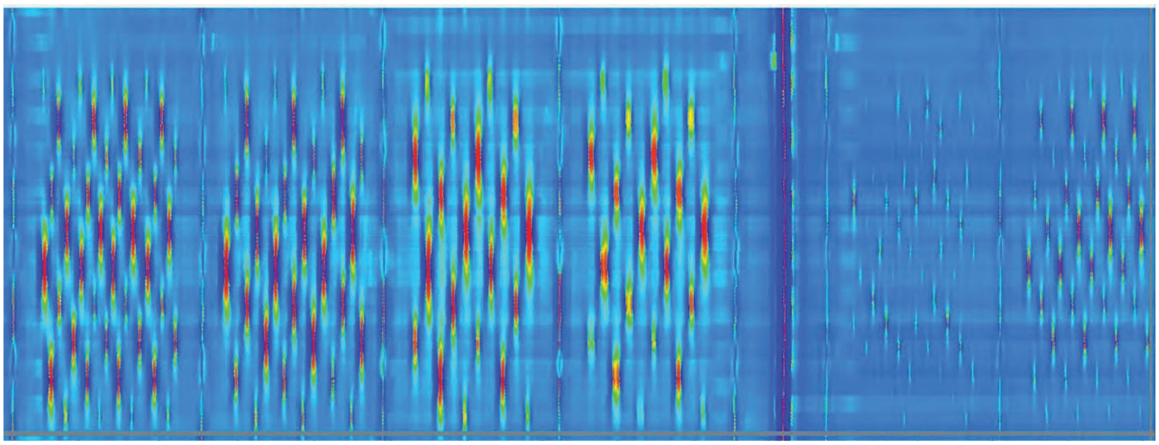

Figure 5: MFL-A ILI Pull Test Data (Novitech[7])

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[7] https://novitechinc.com/integrity-threats/metal-loss/

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Pull tests can also be advantageous if properly designed to accomplish various objectives. One could demonstrate performance inside or outside the boundaries of the documented essential variables and/or performance specification. If incorporated into the ILI selection process, pump/pull tests can provide an opportunity to verify ILI system performance prior to the inspection and support defining the goals and objectives of the ILI. The calibration process for the ILI system should be thoroughly reviewed and understood by working with the ILI service provider. ILI calibration will typically include multiple pull tests targeting specific flaw types and dimension classes. These pump/pull tests support verification of the performance specification and ultimately the qualification of the ILI system for use on the targeted threat. See
Figure 6 for an example of data from an EMAT ILI system calibration pull test.

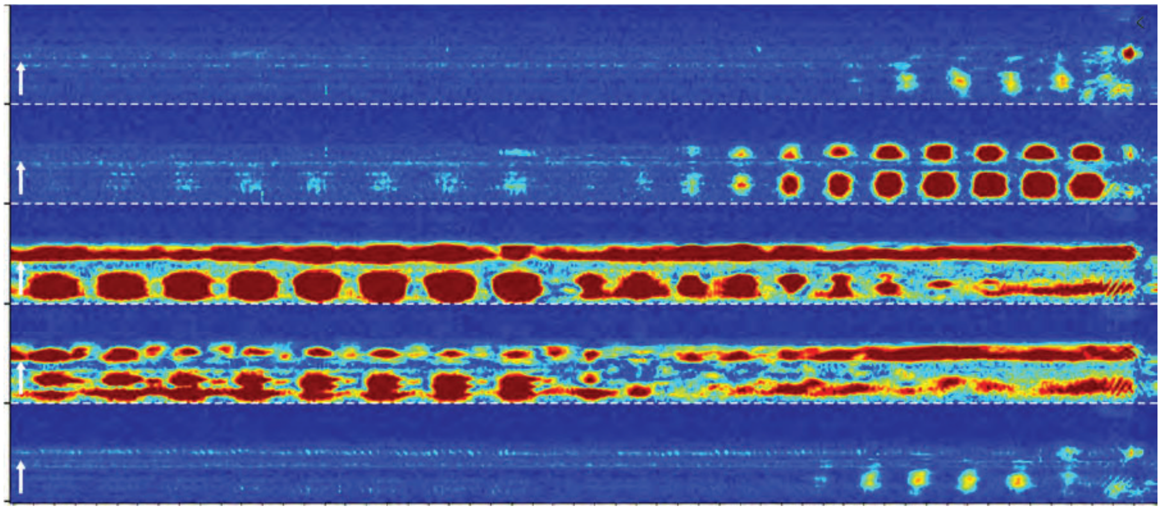

Figure 6: EMAT-C Pull Test Data (ROSEN Group[8])

Figure 6 is a stagged b-scan view of EMAT-C spectral analysis. The Y-axis represents five channels of data, and the X-axis is log distance. The flaws are synthetic cracks (notches) with controlled dimensions varying in length from 40mm-80mm and depths from 30% to 100% of nominal wall thickness. The pull test objective was to assess ILI capabilities for toe cracks.

The Tool Data Sheet (TDS) will prescribe the essential variables which are communicated as a range of inspection conditions for pipeline attributes (i.e. wall thickness) and pipeline operations during inspection (i.e., product, pressure, temperature, and flow rate). Generally, the essential variables must be satisfied for the performance specification to be applicable. Deviations from the essential variables can compromise the data quality, results of the data analysis, and confidence or certainty in the reported results.

Ensuring the ILI system's essential variables are met may not be sufficient to qualify an ILI system for an integrity assessment outside of low-risk pipelines. However, pipeline operators should review the qualification process and methodology for each anomaly type documented in the performance specification for each ILI system considered for use as an integrity assessment. This will provide clarity on the ILI system's ability to satisfy the integrity related goals and objectives. API 1163 allows ILI services to qualify a performance specification using one or more of the following methods: verified historical data, large-scale tests from real or artificial anomalies, and/or small-scale tests, modelling,

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[8] https://ww.rosen-group.com/global/solutions/services/pipeline-crack-detection-and-assessment.html

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and/or analysis. POF 100 recommends that the basis for the performance specification for each anomaly type be clearly stated. It provides the following where multiple methods can be used:

- Modelling
- Limited pull tests and modelling (where effects of essential variables have not been fully tested by pull through runs and anomalies are predominantly manufactured)
- Extensive pull through tests covering range of speed and wall thickness using a combination of manufactured and natural anomalies
- Limited field verification with less than 20 operational runs
- Extensive field verification results reviewed on an annual basis.

Pipeline operators are encouraged to establish their own ILI qualification process for threat specific ILI assessments. This will ensure that an ILI system has sufficient maturity and capabilities to meet the ILI goals and objectives for specific anomaly types, pipeline conditions, anomaly assessment methodologies, and risk. The qualification process should consider the ILI system's documented qualification process and historical operational and reporting performance for the targeted integrity threats.

Step 3 is to review the performance specification for nomenclature, definitions, limitations, detection thresholds, POD, POI, and sizing accuracy. The pipeline operator should fully understand the definitions of nomenclature and the analysis process associated with these anomaly type documented in the POD, POI, and sizing accuracy tables. Nomenclature and reporting can vary between ILI systems and ILI service providers. The performance specification will communicate the level of confidence or certainty that is expected for the reported anomalies resulting from data analysis. This is important to investigate and understand how the performance and reporting capabilities of the ILI system can enable the ILI assessment workflow within API 1163. See **Figure** *7*.

The detection/reporting thresholds and sizing accuracy should be appropriate to perform the anomaly assessment and fitness for service activities associated with the integrity assessment. If one or more of the essential variables or the performance specifications cannot be met, then either the goal(s) and objectives can be modified, or compensatory measures can be agreed and documented between the pipeline operator and the ILI service provider. Many ILI systems can accommodate minor deviations from the essential variables with augmented data analysis routines and still meet the performance specification. In these cases, the ILI final report should document how the deviation(s) was addressed.

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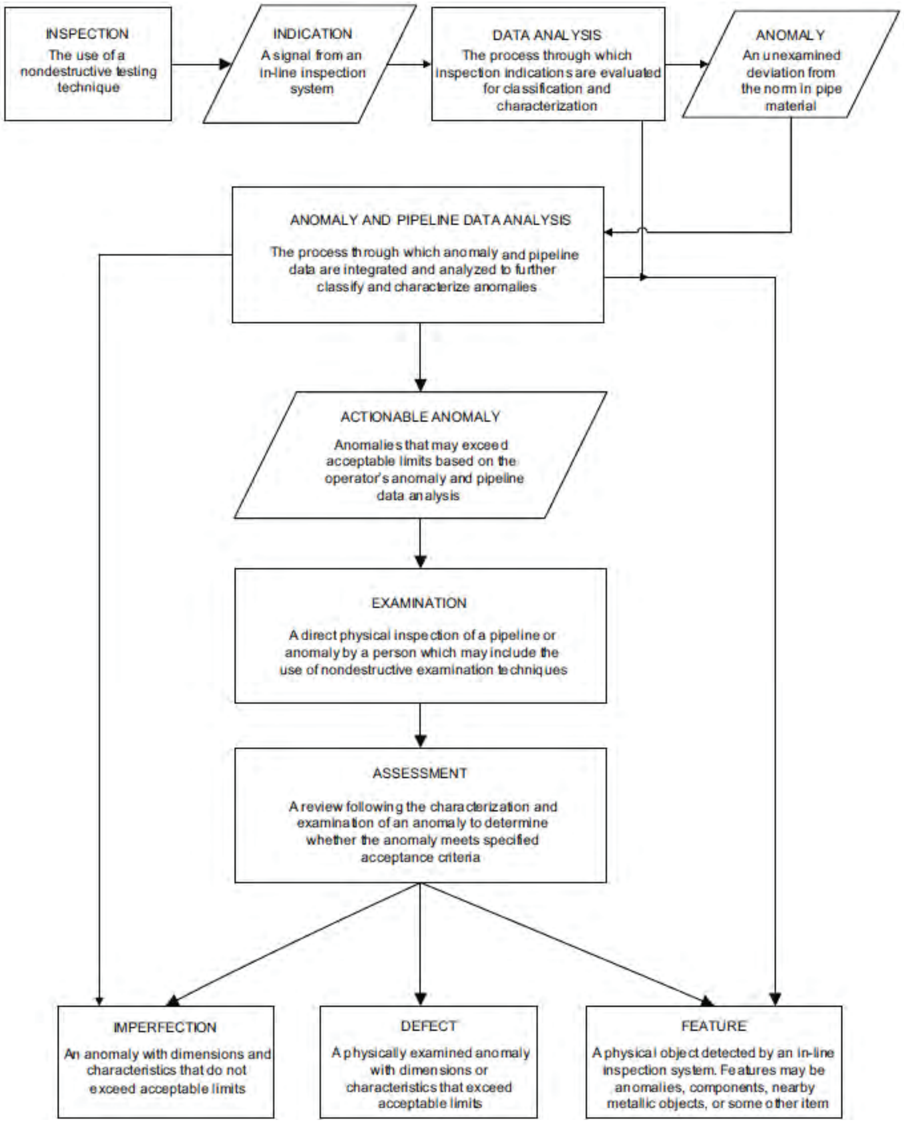

Figure 7: Inspection Terminology per API 1163

Step 4 is establishing the qualification requirements for each ILI. Leveraging historical ILI system performance is a well-accepted practice for qualifying an ILI system. However, it is critical that due diligence is taken for the specific threat and morphology considering the pipeline attributes and operating conditions. The ILI system qualification process should be documented and be an integral part of the ILI selection process. In doing so, challenges such as confirmation bias and assumptions can be mitigated. Robust ILI qualification programs may require significant lead times to ensure appropriate review and assessment. Pipeline operators are recommended to leverage information available through peers, ILI service providers, and industrial knowledge through publications to make this process more efficient. Annual meetings with ILI service providers should be scheduled to review qualified ILI systems for changes and continual improvement, in accordance with API 1163's sections 6.4.4 Qualification of Performance Specification – Review and Revision Requirements and 10.5 Quality System Review

Case Studies

Magnetic Flux Leakage and Shear Wave ILI Systems

In a recent project a pipeline operator requested support to select an appropriate ILI system for the assessment of the corrosion on a pipeline segment. To support this goal the previous ILI results were reviewed to identify the next ILI objectives. **Figure 8** is the distribution of reported metal loss anomalies with POF classifications for the previous ILI assessment.

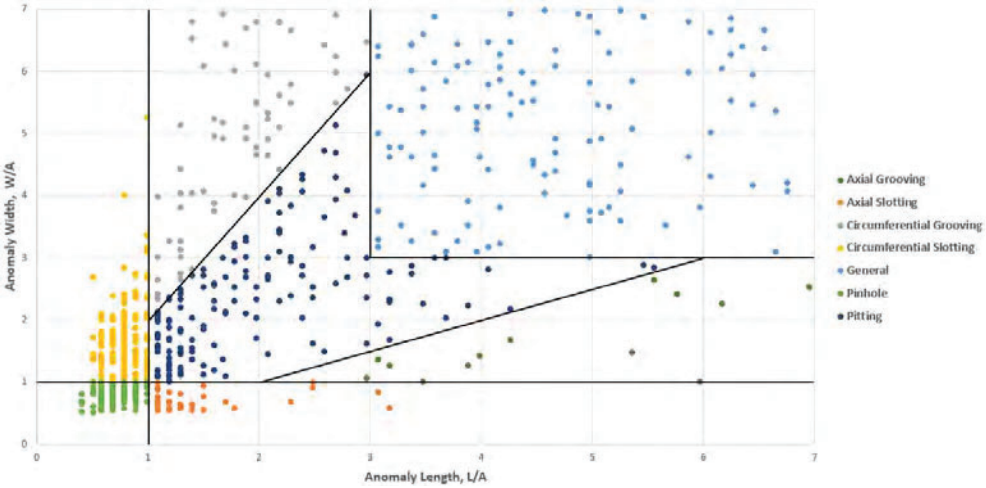

Figure 8: Baseline ILI Metal Loss Distribution of POF Classifications

The metal loss morphologies include all metal loss dimension classes. To understand the expected performance of the previous ILI the performance specification was reviewed. **Table 3** is a summary of the performance specification. However, the previous ILI was not qualified to assess all reported metal loss anomalies by the ILI service provider or the pipeline operator. Further data integration concluded that the greatest integrity concern for the corrosion threat was the impact of pinhole and pitting on burst pressure calculations and leaks.

Table 3: Vendor A: MFL-A Detection and Sizing Specification

Detection and Sizing MFL-A Specification	General	Pitting	Circ. Grooving	Circ. Slotting	Axial Grooving	Axial Slotting
Depth at POD = 90%	0.1t	0.10t	0.1t	0.10t	0.1t	0.1t
Depth Sizing Accuracy (80% Certainty)	± 0.1t	± 0.1t	± 0.1t	± 0.1t	± 0.1t	± 0.1t

The pipeline operator's ILI standard, which defined the reporting requirements, required the reporting of the burst pressure calculations using ASME Modified B31G and the Effective Area Method[9] assessments for metal loss anomalies. Therefore, these calculations are part of the ILI's explicit objectives. However, neither the pipeline operator nor the ILI service provider addressed this gap during the ILI System Selection process. This is critical because both ASME B31G assessment methods require the use of reported depths. The obvious question then becomes, "how should the

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[9] ASME B31G-2012, Manual for Determining the Remaining Strength of Corroded Pipelines

depth parameter for ASME B31G assessment be determined where Pinhole anomalies are reported?”. This scenario is illustrated in **Figure 9**.

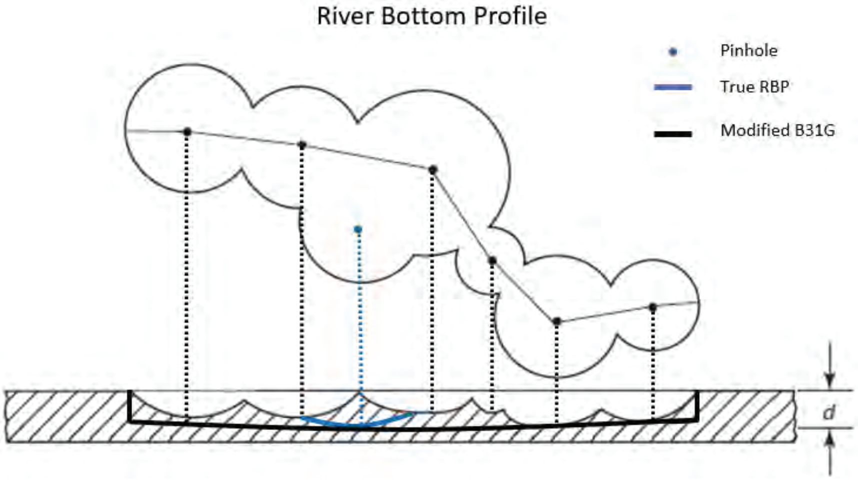

Figure 9: Illustration of River Bottom Profile

The lesson learned is that additional risk and uncertainty were introduced into the integrity assessment when the MFL-A ILI system’s capabilities are not explicitly reviewed. Additionally, the personnel qualifications and data analysis process for performing Effective Area Method were not reviewed and qualified prior to performing the ILI.

Multiple MFL ILI services providers were engaged to review tool availability and performance specification. Of the qualifying service providers one ILI system and associated performance specification was identified for further vetting. The goal of the ILI assessment was for the ILI system to provide appropriate characteristic data on the metal loss morphologies presented in **Figure 8** to perform anomaly assessments, including ASME Modified B31G and Effective Area Method. The ILI system’s performance specification is summarized in **Table 4.** The ILI service provider was also interviewed to review the ILI qualification process for the Pinhole inspection capabilities and performance history. Using guidance in POF 100, the qualification for Pinhole assessment was establish based on extensive pull tests using fabricated flaws and operational history greater than 20 inspections with field data for validation.

Table 4: MFL-A Performance Specification Summary

Detection and Sizing MFL-A Specification	General	Pinhole	Pitting	Circ. Grooving	Circ. Slotting	Axial Grooving	Axial Slotting
Depth at POD = 95%*	0.1t	0.1t	0.10t	0.1t	0.10t	0.1t	0.1t
Depth Sizing Accuracy (80% Certainty)	± 0.1t	± 0.1t	± 0.1t	± 0.1t	± 0.1t	± 0.1t	± 0.1t

* does not include SMLS pipe

However, as part of the ILI system selection it was agreed to design and fabricate a flaw spool to verify ILI system performance to meet the ILI’s goal. The objective of the pull test was to verify, and calibrate as appropriate, the use of the Modified B31G and the Effective Area Method for Pinhole, Pitting, and General metal loss classifications. The flaw spool was developed with 28 flaws targeting different metal loss morphologies and depths. **Figure 10** is an illustration of a set of metal loss flaws with pinholes the flaw spool. **Figure 11** is an illustration of a metal loss flaws with a target river bottom

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profile to verify the ILI system's ability to generate the river bottom profiles associated with the Effective Area Method. Successful pull test results confirm the ILI system's qualification for the ILI goal and objectives outlines in the clients ILI Standard and scope of work.

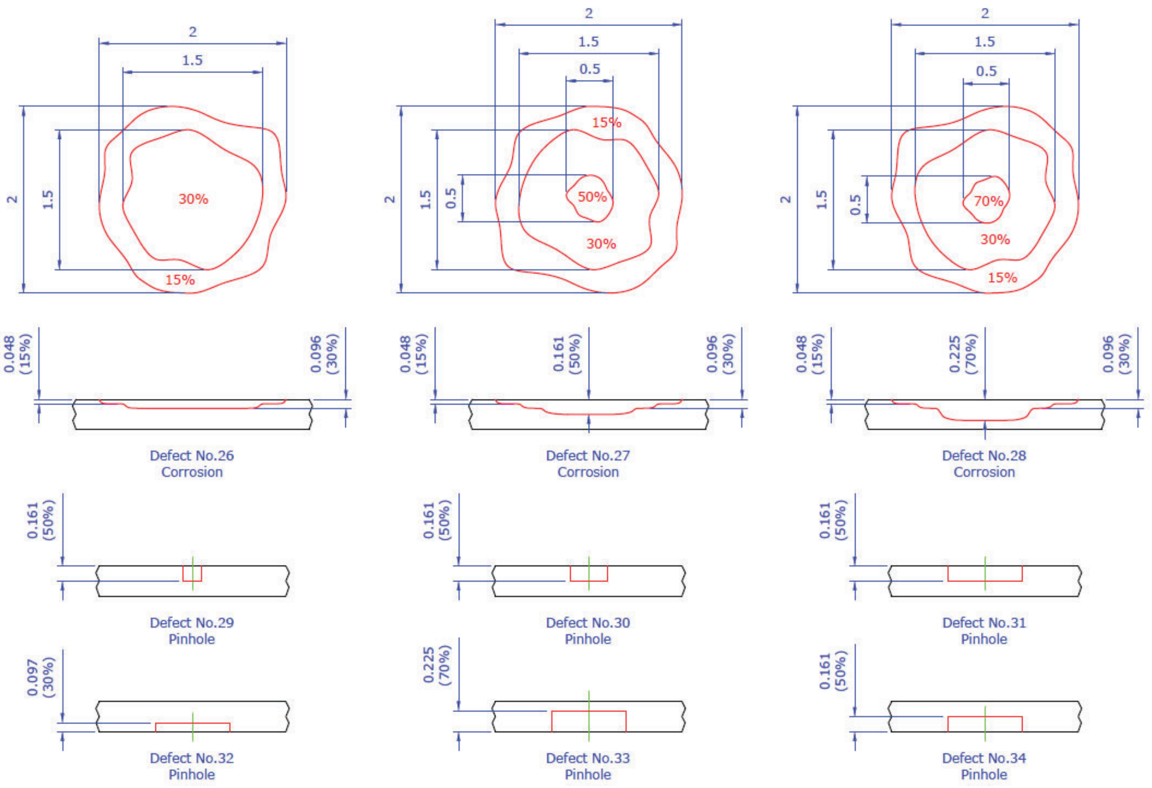

Figure 10: Set of Metal Loss Flaws with Pinhole

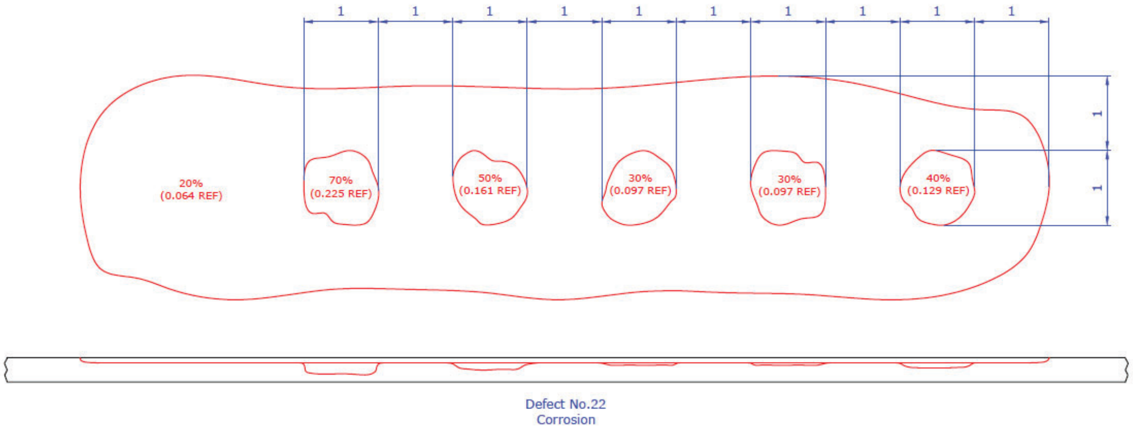

Figure 11: Extensive Metal Loss Flaw for Burst Pressure Calculation Verification

UT Shear Wave Case Study

In another recent project, a pipeline operator requested support in qualifying an ILI system for performing an integrity assessment on a pipeline with ERW pipe and a target threat of hook cracks. In 2019 a shear wave UT ILI was completed and approximately 275 Longitudinal Weld Anomalies were reported with no further classification. The pipeline operator's ILI Standard did include these anomaly types as acceptable reportable anomalies. The POI specification for the ILI system included various crack-like anomaly types including Cracks, Longitudinal Weld Anomaly, and Pipe Mill Anomaly. However, the pipeline operator did not vet the data analysis and reporting processes associated with this ILI system prior to inspection. This vetting would have enabled a better understanding of how the analysis process determined when an anomaly was classified as Crack, Longitudinal Weld Anomaly, or Pipe Mill Anomaly. The ILI's performance specification did not provide further clarification or definition for Longitudinal Weld Anomalies. **Table 1** summaries the POI information for the ILI system. Crack-like anomaly detection and sizing capabilities were specified as being applicable to Fatigue Cracks, Toe Cracks, Lack of Fusion, Hook Cracks, Surface Breaking Laminations, and Stress Corrosion Cracking (SCC). The performance specification did not provide sufficient clarity as to the ILI system's ability to discriminate between Crack, Longitudinal Weld Anomaly, or Pipe Mill Anomaly. A review the ILI service provider concluded that further classification was not possible.

As a result, all reported Longitudinal Weld Anomalies were a conservatively assessed as cracks in the long seam. Reported anomaly lengths greater than 12 [in] accounted for approximately 75% of the reported anomalies. The maximum reported anomaly length was greater than 100 [in]. By treating these reported anomalies as potentially injurious cracks and with the reported lengths, most of the anomalies were actionable and requiring an immediate response. The response was an appropriate long term pressure reduction and dig program to further understand the ILI's performance. Greater than 50 excavations were conducted, and re-analysis of the ILI data using the field data concluded that the ILI system was not able to refine the dig program to near-term injurious defects and reliably provide detection, identification, and sizing for hook cracks. A summary is provided in **Table 5** for cracks and lack of fusion flaws discovered in-situ.

Table 5: Verified ILI Performance

Probability of Detection (POD)		**POD**	**POI**
# of Discovered Flaws	27	< 50%	
# of ILI Reported Anomalies	5		
Probability of Identification (POI)			
Hook Crack			
# Discovered	6		< 50%
# ILI Reported - Internal Crack-like	1		
Lack of Fusion			
# Discovered	21		< 50%
# ILI Reported – External Crack-like	1		
# ILI Reported – Internal Crack-like	2		
# ILI Reported – Longitudinal Weld Anomaly	1		

A lesson learned was that insufficient review of the performance specification and anomaly classification process determine POI capabilities resulted in a significant impact to operations

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including long term pressure reduction, greater than 50 excavations, and continued uncertainty in the pipeline's integrity. The pipeline had a verifiable, traceable, and complete pressure test record to substantiate the Maximum Operating Pressure (MOP) and a fatigue assessment concluded low risk of fatigue growth. The predominant pipe material was made using Electric Resistance Welded (ERW) pipe circa 1970. A goal of the ILI system was to gain an understanding of the location of cracks in the pipeline, including hook cracks, and their fitness for service. However, this was goal was not documented as part of the ILI's goal and communicated to the ILI service provider as part of the ILI scope. As a result, the ILI service provider was not able to communicate the ILI system's qualification and historical performance associated with ERW long seam assessments and hook cracks. This ILI system used a pulse-echo measurement principle and had known limitations associated with hook crack flaws.

Prior to performing the next ILI assessment, the pipeline operator documented the primary goal of the ILI and implemented a two-step ILI qualification process. The ILI goals were to 1) identify the location of crack-like flaws and hook cracks in the pipeline with a POI greater than 90%, and 2) provide detection of critical flaw sized to enable fitness for service assessments. The first step in ILI qualification was a review of the ILI services providers qualification process for the published performance specification, including a review of historical performance related to hook cracks. The second was to develop a bespoke spool piece with various fabricated flaws for performance verification of POD, POI, and sizing accuracy of hook cracks. This spool piece would also serve as an opportunity to get familiar with the data analysis process. This process revealed that the ILI system leveraged both pulse-echo and pitch-catch shear wave UT technology to reliably detect and identify hook cracks.

The ILI system's detection capabilities were plot with the critical flaw sizes for the predominate pipe material. It was concluded that the ILI system's performance would be sufficient to enable fitness for service assessments.

Figure 12 provides illustrations of the critical flaw curve and ILI detection capabilities.

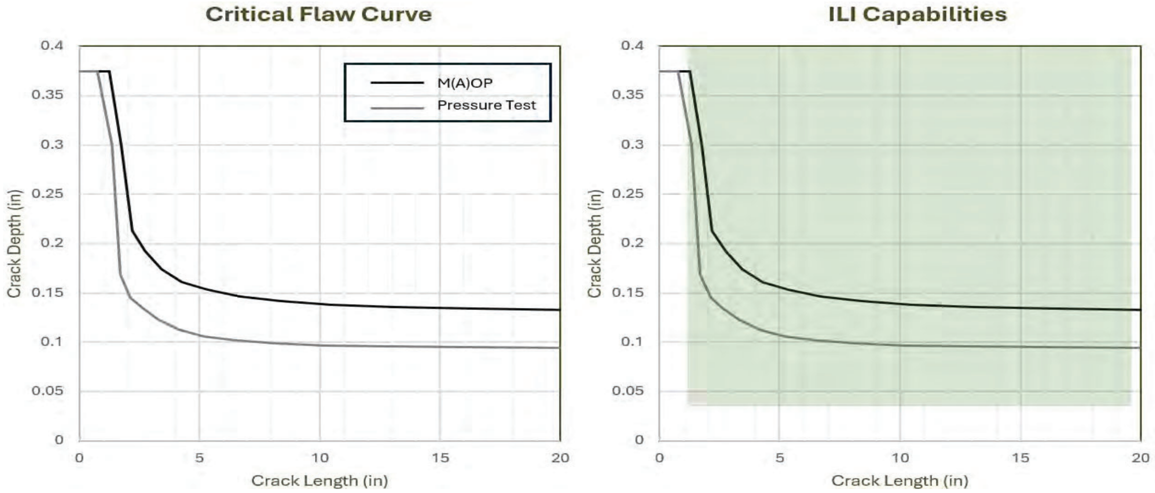

Figure 12: Critical Flaw Curve for Cracking

The flaw spool was designed to have 30 flaws and various flaw types including notches, synthetic cracks (penetrators), and hook cracks. **Figure 13** illustrates three flaw types in the flaw spool to verify the ILI systems ability to discriminate between blunt notches, tight straight cracks (penetrators), and hook cracks with appropriate tilt.

Figure 14 provides a simple overlay of the ILI reported flaws with the fabricated flaws.

Table *6* provides a summary of the ILI performance results. Using guidance in POF 100, the qualification for crack assessment, including hook cracks, was established based on extensive field verification results reviewed on an annual basis. An interview with the ILI service provider reveals numerous industry publications regard performance validation using extensive field validation work. This material was reviewed and accepted as evidence of performance qualification for the capability claims made in the performance specification. In addition, the successful results test results from the flaw spool confirm the ILI system's capabilities to successfully 1) identify the location of crack-like flaws and hook cracks in the pipeline with a POI greater than 90%, and 2) provide detection of critical flaw sized to enable fitness for service assessments. These goals were outlined in the clients ILI Standard and scope of work.

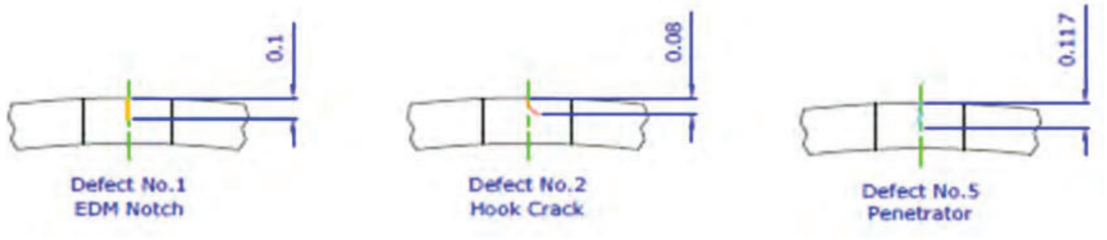

Figure 13: Fabricated flaw types for Crack ILI Test

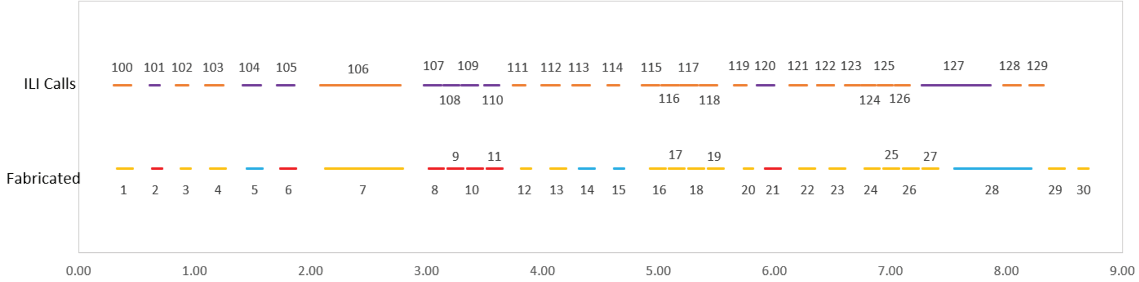

Figure 14: Overlay of ILI results with Flaw Spool

Table 6: Shear wave UT POD and POI verification results

Probability of Detection (POD)	Count	POD	POI
# of Features in Spool	30	100%	
# of Features Reported	30		
Probability of Identification (POI)			
EDM Notch			
# Known	19		100%
# Identified	19		
Penetrator Crack			
# Known	4		100%
# Identified	4		
Hook Crack			
# Known	7		100%
# Identified	7		

Conclusions

The ever-growing demand for ILI technologies to support integrity management plans and provide solutions to address evolving operational, integrity, and risk continue to create an attractive market for technology development. Each ILI technology and its application by ILI service providers must be vetted to ensure it is qualified for the inspection goals and objectives. API 1163 provides requirements for ILI system selection of new and existing technologies. The two case studies reviewed demonstrate how inadequate review of performance specifications can lead to increased risk and integrity costs. Several interpretations were provided to support ILI system selection:

- The ILI service providers documented performance specification qualification process and results should be reviewed prior to the ILI.
- The goals and objectives of an ILI must be documented and consider the target threat, its morphology, and the anomaly assessment method to be used. This document should be reviewed with the ILI service provider to ensure the appropriate use of the ILI system.
- Pipeline operators should implement a documented qualification process for each ILI service provider and ILI technology. This qualification process should consider the target threat, its morphology, anomaly assessment method, and the ILI service provider's performance specification qualification process.
- POF 100 should be used to support the ILI system selection process and establish the goals and objectives for the ILI.
- The ILI system selection process is a collaborative effort between the pipeline operator and ILI service providers.

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