Field verification for in-line inspection

Recommended Practice

POF 310

December 2023

Foreword

This document has been reviewed and approved by the Pipeline Operators Forum (POF) and is based on knowledge and experience available from POF members and others at the date of issue. It is stated however, that neither POF nor its member companies (or their representatives) can be held responsible for the fitness for purpose, completeness, accuracy and/or application of this document.

Comments on this recommended practice and proposals for updates may be submitted to the Administrator at specifications@pipelineoperators.org with the form which is available on the POF website (www.pipelineoperators.org).

The objective of in-line inspection (ILI) is to obtain data on the pipeline condition as part of the pipeline integrity assessment process. A key part of the process is validation of the ILI tool performance and analysis process through field verification.

The quality and consistency of data obtained from the field is important for statistical validation of the performance of the ILI processes. In many cases the operator is only focused on confirmation of a reported anomaly rather than the performance of the overall inspection process.

This recommended practice should be read in conjunction with POF 100 [1] and POF 300 [2]. These documents can be found on the POF website (www.pipelineoperators.org).

Techniques for field inspection have developed over time. As new practices become available it is important that the operators and ILI contractors update their practices and procedures to reflect best practices.

This recommended practice will also be useful when referring to performance specification validation requirements referenced in API 1163 [3].

NOTE: Although this recommended practice is quite extensive, the procedures, information and form included in this document are provided only as guidelines. They are not intended for adoption without review and customizing for all circumstances. Operators or other users choosing to adopt a similar approach should base it on their own organization, structure responsibilities and permitting procedures.

Changes December 2023

The 2023 version of this document supersedes the 2012 version. The main technical changes are:

- The inclusion of additional anomaly types specified in the 2021 version of POF 100 *Specifications and requirements for in-line inspection of pipelines*.
- The inclusion of state-of-the-art NDE techniques.

The document has also been restructured and editorially updated.

Contents

1 Introduction

An ILI project is not complete until the reported inspection results have been validated by the operator. Various validation levels can be used, and more guidance on this is given in API 1163 [3]. Field verification can be an important element in the validation process.

A large number of verified anomalies helps distinguishing systematic issues from statistical outliers. ILI contractors need good data quality field data to help validate the tool performance specifications and drive continuous improvement. A subset of validation results, where the ILI tool has not performed to specification, is insufficient.

To achieve consistency with data collection it is necessary to set standards and protocols to be followed.

This requires trained field personnel to gather the data with the required accuracy and competency so that the results can be relied upon. The techniques and equipment used should be tested and certified in calibration.

Significant problems have occurred where reported anomaly sizes are incorrectly measured in the field. This has an impact not only on the validation of the reported anomalies but also on determining the as-run performance.

Field personnel assigned to dig verification should be certified and have the right level of competency to use the equipment to measure the reported anomalies. The recommended inspection methods for different anomaly types are summarised in Table 1.

Table 1 – Recommended inspection methods

Reported anomaly	Inspection methods
External corrosion	Depth micrometer, laser scanning
Internal corrosion	Manual UT, encoded UT/PAUT/FMC, MFL, radiography
External crack (Isolated)	MPI, Angle beam UT probes, PAUT, FMC, ToFD, ECA, Tangential ECA, ACFM, Stepwise grinding
External crack colony (e.g. SCC)	MPI, Angle beam UT probes, PAUT, FMC, ToFD, ECA, Tangential ECA, Stepwise grinding
Internal crack	Angle beam UT probes, PAUT, ToFD
Dents and/or ovality	Visual and laser scanning, depth micrometer, vernier caliper
Gouge	Visual and laser scanning, MPI, PAUT, ToFD
Buckle, ripple or wrinkle	Laser scanning, depth micrometer
Roof-topping	Laser scanning, profile gauge, depth micrometer
Lamination	Straight beam UT, angle beam UT, PAUT, FMC, MPI
Coating disbondment	Coating adhesion tests, coating removal
Hard spot	ECA, etching, hardness testing

It is important to have a consistent and reliable approach to field verification activities. The anomalies should be accurately measured in length, width and depth. When evaluating anomalies, it is important to understand the extent of the anomaly and how its interaction with adjacent anomalies is accounted for in the report.

This recommended practice provides ILI field data verification and reporting guidance that can be used to support the pipeline integrity management and ILI process.

Most of the recommendations presented in this recommended practice are applicable to buried onshore pipelines. For subsea pipelines, specialist NDE systems are available to perform external inspection and can be used for verification of some anomalies reported by ILI, including internal and external metal loss and cracks, using inspection methods such as ultrasonic testing (UT) and acoustic resonance technology (ART).

2 Definitions and abbreviations

2.1 Definitions

For the purposes of this document, the definitions in POF 100 [1] apply.

2.2 Abbreviations and acronyms

For the purpose of this document, the following abbreviations and acronyms apply:

ACFM	Alternating Current Field Measurement
AGM	Above Ground Marker
CD	Crack Detection
CP	Cathodic Protection
CT	Computed Tomography
DOC	Depth of Cover
ECA	Eddy Current Array
FMC	Full Matrix Capture
GPS	Global Positioning System
ILI	In-line Inspection
MFL	Magnetic Flux Leakage
MPI	Magnetic Particle Inspection
NDE	Non-Destructive Examination
OD	Outer Diameter
PAUT	Phased Array Ultrasonic Testing
RGW	Reference Girth Weld
SCC	Stress Corrosion Cracking
TDC	Top Dead Centre
ToFD	Time of Flight Diffraction
UT	Ultrasonic Testing

3 Overall procedure

Field verification involves the following steps:

1. Gathering of relevant ILI documentation and procedures for field verification.
2. Planning.
3. Location of the required pipe joint in the field and access preparation.
4. Excavation.
5. Coating removal, visual inspection & surface preparation.
6. Layout of ILI anomaly boxes.
7. Detailed NDE & recording of anomaly dimensions.
8. Repair (if applicable).
9. Recoating (if applicable).
10. Reinstatement of the pipeline.
11. Reporting.

The overall procedure is illustrated in Figure 1.

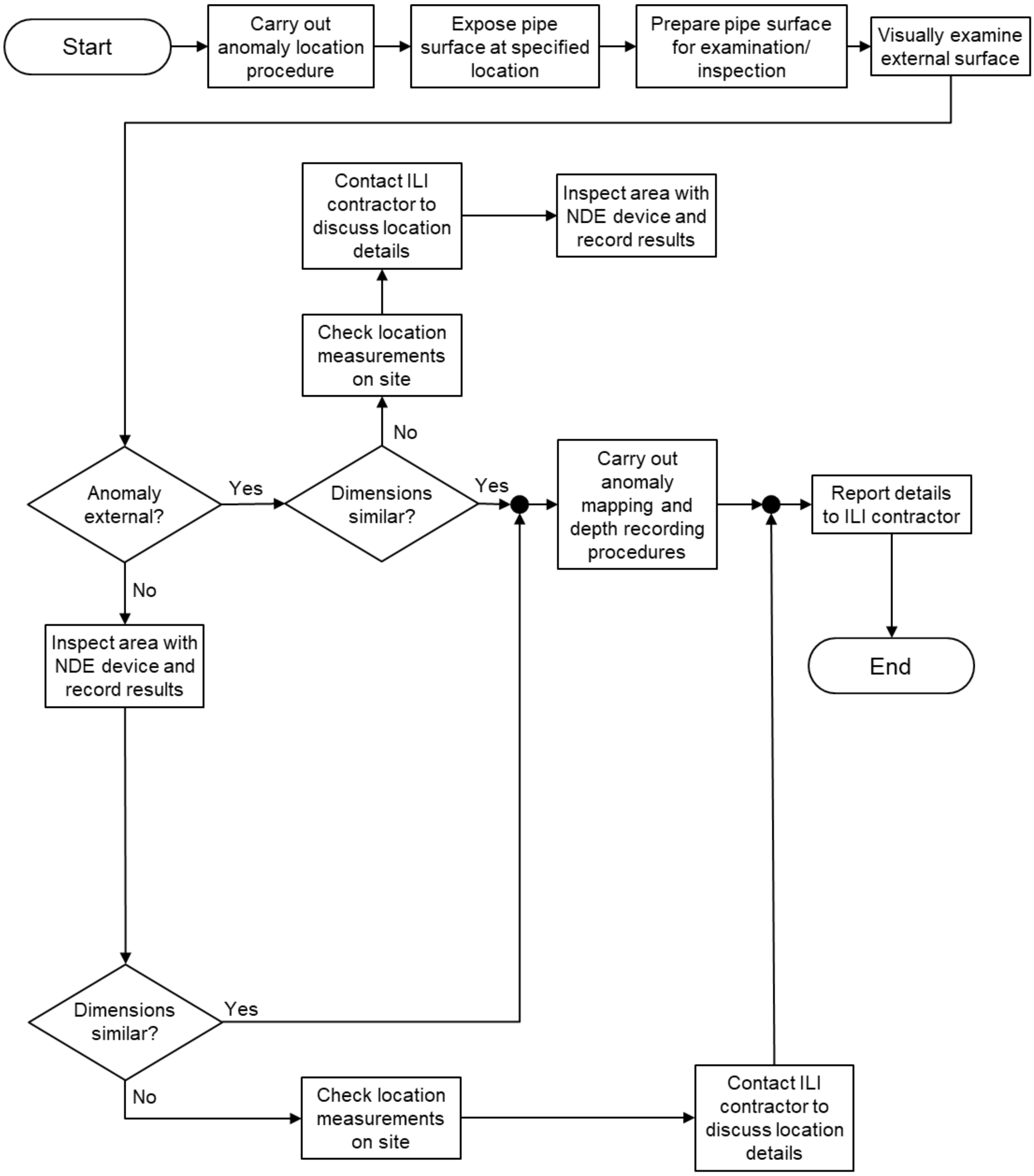

Figure 1 - Field verification process flowchart

4 Planning

4.1 Safe working practices

All work on site should follow appropriate safety procedures and protocols, local regulations and company policies. It is important that each operator and contractor evaluate the risks and take appropriate steps to avoid incidents. Factors to consider include:

- Site access control.
- Right of way preparation.
- Site-specific emergency response and fire safety.
- Contractor safety.
- Site security.
- Securing permits.
- Operating pressure reduction.
- Excavation and shoring.
- Presence of other buried utilities.
- Removal of non-asbestos coatings.
- Removal of coatings that may contain asbestos.
- Grinding and sanding pipeline anomalies.
- Backfilling and reclamation.
- Site assessment questionnaire and safety check list.
- Daily tailgate safety meetings.

The quality of the site preparation can influence the inspection tolerances that can be achieved and therefore emphasis should be on preparing a safe excavation with easy access and sufficient working space for the NDE methods to be employed.

4.2 Personnel

Personnel performing NDE (e.g. ultrasonics) for location and sizing of anomalies should be Level 2 qualified in the relevant technology in accordance with ISO 9712 [4] or equivalent. The NDE procedure should be approved by a person who is Level 3 qualified in the relevant technology.

4.3 ILI documentation

Finding and sizing anomalies in the field requires information gathered during the ILI run. Section 7 of POF 100 describes ILI reporting requirements. A listing of required information for a verification exercise is given below.

- ILI pipeline listing (spool count, joint lengths, feature distances).
- AGM listing (AGM marker locations, and odometer references).
- GPS coordinates (GPS survey reports).
- ILI contractor dig sheet(s).

- Relevant NDE procedures.
- Updated Pipe book which contains details of spools, joint length, previous repairs etc.

If the field verification takes place before the final ILI report has been issued, it is recommended to confirm that the target joint has been fully analysed and that a complete anomaly listing is available. This enables the operator to decide whether to include additional anomalies nearby in the verification. Inspecting such secondary anomalies can often yield results over a wide range of anomaly sizes without adding significant costs. It may be possible to gather a representative set of anomalies to assess the ILI reliability early on in the verification process.

4.4 Equipment

Recommended equipment for finding and sizing anomalies in the field is given below.

4.4.1 GPS receiver

GPS receiver with horizontal location accuracy better than 1 m.

4.4.2 Pipeline locator

A pipeline locator device should be available for detection of the pipeline centreline and capable of pinpointing a pipeline in a multi pipeline corridor.

4.4.3 Measuring devices

- A 30 m (or longer) measuring tape or a 30 m slack chain for measurement of long distances along the pipeline.
- Laser range finder for measuring locations that are not typically accessible. The laser range finder should have an accuracy of +/- 30 cm at 300 m with magnification of 6x.
- A 7.5 m or longer tape or ruler to allow measurements within a pipe joint.
- Flexible (non-metallic) measuring tape to measure circumferential distances.
- 30 cm long magnetic rulers to attach to the pipeline for measurement of anomaly lengths and photography reference.
- Clock tape (pipe wrap) for required pipeline diameter.
- Centering head.
- Stud-finder (magnetic).
- Plumb line.
- Micrometer - adequate to measure external corrosion to a depth 80% of the pipe wall, with a tip diameter of approximately 1 mm.
- Bridging bar with a reach exceeding 60 cm.
- Profile gauge.

4.4.4 NDE equipment

- Laser scanning unit.
- Ultrasonic flaw detector with suitable transducers adequate to define internal wall loss, cracks and stress corrosion cracks.
- Ultrasonic map scan unit with appropriate transducers for mapping and sizing of internal material loss and wall thickness (if applicable).

- Crack measuring equipment:
    - Ultrasonic equipment with shear wave or phased array transducers.
    - ACFM instrument.
    - Eddy current testing equipment with suitable probes and/or arrays.
    - MPI equipment.
    - Dye penetrant testing kit.
- Portable hardness tester.

4.4.5 Marking and other devices

- Grease pencils.
- Black markers.
- Magnet mounted paper to mark indications and measurements for photographs.
- Markal B paint stick(s) (white & / or yellow) / lumber crayons
- Permanent markers (not black – blue or red preferred).
- Carpenters pencil(s).
- Carpenters chalk line for marking long, straight lines.
- 0.9mm mechanical pencil(s) with lead refills (optional blue or red lead).
- Spray paint (orange or red preferably & non-acrylic for light coating).
- Liquid white out (pen style).
- Grid stencils.
- Magnifying glass.
- Plastic bags for sample collection (for soil & salt formation).

4.4.6 Documentation devices

- High resolution digital camera.
- Field data collection system (digital or paper data reporting).

4.4.7 Calibration

All applicable equipment used in the field requires a valid calibration as prescribed by the respective manufacturers.

4.4.8 Availability of the equipment

The selected GPS, ultrasonic equipment, pipe locator equipment and any (portable) other electronic devices should be fully operative and with batteries in full charge. Follow the check up and maintenance procedures as stated in each equipment's manual. A spare set of fully charged batteries or an alternate power source should be available.

5 Locating anomalies in the field

5.1 Overview

Locating ILI anomalies can be a difficult task, which can cost the pipeline operator valuable time and resources. Therefore, it is important that appropriate techniques are used at each stage in locating anomalies.

This chapter gives guidelines for locating pipeline anomalies efficiently and effectively.

The required pipe joint can be located either by distance measurements along the pipeline or by using GPS.

The excavation report should clearly state the location verification procedure that has been utilized for each anomaly dig site location to give the ILI contractor confidence in the position of the anomaly relative to the reported anomaly.

The correct identification of each dig site location is a fundamental requirement of the ILI program. This allows the information collected from the in-ditch examination portion of the program to verify the anomaly size and ensure that the pipeline will be remediated per operator specifications and regulatory requirements.

The importance of performing this procedure effectively can be best illustrated by understanding that when an anomaly cannot be identified on the pipeline there is a 90% probability that the investigation is in the wrong location. The 90% figure is applicable in spite of even the improved technologies and processes that are in use today.

Measuring and recording the actual pipe condition is an essential element of the verification process. The anomaly can only be considered to be remediated if the measured data has been correlated with the data provided by the ILI tool, or if the origin of any discrepancy has been identified.

The additional information to be gathered as per this procedure can be used to determine the root cause of the anomaly and used by the operator to correct the existing conditions to prevent future problems with the pipeline.

If all of the recommendations of this dig verification procedure cannot be met, then the Project Manager or their designee should complete an exception report.

No excavation or dig site investigation should commence until the location is confirmed with the guidance provided by this procedure.

5.2 Preparatory measures

Before starting any field verification activities, it is advisable to check if the distance information in the ILI report matches the operator's documentation.

If an operator’s pipe tally is available, its pipe sequence should be correlated with the sequence provided in the ILI report. The identification of installations can be used as references for the correct numbering of the pipe joint sequences.

Additionally, for proving whether the odometer factor of the ILI tool was appropriately chosen, the pipe lengths of a number of pipe joints within an easily accessible pipeline section (e.g. immediately after the launcher) should be measured and compared with the figures provided in the final report. Thus, the general accuracy of the odometer system can be assessed and, if necessary, corrected at an early stage.

5.3 Location by above-ground measurement

5.3.1 Reference points

Wherever possible, the position of reported anomalies is related to reference points that can be easily identified and located in the field. Reference points are either pipeline fittings, such as mainline valves, offtakes or significant bends, or artificial reference points, such as AGMs; these will have been placed on or near the pipeline at the time of the inspection.

To locate the pipe joint containing the anomaly, the distance from the girth weld at the upstream end of the joint to a number of upstream and downstream reference points is provided in the dig sheet (in accordance with POF 100). This distance refers to the pipeline route measured with the odometer wheels. The horizontal above ground distance measured between two pipeline locations might be different if the pipeline route deviates from the straight connection line between these points.

This procedure can be applied for onshore, buried pipelines, constructed with ferrous materials and also for areas under a certain depth of water, providing that certain precautions are taken in the measurement for depth of cover (DOC). This chapter describes the procedure to identify the spatial location of a pipeline by locating the pipeline centreline and measuring the DOC. Both operations are completed by use of a pipeline locator.

With reference to pipeline construction, the centreline and DOC are measured for reasons associated with preserving the integrity all along the pipeline as work is performed.

Precise determination of the centreline of a pipeline is critical to identify its spatial position. Furthermore, a precisely obtained centreline is the backbone for spatially based alignment of additional data collected on the right of way. Data corresponding to above ground surveys are all aligned through common spatial coordinates.

The location of the pipeline should be accurately identified and clearly marked at sufficient distances to allow stakes showing location of the pipe to be visible from any location along the pipeline.

The inspection report reference point will identify a starting location and specify the length of pipeline to be measured and marked for centreline location and DOC.

Before attempting to locate the centreline of the pipeline, complete a Job Safety Analysis or Risk Assessment of the right of way to determine if any environmental or safety problems may exist (dangerous animals, uneven terrain, hunting season, etc.)

5.3.2 Pipe location and marking

The centreline of the pipeline should be located using a pipe locator.

In areas where direct soil access is available, the located centreline should be marked by stakes at intervals no greater than 60 m. In some cases, such as in hilly areas, near points of inflection (PIs), or near roads or other crossings of the pipeline right-of-way, the centreline should be staked at closer intervals, normally with 30 m between markers.

In areas covered with hard surfaces, spray paint should be used to mark the centreline location.

5.3.3 Measuring depth of cover

The DOC is defined as the distance between grade and the top of the pipeline.

DOC should be measured using a radio-detection pipeline locator at each staked location and the depth written on the stake with a permanent marker. In areas covered with hard surfaces, spray paint should be used to mark the DOC.

If the pipeline locator indicates that the DOC is less than 1.5 m, DOC should be verified by physically probing the pipe. The probe tool should be designed such that neither the pipe coating nor the pipe is damaged during the physical probing operation.

5.3.4 Location of the excavation site

The distances from the upstream & downstream reference points reported in the dig sheet should be measured along the marked centreline to identify the expected location of the reference girth weld. In the (likely) event of a gap or overlap in the two measurements, the interval should be interpolated in proportion to the two measurements. An example is given in API 1163, Annex F.

5.4 Location using GPS

If the ILI data has been aligned to the pipeline GPS coordinates then the excavation site and reference girth weld can be directly identified by visiting the reported location of the anomaly using a GPS receiver.

Several GPS receivers have skyplot and DOP (satellite geometry) forecasting or they can be consulted online. GPS data collection should be planned around the times of the day when the satellite geometry is best to maximize productivity and accuracy.

To ensure that there is no major deviation from the reference points, the measured GPS coordinates should be compared with the reported coordinates of the nearest above ground reference points.

6 Pipeline excavation and pipe inspection

6.1 Before starting

Whenever excavating or conducting a detailed inspection of an operating pipeline it should be recognised that a simple data verification exercise can become a full pipeline emergency if either the excavation process goes wrong or the anomaly is larger than predicted from the inspection.

All parties involved in the excavation and inspection process should review the risk assessments; ensure that permits to work are in place and are understood; communications are working and that emergency response procedures and systems are in place.

Before excavation begins a recognised competent person should develop an excavation plan. The plan should include pipeline pressure reduction, type of soil, depth of excavation, type of shoring or sloping required, proximity to structures, traffic issues and communication with other services and utilities such as the “One Call” system. Notification to other utilities and services should be made at least 72 hours before excavations commence.

Pipeline operating pressure should be reduced by 10 – 20% during the excavation and verification activities to prevent failure of anomalies during verification.

6.2 Identification of dig site reference / origin

Defining the dig site origin, or reference point (usually the upstream girth weld or reference girth weld) is required to ensure that all subsequent measurements used within each dig site accurately reflects the values that were measured by the ILI equipment.

The bulk of this is covered during the location verification process, but the identification of the reference girth weld is a critical step to both validating the tool performance and capturing accurate data for comparison with future ILI run results.

The following steps should be followed:

1) Identify and document the reference girth weld both within the report and with the use of digital photography (see Figure 2).
2) Measure the length of the pipe joint.
3) Identify, measure the position, document the type and location of the seam weld(s) present on the anomaly pipe joint to allow for:
   - Verification of the ILI orientation accuracy (if technology capable).
   - Reference for additional measurements from TDC, see Figure 3.

A magnetic stud finder can be used to confirm weld locations if the coating cannot be disturbed.

The direction of flow during the inspection should be considered when verifying reported clock positions.

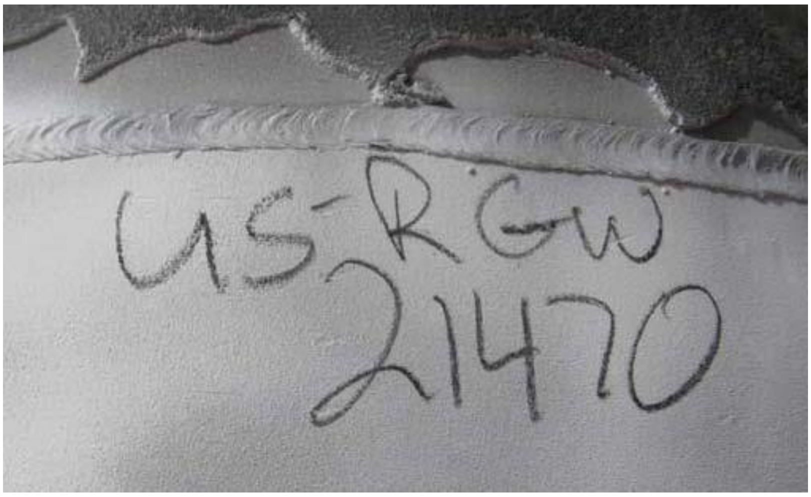

Figure 2 - Digital photograph of reference girth weld with markings

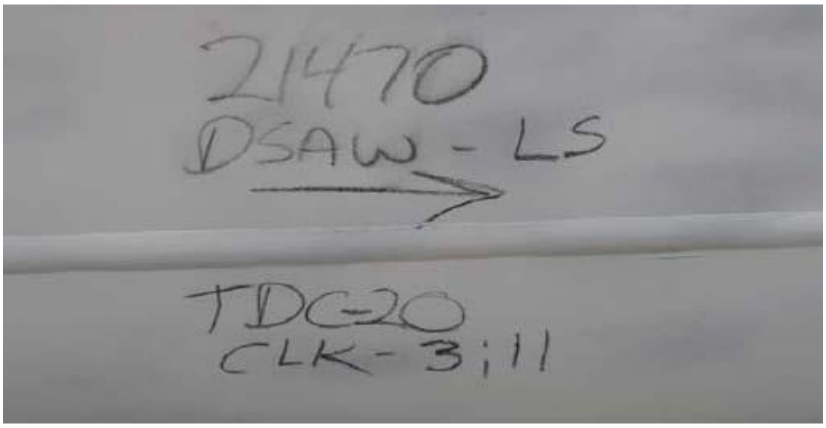

Figure 3 - Digital photograph of longitudinal seam weld with clock position and flow direction.

6.3 Environmental measurements

During the excavation, environmental data such as soil type, should be noted as an input to future assessment of the identified anomalies. Other potentially useful data such as pH, soil resistivity, CP potentials, pipe surface pH, coating condition and depth of cover may also be collected during the excavation process.

6.4 Location of anomalies

To locate the reported anomaly within the pipe joint, the distance from the upstream and downstream girth welds to the anomaly, and the location of the anomaly around the circumference of the pipe (as viewed in the direction of flow), are provided in the dig sheet.

If the pipe joint length does not match the inspection sheet, the position of the anomaly relative to the reference girth weld can differ from the reported position by the difference in reported joint length. The most likely position can be determined by interpolation between the upstream and downstream girth welds.

If the pipe joint contains a bend, the distance from the reference girth weld should be measured along the extrados or TDC of the bend as specified by the ILI contractor. If the bend is close to one end of the pipe joint, distance should be measured along the straight portion of the joint.

If the anomaly to be verified cannot be found in an excavated pipe joint, it should be assumed first, that the located pipe joint might be wrong. For verifying this, proceed as follows:

- Measure length and wall thickness of excavated pipe joint as well as of the two adjacent joints.
- Determine position of longitudinal weld for the pipe joint concerned as well as for the two adjacent joints (o'clock position when looking downstream, considering the flow direction during the inspection tool run). If the pipes are spirally welded, determine the circumferential start and end positions of the spiral welds directly at the girth welds.
- Compare this information with the pipe tally to locate the correct pipe joint relative to the excavated one.

If this does not result in the identification of the correct pipe joint, the information should be provided to the data analysis department of the ILI contractor for further investigation.

6.5 Inspection window

An inspection window should be identified encompassing the anomaly box and allowing for inspection tolerances. The inspection window should extend a minimum of 0.3 m beyond the reported anomaly box in all directions as shown in Figure 4. The required area should be confirmed with the NDE technician.

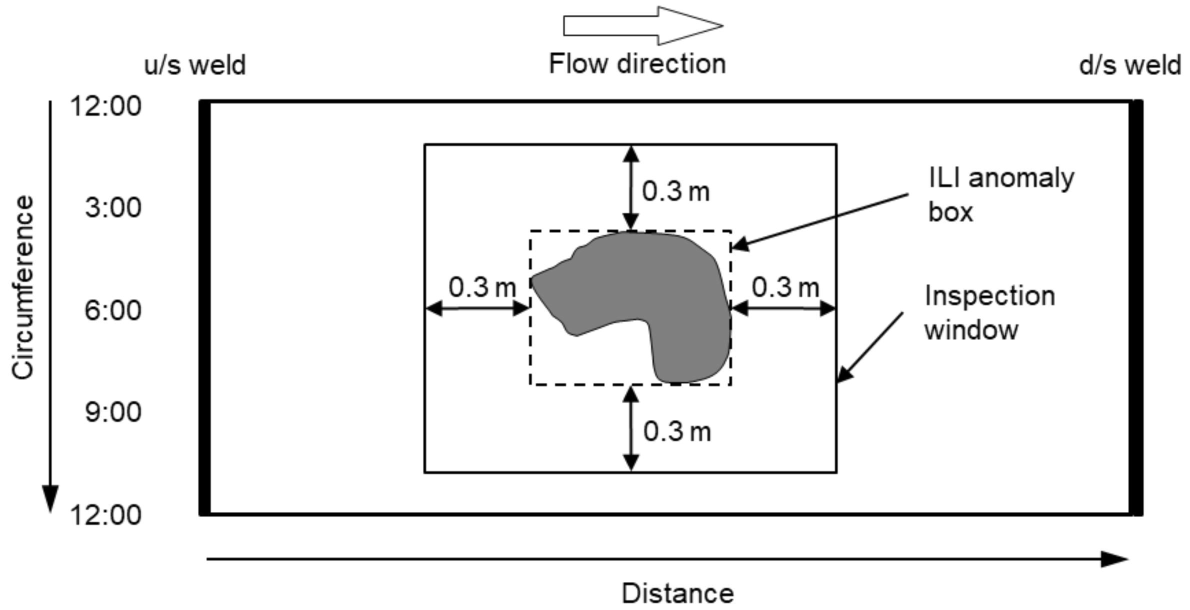

Figure 4 - Inspection window

6.6 Coating removal and surface preparation

Identification of anomalies will require an area of the external coating to be removed. The area of coating removal should include the identified inspection window as a minimum but ideally the full circumference of the pipe.

Any coating damage, imperfection or presence of debris/deposits on or beneath the coating should be documented and photographed.

To achieve satisfactory recording and measurement of the anomaly the specified area of pipe surface should be cleaned back to bare bright metal (ISO 8501 Sa 2.5/St 3 equivalent) [5].

There are a number of methods for removing coating primer and corrosion products including:

- Solvent cleaning.

- Wire brushing.
- Grit blasting.

For certain types of corrosion product it is not possible to produce a finish resembling bright metal when cleaned using a wire brush. In this instance grit blasting is the preferred method to remove the entire corrosion product.

If electromagnetic NDE technologies (ECA, Tangential ECA, ACFM, MPI) are to be used, grit blasting is recommended to remove mill scale and reduce magnetic noise in the inspection.

Surface preparation requirements should be confirmed with the NDE technician.

6.7 Identification of anomalies

Following coating removal, any external metal loss, dents or the girth weld that contains an anomaly should be easily identified. The position of reported cracks, internal metal loss or mid-wall anomalies should be marked on the outside of the pipe in preparation for further examination.

Shallow dents can usually be identified by running one's hand along the pipe surface, or by placing a straight edge along the pipe.

7 Layout of anomalies

7.1 Definition of ILI anomaly dimensions

Understanding the ILI technology employed, and its dimensional formatting of the listed anomalies is a critical part of this process. The anomaly reference point stated in the dig sheet should be provided to the NDE technician.

The following information should be determined prior to any ILI anomaly layout commencing:

- Where is the origin of the ILI anomaly (distance listed from upstream / downstream girth weld)?
- Leading edge (upstream edge) / centre / trailing edge of anomaly "box".
- Where is the listed orientation (clock position or degree position) of the ILI anomaly?

The anomaly orientation should be converted into a circumferential distance from TDC:

- Degree position can be converted to circumferential distance by multiplying by (π x OD/360).
- Appendix 1 provides guidance on conversion of clock position to circumferential distance.

Once these are established the remaining dimensional information from the dig sheet, pipe tally, or ILI spreadsheet can be referenced and accurately transposed onto the pipe surface (see Figures 5 & 6).

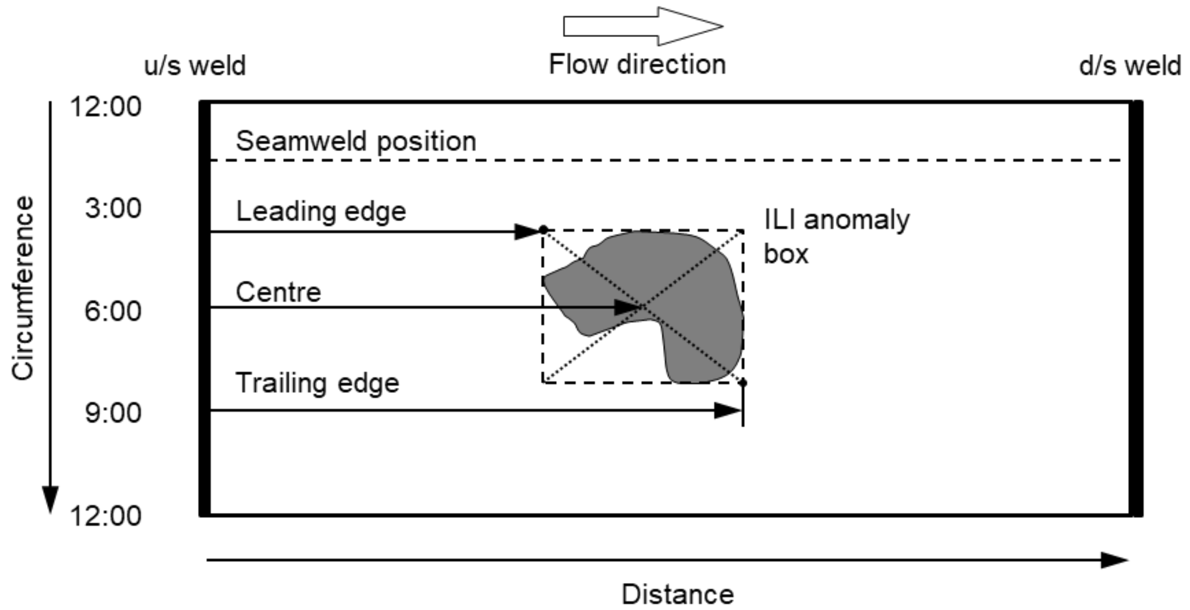

Figure 5 - ILI anomaly axial position (Distance from upstream weld)

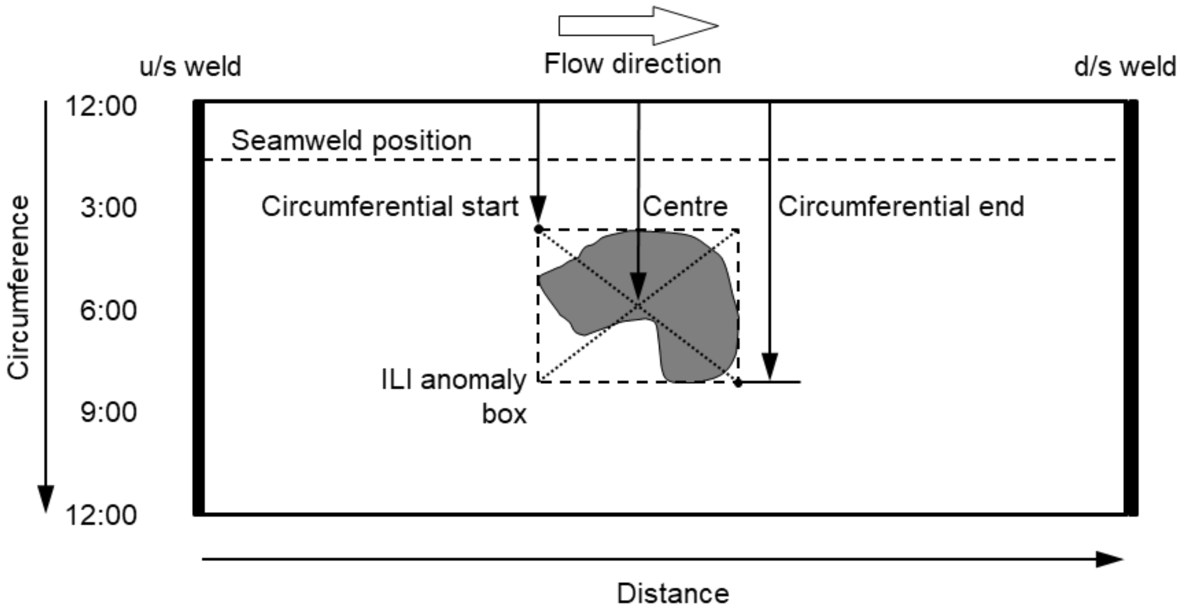

Figure 6 - ILI anomaly circumferential position

7.2 Anomaly layout

The ILI anomalies should be laid out on the bare pipe surface prior to commencing NDE.

Once all the reference information can be identified on the pipe surface the anomalies should be laid out as follows:

- Identify and place a small mark at the "anomaly origin" (e.g. leading edge) location of the listed ILI anomaly based on the dig sheet information.
- Identify and place a small mark at the location of the listed ILI anomaly orientation (measurement from TDC/clock position/degree).
- Mark out the anomaly rectangle (see Figure 7) on the pipe joint as per the listed ILI anomaly dimensions (from the dig sheet or pipeline listing).
    - Black or grey markings should not be used prior to magnetic particle testing.
    - For cracking, only the corners of the anomaly box should be marked to avoid hiding MPI indications.

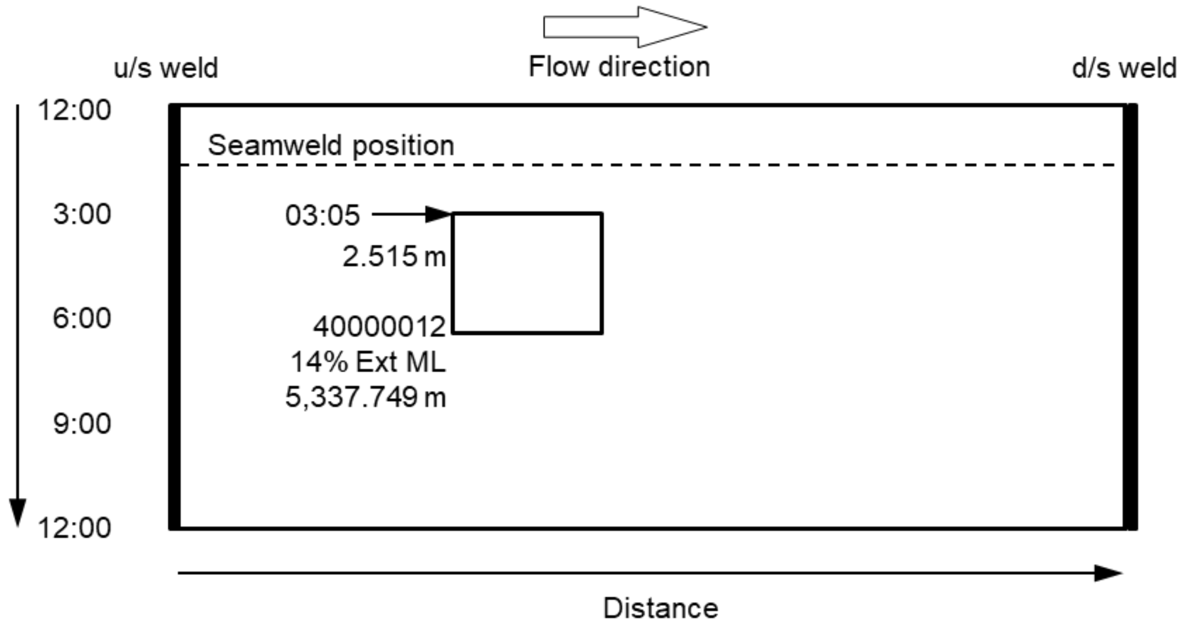

Figure 7 - ILI anomaly dimension layout

If no width is reported for the anomaly then the anomaly start and end should be marked with short vertical lines connected by a horizontal line (see Figure 8).

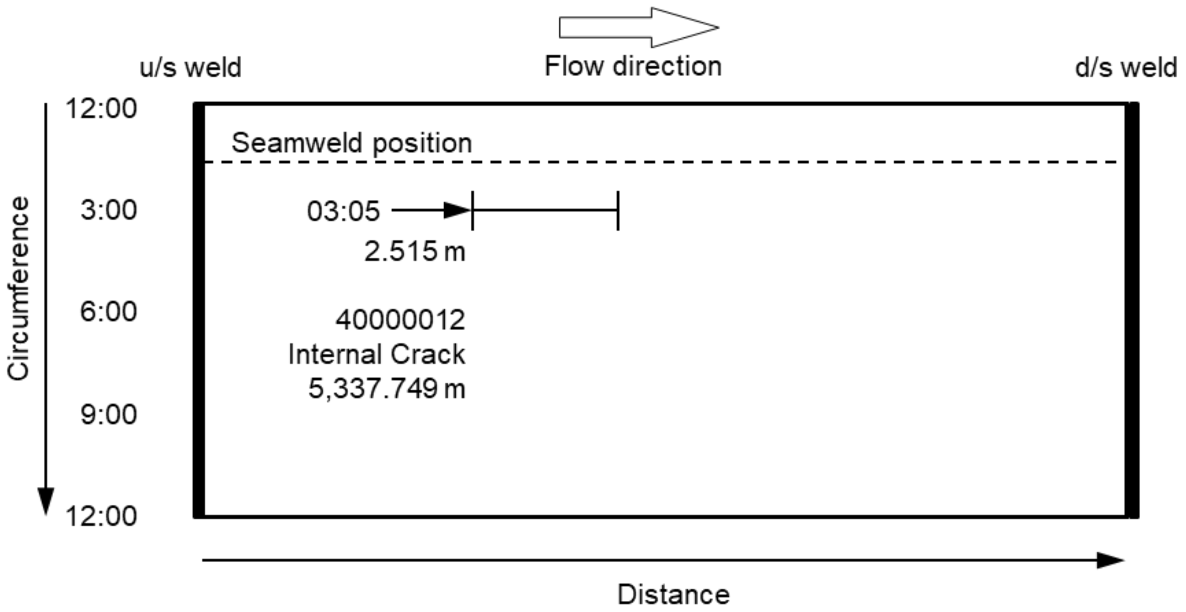

Figure 8 - ILI anomaly dimension layout (zero width anomaly)

The following information should be written on the pipe surface for each ILI anomaly listed with a marker or pencil (unique colour is preferred):

- Anomaly ID & joint ID.
- Anomaly type.
- Max Depth (% / mm).
- Odometer / Absolute distance.
- Orientation (o'clock / degree).

- Relative distance from RGW (axial distance).

This should be repeated for all listed anomalies within the exposed section of pipeline.

7.3 Unidentified/misidentified anomalies

If the reported anomaly cannot be identified, or its location within the pipe joint differs significantly from what is described in the ILI report (and the correct pipe joint has been confirmed in accordance with 6.4):

- The pipe surface should be examined for irregularities or imperfections that may have caused a wrongly reported ILI anomaly (false call).
- These should be documented, and the ILI contractor contacted for support.

If the anomaly type is found to be different to that reported by the ILI, the anomaly and pipe should be examined for characteristics that could explain the misidentification. For example, if a reported crack colony was verified as metal loss, it should be documented whether the metal loss was sharp-edged.

8 Anomaly inspection

8.1 General

Following layout of the anomalies on the prepared pipe surface, anomalies should be inspected using one or more NDE methods.

Field NDE methods are not exact and will have a tolerance level that depends on equipment resolution, working conditions and operator experience. The overall system tolerances should be considered when evaluating the results.

When performing anomaly specific integrity calculations, larger tolerances are conservative as they allow for more uncertainty to be included in the integrity calculation. However, when evaluating ILI sizing performance to API 1163, larger tolerances increase uncertainty in the ILI performance and create an artificial confidence in the data as the anomalies are within the combined tolerance of the measurements meaning they are within specification measurements.

Table 2 presents typical tolerance values for the main NDE methods recommended. The lowest tolerance values are those that are achievable in ideal conditions, while the higher values represent tolerances achieved in blind trials in field conditions [6,7].

Table 2 - Typical NDE tolerances

<table>
<tr><th>NDE Method</th><th colspan="2">Application</th><th>Tolerance
(± mm)</th></tr>
<tr><td>Measuring tape</td><td colspan="2">Anomaly length
Anomaly width</td><td>1 – 2</td></tr>
<tr><td>Depth micrometer</td><td colspan="2">External metal loss depth</td><td>0.05 – 0.15</td></tr>
<tr><td>Laser scan</td><td colspan="2">External metal loss depth</td><td>0.1</td></tr>
<tr><td>UT (0°)</td><td colspan="2">Reference wall thickness
Internal metal loss depth</td><td>0.1 – 0.25</td></tr>
<tr><td rowspan="4">Angle beam UT</td><td rowspan="4">Crack depth</td><td>Manual</td><td>0.5 – 3</td></tr>
<tr><td>PAUT</td><td>0.5 – 1.5</td></tr>
<tr><td>FMC</td><td>0.3 – 1</td></tr>
<tr><td>ToFD</td><td>0.3 – 1</td></tr>
<tr><td>ACFM</td><td colspan="2">Crack depth (isolated cracks)</td><td>+5, -1</td></tr>
<tr><td>Tangential ECA</td><td colspan="2">Crack depth</td><td>0.3 – 0.5</td></tr>
</table>

It can be beneficial to carry out blind trials for specific NDE personnel to determine the tolerances that can be achieved by individual inspectors and support the application of lower end tolerances.

8.2 Wall thickness measurement

The reference wall thickness of the pipe containing the anomaly should be measured in sound pipe adjacent to the anomaly or weld using UT.

UT wall thickness measurement should use dual element transducers with a focus distance effective for the (remaining) wall thickness.

8.3 External metal loss

Length and width of isolated anomalies should be measured using a measuring tape or ruler.

The axial and circumferential extent of larger metal loss areas should be recorded by rubbing and photography, or by laser scanning.

The depth of metal loss should be measured using a depth micrometer and bridging bar or by laser scanning.

The remaining ligament thickness should be measured using UT (see also 8.3.3).

8.3.1 Area mapping by rubbing and photographic methods

An effective and easy method of mapping is by taking a simple rubbing. This is achieved by placing a sheet of paper over the anomaly, holding the paper firmly in place with small magnets and rubbing the long edge of a wax crayon over the surface of the paper. The edges of the anomaly will be delineated and if required, can be highlighted by careful manipulation of the crayon.

The anomaly reference point should be marked with a cross on the paper.

The following parameters should be annotated on the paper:

- Anomaly identity (e.g. ILI report number and anomaly number).
- Direction of flow.
- Orientation of the anomaly.
- Distance of the anomaly from the nearest girth weld.

The rubbing technique has a definite advantage over photographic recording methods in that it is possible to record all subsequent measurements directly on the rubbing in the appropriate location e.g. wall thicknesses or each individual pit depth in multiple pitting.

Photographic recording with digital camera can be used additionally.

8.3.2 Depth measurement

An effective method for recording external metal loss depth is by using a depth micrometer in conjunction with a large bridging bar.

The micrometer anvil should be ground to a taper with a tip diameter of approximately 1.0 mm. This will enable entry into the small diameter pitting and concave surfaces found at the bottom of most metal loss anomalies.

8.3.3 Remaining ligament thickness

Care should be exercised when attempting to measure remaining ligament thicknesses directly within an area of external damage because there is extra couplant under the transducer when mounted on concave surfaces, which results in an overestimated reading.

Decisions on assessing the significance of the damage are primarily based on the remaining ligament thickness. It is therefore important to obtain a reliable reading. This is best accomplished by obtaining the minimum ultrasonic thickness reading immediately surrounding the damage and subtracting the mechanical depth measurement.

Seamless pipe can have significant manufacturing-related thickness variations, even on a small scale. To derive the remaining ligament from external depth measurements, thickness readings should be taken close to the damage at multiple locations around its circumference.

8.3.4 Area mapping and depth measuring by laser scanning

The extent and depth of external corrosion patches can be measured by laser scanning. The resolution of laser measurement is very high but accuracy of depth measurement is determined by the ability of the software to reconstruct the un-corroded surface. Significant measurement artefacts have been observed in case of seamless pipe or pipe shell deformations. In order to maximise accuracy, the laser scan area should extend a minimum of 150 mm beyond the corroded area in all directions.

Laser scanning can offer significantly higher resolution data than can be collected by manual methods and also allows signal to signal comparison of ILI data both for detailed understanding of tool performance and lower conservatism in the integrity assessment of that anomaly. The data can also be revisited for further evaluation after the inspection.

8.4 Internal metal loss

The presence & extent of reported internal metal loss may be confirmed using radiography or a handheld MFL scanner before detailed NDE commences.

The axial and circumferential extent of the metal loss area and the remaining ligament thickness should be measured using UT or, if required due to access limitations, radiography.

For some epoxy coatings, it may be possible to conduct UT without coating removal. The NDE technician should determine whether the coating is smooth and consistent enough for the inspection. The instrument must then be set to an echo-to-echo mode to avoid significant overestimation of the remaining ligament.

8.4.1 Manual UT

Manual ultrasonic equipment is a basic methodology to measure the (remaining) wall thickness. It is advised to use a flaw detector with an A-scan display. Depending on the operator’s requirements, the manual UT method can be used to report the minimum wall thickness or a grid of measured wall thicknesses.

The measurement grid should be marked on the external surface of the pipe within the identified inspection window as shown in Figure 9.

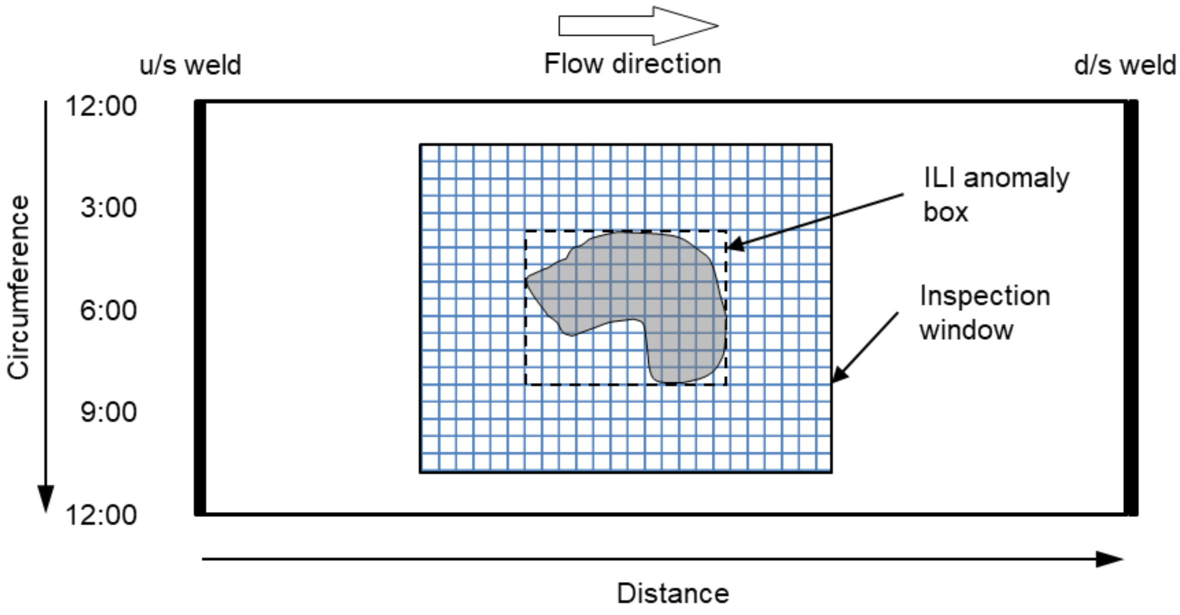

Figure 9 – Measurement grid

Recommended grid sizes are 10 mm x 10 mm or 25 mm x 25 mm and may be marked using a grid stencil and spray paint.

8.4.2 Ultrasonic C-scan mapping equipment

C-scan ultrasonic mapping equipment is the preferred methodology to map and size the remaining wall thickness.

With the C-scan unit, the marked ILI anomaly can be scanned for the actual wall thickness whereby the X and Y coordinates of the transducer are stored.

The distance to the reference girth weld and the orientation should be recorded for the anomaly reference point.

8.4.3 Internal metal loss in welds

It may be impossible to quantify severe internal metal loss in welds without removing the weld cap first. In such cases, a ToFD inspection can be an alternative to measure the remaining ligament down to around 2 – 3 mm.

8.5 Cracks

8.5.1 Identification

External cracks should first be inspected using MPI or ECA to determine their location and length. Mapping with ECA is a fast alternative for 100% inspection of all exposed pipe, so that MPI is only needed where photographs are required, and it can be limited to areas with cracking.

Non-external cracks should be identified using angled beam UT (conventional, PAUT, FMC or ToFD).

Due to the different sensitivity of various set ups and procedures used, the detection capability of inspection systems will vary. These should be proven against a reference block to demonstrate the minimum detectable anomaly size.

8.5.1.1 Identification of sloping and mid-wall cracks

Cracks open to the surface of the pipe wall normally provide a strong corner reflection when measured with UT. This works best with beam angles around 45°.

The detection of an embedded crack, however, is strongly influenced by its form and angular orientation. The echoes from parts of the crack which are located deeper within the pipe wall are only received by an ultrasonic probe if the incidence angle fits to the crack angle.

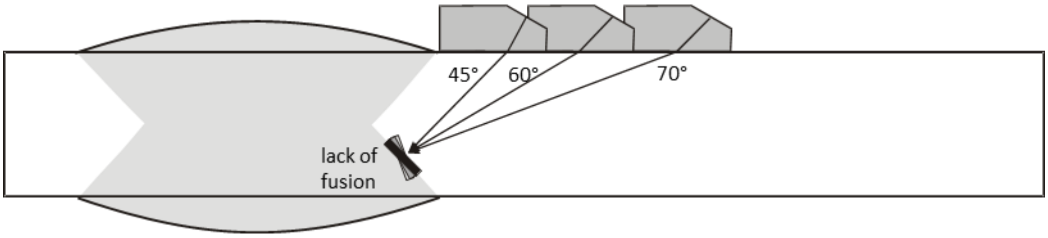

Figure 10 - Lack of fusion hit by ultrasonic beams of different angles

Figure 10 shows a lack of fusion hit by 45°, 60° and 70° beams. Which of these beams has the strongest echo depends on the angular orientation of the lack of fusion. Best practice is a probe with an angle of ± 3° perpendicular to the plane of the crack. The 70° probe, for example, is the best solution for 20° sloping mid-wall cracks.

Best practice for the detection of mid-wall cracks is to use at least three angular probes (e.g. 45°, 60°, 70°) and compare the time-of-flight and signal amplitude values of the different probes with each other.

Side-wall lack of fusion is expected along the bevel from the weld preparation during pipe construction. If available, the weld geometry should be provided to the NDE technician, so that the inspection procedure can be optimized.

Mid-wall anomalies with unknown orientations can be difficult to detect with manual UT or PAUT. This can be improved for wall thicknesses exceeding around 8mm by combination with ToFD.

Both the start and end depth of cracks (distance from OD) should be documented.

A sketch should be provided, illustrating the crack orientation and its position relative to the weld.

8.5.1.2 Identification of cracks in weld areas

Detecting a crack within a weld zone using a manual angled beam UT is sometimes difficult due to the presence of the weld cap preventing placement of the ultrasonic probe at the pipe wall such that the crack is hit with the angular beam axis.

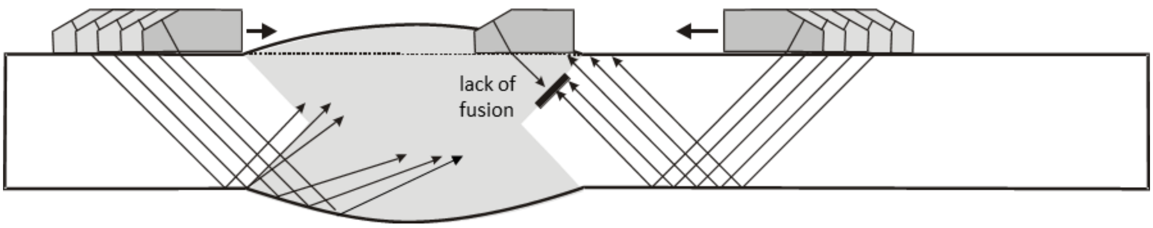

Figure 11 - Manual UT detection of a lack of fusion

Figure 11 shows a lack of fusion which can be detected with an angular probe approaching from the right side via full skip. A detection from the left side via half skip is only possible if the weld cap is ground off. Due to the undefined and curved surface of the weld cap, lack of fusion can only be detected with reasonable confidence if present on the same side of the weld as the transducer. The weld cap can even yield geometric echoes, possibly misinterpreted as cracks.

A sketch should be provided, illustrating the crack orientation and its position relative to the weld.

The echo depends on the angular orientation of the lack of fusion relative to the UT beam angle. Measurements should be repeated with probes with different angles (see also Figure 10) and from both sides of the weld.

Phased array UT (PAUT) allows the generation of multiple incident angles, thus covering a wider volume without probe movement. The requirements regarding the angle relative to the anomaly still apply, so a thorough scan plan is required to ensure a successful inspection. This is particularly important if the probe is mounted in a scanner at a fixed distance from the weld, see Figure 12.

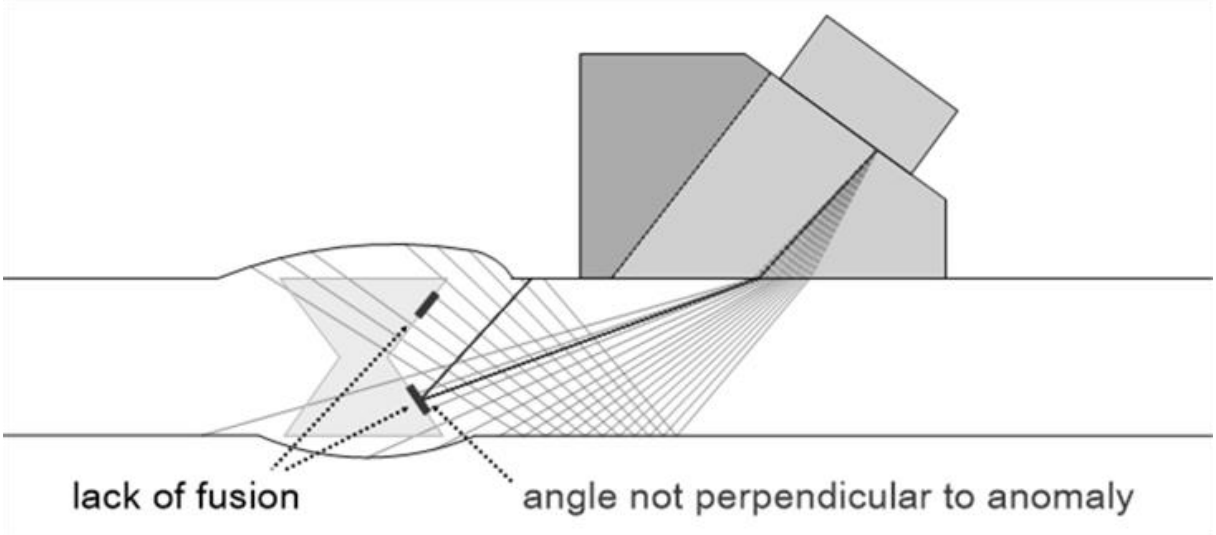

Figure 12 – PAUT setup

Depending on the expected cracks, inspections at different distances from the weld may be required. As for conventional UT, the weld should always be inspected from both sides. For wall thicknesses above around 8 mm, a combination with ToFD can improve the detection of mid-wall anomalies.

PAUT allows a multitude of different scan setups, in terms of angles, number of beams, and focus, so the scan plan and the applied instrument settings should be documented. Full matrix capture (FMC) is an advanced variant of PAUT which may offer sharper images for better identification and easier sizing.

The Time-of-Flight Diffraction technique (ToFD) allows detection and sizing of embedded cracks, inclusions and porosities, especially for wall thicknesses around 8mm or more. ToFD can be the only solution to quantify deep internal metal loss in girth welds (e.g. lack of penetration) which may otherwise be underestimated by conventional angle beam UT or PAUT.

ToFD has limitations for anomalies within 2 - 3mm from the ID and OD, so it is often used to compliment PAUT inspections.

8.5.1.3 Skewed, tilted and hook cracks

The orientation of a crack relative to the pipe axis (skew angle) should be documented.

The approximate tilt angle of a crack relative to the surface normal should be documented, and it should be indicated whether the crack tilt is predominantly tilted upstream, downstream, clockwise or counter-clockwise (see Figure 13).

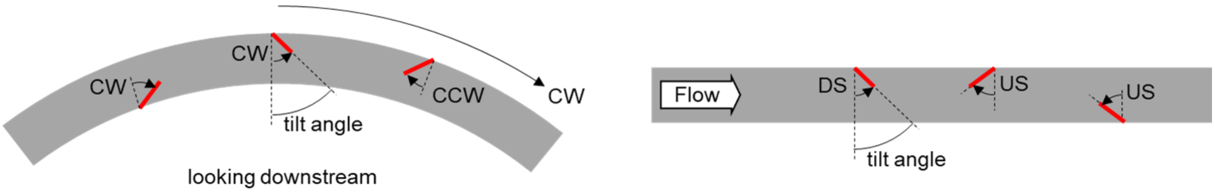

Figure 13 – Crack tilt angle

A sketch should be provided, illustrating the crack orientation and its position relative to the weld.

8.5.2 Length and depth measurement

Length and depth of individual cracks should be determined using one or more of the following methods:

- Angle beam UT (including PAUT, FMC and ToFD)
- ACFM
- Tangential ECA
- Stepwise grinding.

8.5.2.1 Length verification

Crack detection (CD) ILI systems determine the edges at both sides of a crack using a minimum depth detection threshold (typically 1 mm) whereas MPI produces indications on smaller crack depths and therefore using MPI for the verification of surface-breaking external cracks can result in lengths much greater than reported by the ILI tool (see Figure 14).

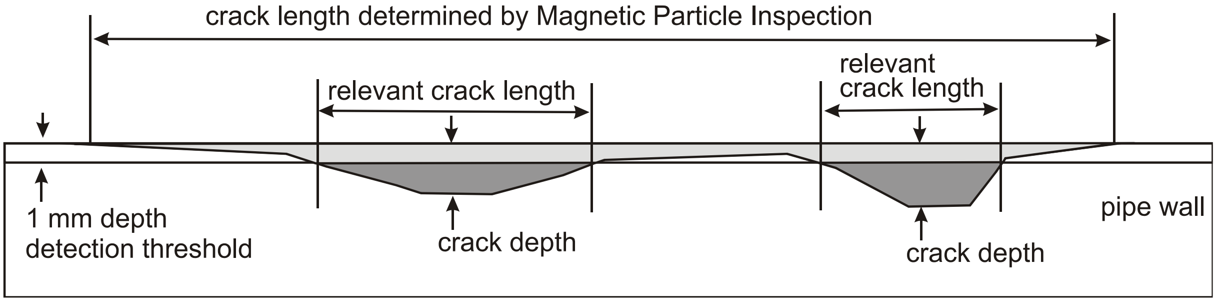

Figure 14 - Nomenclature of crack dimensions

To fully verify an ILI-reported length it is necessary to grind the crack area down by 1 mm and then repeat the MPI so that only the "relevant" crack extent should be indicated.

8.5.2.2 Depth verification

Good quality crack sizing validation data is heavily reliant on the quality of the NDE procedure and the competence of the technician collecting the data. Understanding the expected tolerance of the NDE system (technique and personnel deploying it) is beneficial in understanding the performance of both systems. Using upper bound tolerances in Table 2 is conservative for assessing ILI performance, while improved in-field tolerances can be demonstrated by blind trials, performance on cut outs or step wise grinding.

Some anomaly morphologies can be very challenging for conventional and advanced NDE methods to size. In these cases, it can be beneficial to cut out these anomalies for detailed sizing and classification. Once cut out X-ray computed tomography (CT) can be undertaken to provide sizing with a high confidence. Classification and high accuracy laboratory sizing can also be performed on cut out sections which increases the confidence in the ILI performance and can be used to understand in-field NDE performance.

8.6 Crack colony

In addition to the recommendations in 8.5, the following attributes should be documented for crack colonies (e.g., near-neutral or high-pH SCC):

- Overall length & width of the colony.
- Crack density (dense/sparse).
- Crack orientation (axial/circumferential/diagonal/branched)
- Maximum interlinking crack length
- Location of the deepest point within the crack field.

Further information can be found in the CEPA Recommended Practice for SCC [8].

8.7 Dent

Dents should be measured using laser scan or a depth micrometer with bridging bar. The bridging bar must be longer than the deformed area and its length should be documented.

Apart from dimension measurement, confirmation is required whether a dent is smooth or kinked, plain or complex, and restrained or unrestrained.

For complex dents, anomalies within the dent should be verified using the relevant techniques for the anomaly type (e.g. metal loss, gouge, crack), modified if necessary to accommodate the changed geometry.

Removing the soil loading on the pipeline during excavation may allow the dent to spring back, leading to smaller measured depth than reported by ILI.

8.8 Gouge

Gouges should be measured using the procedures for external metal loss in 8.2. In addition, MPI should be performed at the base of the gouge to determine the presence of cracking.

8.9 Ovality

Ovality should be measured using laser scan or a vernier caliper.

8.10 Buckle/Ripple/Wrinkle

Geometric anomalies including buckles, ripples and wrinkles should be measured using laser scan or a depth micrometer with bridging bar. A profile gauge can be used to document the shape of the anomaly.

8.11 Roof topping/peaking

Roof topping angle and height should be measured using laser scan or a profile gauge.

8.12 Lamination

Laminations should be mapped using straight beam and angled beam UT.

Magnetic particle inspection should be performed to determine the presence of any surface breaking laminations.

8.13 Coating disbondment

The presence of coating disbondment at the ILI-reported location should be confirmed through a knife test, whereby x-shaped cuts are made through the coating and the knife blade used to peel back disbonded coating.

Following confirmation of coating disbondment, the disbonded area of coating should be removed to confirm the axial and circumferential extent.

8.14 Hard spot

Hard spots should be mapped using eddy current techniques such as ECA.

Once the axial and circumferential extent of the hardness anomaly has been confirmed, the pipe surface should be polished to at least 320 grit and etched with a Nital solution to make the material change visible.

A 10 mm x 10 mm dot grid should be drawn encompassing the anomaly and multiple hardness measurements taken in each grid square using a portable hardness tester. The maximum and average hardness in each grid square should be reported.

9 Pipeline recoating and reinstatement

Following the completion of NDE, and any required remediation, the area of removed coating should be repaired using a compatible repair coating and holiday tested before the excavation is reinstated.

10 Reporting

The NDE technician should provide a full inspection report for all inspected areas.

The pipeline operator should complete the field verification feedback form (POF 311) [9] as a simple comparison of the ILI-reported and field measured anomalies. This includes anomaly dimensions and location information.

11 References

1. Pipeline Operators Forum, *Specifications and requirements for in-line inspection of pipelines*, POF 100, 2021
2. Pipeline Operators Forum, *Achieving successful in-line inspection*, POF 300, 2021
3. American Petroleum Institute, *In-line Inspection Systems Qualification*, API 1163, Third Edition, 2021
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6. F. Caleyo et al, *Method proposed for calibrating MFL, UT ILI tools*, Oil & Gas Journal, Sept 13, 2004.
7. British Standards Institute, *Guide to methods for assessing the acceptability of flaws in metallic structures,* BS 7910, 2019
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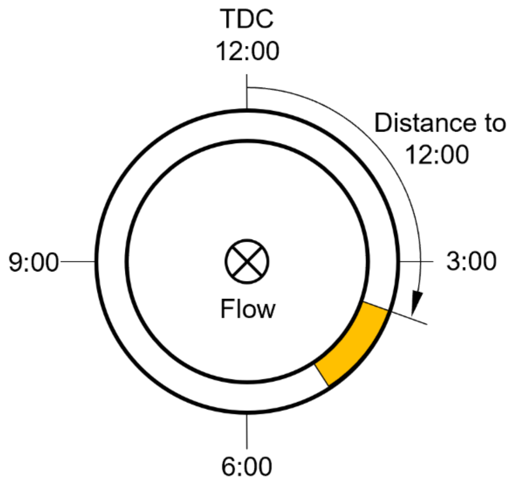
9. Pipeline Operators Forum, *ILI field verification feedback form*, POF 311, 2021

Appendix 1: Conversion of clock position



Circumferential distance corresponding to 1 hour = $\frac{\pi \times OD}{12}$

Circumferential distance corresponding to 1 minute = $\frac{\pi \times OD}{720}$

Some sample calculations:

NPS (INCH)	DN (MM)	OD (MM)	CIRCUMFERENCE (MM)	1 HOUR (MM)	1 MINUTE (MM)
16	400	406,4	1276,7	106,4	1,8
20	500	508,0	1595,9	133,0	2,2
24	600	609,6	1915,1	159,6	2,7
26	650	660,4	2074,7	172,9	2,9
28	700	711,2	2234,3	186,2	3,1
30	750	762,0	2393,9	199,5	3,3
32	800	812,8	2553,5	212,8	3,5
36	900	914,4	2872,7	239,4	4,0
40	1000	1016,0	3191,9	266,0	4,4
48	1200	1219,2	3830,2	319,2	5,3
56	1400	1422,4	4468,6	372,4	6,2