THE CHALLENGE OF AN ALL-IN-ONE INSPECTION - FIRST RESULTS AND BENEFITS

Authors : S. Benichou, C. Senah, TRAPIL, FR

Co-Authors : B. Marquis, D. Le Friant, H.Ez Zaki TRAPIL, FR

ABSTRACT

For more than 5 years, TRAPIL has been researching, as a pipeline operator, an inspection tool that would allow, in a single run, the detection, location, identification and sizing of dents, metal losses and crack anomalies (axials and circumferentials) affecting liquid product pipelines.

The search for an “all-in-one” tool would indeed allow significant gains in terms of pipeline operation. The runs are indeed done at reduced speeds, an “all in one” tool would therefore make it possible to limit the runs number, and thus the flow reductions, and thus the operating losses.

Phased Array UT technology is a disruptive technology that allows for a wide range of adjustments. TRAPIL therefore turned to this technology to try to achieve this all-in-one run.

TRAPIL relied on its existing tool XTRASONIC NEO, its test bench based in Poissy, regulatory obligations, its experience, and its buried pipes in order to establish its specifications.

The objective of this presentation is to present how TRAPIL managed to develop this tool, the successes and points for improvement generated during this process, as well as the first encouraging results obtained.

INTRODUCTION

As discussed in the 2023 Concawe Report N°6/23 [1], pipeline operators are confronted with multiple sources of risk to pipeline integrity, including spillage incidents caused, for example, by mechanical failure, operational activities, corrosion, natural causes, third party activities or other factors.

Over the years, technically advanced devices and non-destructive testing methodologies have been developed in order to reduce these risks. However, until recently, operators have been using individual inspection tools or very large size combined tools to detect and measure specific defects, such as lamination, corrosion, dent with or without metal loss or cracks. This means that operators around the world have to manage multiple inspection runs or alter facilities, requiring subsequent correlation of separate sets of inspection data.

In order to avoid these unnecessary processes, to minimise costs, sources of error, operational conflicts and to improve safety, Trapil has designed and produced a new in-line inspection tool, XTRASONIC-NEO.

In order to monitor and maintain the integrity of pipeline networks using the very high measurement resolution of this new ILI tool (in longitudinal, circumferential and radial directions), a high POD (probability of detection) and sizing accuracy are required. These capabilities are crucial for any long-term pipeline assessment activities, e.g. corrosion, lamination and crack growth analysis, maintenance planning, repair work and inspection intervals.

This publication presents:

- XTRASONIC NEO technology and advantages

- Introduction to the principle of SCC and fatigue crack

- How to adapt the ILI analysis process in order to verify and improve detection, identification and sizing of cracks?

- Conclusion

1. XTRASONIC NEO technology and advantages

Since 1978, Trapil has built and operated several ILI tools and technologies, including like MFL, UT, Calliper, and the latest XTRASONIC-NEO, with Phased Array Technology UT probes. Trapil's pipeline network is 65 years old and exhibits several of the types of defects referred to in the May 2023 Concawe (Report 6/23), and shown in the figure below.

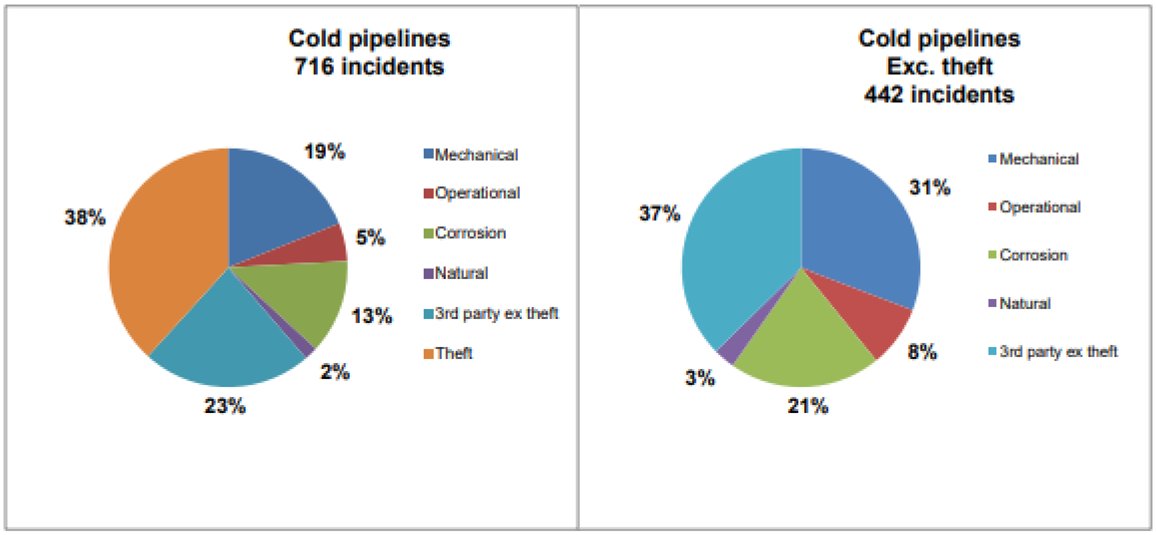


Figure 1 : 2023 Concawe Report [1]

In recent years, Trapil has focused on UT technology, which allows for:

- Detection/discrimination of inner/external/mid wall thickness
- Good reproducibility and accuracy
- High speed inspection
- Sizing accuracy
- Inspection of large range of wall thicknesses or diameters (WT 2,5-25mm; Ø 8-32'')

Trapil has identified all of the advantages of Phased Array Technology over conventional UT, and has launched a new development schedule.

Why Phased Array technology is better than conventional transducer?

- Improvement of worksite safety and limitation of operating costs through use of very small and compact tools with detection of dent, metal loss, axial and circumferential cracks in a single run,
- The cost of phased array tool's construction is lower than a conventional transducer tool for an equivalent resolution, inspection's speed in a single run,
- Parameter flexibility by setting delay laws (search for specific defects, incidence angle deviation, focusing, welded areas, degraded surface condition),
- Configurable circumferential resolution with the switching step (finding of small area defects)

With this kind of UT probe multiple features can be used to steer, focus and scan beams with a single transducer assembly. Beam steering can be used for mapping components at appropriate angles (Figure 2). This can greatly simplify the inspection of components and defects with complex geometry. Electronic focusing enables optimisation of the beam shape and size at the expected defect location, as well as further optimisation of probability of detection. The capability of focusing at multiple depths also improves sizing of critical defects for volumetric inspections (Figure 3).

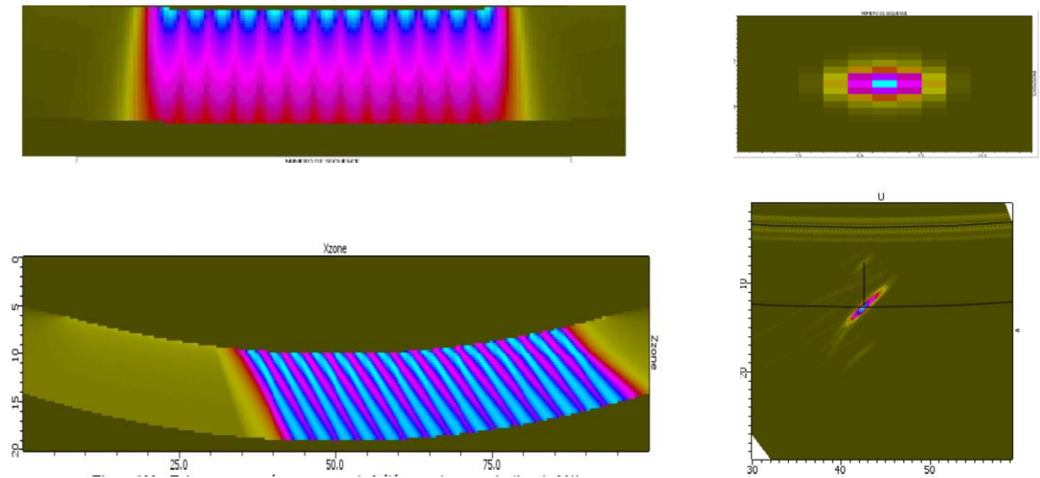


Figure 2 : Beam steering (longitudinal wave 0° and shear wave 45° on left hand side) and defect mapping (corrosion and crack on right hand side)

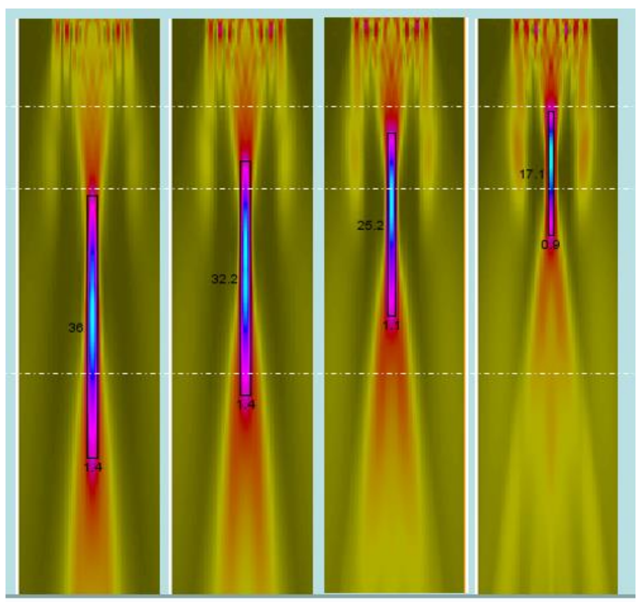


Figure 3 : Electronic focusing

Focusing can significantly improve signal-to-noise ratio in challenging applications, and electronic scanning across many groups of elements means that C-Scan images can be produced very rapidly.

This technology combines a certain number of sensors and non-destructive ultrasonic control techniques which aim to detect, identify and size as many types of defects as possible. To control the thickness and geometry, the use of multi-element probes produces a longitudinal line which will travel through the liquid medium and the steel wall thickness. The analog signals corresponding to the different echoes are digitized and stored in the device's memories.

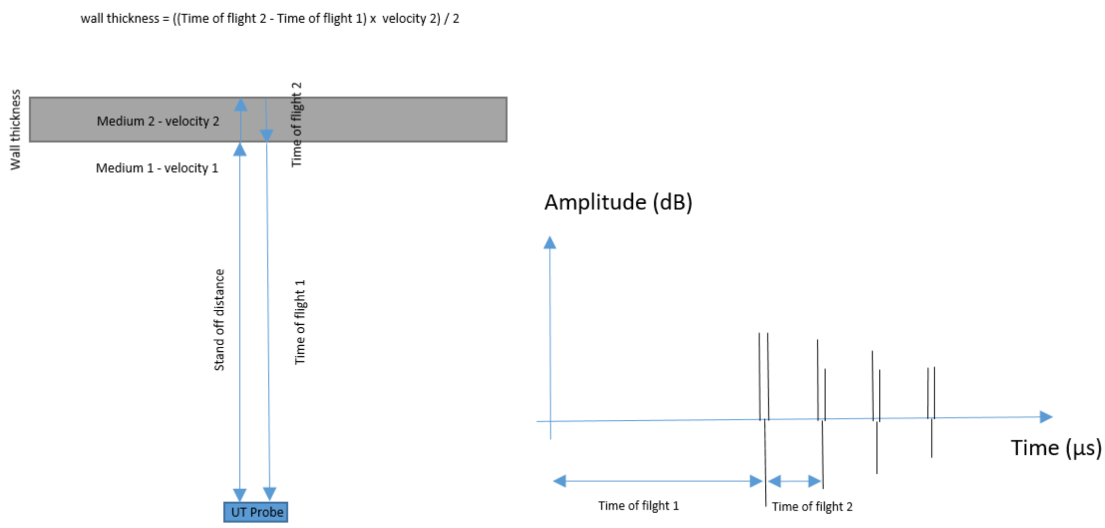


Figure 4 : wall thickness measurement principle

To detect the axial and circumferential cracks, phased array probes are also used to produce shear waves. The analog signals corresponding to the different echoes (inner surface echo, external or internal crack echo) are digitized and stored in the inline inspection tool's memories. The depth of crack is depending on the echo's amplitude, higher the amplitude is, deeper the crack is.

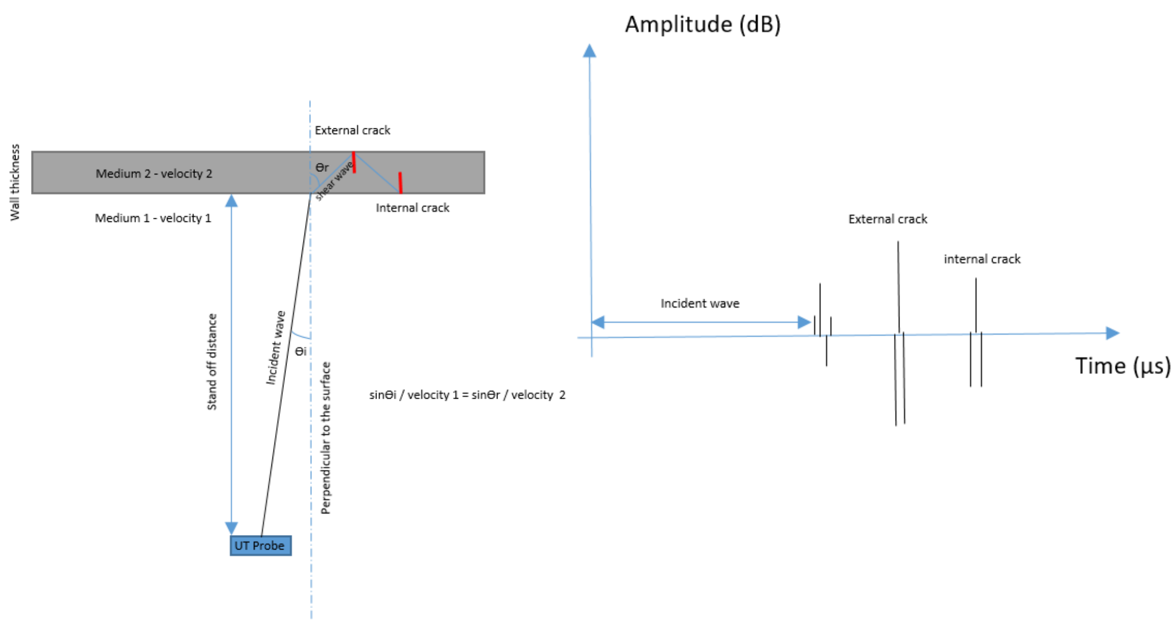


Figure 5 : Crack detection principle

2. Introduction to the principle of SCC and fatigue crack in pipelines

In a pipeline, constraints are exerted in all directions. Besides that, main constraints (Figure 6) are circumferential (referred to circumferential stress) and longitudinal (referred to longitudinal or axial stress)

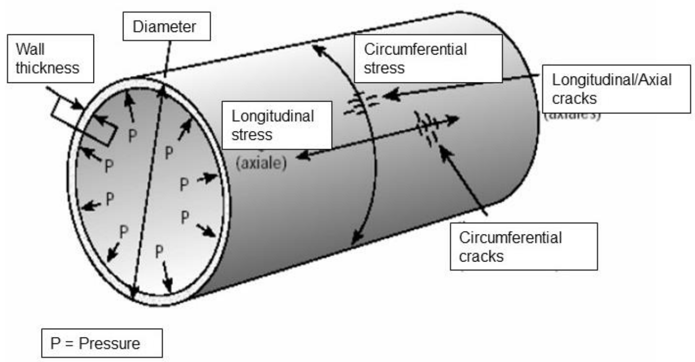


Figure 6 : Different constraints on a pipeline [2]

Fatigue cracks appears perpendicular to the direction of the principal tensile stress. Most often, we find longitudinal cracks because the hoop stress is the highest;

It is important to differentiate fatigue cracks from stress corrosion cracking (SCC). These two types of defects do not occur under the exact same conditions.

2.1. Fatigue Axial cracks

The occurrence of axial cracks in pipelines is primarily explained by the fatigue. Fatigue is a phenomenon in which materials or structures undergo damage and deterioration over time due to the repeated application of cyclic or fluctuating loads. The different sources of circumferential stresses (induced by loads) are as follows:

- The internal operating pressure is the most significant stress component and at the origin of fatigue phenomenon.
- The manufacturing of the pipeline induces residual stresses.
- Internal pressure acting on a geometric deformation (ovalization, dents…) on pipe generates bending stress. This configuration can accelerate the fatigue failure phenomenon.
- At welds or in conjunction with grooves, corrosion pitting, scratches, stress concentrations may develop.
- Settling and ground movements induce secondary stresses.
- Temperature changes along the pipeline axis.

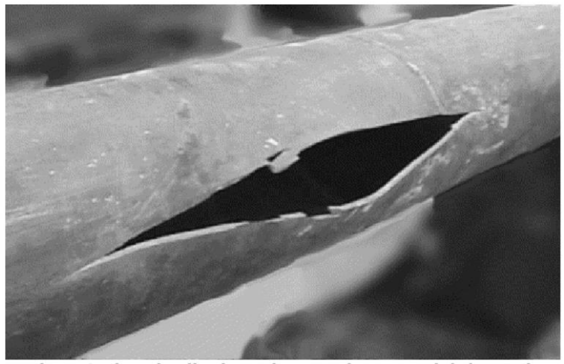


Figure 7 : Fatigue longitudinal crack [7]

2.2. Circumferential cracks

Circumferential cracks are the result of longitudinal stresses induced by:

- Internal operating pressure results.
- Landslides and soil settlements.
- Temperature variation along the pipeline axis.
- Near girth weld with pipeline misalignment.

Figure 8 : circumferential fatigue crack in a CO_2 transport pipeline due to ground movements [6]

2.3. Stress corrosion cracking

Stress Corrosion Cracking is a type of corrosion-related damage that can occur in pipelines and other materials. SCC typically appears in crack field form when three main factors are present:

- Corrosive Environment: SCC occurs when a material is exposed to a corrosive environment, such as high chloride levels, sulfide compounds, other aggressive chemicals, near neutral PH (Exposure to water can occur when the pipeline's coating is damaged).
- Tensile Stress: SCC is often associated with the presence of tensile stress on the material. This stress is mostly due to internal pressure generated by the fluid. It also can be from external factors, such as mechanical loads, or internal factors, such as residual stresses from welding or manufacturing processes. This condition is explained with details in 1.1 and 1.2.

- Material Susceptibility: Some materials are more susceptible to SCC than others. Certain alloys and materials are more resistant to stress corrosion cracking, while others are more prone to it.

When these three factors combine, stress corrosion cracking can occur in pipelines, leading to the formation of cracks and potential structural integrity issues.

SCC can be axial or circumferential, taking into account stresses described earlier.

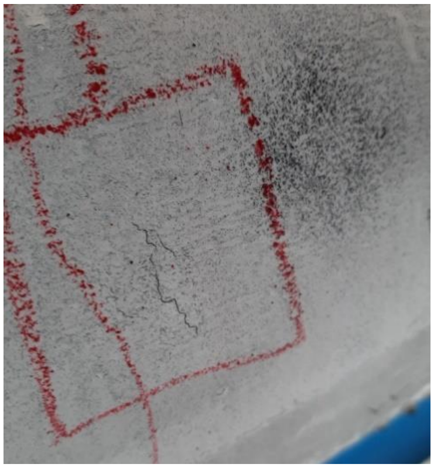


Figure 9 : Circumferential crack field SCC from TRAPIL field investigation

Figure 10 : Axial crack field SCC from TRAPIL field investigation

2.4. « Spider cracks »

“Spider cracks” are SCC crack fields with both longitudinal and transverse components. Their formation is characterized by a high local longitudinal stress and conditions.

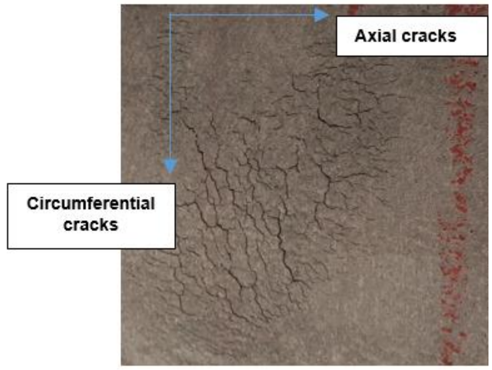


Figure 11 : "Spider cracks" from TRAPIL field investigation

Detecting and identifying such defects on a pipeline would allow the implementation of an appropriate integrity management policy.

3. How to adapt the ILI analysis process in order to verify and improve detection, identification and sizing of cracks?

Assessing the success of an ILI process involves evaluating accuracy. Non-destructive inspection accuracy is typically stated in terms of detection, identification and sizing:

- Detection is evaluated with the POD (Probability Of Detection): the probability of a feature being detected by an ILI tool [3]**.**
- Identification is evaluated with the POI (Probability Of Identification): The probability that the type of anomaly or another feature, once detected, will be correctly classified (e.g. as metal loss, dent, etc.) [3]
- Sizing is evaluated with POs (Probability Of Sizing): The accuracy with which an anomaly dimension or characteristic is reported. [3]

Those probabilities are defined by API-1163 [3] and POF [4].
Additionally, there are different levels of verification processes (Figure 12) that allow for calculating POD (Probability of Detection) and POI (Probability of Identification) and POs (Probability Of Sizing).

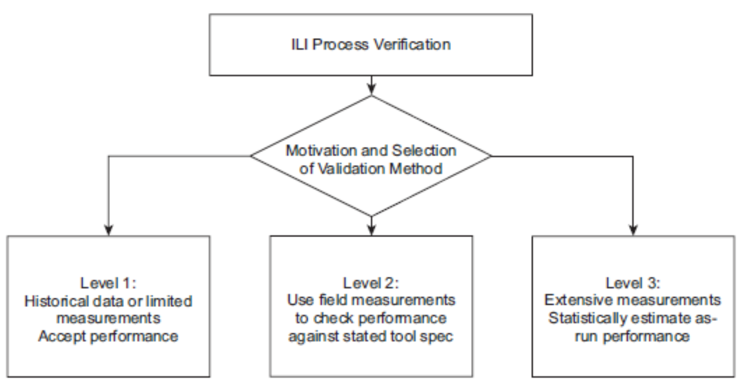


Figure 12 : Overview of Three Levels of ILI Validation from API-1163 [3]

3.1. Having access to known field datas

The ILI tool analysis process verification and improvement starts with a carefully chosen population of defects, which include :

- Real defects in order to evaluate Probability of Detection (POD) and identification (POI). The use of these defects for sizing evaluation can distort the results as they are evolving.
- Artificial defects to replicate real cracks or metal loss. These defects are useful for assessing the Probability of Detection (POD) as well as Probability of Sizing (POs). Evaluating the Probability of Identification (POI) on these anomalies is less relevant due to their differences (especially profiles and morphology) from real defects.

'Pull Through' tests are carried out with the ILI XTRASONIC-NEO tool on defects listed in Table 1 to give comprehensive coverage of all defect shapes.

Defect Identity	Axial/Circumferential/Both	Artificial/Real	Number
Metal loss	-	Artificial	4
Crack field	Axial	Real	101
Crack field	Circumferential	Real	22
Crack field	Both ("Spider cracks")	Real	14
Notch like	Axial	Artificial	4
Notch like	Circumferential	Artificial	4

Table 1 : Types and number of defects on Trapil's spool

In order to establish POD and POs, experimental tests were conducted throughout TRAPIL's hydraulic test spool located at its Paris region site (12"-14''x70m).

Figure 13 : Trapil's 12 and 20" test spool in Poissy

3.2. Evaluating and improve sizing of artificial defects

During the data analysis, all artificial defects listed in Table 1 had been detected. However, as explained earlier, the most interesting aspect of those defects is to compare the sizing ILI tool process and the sizing field data. This is done in order to evaluate ILI tool POs. This also allows for adjusting the tool calibration or process by modifying parameters such as:

- Depth sizing chart
- Algorithmic tools for sizing models
- Data analysts training

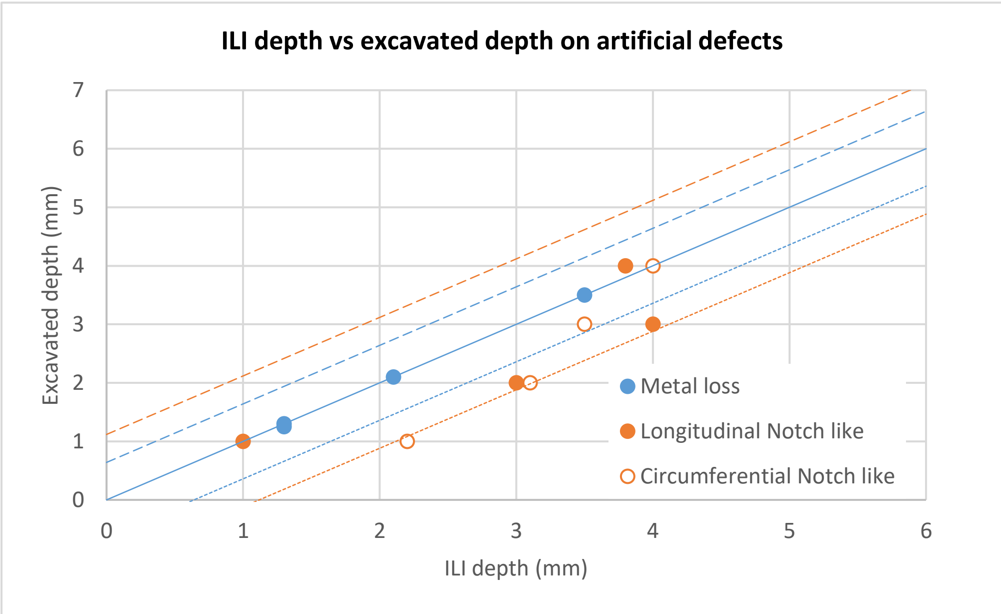


Figure 14 : Sizing depth comparison between ILI tool process and excavated datas on artificial defects

In this case the target was +/-0.4mm for metal loss and +/-1 mm for notch like/cracks with 90% certainty. Results Figure 14 proved that the ILI tool analysis process reached this target.

Artificial defects will serve as reference points. It would be interesting to have more of these calibration reference points in order to improve our depth sizing chart.

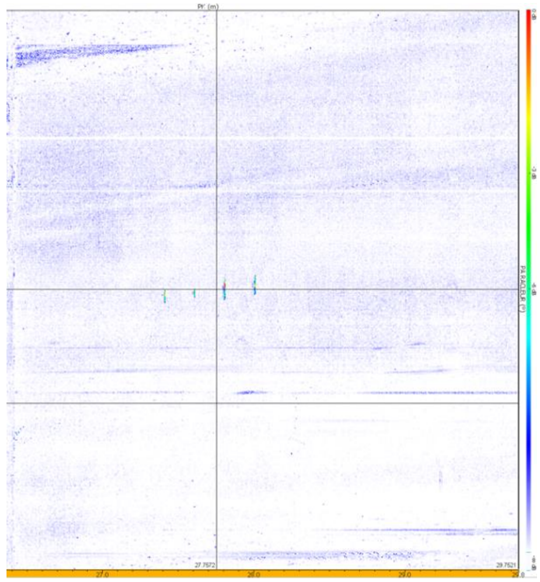


Figure 15 : Circumferential articifical notch-like on data analysis software

3.3. Evaluating and improve POD of real defects

3.3.1. Evaluating POD

As explained earlier, the pipeline sections containing defects are collected from the field. The aim is to assess the ILI (In-Line Inspection) process's ability to detect actual longitudinal and circumferential crack fields.

- Initially, the defects were detected, identified, and sized in the field by a non-destructive testing company. The detection was performed by magnetic testing, on the other hand crack fields were sized using TOFD (Time-of-Flight Diffraction) technique.

Figure 16 : Crack field pipeline section on Trapil's spool test during the field investigation

- Then, we performed a run with the XTRASONIC-NEO ILI tool on the bench.
- The analysis of defects was conducted by a Level 3 data analyst [4] :
    - One the one hand, longitudinal crack view was analyzed and compared to field datas
    - On the second hand, circumferential crack view was analyzed and compared to field datas

The amount of defect detected by the non-destructive testing company are shown on Figure 17 whereas those detected by the ILI tool process are exposed on Figure 18.

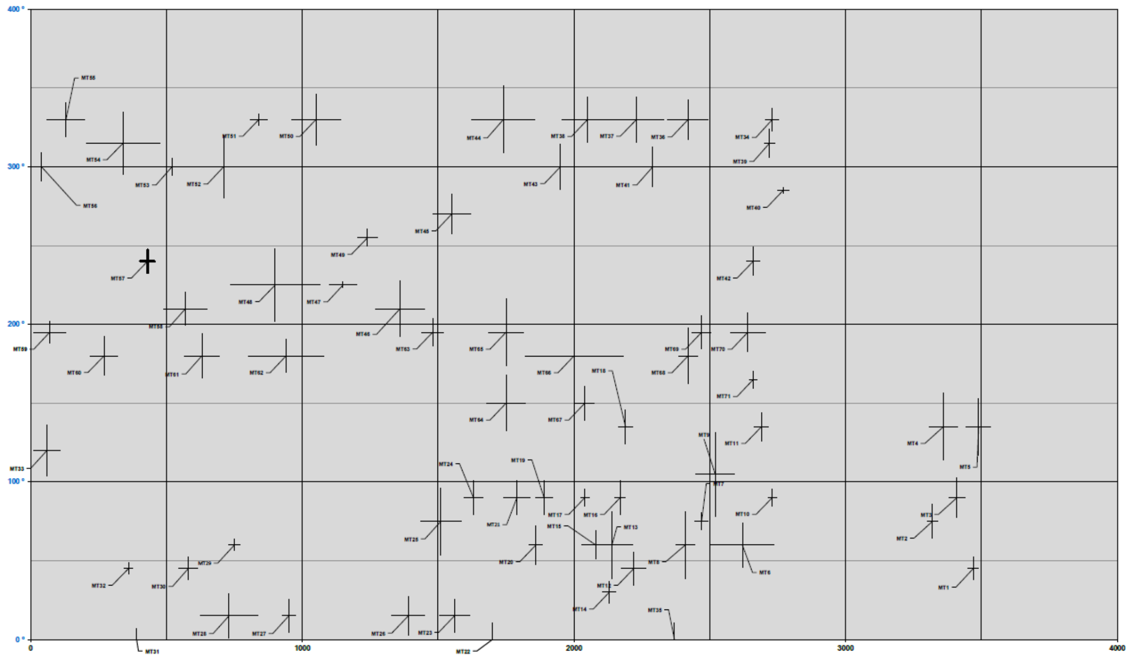


Figure 17 : Crack field detected in field by the non-destructive testing company

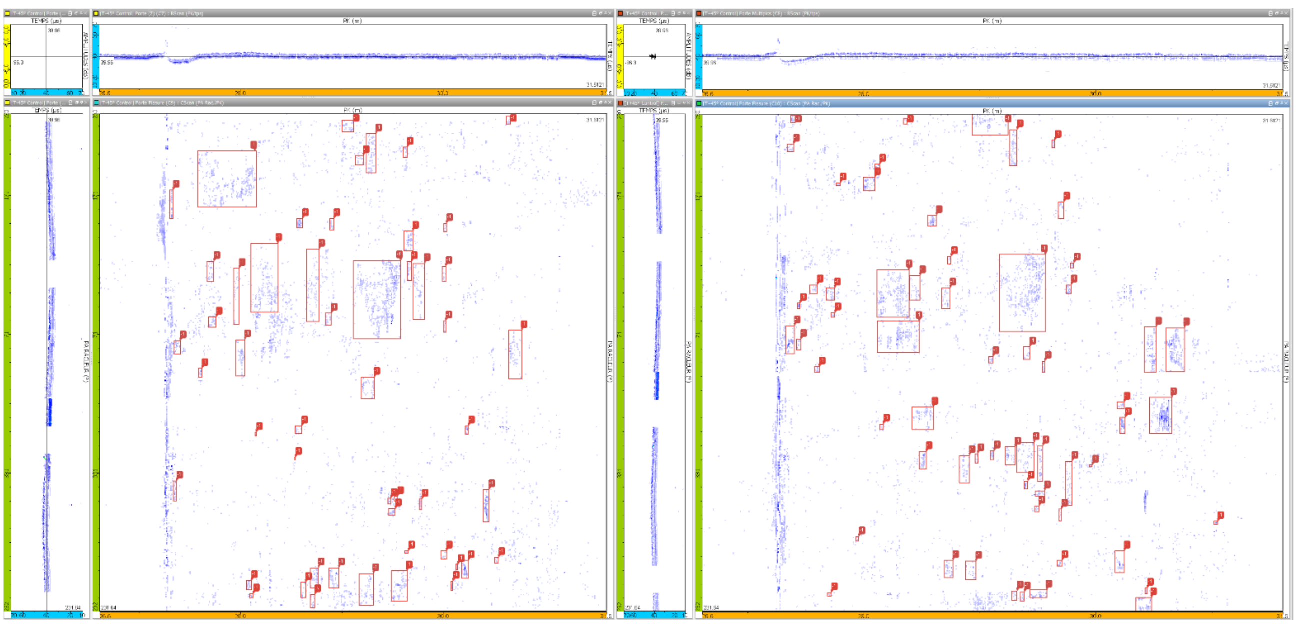


Figure 18 : Crack field signals on the ILI tool data analysis software (Longitudinal cracks view)

Comparisons between field data and ILI tool analysis have allowed us to plot the POD curves. Results of this independent analysis between longitudinal and circumferential cracks are exposed on Figure 19.

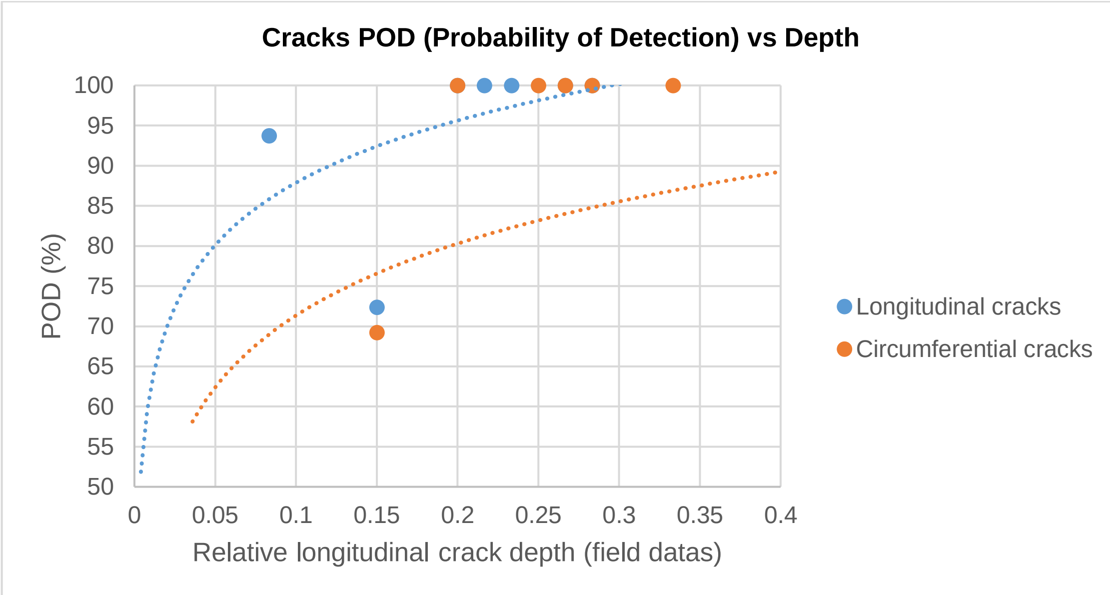


Figure 19 : Longitudinal and circumferential cracks POD after independent analysis

In this case the results proved that the ILI tool XTRASONIC-NEO process:

- Exceeded the POD target of 90% for longitudinal crack depth ≥ 1mm.
- Reach the POD of 78% for circumferential crack depth ≥ 1mm.

These results illustrate the challenges that are often associated with the detection of circumferential cracks, in opposition to longitudinal cracks. This could be partly explained by several factors, including the orientation of a significant portion of circumferential cracks (skew). Crack skew describes how the crack deviates from being perfectly perpendicular or parallel to a particular direction. Understanding the skew of a crack is important in non-destructive testing, as it can impact the way cracks propagate or how they are detected and analyzed.

3.3.2. Improve POD

In order to improve POD of circumferential cracks, ILI tool XTRASONIC-NEO offers the possibility to cross longitudinal and circumferential datas. This enables us to:

- Improve POD of circumferential cracks with a skew. Some circumferential cracks might be more visible on longitudinal analysis software views due to their skew. It can also work for longitudinal cracks.
- Identify “spider cracks” which represents a challenge for the ILI tool XTRASONIC-NEO (chapter 3.4).

After cross-referencing the data from circumferential and longitudinal crack views on the data analysis software, POD results were enhanced for circumferential cracks. The new POD results for circumferential cracks is represented by the red curve on Figure 20.

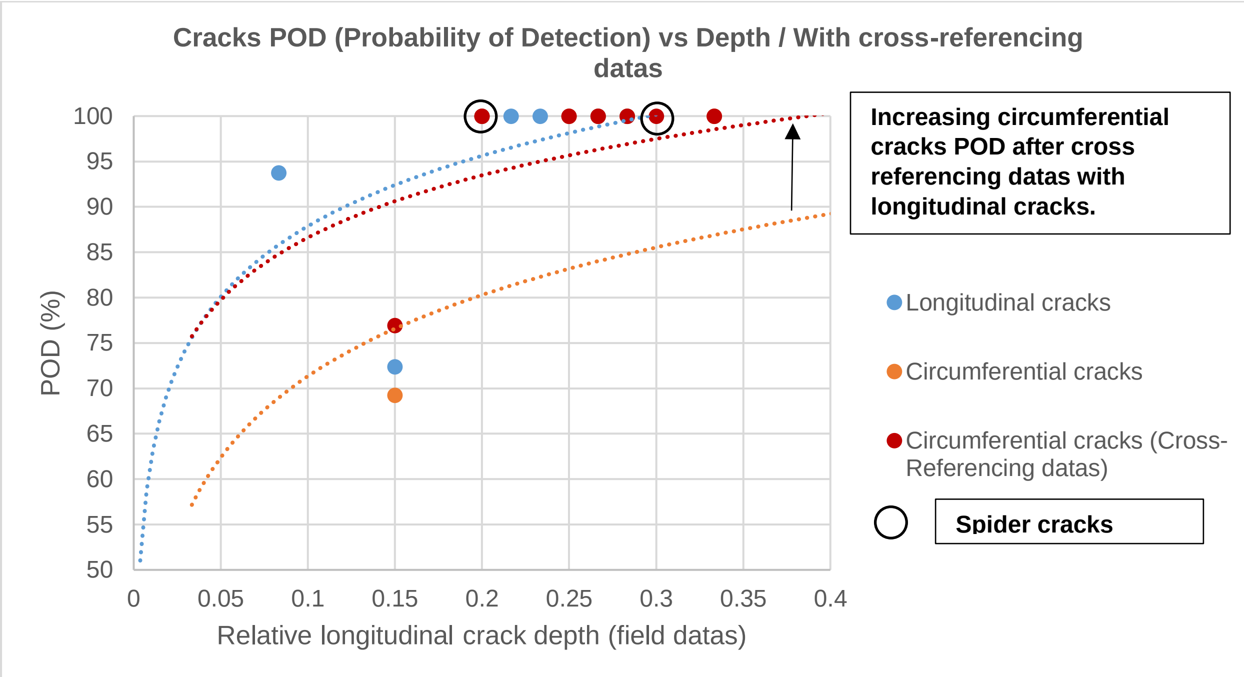


Figure 20 : Longitudinal and circumferential cracks POD after cross referencing analysis.

Indeed, we achieve a POD of 85% for circumferential crack depth ≥ 1mm (Figure 20). This information reinforces our belief that an all-in-one inspection would enhance the POD for cracks.

Examining the cracks pictures from field, it has been noticed that cracks responsible for the improvement of circumferential POD are “spider cracks”. It have longitudinal and circumferential component.

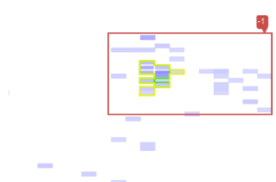
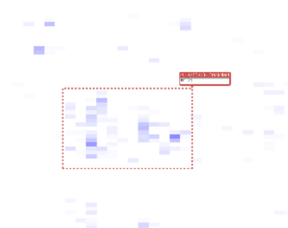
Crack on field	Crack on data analysis software (Longitudinal view)	Crack on data analysis software (Circumferential view)
		

Figure 21 : Example of « Spider crack » visible on both data analysis software views (Longitudinal and circumferential)

3.4. Introduction to the identification of spider cracks

We have just showed that it is possible to improve crack POD crossing circumferential and axial views from data viewer Software. Furthermore, this method could enable the identification of “spider cracks” in the data analysis final report. The Figure 22 below describe the ILI analysis in order to identify it.

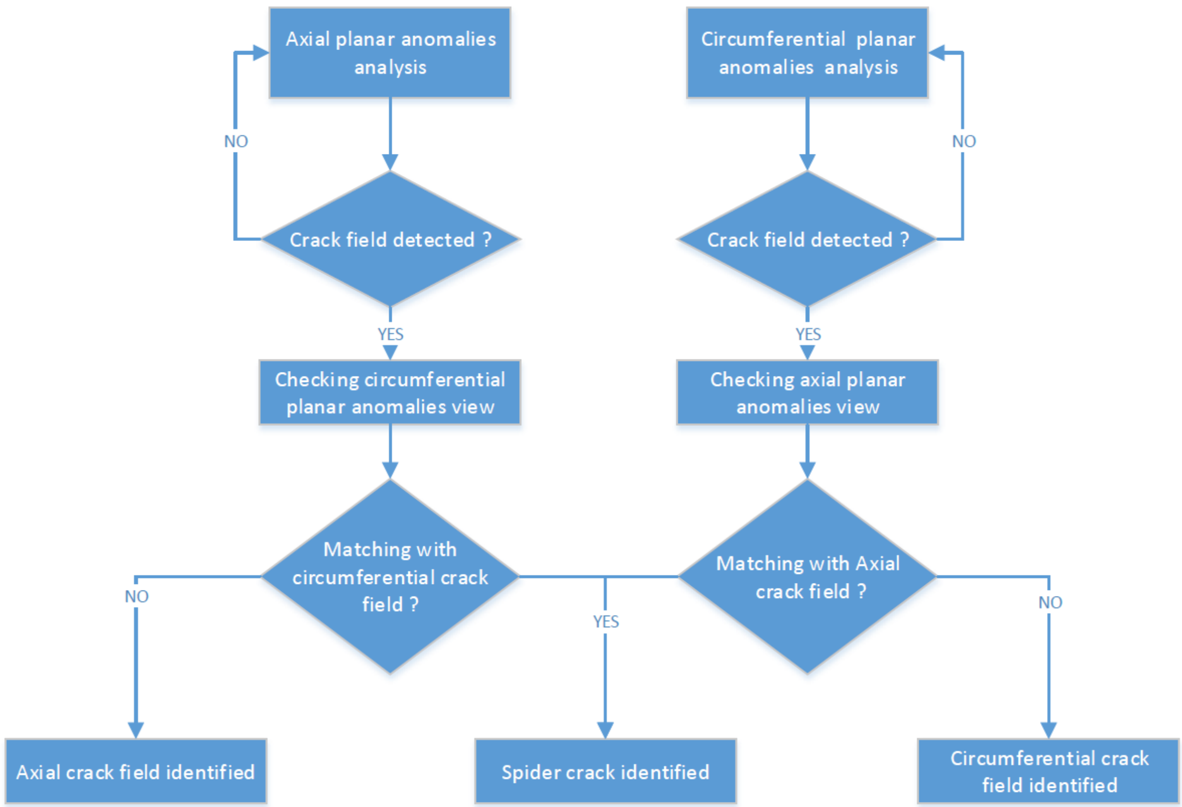


Figure 22 : Analysis workflow adapted to "spider cracks" identification

3. Conclusion and perspectives

The validation of the performance of an ILI tool is an iterative process, which requires a lot of field data. The performance shown in this article was produced as part of a standard calibration. The use of Phased Array Technology significantly improves detection thresholds and measurement accuracies, while offering advantages in terms of compactness, modularity and cost of use. This type of tool will definitely improve pipeline integrity management. As a result, the cross-referencing analysis between circumferential and longitudinal crack data enhances the POD and POI, highlighting the interest of developing a all-in-one inspection tool.

***Reference ***

[1] Performance of European cross-country oil pipelines – Statistical summary of reported spillages in 2021 and since 1971 M. Cech J. Armstrong W. Guijt A. Haskamp I. Huidobro Barrio *Concawe Report N°6/23. May 2023*

[2] Etude de la nocivité des défauts dans les canalisations sous environnement hydrogène*. Bellahcene Tassadit. 2012*

[3] API STD 1163 In-line Inspection Systems Qualification. *2013*.

[4] POF 100 Specifications and requirements for IL. *Pipeline Operators Forum. 2021*

[5] ASNT ILI-PQ-2017 In-line inspection personnel qualification and certification. *2017*

[6] Failure Investigation Report. Denbury Gulf Coast Pipelines LLC. Pipeline Rupture/Natural Force Damage. *2022*

[7] The effect of pipe material on the behavior of water leakage through longitudinal cracks under pressure. *M. Dinka, D. Madyira. 2012.*