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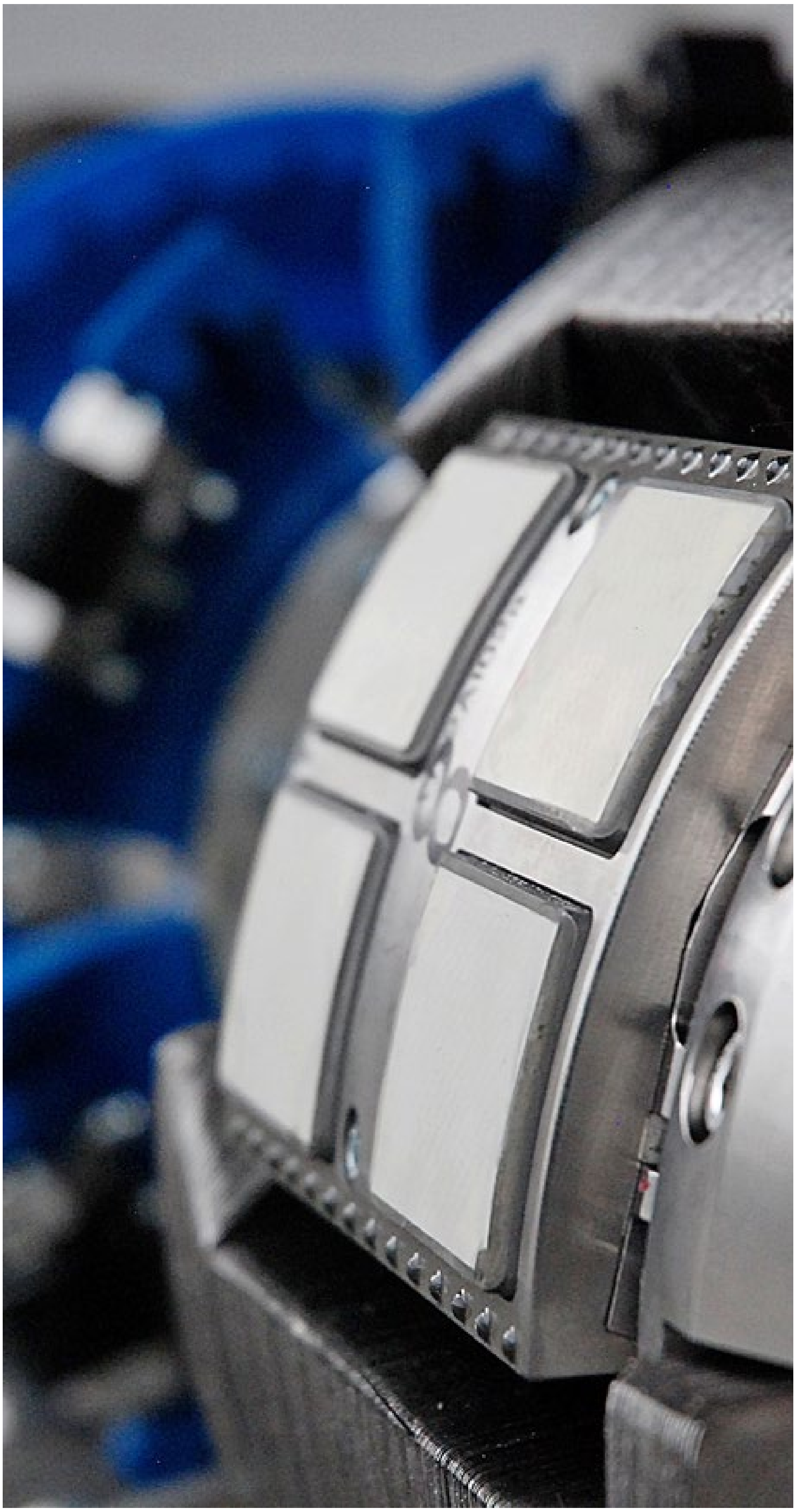

Safety & Inspection

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Selecting the proper inspection programs

Dr. Khalid A. Al-Jabr
Asset Management
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Considering systemic approaches and effective models, with detailed steps and an integrated management program for all components and assets in any pipeline network can enhance the reliability of the network, and promote the system to the next level of excellence. Pipelines comprise of the most efficient methods of energy transportation and distribution, if they are designed, constructed, and maintained according to the proper standards and practices. Thus, it is important to regularly inspect and maintain pipelines to avoid the shortening the pipeline service lifetime at all stages of the pipeline's lifetime cycle. Contributing factors to lifespan decline include: design errors, commissioning, operation interval caused by either external influences (mechanical damage) or internal factors (corrosion issues), or during maintenance (errors in repairs).

Moreover, the proper inspection programs can also, improve safety records by avoiding failures and injures, and also avoid environmental damage.

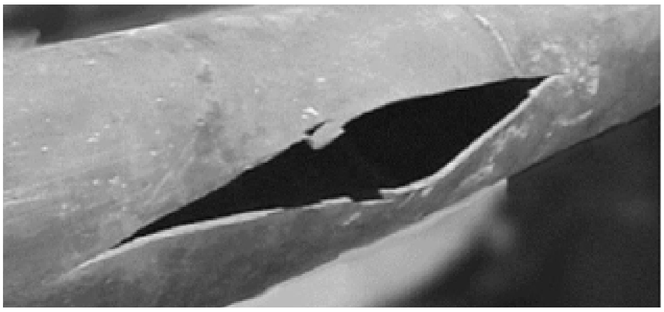
In this issue of the Pipeline Technology Journal, we will see how safety procedures and inspection techniques can be applied and implemented to the pipeline systems, according to experts in the pipeline industry. It is exciting to see the safety & inspection practices in the hands of those who are closest to the critical problems, bringing all their deep expertise in pipeline integrity to the table by summarizing the best practices, engineering standards, initiatives, new projects, new technologies, lesson learned and success stories in the pipeline field.

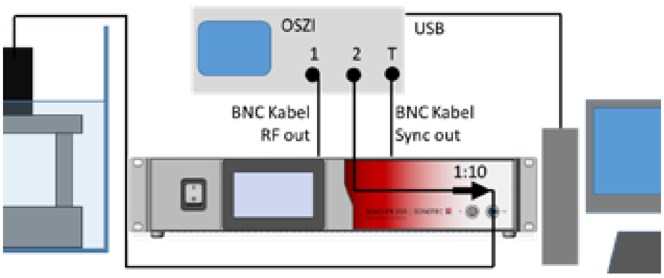
Sincerely,

Dr. Khalid A. Al-Jabr
Asset Management
Engineering Specialist
UK Chartered Engineer
Certified Reliability Leader

This Issue's

COMPLETE CONTENT





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19th Pipeline Technology Conference (ptc 2024) – Leading the Future of Pipeline Technology

The 19th Pipeline Technology Conference (ptc) returns to Berlin, bringing together global experts and innovators in the pipeline industry. ptc 2024 promises to be a landmark event, featuring discussions on hydrogen, CO_2 transport, methane emissions and pipeline construction, pivotal to the future of energy and infrastructure.

Prime keynote speaker will be Stefan Wenzel, the Parliamentary State Secretary at the German Federal Ministry for Economic Affairs and Climate Action. His insights into the interplay of economic policies and climate action are expected to provide a thought-provoking start to the conference, underlining the critical role of pipeline technology in a sustainable future.

The ptc Conference will host a series of enriching panel discussions. These sessions are carefully curated to focus on emerging trends in energy resilience, methane emissions, hydrogen technology, and digital transformation and cyber security. Attendees will gain valuable insights from industry leaders and partake in engaging debates.

A special feature of this year's event is the Global Women in Pipeline initiative. This segment is dedicated to highlighting and supporting the vital role of women in the pipeline industry. Through various activities, including networking events and focused discussions, the forum celebrates diversity and aims to empower women leaders and professionals.

Read the full article here:
https://www.pipeline-journal.net/news/19th-pipeline-technology-conference-ptc-2024-leading-future-pipeline-technology

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Insights

Well-known industry experts share their experience, insights and opinions on pipeline related topics

Defects in Pipelines and their Assessment

P. HOPKINS > PHIL HOPKINS LEARNING LTD.

Abstract

There are over 4 million kilometres of transmission pipelines transporting crude oil and its products, and natural gases around the World. These costly and valuable, but potentially hazardous, assets are ageing, with most over, or approaching, 50 years old. This ageing can cause defects such as corrosion in the pipelines, but the good news is that these pipelines are not exhibiting increased failure rates. Part of the reason for this is good management of the pipelines, and also the ability to find and assess these defects, both quickly and safely. This article explains how the industry assesses the defects, and why pipelines continue to perform safely.

1. Introduction

Transmission pipelines are the most popular method of transporting natural gas, crude oil, and its products, as they are cost-effective and safe [1], Figure 1.

They are a hugely important and valuable asset:

- they are one of a nation's critical infrastructures;
- they have a total length of about 4 million kilometres in the World today;
- assuming pipeline construction costs (which vary dramatically due to varying length, diameter, terrain, region, etc.) of ~$US5,000,000/km, the replacement cost of the world's pipelines is $20,000 billion; and,
- these pipelines support a huge oil and gas business: crude oil is one of the most traded commodities in the World at around $1,000 billion dollars per year [2].

1.1 Pipelines are Ageing...

This pipeline asset is ageing; for example, the USA's oil and gas transmission pipeline system is over 800,000 km (500,000 miles) in total length [3, 4]:

- 67% of the USA natural gas pipeline system was built before 1970; and,
- 55% of the liquid pipeline system was built before 1970.

This means well over 50% of this system is over 50 years old, but there is no evidence of this ageing causing more failures or incidents on pipelines [5, 6, 7]. This may be surprising, as ageing during operation will inevitably introduce defects and damage in the pipelines, such as corrosion (due to the pipelines being in contact with soil/seawater) and dents (due to, say, earth-moving equipment inadvertently hitting a buried pipeline) [8]. The term 'defect' usually means substandard, but in this article it means a flaw/discontinuity/anomaly that exceeds specified acceptance limits in a pipeline or its welds [9]. Defects can also be introduced during the pipeline materials manufacture, and transportation/construction.

Certainly, operators of our ageing pipelines now have a better understanding of '... welding, inspection, condition monitoring using in-line inspection and improved procedures for damage prevention and detection...' [7]. Additionally, they now adopt 'pipeline integrity management' processes to ensure pipeline safety. This is important - operators have historically relied on pipeline maintenance and inspection to ensure the pipeline was safe [10]. This approach is focused on the pipeline itself, and the supporting systems, and is delivered through an operator's inspection program. It has a bias: it ensures a pipeline does not fail (i.e., it is concentrated on controlling the probability of failure), paying little attention to any consequences of failure, which is short-sighted, as risk of a pipeline failure is a product of its probability and consequences.

Integrity management of a pipeline takes a much wider view, as it includes the environment around the pipeline, as well as the pipeline. This means that operators

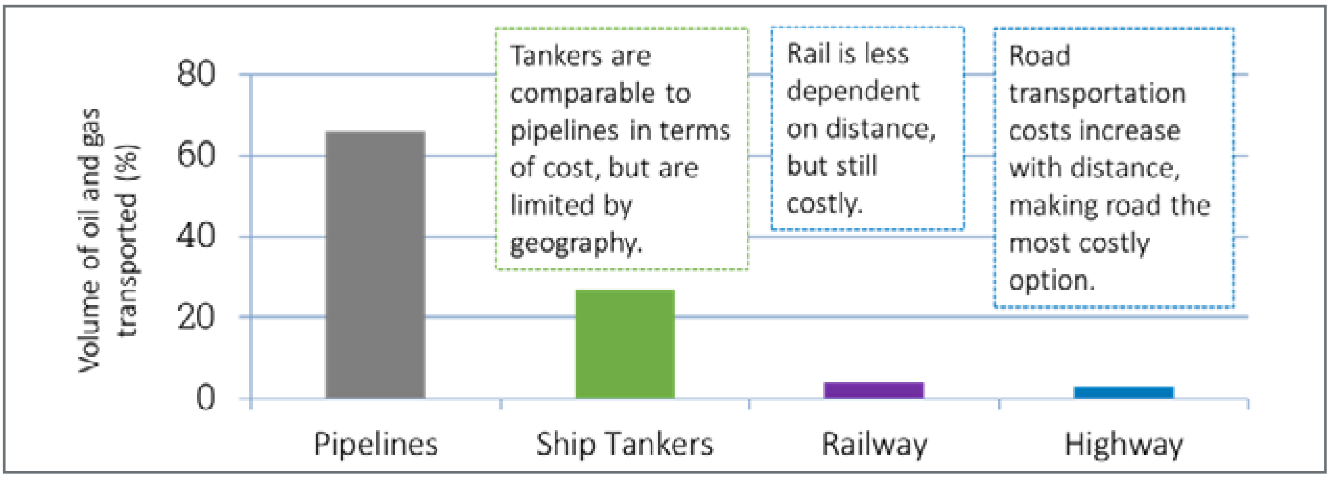


Figure 1: Pipelines Transport most of our Natural Gas and Oil.

are required to know more about [10]:

- the areas their pipeline crosses;
- the type and density of the population in those areas; and,
- the presence of environmentally-sensitive areas around the pipeline.

1.2 Defects during Operation

Integrity management allows understanding and control of both the probability of failure, and the potential consequences of failure of a pipeline on its route [10]. Part of this pipeline integrity management process is managing defects in the pipeline, as they appear. Defect control and assessment are very important as these defects often appear as the headline cause of pipeline failures, Figure 2 [11], although it has been argued that human error plays a far bigger role [12].

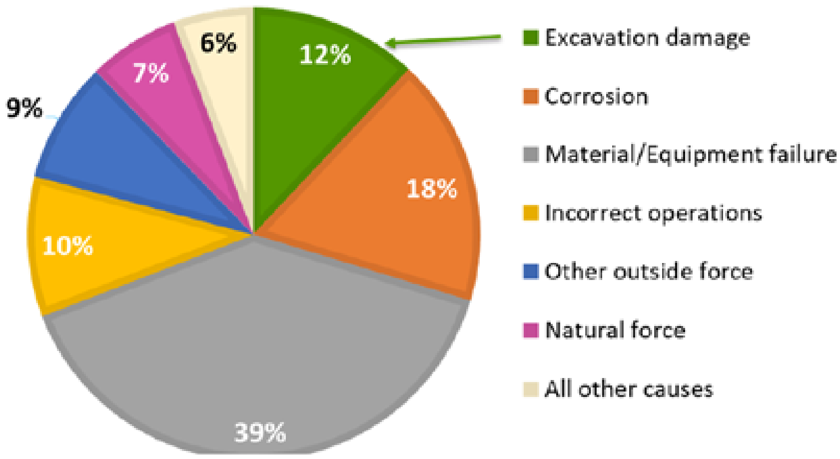
This article covers how these defects are assessed and managed, and why they are not causing increasing failures as the pipelines age.

2. Assessing Damage and Defects in a Structure

Damage or defects in a structure are not necessarily unacceptable. A defect may have failed a quality standard, but it may not be a threat to the structural integrity. How do we show it is not a threat?

The UK standard BS 7910 [13] states: '*Where it is necessary to examine critically the integrity of new or existing structures by the use of non-destructive testing (NDT) methods, acceptance levels are required for any flaws that might be revealed. These often already exist as quality control levels (for example in a construction code); however, in this British Standard the derivation of acceptance levels for flaws is based upon the principle of fitness-for-service.*

The 'fitness-for-service' principle is that a structure is considered to be adequate for its purpose, provided the conditions to cause failure are not reached. BS 7910 [13] states: '*Decisions on whether rejection, down rating and/or repairs are required [for these flaws which are more severe than the quality control levels] may be based on fitness-for-service, either in the light of previously documented experience with similar material, stress and environmental*



- Excavation damage (damage to the external coating of the pipe, or dents, scrapes, cuts, punctures, etc.).
- Material/Equipment failure (pumps, valves, welds, laminations and inclusions, blisters, etc.). Most failures were of equipment.
- Incorrect operations (human error/mistakes such as directing the flow of fluid, draining, or filling a vessel or tank, performing routine maintenance, etc.).
- Other outside force (vehicle or equipment contact not related to excavation, vandalism, sabotage, terrorism, etc.).
- Natural force (earth movement, landslides, subsidence, earthquakes, high winds. etc.).

Figure 2: Causes of Pipeline Failure in USA (2002 - 2021)

combinations or on the basis of an engineering critical assessment (ECA) ...'. The USA fitness-for-service standard, API 579 [14], also gives definitions and guidance on ECAs and fitness-for-service.

The U.S. Department of Transportation (DOT)'s Pipeline and Hazardous Materials Safety Administration (PHMSA) [15] states that an ECA is a documented analytical procedure to determine the maximum tolerable sizes for imperfections.

2.1 We use Fracture Mechanics

The fitness-for-service principle allows the assessment of defects. All structures will contain defects, but what methods are used in fitness-for-service?

'Fracture mechanics' is the study of the effect of defects (primarily sharp defects such as cracks) on structures subjected to forces. Fracture mechanics explains how materials behave when they contain defects, and gives the methodologies and equations we need to assess the significance of the defects. The theoretical studies began with A.A. Griffith (1893–1963), and its modern application was developed by G. R. Irwin (1907 – 1998), A. A. Wells (1924 – 2005), and J. R. Rice (1940 -).

Organisations, such as the American Petroleum Institute (API) and British Standards Institute (BSI) have produced documents (BS 7910 [13], and API 579 [14]) that give a full fracture mechanics methodology applicable to all structures. They give the necessary equations, procedures, etc., and help with the necessary assumptions and safety factors.

In summary, fracture mechanics gives the equations needed to determine if a defect might fail the structure, but it also needs information on (Figure 3):

- the defect (e.g., its size);
- material properties (e.g., strength and 'toughness'); and,
- the applied stresses on the structure.

We need a measure of the material's resistance to these defects. This resistance is provided by the material's 'toughness': the higher the material's toughness, the more resistance to the presence of a defect. If we do not know, or cannot measure, the material's toughness, we have a problem: its absence is equivalent to calculating if a structure will fail under certain loading conditions, but the structure's strength is not known.

It should be noted that the toughness required by fracture mechanics is the 'fracture toughness': this is a quantitative measure, and is usually measured in terms of 'stress intensity factor' (K), from a laboratory test. The pipeline industry does not, and has not, measured the fracture toughness of its pipeline material. The industry does measure a material parameter called the 'Charpy energy', from a notched impact specimen test. Charpy energy is not a measure of a quantitative fracture toughness; therefore, this energy must be correlated with quantitative fracture toughness measures (the stress intensity factor toughness, Kc). This correlation can introduce large errors in estimating fracture toughness, and the Charpy energy can only be viewed as a proxy toughness value. API 579 and BS 7910 contain correlations.

We have measured this Charpy energy value of materials for over 100 years – Charpy values in line pipe steels have increased from about 20 J in the 1950s, to over 100 J from the 1990s [16]. These data, qualitatively, indicate an increase in fracture toughness over the decades.

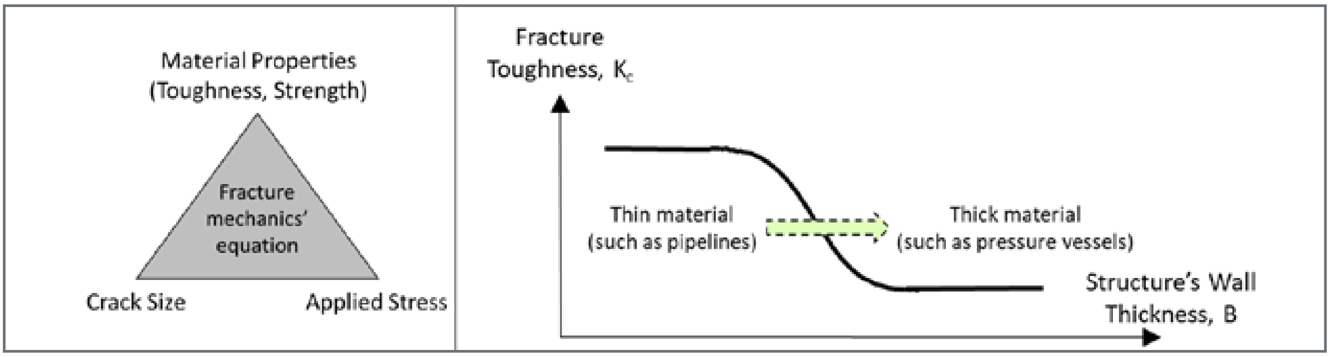


Figure 3: Inputs needed when applying Fracture Mechanics, and Effect of Thickness.

This indication of increasing toughness with time will be one of the reasons why pipelines are not failing today – they have increased resistance to defects, particularly sharp defects such as cracks. Additionally, a material's fracture toughness is affected by other parameters such as temperature (a pipeline steel's toughness increases with temperature) and thickness (toughness decreases with increasing wall thickness, Figure 3). The latter means that our thin-walled pipelines (most pipelines are below 20mm wall thickness) have inherently higher toughness, and consequently can tolerate large defects.

The improved material properties, with the inherent improved toughness of the thin-walled pipelines, along with the improvements in pipeline integrity management, all contribute to controlling failure levels.

3. Assessing Defect and Damage in Pipelines

3.1 The Early Days

Most oil and gas pipelines were built between the 1950s and 1960s, and this was a period when fracture mechanics was still developing, and defect assessment was relatively new. There was little need for defect assessment: the pipelines were relatively new, and defect-free, and there was no easy way to detect the defects, should they be present.

Some pipelines were showing signs of age in the late 1960s (e.g., corrosion), particularly in the USA where most the pipeline system was installed well before 1970, so the industry needed guidance on defects in pipelines.

The research organisation Battelle in Columbus, Ohio, USA did early fracture mechanics work on pipelines. Fracture mechanics methods had been available since the 1950s, but in the 1950s/60s they were still 'new' and not well-developed. Methods did exist in the 1950s for brittle materials, and thick-walled structures (such as nuclear pressure vessels), but these methods were not directly applicable to thin-walled structures such as pipelines, which were made from relatively tough and ductile materials. Additionally, the pipeline industry had not, and did not, measure the fracture toughness of its materials – this toughness is needed in fracture mechanics' analyses.

Battelle and other workers conducted full scale tests on defective pipeline sections to overcome limitations in fracture mechanics for pipelines, and the absence of quantitative measures of toughness. They developed 'semi-empirical' (a combination of theory and experiments) methods to predict the failure pressure of defects such as corrosion and cracks in pipelines. Battelle produced fracture mechanics equations to predict how defects would behave, but they had to use the Charpy energy as a proxy value of toughness [17, 18].

3.2 Assessment Today

The pipeline industry has developed its own methods for assessing a variety of defects, and also uses BS 7910 and API 579; for example, the benchmark standard for assessing corrosion and grinding areas in pipelines is ASME B31G [19]. Equivalent guidelines exist for dents, dents and gouges [20], and cracks [8]. Crack assessment needs knowledge of a material's fracture toughness, but, as noted above, a correlation with Charpy energy will be necessary (assuming the Charpy energy value is known). The use of this correlation is a particular problem with crack assessment, as it introduces uncertainty and inaccuracies. The correlations are not a problem when we assess corrosion: corrosion is a blunt defect and is not sensitive to toughness in most pipeline steels. Corrosion failure is mainly governed by the strength of the pipe: the strength of a pipe is known from manufacture. This means that corrosion assessment is not a problem: the fracture mechanics models we use are reliable.

4. Concluding Remarks

Defects, such as corrosion and dents, in pipelines, can be assessed using accepted, reliable, published methods [e.g., 19, 20]. Similarly, cracks detected in pipelines can be assessed using both international fracture mechanics' standards [13, 14] and industry guidelines [9]. The absence of material properties (fracture toughness) does lead to uncertainties in crack assessment, but this absence does not affect the reliability of methods used on corrosion and dents. Nevertheless, the absence of toughness data in the pipeline industry has been a long, on-going problem.

4.1 We Rely on Inspection Vehicles

An important point to make is that we rarely directly assess a defect – we usually rely on the results of a pipeline inspection by an in-line inspection vehicle, and the assessment is of the reported defects. Consequently, our assessment is heavily dependent on the accuracy and reliability of the inspection vehicle. These vehicles have tolerances; therefore, defects can be, and will be, under/oversized, and can be missed completely. These uncertainties must be accommodated in the assessment, with suitable safety factors, verification digs, in-depth knowledge of the vehicle's capabilities, knowledge of the pipeline and its defects, etc.

4.2 Follow the Rules...

It is important to understand the defect being assessed (type, position, size, and origin), and it is useful to have some basic rules on defect assessment; for example:

- use competent staff [9];
- always understand the type and cause of any defect you are assessing before an assessment (this will dictate the type of inspection, the assessment method, and any growth of the defect);
- understand and use the best assessment practices;
- use all relevant data (e.g., inspection data, operations records, maps, etc.);
- check calculations, inputs, outputs, and assumptions;
- always appreciate the consequences of any failure of the defect (this will affect your safety factor).

4.3 Defect Assessment is a Process, directed by Qualified People

Any defect assessment is a process – it is not simply a calculation. It requires (and relies on) [9]:

- a pipeline/product/configuration suitable for inspection/testing;
- pipeline records (e.g., material properties);
- an accurate and reliable detection method (e.g., in-line inspection (ILI)), followed by robust data analysis);
- engineering critical assessment of the defect; and,
- field verification and repair, mitigation, or re-assessment.

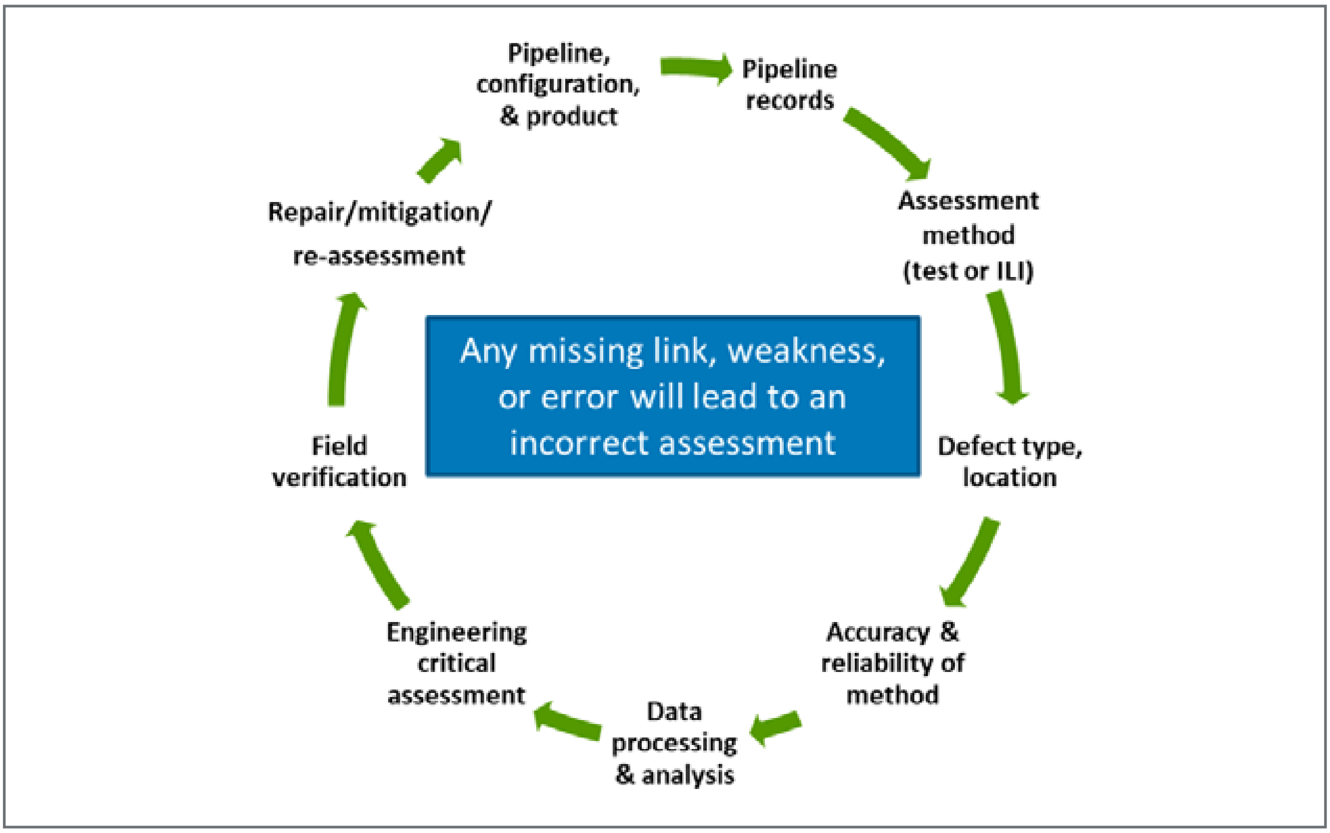


Figure 4: Defect Assessment Process.

Each stage of the process can introduce errors, Figure 4 [19]. Indeed, API 1176 [9] says: *'When managing cracks, a lack of adequate data for making critical integrity decisions can make the use of assumptions necessary'. Additionally, API 1176 emphasises the need for competent, qualified people to perform defect assessments: 'Effective integrity management of cracks relies on qualified people using defined and appropriate processes to operate well maintained and reliable facilities'.*

Finally, we usually use software to assess defects, as some of the calculations are complex. Be careful – you need to know the strengths and weaknesses (i.e., their underlying assumptions) of any software used. Do not fly blind....

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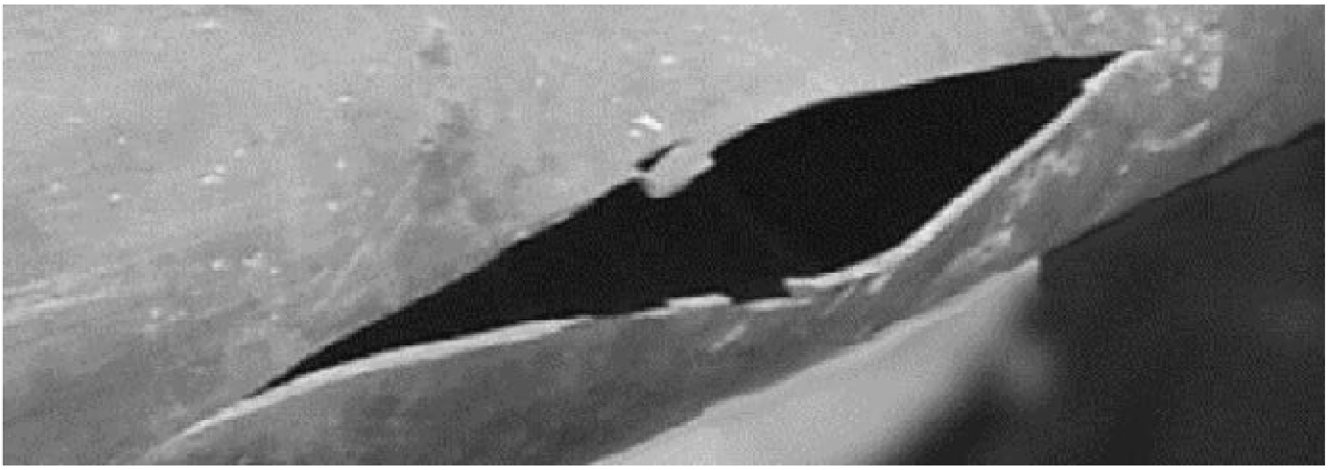

The Challenge of an All-In-One Inspection - First Results and Benefits

S. BENICHOU, C. SENAH, B. MARQUIS, D. LE FRIANT & H. EZ ZAKI > TRAPIL

Abstract

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

The search for an "all-in-one" tool would generate gains in terms of pipeline operations. The runs are done at significantly reduced speeds, an "all in one" tool would therefore make it possible to limit the runs number, and thus the flow reductions, and the operational losses.

Phased Array UT technology is a disruptive technology that allows 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, regulatory obligations, its experience, and its buried pipes to establish its specifications.

The objective of this paper is to show 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.

1. 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 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 must manage multiple inspection runs or alter facilities, requiring subsequent correlation of separate sets of inspection data.

TRAPIL has designed and produced a new in-line inspection tool, XTRASONICNEO® to avoid these unnecessary processes, to minimise costs, sources of error, operational conflicts and, overall to improve safety.

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), 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.

2. XTRASONIC NEO® technology and advantages

Since 1978, Trapil has built and operated several ILI tools and technologies, including MFL, UT, Caliper, 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.

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

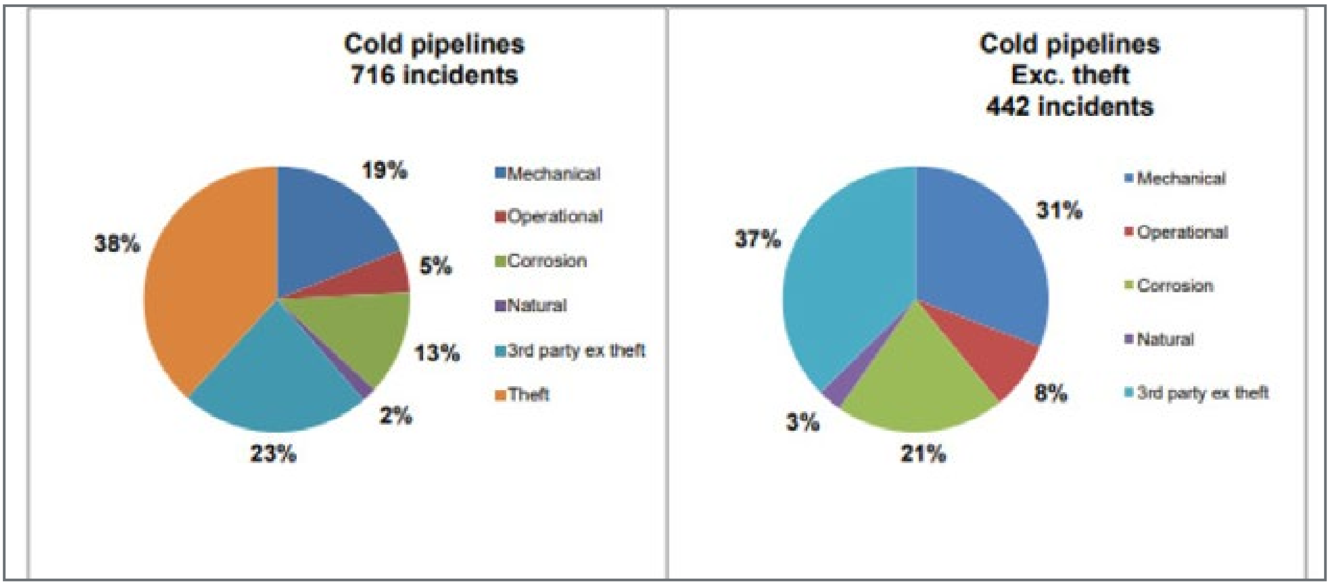

Figure 1 : 2023 Concawe Report [1]

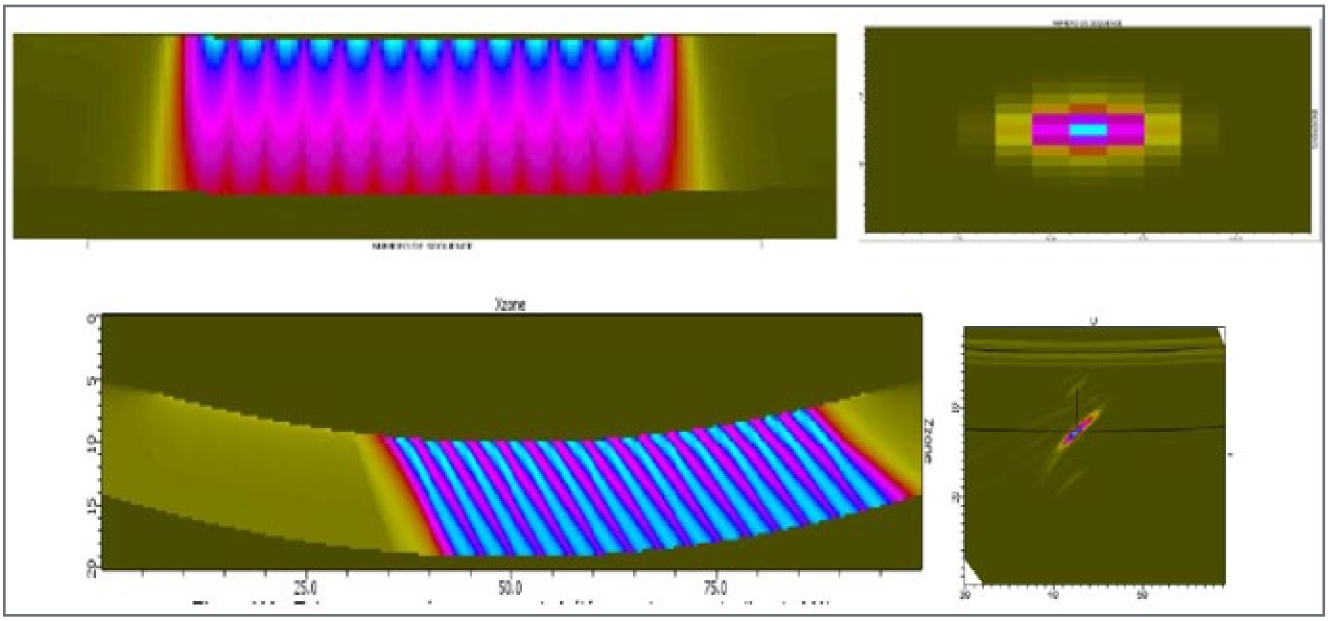

Figure 2 : Beam steering (longitudinal wave 0° and shear wave 45° on left hand side) and defect mapping (corrosion and crack on right hand side)

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 on multiple depths also improves sizing of critical defects for volumetric inspections (Figure 3).

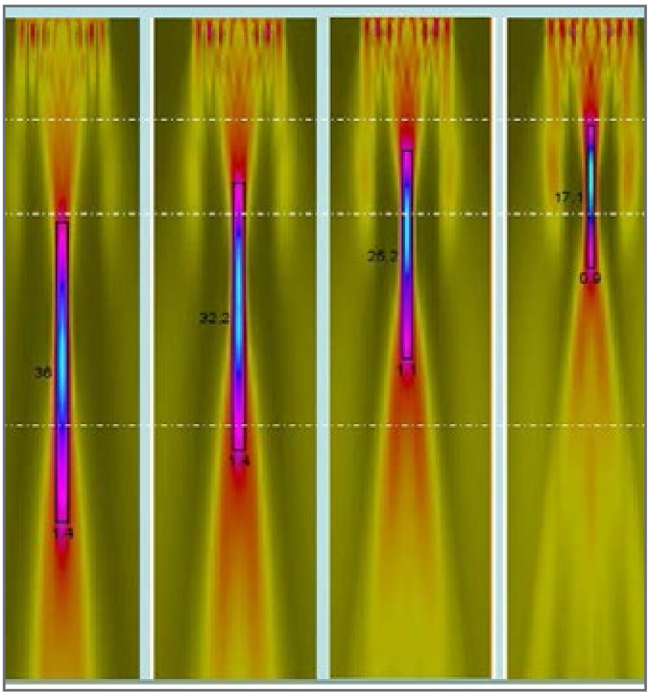

Figure 3 : Electronic focusing

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

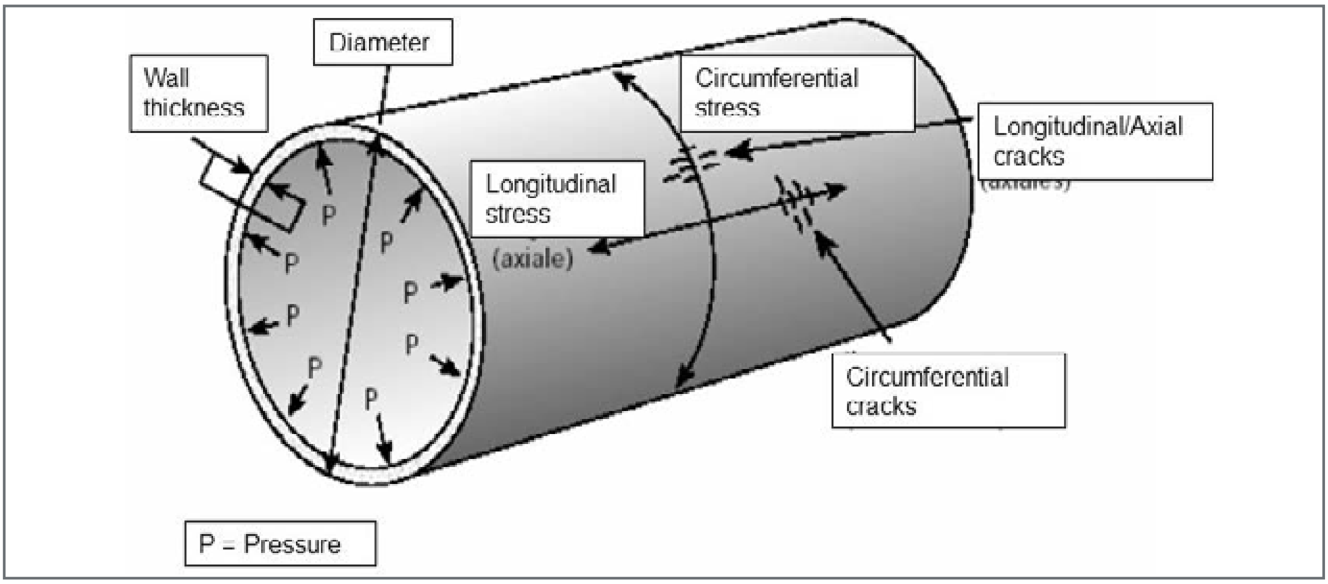

Figure 4: Different constraints on a pipeline [2]

medium and the steel wall thickness. The analogue signals corresponding to the different echoes are digitized and stored in the device's memories.

3. 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 4) are circumferential (referred to circumferential stress) and longitudinal (referred to longitudinal or axial stress)

Fatigue cracks appear perpendicular to the direction of the principal tensile stress. More 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.

3.1 Fatigue Axial cracks

The occurrence of axial cracks in pipelines is primarily explained by 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.

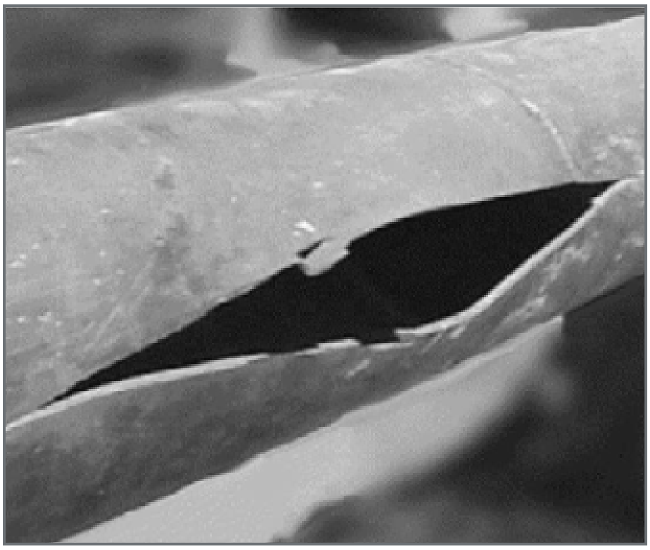

Figure 5 : Fatigue longitudinal crack [7]

3.2 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 6: circumferential fatigue crack in a CO2 transport pipeline due to ground movements [6]

3.3 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, when considering stresses described earlier.

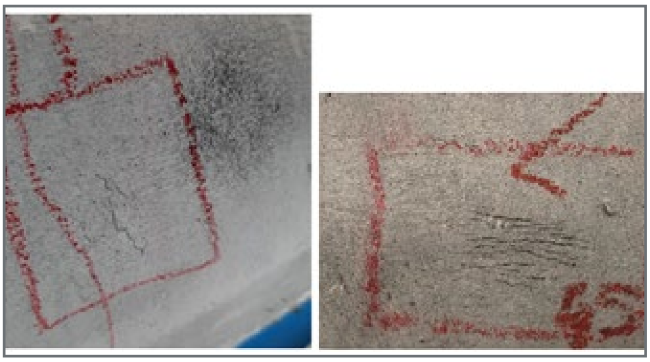

Figure 7: Circumferential and axial crack field SCC from TRAPIL field investigation

3.4 « Spider cracks »

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

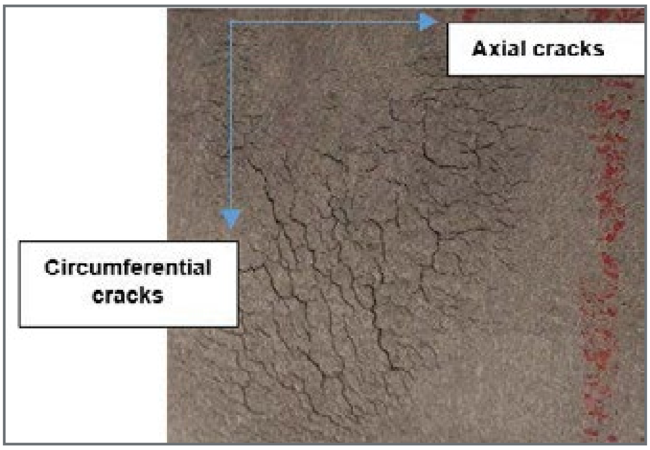

Figure 8: "Spider cracks" from TRAPIL field investigation

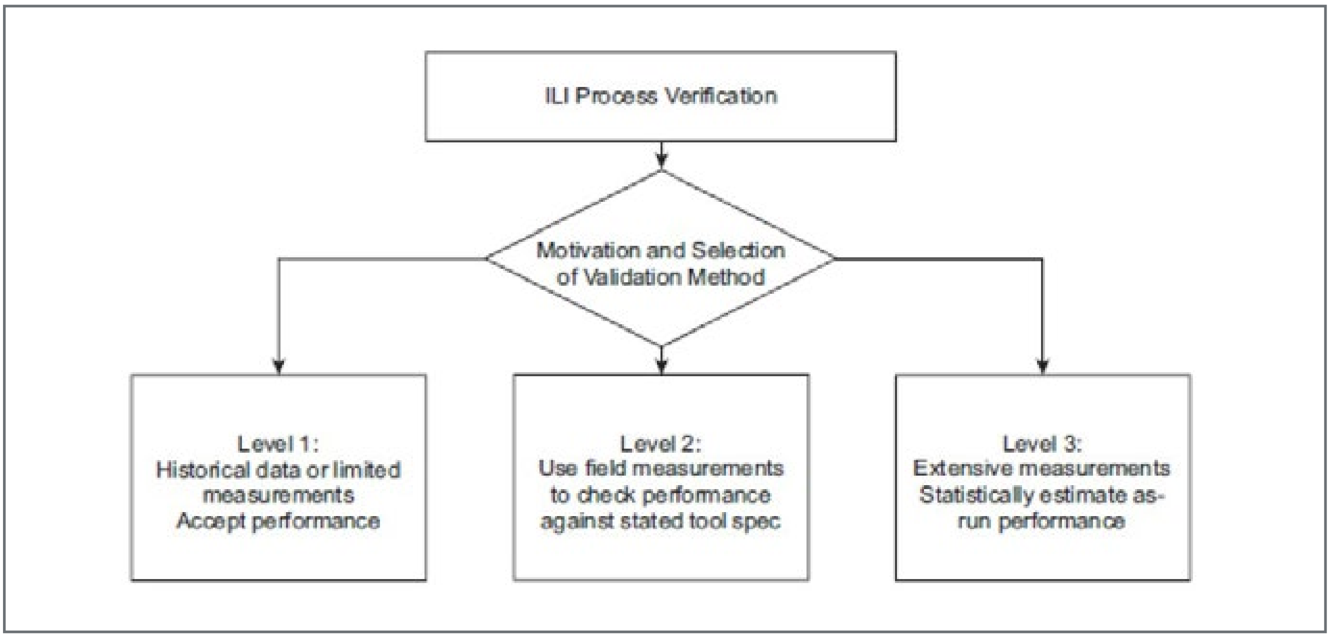

Figure 9: Overview of Three Levels of ILI Validation from API-1163 [3]

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

4. How to adapt the ILI analysis process to check 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).

4.1 Having access to known field data

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

- Real defects 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.

Experimental tests were conducted throughout TRAPIL's hydraulic test spool (12"-14"x70m) to establish POD and POs

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

Figure 10: Trapil's 12 and 20" test spools

4.2 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 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

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 to improve our depth sizing chart.

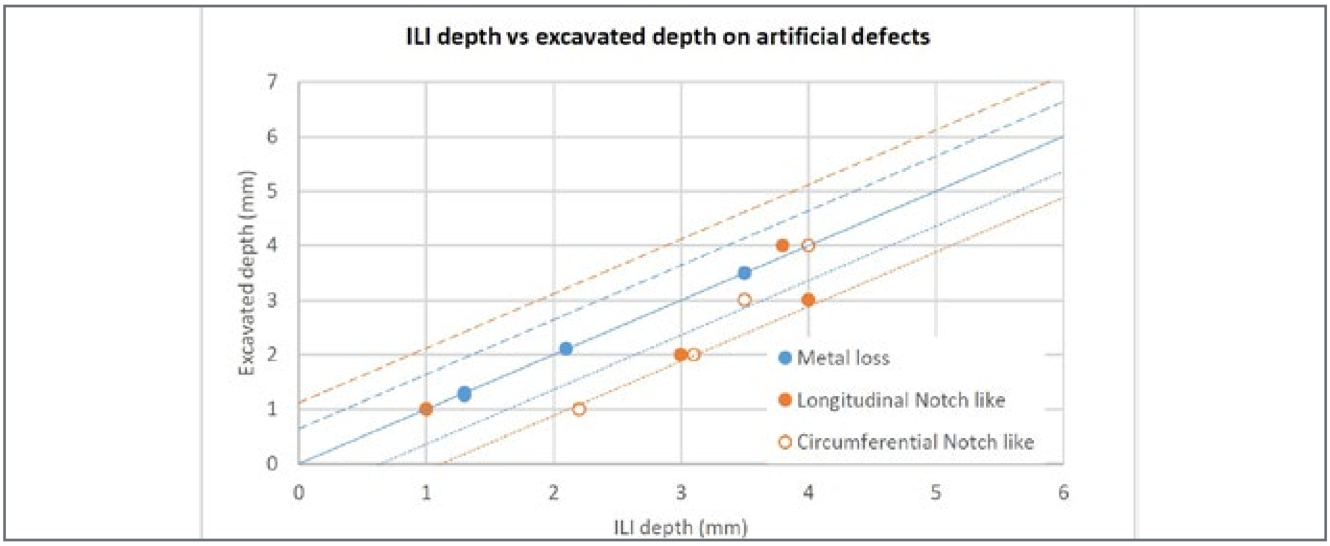

Figure 11: Sizing depth comparison between ILI tool process and excavated data on artificial defects.

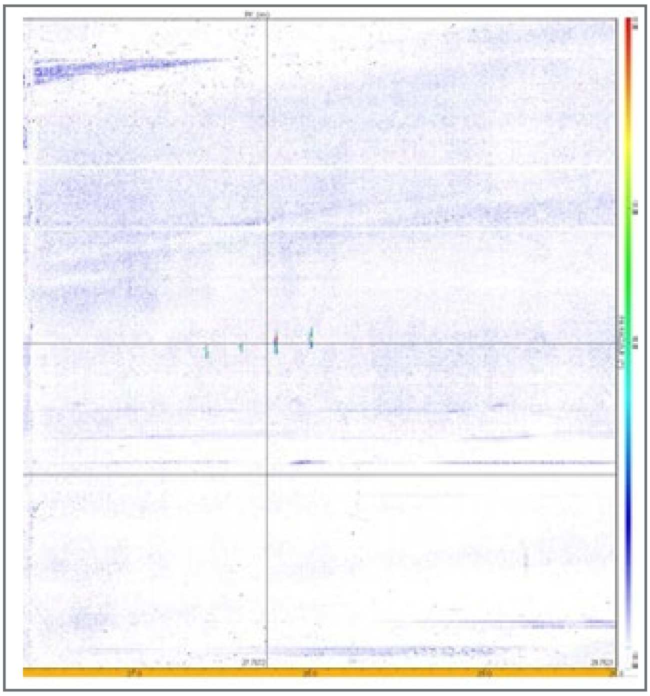

Figure 12: Circumferential artificial notch-like on data analysis software

Figure 13 : Crack field pipeline section on Trapil's spool test

4.3 Evaluating and improve POD of real defects.

4.3.1. 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.
- 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 data.
    - On the second hand, circumferential crack view was analyzed and compared to field data.

The amount of defect detected by the non-destructive testing method is shown on Figure 14 whereas the amount detected by the ILI tool process is exposed on Figure 15.

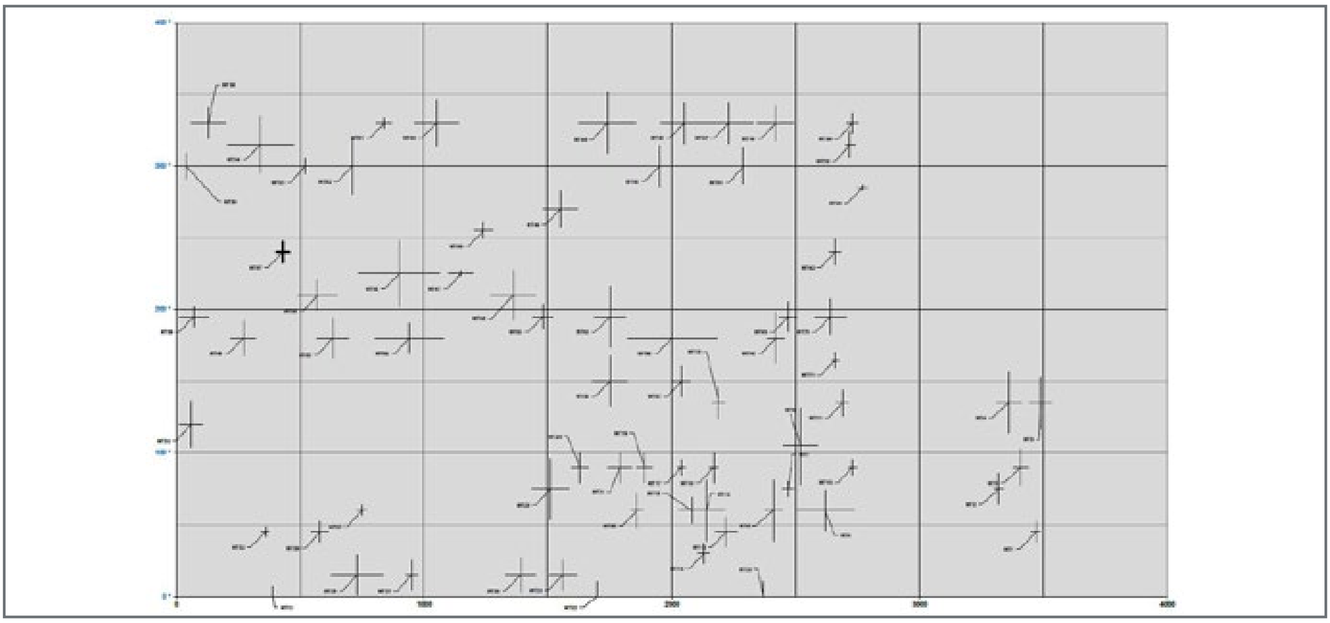

Figure 14 : Crack field detected by the non-destructive testing method.

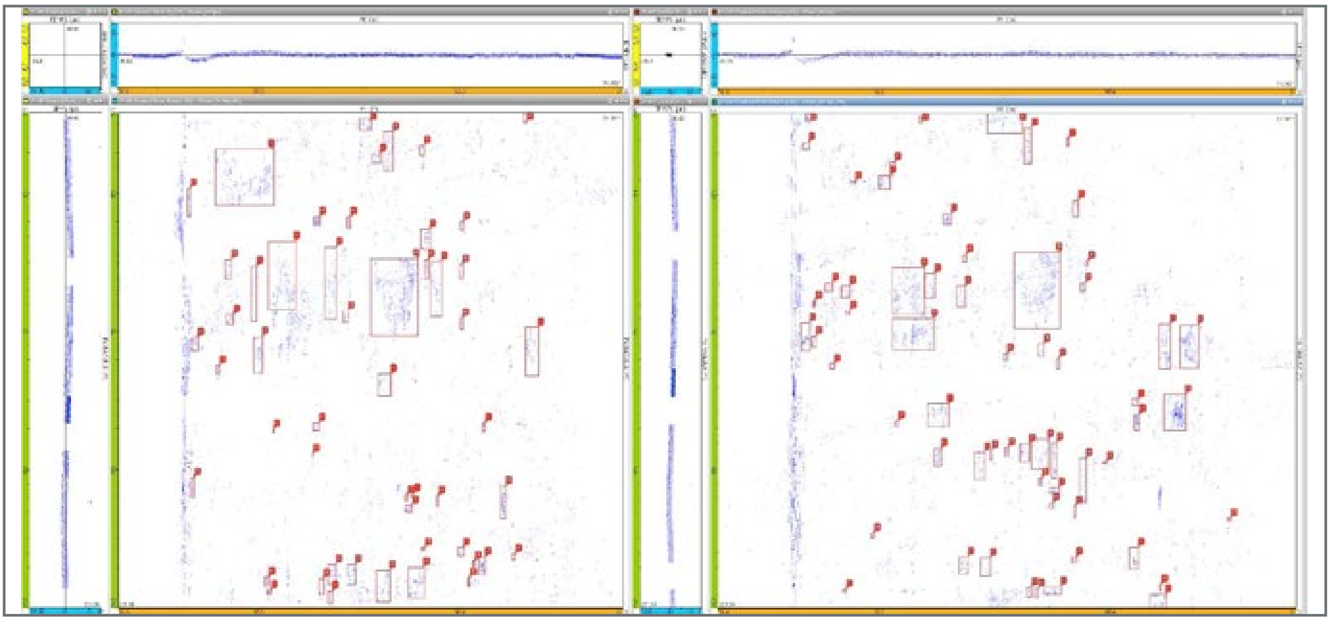

Figure 15: Crack field signals on the ILI tool data analysis software (Longitudinal cracks view)

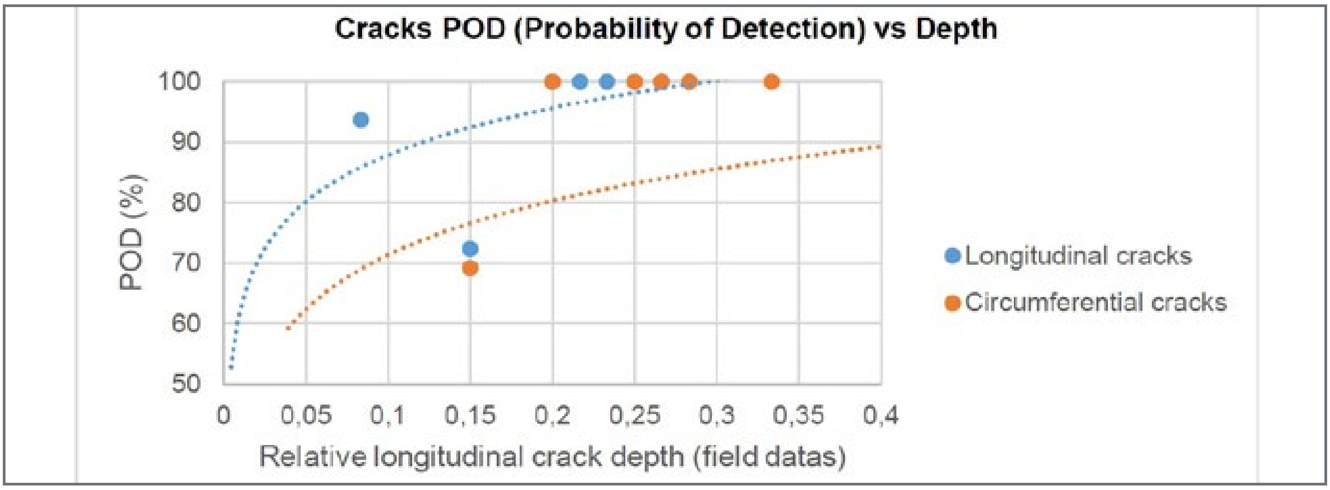

Figure 16: Longitudinal and circumferential cracks POD after independent analysis

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 16.

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

To improve POD of circumferential cracks, ILI tool XTRASONIC NEO® offers the possibility to cross longitudinal and circumferential data. This enables us to:

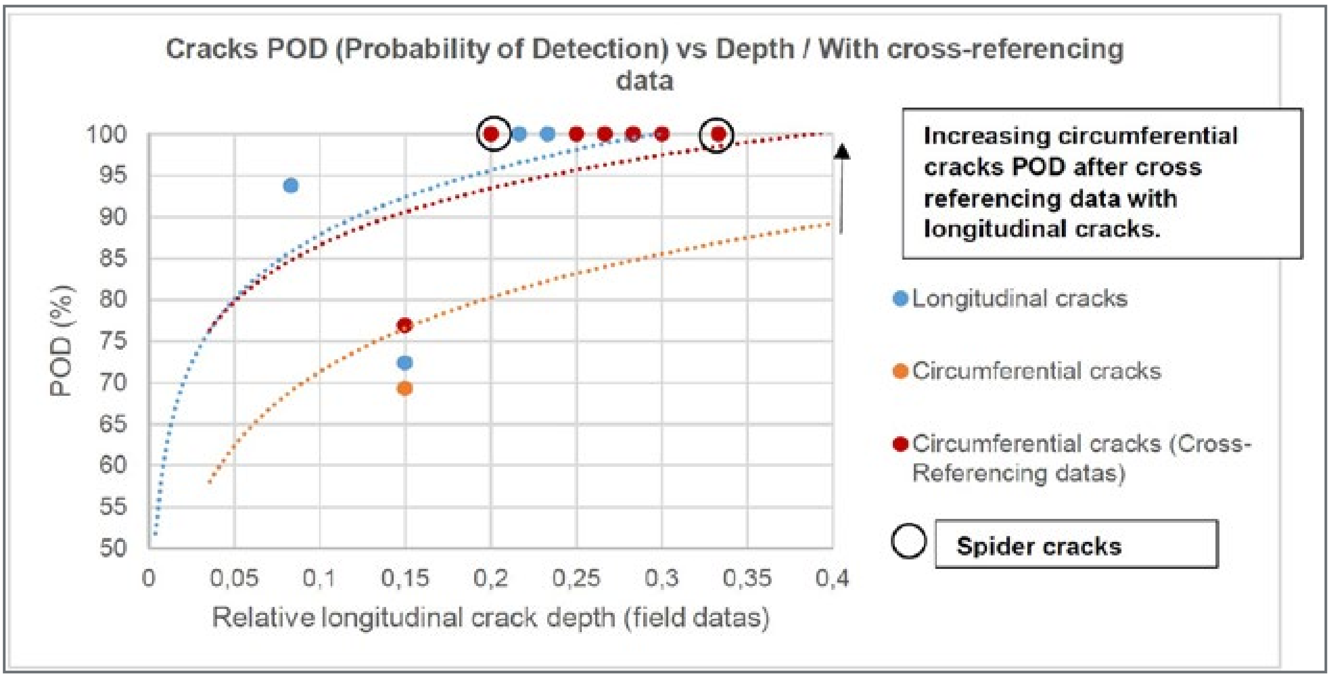

Figure 17 : Longitudinal and circumferential cracks POD after cross referencing analysis.

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

Figure 18 : Example of « Spider crack » visible on both data analysis software views (Longitudinal and circumferential)

- 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 are represented by the red curve on Figure 17.

Indeed, we achieve a POD of 85% for circumferential crack depth ≥ 1mm (Figure 16). This information reinforces our belief that an all-in-one inspection would enhance the POD for cracks.

Examining the cracks pictures from field, we note that cracks responsible for the improvement of circumferential POD are "spider cracks". They have longitudinal and circumferential components.

5. 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 improve pipeline integrity management. As a result, the cross-referencing analysis between circumferential and longitudinal crack data enhances POD and POI, highlighting the interest of developing an all-in-one inspection tool.

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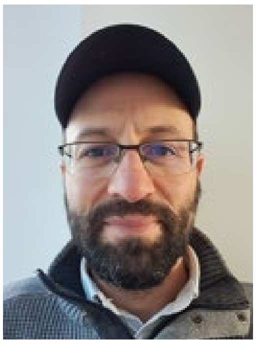

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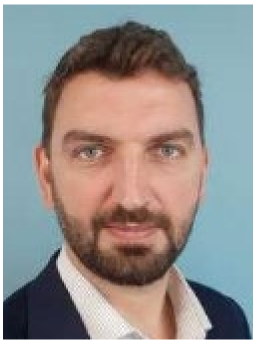

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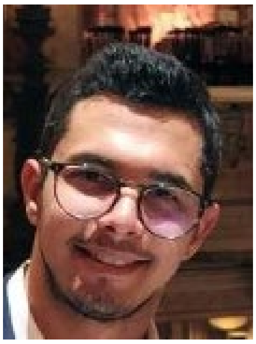

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Small Diameter Pipeline Inspection

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Abstract

Conventional tools for inspecting pipelines have historically been designed for long length, larger diameter transmission lines, typically up to 48 inches. Correspondingly, pipeline inspection gauges (PIGs) designed to inspect these pipelines have comparable diameters and consist of multiple carriages equipped with diverse inspection tools, logic, onboard power and odometry. There is an increasing requirement to examine and assure integrity of smaller diameter pipelines, particularly those traditionally considered 'unpiggable'. Intelligent (often termed smart) pigs developed for these pipelines do not have the luxury of size to house the necessary technologies. The means of entry into the pipeline is often a key limitation, along with navigation challenges and inspection economics.

This paper introduces and investigates the challenges associated with inspecting smaller diameter pipelines, typically with diameters less than 12 inches. It details the advantages offered by single bodied intelligent pigs in overcoming these challenges, emphasising enhanced navigation and compatibility with in-line valves. Additionally, the article provides an overview of their efficacy in conducting wall thickness measurements, verifying cleanliness, and detecting a range of different defects (size and morphologies).

The paper also explores a more extreme and innovative instance of further miniaturising ultrasonic intelligent pigs. It highlights the performance of the 4th Generation single bodied intelligent pig, which has the capability to inspect pipes with diameters as small as 1.5 inches. The topic within the paper is a discussion on anticipated future trends in the inspection of smaller diameter pipelines, emphasising the need to diversify the inspection technologies to satisfy the requirements of sustainability and energy transition.

1. Introduction

Pipelines are seen as the most reliable and safest infrastructure for transporting fluids (water, natural gas and oil etc.) [1], however, to assure the integrity of pipelines, there requires to be a robust program of inspection and analysis.

A significant threat to the transportation of fluids is a failure occurring within the pipeline wall, the impact of which can result in life threatening injuries, environmental contamination, social and economic harm. There are a range of credible failure threats to be considered including, pitting, cracking, fatigue, erosion and third part interference [2].

Inspection tools which can detect defects and provide information on the condition of a pipe are thus critical. This has been widely acknowledged across the industry and it is why there is a significant interest in non-destructive testing (NDT), structural health monitoring (SHM), and asset integrity management (AIM). It is necessary to understand the failure modes, degradation mechanisms and minimum tolerances to create a robust inspection and integrity regime.

The most common method of inspecting pipelines is via intelligent pig. Such a tooling is inserted (launched) into the pipeline and travels along the pipework facilitated by the pressure differential of the pipeline product, or other pumped fluid.

There are two primary categories of pigs [3, 4, 5]. Mechanical pigs are predominantly used for cleaning and purging operations and do not typically provide any information on the condition of the pipe. The second type, and the focus of this article, is the intelligent pig. These contain sensors and logic that detect and measure to give an insight to the condition of the pipe structure. Unlike hand-held inspection approaches, the intelligent pig has the benefit of free flowing through the pipeline and continually measuring across a broad surface grid in a short amount of time. The axial resolution of the inspection campaign is influenced by the speed at which the pig travels through the pipeline.

Major challenges present within certain pipeline inventories are the so called 'unpiggable' pipelines [6, 7, 8]. Unpiggable is a phrase commonly used to describe pipelines that cannot easily be inspected by a traditional tooling. There are several factors that can cause a pipeline to be considered unpiggable: bend geometry, significant diametric change (or the diameter is out of scope), variation in pipe material, the product that the pipeline is carrying and the economic expectations for short length pipelines.

The service life of unpiggable pipelines maybe based on predictive or empirical models. Solutions to inspect such pipelines, serve to inform and to de-risk through the determination and assurance of integrity.

The intelligent pig can carry a range of different sensor technologies dependant upon the NDT requirements. Magnetic flux leakage (MFL), and ultrasound (UT) are the most widely used NDT technologies [9, 10].

MFL is a technology that utilises strong magnets action on the pipe wall, a magnetic sensor is positioned between the magnetic poles and detects any magnetic field leaking from the pipe wall. The leakage field detects changes when there are anomalies in the pipe wall, and this can be interpreted to identify regions of defects.

Ultrasound is an elastic wave that is transmitted into the pipe wall, the wave then propagates through the pipe wall reflecting from the boundaries, internal and external wall. The reflection from the external wall provides information on the wall thickness, and the reflection from the internal wall provides information on the internal diameter of the pipe (Figure 1). If anomalies are present, the ultrasound will reflect off these allowing for them to be detected and sized accordingly. The most common type of ultrasound transducers are piezoelectric transducers. These require the pipe to be filled with a couplant, normally water, so that the ultrasound can propagate from the transducers into the pipe wall and back again. This therefore limits their application in gaseous mediums.

Another common transducer type is an EMAT (electromagnetic acoustic transducer). These require the pipe to be electrically conductive and ultrasound is generated in the pipe wall. No couplant is required, allowing for their use in gaseous, liquid, and multi-phase pipelines. EMAT intelligent pigs are often used for crack detection as they can transmit the

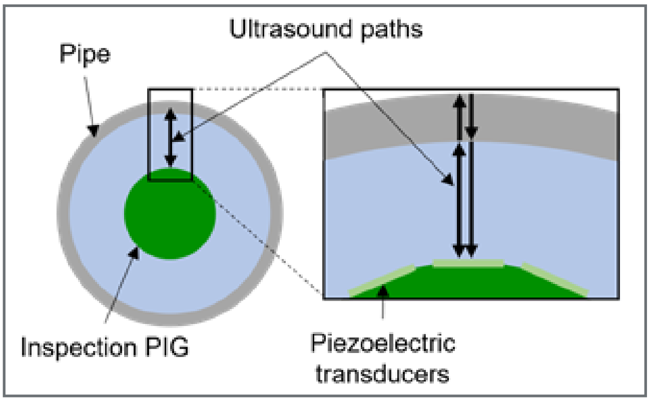

Figure 1: Schematic of a pipe cross section containing an intelligent pig. The ultrasonic paths taken to provided information on a pipe's internal dimensions and the wall thickness are shown.

ultrasound along the length of the pipe, increasing their sensitivity towards small defects.

These are not the only type of intelligent pigs used but are the most common. Examples of other technologies implemented include eddy current and calliper [11]. The intelligent pigs of interest in this article are piezoelectric ultrasound based in which the ultrasound is transmitted perpendicular to the internal diameter wall (Figure 1) allowing for accurate wall thickness and diameter measurements.

In larger diameter pipelines, which are generally straight and do not present significant navigation challenges, the intelligent pig benefits from ample space to accommodate a high density of sensors and the necessary electronics. This is often achieved through the utilisation of multi-carriage tools implementing a variety of inspection technologies[12]. In contrast, smaller diameter pipelines pose a significant challenge in housing the required sensors. Multi-carriage devices can also be utilised but the effectiveness of a solution becomes somewhat moot if the tool cannot enter or successful navigate through the pipeline. It is in these circumstances that a bespoke and effectively designed single bodied intelligent pig becomes the optimal solution.

2. Single Body Intelligent Pigs

Single bodied intelligent pigs are often deployed for the inspection of fired heaters where complex 1D bends and variations in pipe diameters are present. These are the most onerous of circuits, often containing box section geometries.

The requirement to inspect furnaces, heaters, and steam generation units, initially derived from a need to ensuring that decoking and descaling operations have been performed effectively. As the inspection technology matured, this transitioned from cleanliness verification to wall thickness measurements and recent developments in data analysis allowed defect detection to be refined. The principles that are employed by a single body intelligent pigs used for heater inspections are the same as a traditional ultrasound pipeline inspection tool.

The single body intelligent pig described here is a piezoelectric UT tooling which performs wall thickness and defect detection measurements. The centre of the intelligent pig contains the array of piezoelectric transducers, as shown in Figure 2, one end of the tool containing the controlling electronics and memory, the other end contains the power source. The pig is untethered and is propelled through the pass by water pressure. Typical inspection speeds sit between 0.3 and 0.8 ms-1, and a minimum of 15,000 internal radius and wall thickness measurements are gathered every linear metre. This range of single body intelligent pigs are suitable for inspecting tubes and pipes with diameters from 2.5 inches to 12 inches.

Figure 2: Image showing the different sizes of single body ultrasonic intelligent pigs.

Measurements rely on pulse-echo ultrasonic testing, where a single transducer both transmits and receives ultrasound (as illustrated in Figure 1). The initial reflection corresponds to the internal pipe wall, and the subsequent signals are caused by reverberations of the ultrasound within the pipe wall. The time difference between the arrivals equates to two times the wall thickness. The use of multiple reflections, as

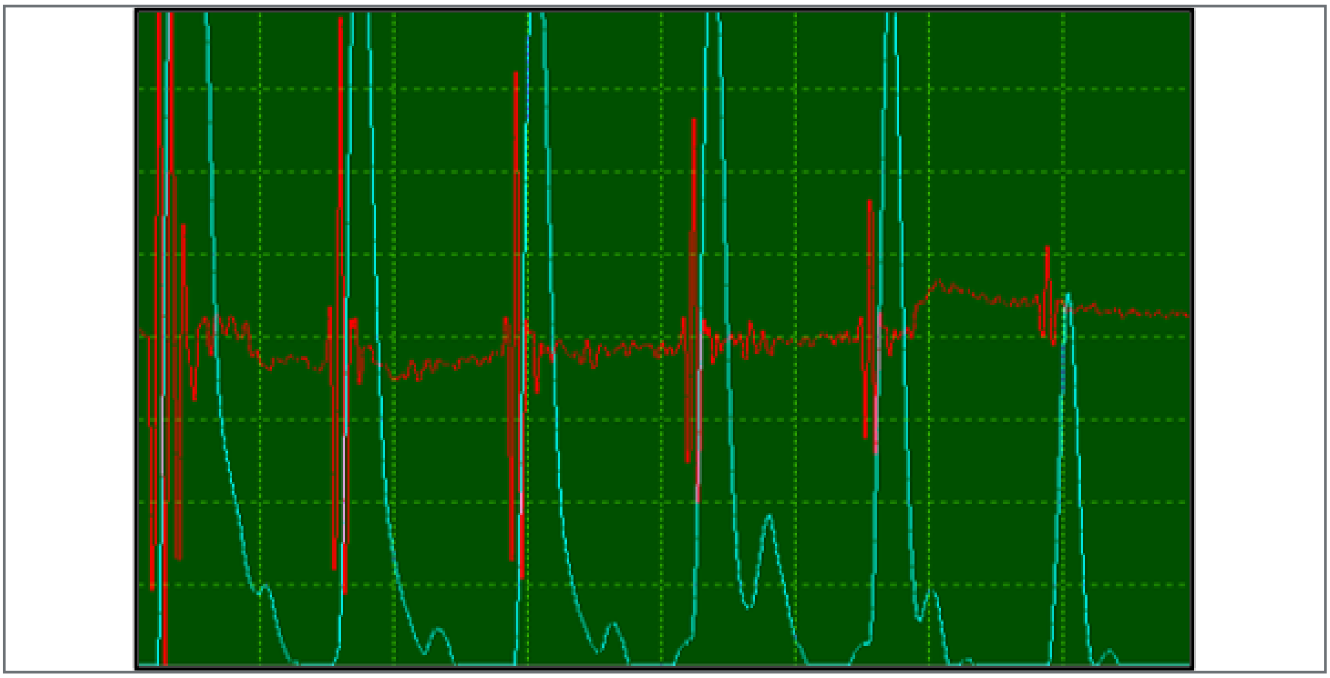

Figure 16: Longitudinal and circumferential cracks POD after independent analysis

seen in Figure 3, enhance the measurement accuracy. Additionally, multiple measurements at a single position are averaged for precision. The intelligent pigs exhibit a typical wall thickness static accuracy of ±0.1 mm and dynamic accuracy of ±0.3 mm. Measurements require accurate speed of sound values for the liquid couplant, and for the pipe wall initial calibrations are performed.

The gathered measurements provide for an accurate indication of the condition of the pipe structure. For example, if an increase in internal radius is detected at the same position as a reduction in wall thickness, this is a sign of internal metal loss. Similarly, if the internal radius remains consistent and the wall thickness decreases, this would indication of metal loss from the external wall.

Due to the volume of data gathered, a 3D map of the wall thickness measurement, internal diameter and external diameter can be generated, Figure 4. This illustrates areas of concern eg. a loss of wall thickness. Areas of remaining internal fouling are shown in the data by a reduction in the internal diameter and a loss of wall thickness measurements, cause by ultrasound scattering.

Location accuracy is achieved by utilising a 6-axis gyroscope, which compensates for any rotation that occurs in the pig during the inspection and detects changes in orientation and acceleration that occur as the pig moves through bends and other complex geometries. An axial location accuracy of ±50 mm is achieved when using known features as reference markers.

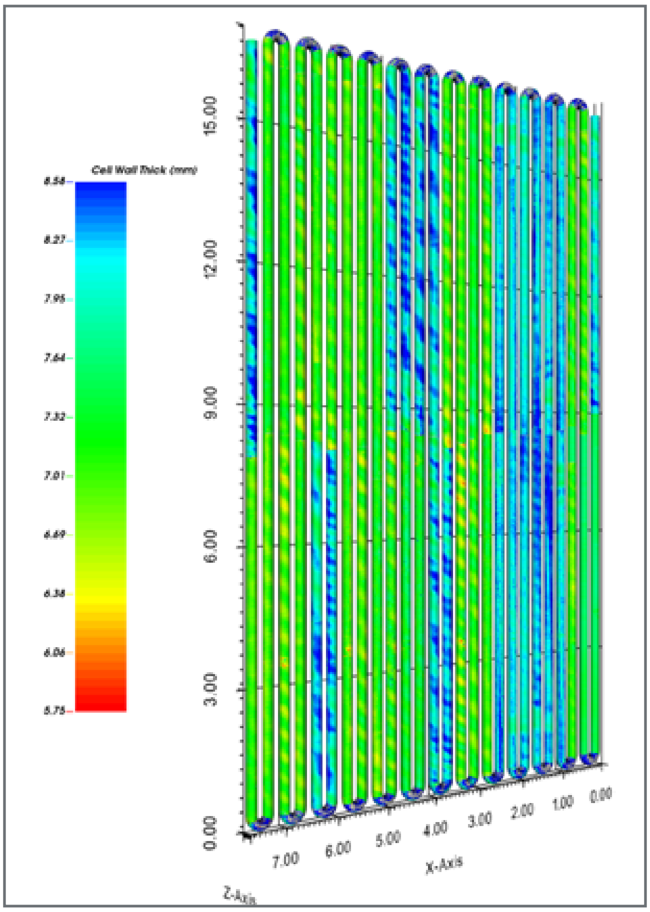

Figure 4: Image showing the wall thickness results presented in a 3D map.

To understand the performance of the single body intelligent pig for detecting small defects, a bespoke defect tube was manufactured containing a series of different size machined defects, Figure 5.

Six different diameter clusters of flat bottom hole (FBH) defects were tested, ranging from 7-30mm. Each size of FBH had various depths introducing an additional variable to the results.

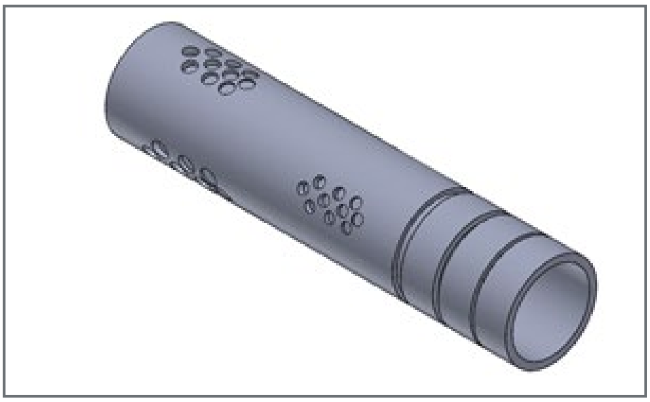

Figure 5: CAD model of artifical defect tube used to assess the performance of the single body ultrasoninc intelligent pig.

The C-scan shown in Figure 6 gives an indication of the defects that were able to be detected. In total, the single bodied pig was able to detect all defect diameters around the entire 360 degrees of the pipe. At the very small range, not all defects in the cluster were completely resolved.

When the defect size becomes comparable to the beam width of the ultrasonic signal, it is unlikely that that ultrasound will interact entirely with the defect and therefore the received signal will consist of both the defect and the full thickness of the pipe wall. If the amplitude of the pipe wall signal is greater than that from the defect, then the defect signal can be masked and detection compromised. This effect is minimised by multiple inspection runs which serve to increase the probability of detection on smaller defects.

The results also showed how the single body intelligent pig was capable of detecting defects of all depths, with the shallowest defect protruding 2mm into the pipe wall. The depth resolution of the tool is not a limiting factor in the tools performance as the temporal resolution of the results combined with repeat measurements through averaging and multiple reflections provide highly accurate measurements. Whilst FBHs approximate defects in pipes, real defects differ with textured surfaces and sitting at angles to the ultrasonic propagation direction. This can result in the ultrasound scattering, increasing the difficulty of detection.

Advancements in the single body ultrasonic intelligent pig involve ongoing research to increase transducer density and improving data science / post processing routines. This will improve the probability of detecting smaller features. In addition, improvements to signal

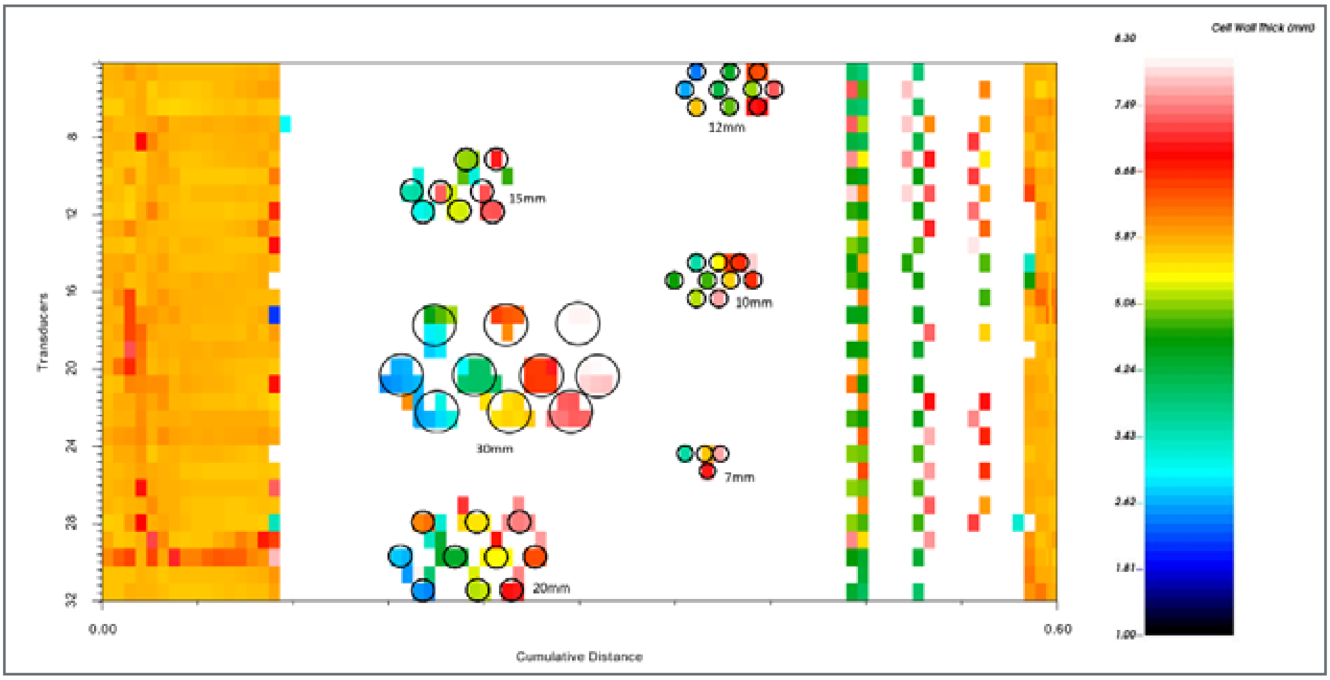

Figure 6: C-scan showing the identification of the flat bottom hole defects present in the test component.

processing routines will help distinguish smaller defect reflections from larger external wall reflections.

Whilst the current generation of single body intelligent pigs performs very well and is capable of identifying small diameter and shallow defects, their suitability for deployment using inline valves is a greater advantage, especially for inspecting traditionally unpiggable pipelines. In contrast, multi-carriage intelligent pigs cannot typically be deployed via inline valves.

The overall aim of the single body intelligent pig is to match, or indeed exceed the performance of the multi carriage alternative, resulting in an inspection solution that is superior technically and more economically viable.

3. Ultra Small Intelligent Pig

Recent advancements in the single bodied ultrasonic intelligent pigs have been concentrated on further downsizing the tool to enable inspection of even smaller diameter inventories. As a result, a 4th generation single body intelligent pig, referred to as the ultra small intelligent pig (USP), has been created.

The USP was developed to inspect a solar steam generation plant, which used parabolic trough collector. The parabolic trough collector had a 2 inch diameter Sch 80 and Sch 160 circuit and was therefore out of scope for the current intelligent pigs available on the market at the time.

Inline inspection was the only feasible option for inspection due to the pipes being encapsulated within a glass tube. This glass tube made it difficult to perform any handheld NDT inspections. It was determined that the only viable solution for inspection was to develop a miniaturised intelligent pig.

Figure 7: The miniaturised intelligent pig. This is the 4th generation of single body ultrasonic intelligent pigs.

The 4th generation intelligent pig is believed to be the world's smallest untethered intelligent pig of its kind. The final design can be seen in Figure 7 and operates using the same inspection routines as introduced already in the article. The piezoelectric transducers around the central circumference of the pig, allows for wall thickness, internal and external diameters, and localised defect measurements to be determined. The miniaturised intelligent pig can operate in pipe diameters as small as 1.5 inches (38 mm internal diameter).

Following the development of the USP, a successful inspection trial was conducted. A summary of selected results is presented in Figure 8, illustrating

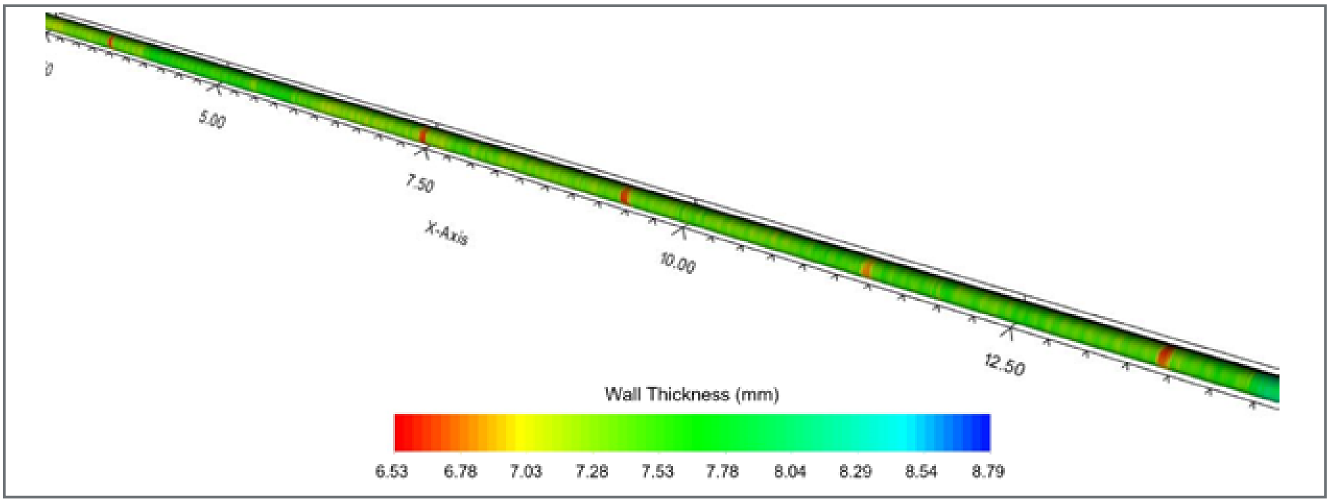

Figure 8: 3D map of the small diameter pipeline inspected using the miniaturised intelligent PIG.

wall thickness values. The outcomes reveal areas of localised external wall loss. These sections of wall loss, occurring at semi-regular intervals, indicated in the 3D map (Figure 8) by the red bands. They signify a wall loss of approximately 1.5 mm. Upon further examination, it was noted that these instances of wall loss coincide with tube section welds and specifically the locations of support structures around the pipe that neighboured the welds.

In summary the development of a miniaturised intelligent pig (USP) allowed for the inspection of a parabolic trough collector, previously unpiggable. In addition, the results from the subsequent inspection highlighted areas of wall loss that will need to be monitored over time to ensure that they do not result in a contributory failure mode. The results highlight the importance of inline inspection and necessity for companies to pursue viable solutions, even within inventory where it is not deemed possible.

4. Future Direction of Small Diameter Pipeline Inspections

The single body intelligent pig can address the access and navigation challenges frequently encountered in small diameter pipelines. Through the use of inline valves, the single body intelligent pig can inspect pipelines that were not originally designed for pigging. Inline valves are relatively non-intrusive and can be left in place as permanent fixtures within the pipeline, facilitating easy repetition of inspections. The single body intelligent pig is designed to fit within the chamber of the inline valve, simplifying both launch and retrieval processes for these pipelines, whilst still providing a high quality inspection capable of detecting small defects.

There is an increasing desire for detecting smaller defects with greater accuracy and achieving more comprehensive coverage of the pipe wall. Ongoing research aims to meet these objectives, exploring various avenues, such as increasing transducer density, optimising logic, enhancing data interrogation and implementing hybrid solutions, all within a single bodied tool.

Furthermore, current technology enables the development of miniature intelligent pigs, allowing for the inspection of new, previously unpiggable pipework. Emerging markets for these miniaturised intelligent PIGs include solar thermal energy plants and parabolic trough collectors, which are becoming more common with the transition to greener energy sources. Solar thermal energy solutions depend on small diameter pipes to ensure that the solar energy can be sufficiently focussed. These pipes are often encapsulated making conventional handheld inspection techniques unsuitable. The most appropriate solution is inline inspection using miniaturised intelligent pigs.

5. Conclusion

This paper has provided an overview into the performance of single bodied intelligent pigs, specifically highlighting their suitability for inline inspection of small diameter, unpiggable pipelines, where economics, access and navigation are key challenges.

The benefit of the single body intelligent pigs is their compact design allowing for easy deployment whilst maintaining inspections capabilities associated with traditional pipeline pigs. The single body tools presented use piezoelectric transducers to generated ultrasonic signals. These signals can measure the pipe diameters and wall thickness but require the pipe to be filled with a liquid to allow for the transmission of the ultrasound into the pipe wall.

A 4th generation intelligent pig has been presented, with results from a trial performed at a solar powered steam generation unit demonstrating the performance of the miniaturised ultrasonic intelligent pig. This miniaturised pig shows with technological developments and intelligent designs how conventionally unpiggable pipes can now be inspected.

A brief discussion on future directions for small diameter pipeline inspections, and how miniaturised intelligent pigs can provide solutions to ultra small tubing networks often associated with alternative energy systems.

Finally, the progressive maturity and weight of successful deployment evidence serves to illustrate that the ability of such single bodied tooling has overcome the challenges of uninspectable inventory. The ability to measure, assess and assure integrity is now within the reach of operators who are able to credibly and economically de-risk their assets.

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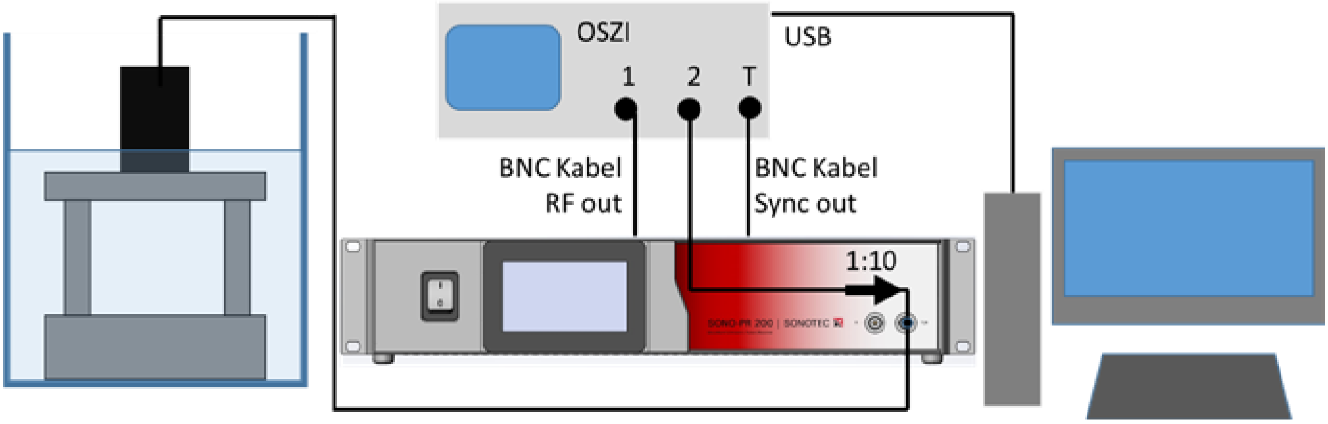


Robust Ultrasonic Transducers for Pipeline Inspection

A. MÜCK > SONOTEC

Abstract

Pipeline inspection for cracks and corrosion through intelligent inline tools relies on ultrasonic probes, demanding a 100% first-run success rate to minimize costs. These probes face harsh environmental conditions within pipelines, necessitating utmost stability for optimal functionality. Material selection and rigorous testing during development contribute to achieving high stability, yet not every application is anticipated. Conducting individual tests, considering factors like medium, pressure, and temperature, becomes crucial to assess inspection feasibility beforehand. The text outlines this testing process, detailing realistic conditions the ultrasonic probes encounter. Criteria for evaluating probe stability and integrity are elucidated, with practical examples. This approach ensures effective ultrasonic inspection while maintaining cost efficiency.

1. ROBUST ULTRASONIC TRANSDUCERS FOR PIPELINE INSPECTION

The inspection of pipelines is important to detect damages such as corrosion and cracks that can lead to accidents. Ultrasonic testing is an inspection method that allows for precise assessment. The design of a probe as well as the quality of the tests are crucial for the results of subsequent testing with smart pigs and their analysis.

2. APPLICATIONS: PIPELINE TESTING

Pipelines are an essential component of our modern world's infrastructure. They transport oil, gas, and a variety of other products over long distances, contributing to energy supply and prosperity. Worldwide, there are more than 3 million kilometers of pipelines, and the market continues to grow.

However, pipeline operation also poses risks. Damage such as corrosion and cracks can lead to accidents and endanger human lives. That is why it is essential to regularly inspect pipelines to detect risks early and ensure efficient use. Ultrasonic testing is used for this purpose, which offers many advantages over other testing methods because it is a very precise measurement method.

In ultrasonic testing with intelligent pigs, pipes are non-destructively tested for their leak tightness, stability, and structural integrity from the inside. Many probes are used to obtain an accurate and complete image of the pipe. The probes are designed to have low variability among themselves and undergo minimal changes during the run. The measurement results of the probes are similar, enabling precise evaluation of the pipeline.

Some factors, such as the temperature and pressure in the pipeline, affect the sound field presentation and ultrasonic signals. They affect all probes equally and can only be partially controlled. Other factors are more controllable. For example, the frequency, sensitivity, and sound field presentation of the probes should be adapted to the task and made as identical as possible to achieve accurate measurement results.

3. COMPOSITION OF A PROBE

The probe is an important component of ultrasonic testing systems used for non-destructive testing of materials. It is used to send ultrasonic waves into the material and capture the reflected waves to obtain information about the inner structure of the material. Therefore, the composition of a probe is crucial for the quality and reliability of the test results.

It consists of several components (Figure 1), which must be carefully selected and assembled according to the requirements for performance and stability. The basic composition of the probe is very similar.

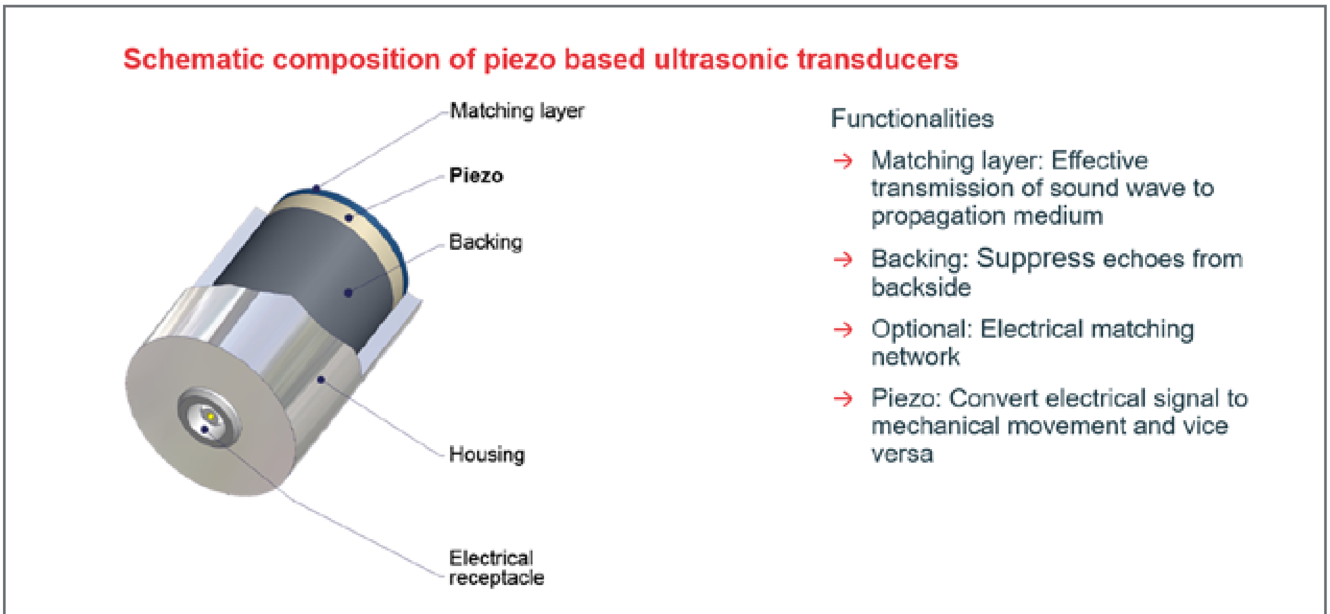


Figure 1: Composition of a probe

However, the environment in which the probe is used can compromise its stability:

- High thermal loads can alter the geometry of the probe and damage the sensitive components
- Heat can accelerate the aging of materials in the probe and impair sensitivity and reliability
- Reactions with the environment can compromise the stability of the probe and alter or destroy the materials
- Heat and chemistry can affect the connections between the individual components

4. TESTS

It is essential to test ultrasonic probes for their properties and stability. The requirements can vary greatly depending on the application and depend on various factors. Some of the most important requirements are:

- Duration of use
- Temperature during transport and during use
- Pressure in the pipeline
- Transport medium in contact with the probe

The duration depends on how long a pig run will be and how often the probe is intended to be used. Life cycle tests can only be accelerated to a certain extent. Longer durations may be required to ensure that the properties remain stable over the desired time period.

Temperature tests are necessary to ensure that the probe works properly under various temperature conditions, including both transport and operation. A shock load due to a rapid change in temperature represents a particularly high challenge.

Pressure tests are another important factor in testing ultrasonic probes. Ingressing medium should not cause any damage. In many applications, the probe also serves as a sealing element, with leaks generally being avoided. In pressure tests, the probe is placed in an autoclave with a holding fixture and exposed to high pressure. This tests whether it can withstand the conditions. DMA analysis is also a useful tool for analyzing the interaction between the medium and the layer.

Different media have different acoustic properties that affect the resulting sound field presentation. Some media are confidential or not available for procurement, making tests under real conditions impossible. To check the performance of the sensor in such a scenario, tests must be simulated in the appropriate medium.

While all forms of testing cannot guarantee 100% optimal inspection results, they significantly increase reliability.

5. EVALUATION CRITERIA

To evaluate the characteristics of an ultrasonic probe, a complete determination of its acoustic properties is necessary. The ISO 22232-2 can serve as a guideline for the procedure. For this purpose, an ultrasonic laboratory testing system (Figure 2) is used.

Relevant parameters include:

- The high-frequency echo signal: sensitivity, center frequency, and bandwidth can be derived from this signal.
- The sound field presentation, i.e., the sound pressure distribution in space when the probe is excited. In this process, a probe and a spherical reflector are situated within the medium. The latter is moved and the position-dependent echo is recorded depending on the position. It is usually displayed in diagrams which show the maximum amplitude in color-coded form.

During the development of new probes or in the case of fault analysis, such investigations are carried out completely.

However, for series production, this is too time-consuming, so the echo signal of a fixed reflector in a suitable fixture is usually used for 100% testing.

In addition to determining the acoustic properties of the probe, it is essential to characterize the state of its

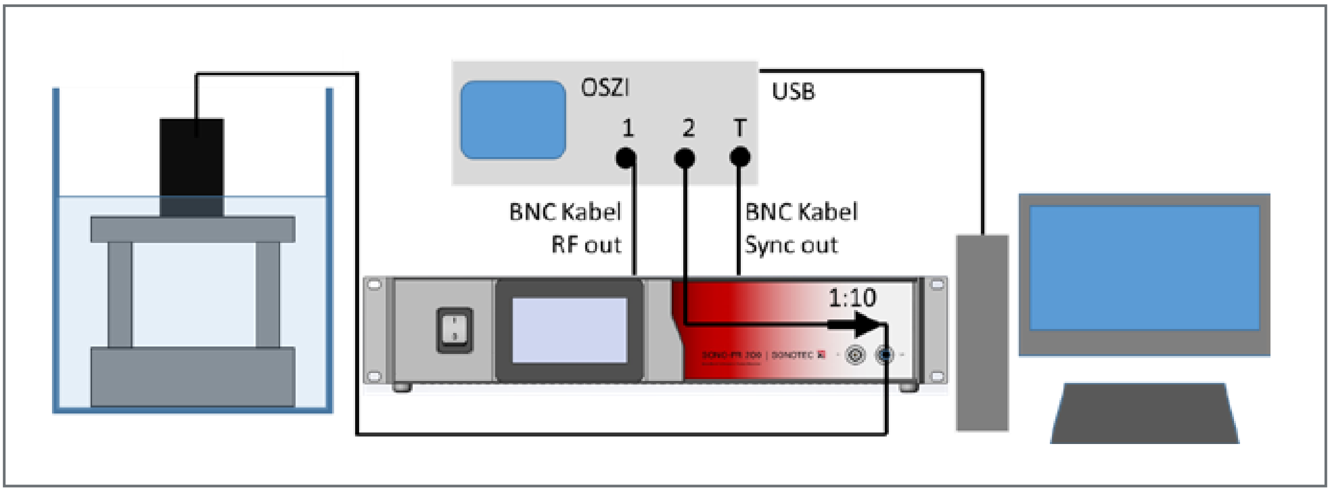


Figure 2: Typical test setup of a series production

components and the influence of the environment on it non-destructively. It is a reliable early indicator of aging and alteration and helps to evaluate the condition before the probe fails. In this process the probe is examined in a test system using high-frequency ultrasound (Figure 3). This allows the dimension, parallelism and homogeneity of layers to be determined. In particular, the quality of the connection between the individual components can be examined in this way.

6. PRACTICAL EXAMPLE

The task was to develop a probe for permanent use in water. Although water is essential for our lives and we take it for granted, it is a very complex substance for a materials scientist and aggressive to plastics.

The acoustic parameters were typical for this application:

- Frequency 5 MHz
- Relative bandwidth 80%
- Aperture 10 mm
- High echo sensitivity

In a risk analysis, the protective layer (matching layer) was identified as a critical point. To achieve optimal ultrasound properties, epoxy resins are typically used as material because they can be cast and processed further and are robust. It had to be clarified to what extent they are stable to water and what lifetime can be assumed.

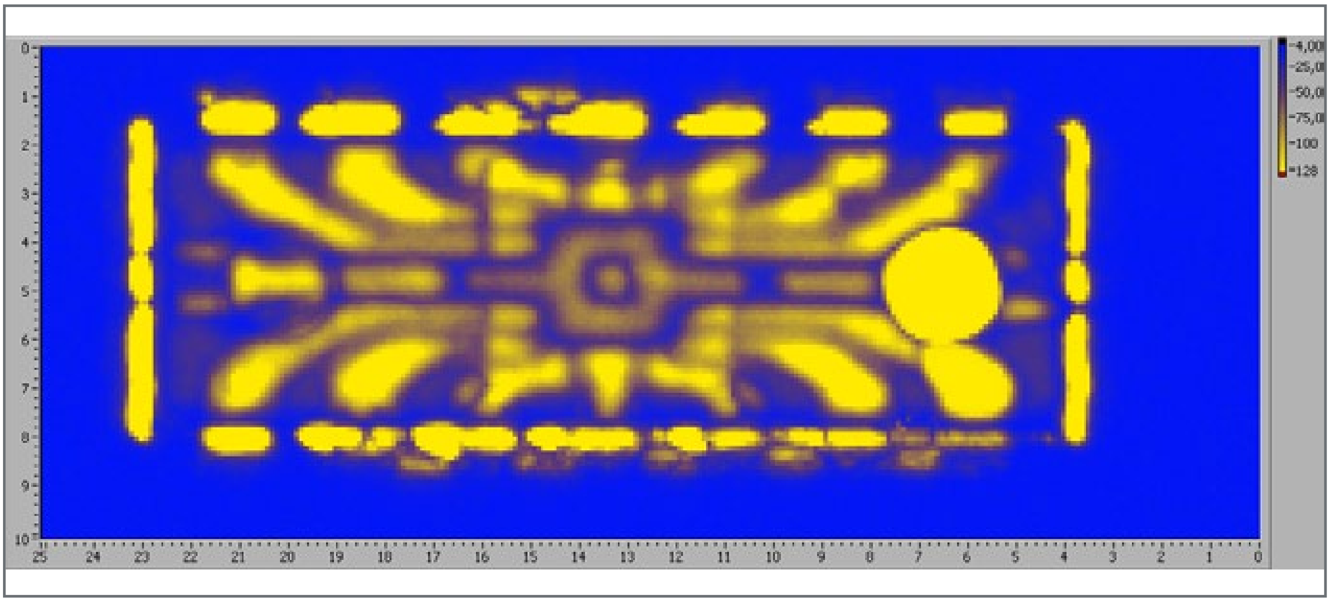


Figure 3: Ultrasonic scan presentation of an integrated circuit. It shows the inner structure and reveals deviations like voids, cracks or deformations.

Several corresponding probes were built, characterized, stressed, and re-measured with different materials. The following tests were defined to assess the stability:

a) Storage in air, -20 °C, 4 hours

b) Storage in water, 50 °C, 3 days

c) Storage in water, 50 °C, additional 7 days

d) Storage in water, 50 °C, additional 7 days

The characterization was performed according to the aforementioned procedure. The results are shown in the following figures (Figures 4 to 5):

After completion, the probe exhibits a typical echo signal. The amplitude is approximately -600 mV. A non-destructive scan of the boundary layer between the matching layer and the piezoelectric element shows a very uniform image, indicating a parallel layer and homogeneous material.

Storage at -20° C does not significantly alter this condition. Only the slight change in color indicates deformation due to different coefficients of thermal expansion.

The storage in water led to a slight decrease in echo amplitude (approximately -1 dB) with essentially identical signal shape. However, significant changes in the protective layer were visible during testing. Based on the information, it can be concluded that water infiltrates the protective layer and changes its structure. Continuing the tests is expected to lead to a progression of the effect, potentially resulting in destruction.

The tests were also carried out with other materials (Figure 5). The results are shown in Figure 6. The change in the protective layer is more severe here. Delamination is already visible at the edge. The amplitude of the echo signal has already decreased by 3 dB. Such a probe would have significantly lower stability and lifespan.

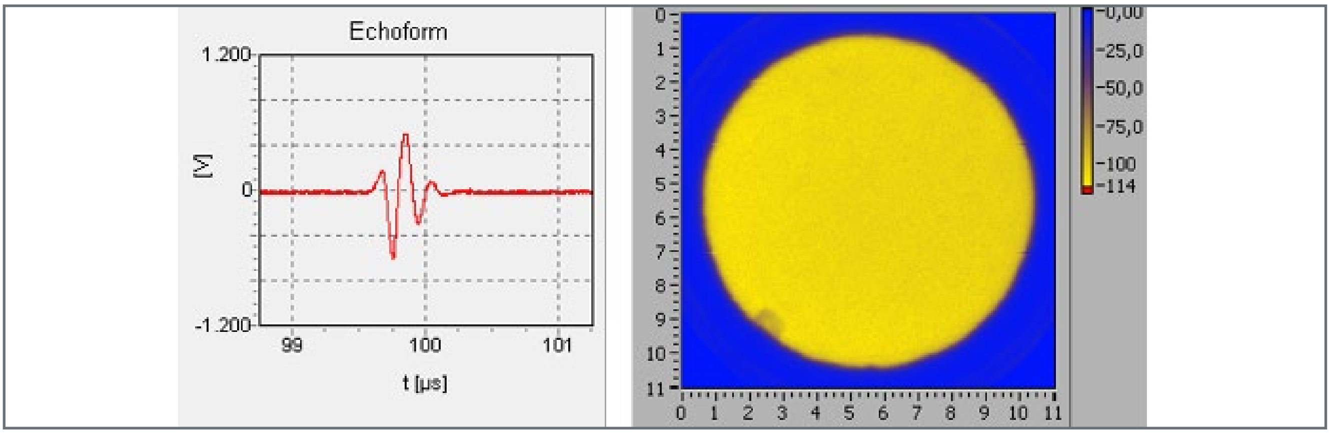


Figure 4: Initial situation, echo pulse, and scan of the protective layer-piezoelectric element connection

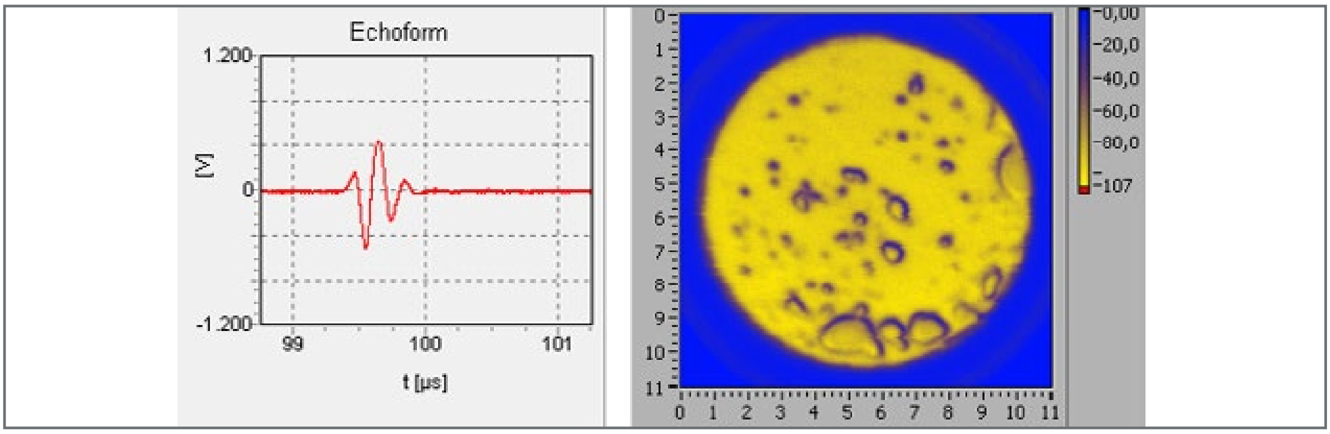


Figure 5: After (d) storage for 17 days in water

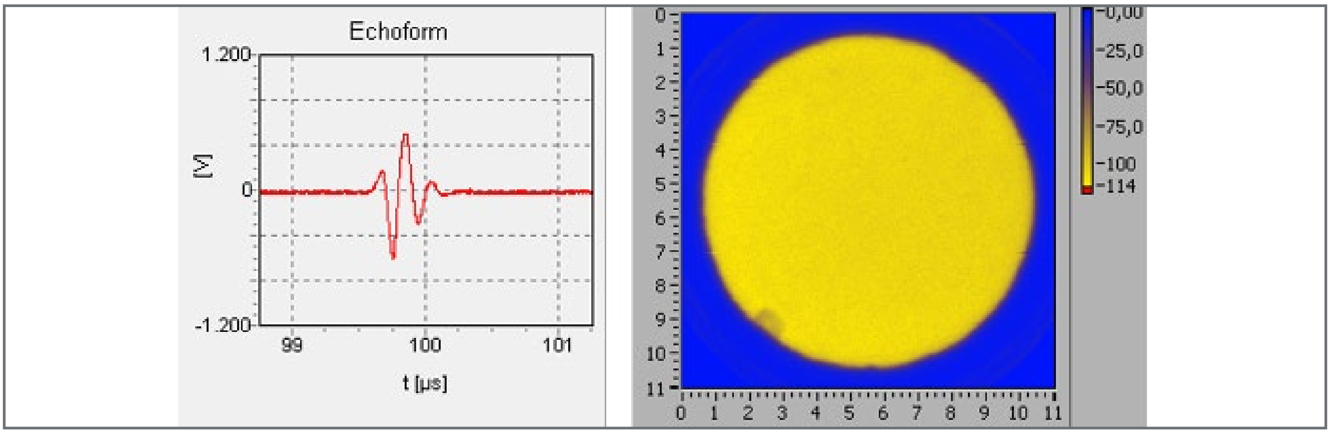


Figure 6: Reference with a different material, before the tests

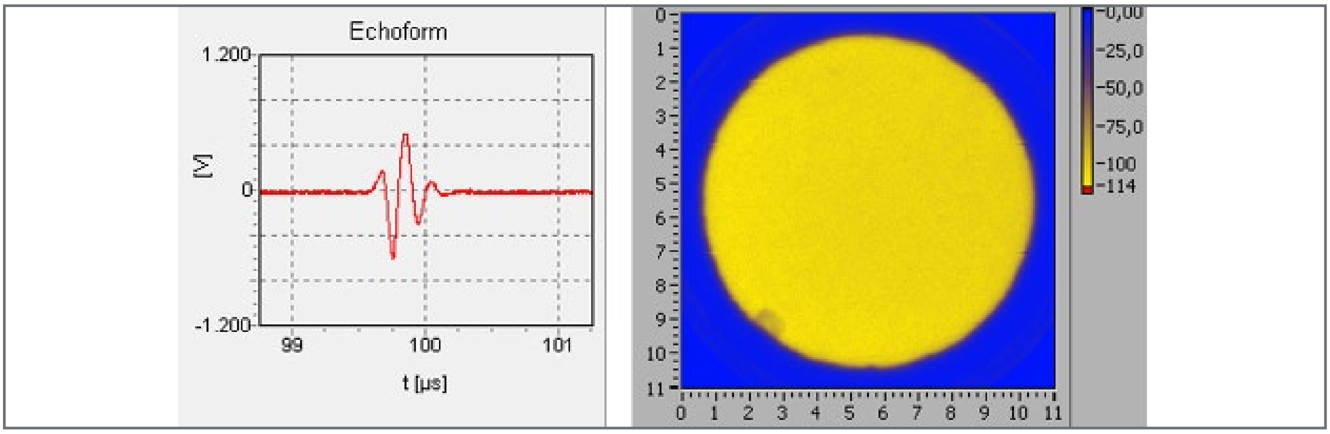


Figure 7: Reference with a different material, after the tests

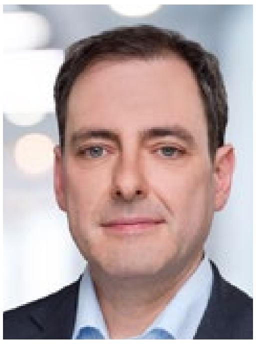
7. CONCLUSION

Ultrasonic probes are indispensable tools for non-destructive material testing. To ensure that these probes actually function reliably and correctly, regular tests to check their quality are essential. There are various investigation options depending on the requirement. If the probes do not provide accurate results, optimization of the design is possible.

Despite harsh environmental requirements, whose effect on the probe component could be observed, the acoustical parameters could be stated stable. Using these results, it was possible to ensure the operation during the expected lifetime.

Andreas Mück emphasizes: "Robust ultrasonic probes are crucial for precise pipeline inspections. Regular, intensive tests are essential to ensure quality and stability and to detect potential risks early on."

AUTHOR



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How to see what cannot be seen within a Disastrous, Highly Corroded Subsea Gas Pipeline during Repair and Pre-Commissioning Process

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Abstract

Repairing a subsea pipeline has its own special challenges. It goes from levelling the pipeline inner pressure with seabed pressure at depth of damage, to cutting the line, installation of smart flanges and spool pieces, and finally going through pre-commissioning steps and miscellaneous pigging operations. During all these steps, it is inevitable to look for a way to find out what is going on inside the pipeline. This happens to be quite challenging due to the fact that there is no easy access to the pipeline through its total length and also it would be almost difficult yet definitely expensive to follow and track each train of pigs. In this paper, a case study has been investigated on a subsea gas pipeline repair. The pipeline had a disastrous operating history and has been damaged and wet-buckled again recently. The process and challenges of pipeline repair and pigging operations are fully explained in this paper. The practical data and calculations during pigging operations are also summarized. Finally, the paper focuses on dewatering operation of the pipeline where it is not easily possible to clearly see what is going through the pipeline and one should investigate the pigging situation based on numerical calculations and comparing them with available indications. Technical challenges along with different aspects of subsea operation concerns and offshore facility requirements will be discussed.

1. Introduction

Offshore pipelines have always their own special challenges in comparison with onshore pipelines. The challenges start with designing and construction phase where one have to consider special materials for pipes, concrete coating for laying at seabed, and pipeline laying with heavy pipe-laying vessels with different methods according to different water depths. Usually J-Lay is used in deep water areas and S-Lay is used in less water depths. Subsea pipelines challenges keep going on during operation phase where the operator cannot have regular patrolling surveys which show pipeline weakness areas and prevent sudden damages before happening.

These challenges come to the most when a pipeline is damaged and needs to be repaired. The subsea pipeline cannot be easily isolated and cut unless the pipeline inner pressure is leveled with the seabed pressure at damage location. Thus, repair team is forced to be mobilized with an additional pre-commissioning equipment comprising of a full fleet of pumps, compressors, pigs and pre-commissioning procedure in order to support the repair process. In addition to that, repair process itself includes a professional subsea diving team to work at required depth and perform cutting, leveling, flange installation, aligning and adjusting the spool piece and finally tightening the bolts and nuts.

Furthermore, during pigging operations and specially while working with compressed air (i.e. dewatering operation), it is not easily possible to track the pig(s) like onshore pipelines. This usually leads to a vague situation where pre-commissioning operator has to evaluate some indications and symptoms for interpretation of complicated conditions.

All these challenges and complexities lead to a special repair process in each subsea pipeline and making it an exciting experience to share.

2. Pipeline Specifications

The pipeline in this paper is a 147km 30" subsea gas pipeline which starts from an offshore gas production platform in Persian Gulf and reaches to onshore gas facility in an island. The pipeline characteristics are summarized in following table. The depth of water through pipeline length is presented in Figure 1.

Nominal Size	30 inch	**Design Pressure**	114 bar
Outside Diameter	762 mm	**Design Temperature**	65°C
Product Transported	Export Gas	**Test Pressure**	132 bar
Approximate Length	147000 m	**Thicknesses**	20.6/17.5/15.9 mm
Material Grade	API 5L X-60 (PSL2)	**Inside Diameters**	720.8/727/730.2 mm
Corrosion Allowance	1.5 mm	**Pipeline Volume**	61000 m^3

Table 1: Pipeline Characteristics [5]

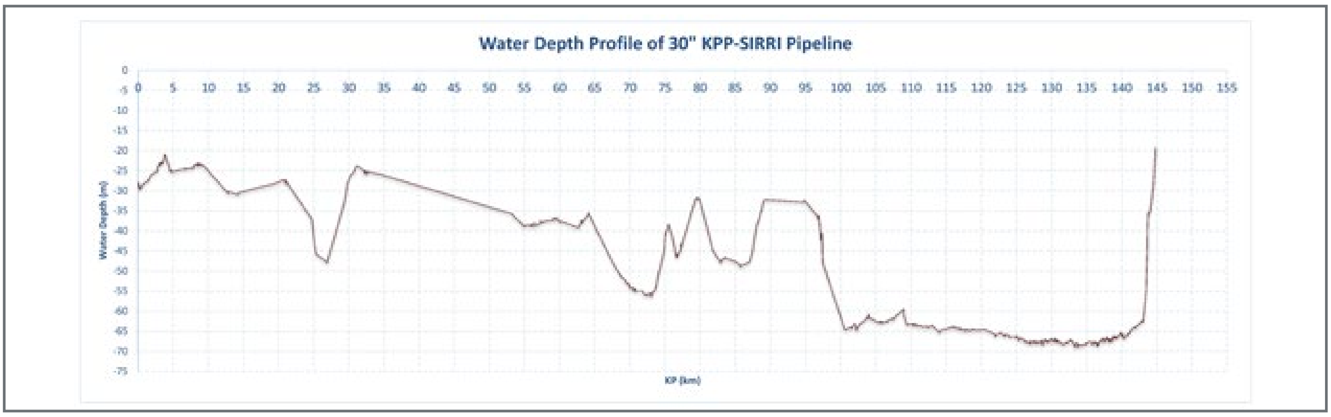

Figure 1: Pipeline Profile at Seabed [5]

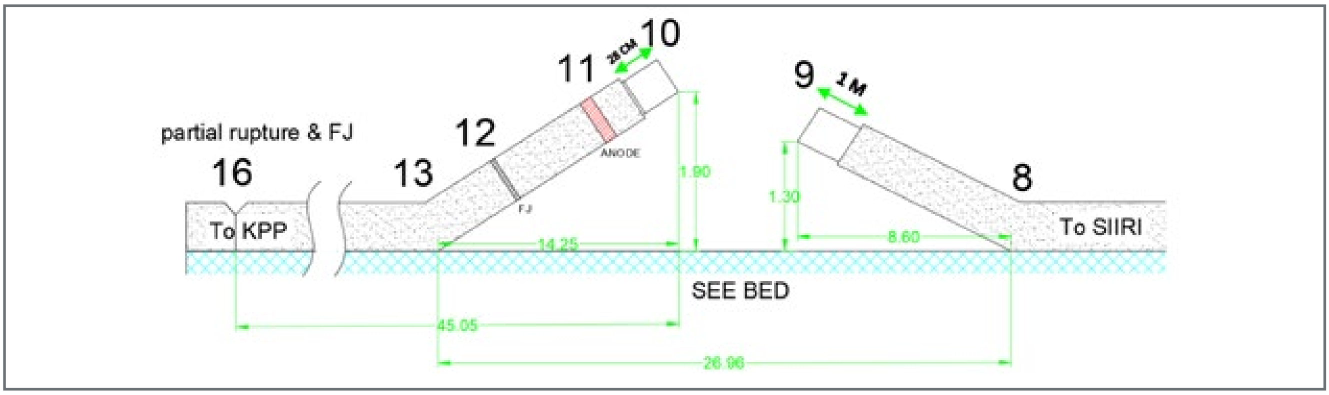

Figure 2: Side View of Ruptured Area [5]

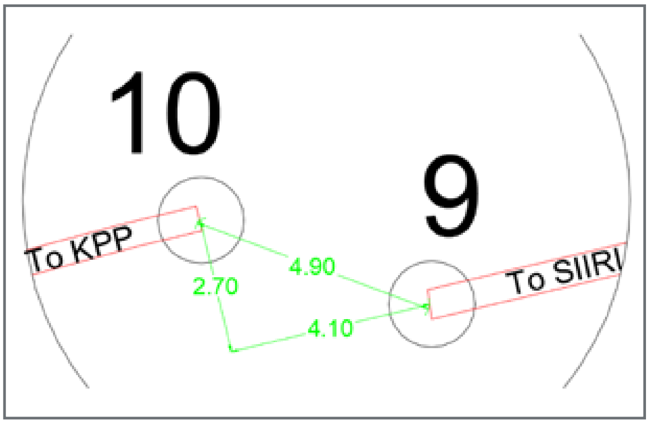

Figure 3: Plan View of Ruptured Area [5]

3. Pipeline Damage History

The pipeline has a long history of improper commissioning and maloperation. It was initially laid around 2005, yet during pipe laying a buckle situation occurred and due to unknown reasons, the pipeline was kept flooded with water for almost two years. This was the main cause of severe corrosion and later damages in the pipeline. Since then, the pipeline has experienced several leaks, repairs, spool installation and numerous clamp installations. The current damage in the pipeline happened suddenly in October 2021 when the pipeline operator witnessed a sudden operating pressure drop to zero.

A prompt survey by helicopter was done and huge bubbles were observed. Later, a subsea survey was performed and a rupture damage was reported around KP70 from platform. Based on survey details, pipeline has to be cut for repairing and spool installation and approximate length will be 72m.

The following figure shows the damage condition at seabed.

4. Repair Process

The considered process for pipeline repair is summarized as below.

1. Subsea Survey, Metrology and Manufacturing Spool Pieces
2. Degassing and Cleaning from Offshore Platform to Rupture Point
3. Degassing and Cleaning from Onshore Facility to Rupture Point
4. Cutting and Installation of Smart Flanges and Spool Pieces
5. Leak Testing
6. Dewatering Operation
7. Swabbing, Drying and Commissioning

5. Initial Degassing and Cleaning

Before the damaged sections of the pipeline are to be cut, the pipeline shall be evacuated from any remaining flammable gases. Although the pipeline is already flooded due to big wet-damage, it was suspicious that some remaining gas might endanger the operation. Thus, for the purpose of safety improvement, a Poly Coated High Density Foam Pig was considered to be propelled through the pipeline in order to evacuate the pipeline from remaining products. This pig running operation was performed from both sides of the pipeline (i.e. launching one pig from platform to rupture point and launching another pig from onshore to rupture point). This operation was performed by injecting filtered sea water (treated with corrosion inhibitor) behind the pigs. This operation was entitled Degassing operation.

After degassing operation, it was decided to clean the pipeline by running metal body pigs. Since the pipeline required appropriate cleaning, this was an opportunistically decision to be made due to following reasons:

- The pipeline was expected to contain a huge amount of debris and corrosion product due to its mentioned history;
- Since the 147km pipeline was already divided into two almost half sections, it was easier to clean each section separately;
- The risk of debris accumulation and pig stuck would largely be decreased in shorter sections of the pipeline;
- If the cleaning operation was to be performed after integrating the pipeline, it was almost not possible to receive the huge amount of debris and corrosion products in either offshore platform or onshore facility. So, discharging the debris at seabed was the only solution to this problem.

Due to abovementioned reasons, two separate cleaning pig runs was performed on each section of the pipeline. These pig running operations were also performed by injecting filtered seawater which was treated by corrosion inhibitor and biocide. The selected pig type was an especially designed pig which was a combination of cup and Bi-Di pigs which is here called a combination pig. This pig is shown in following figure. As it can be seen, it consists of both sealing disks (for sealing purposes, water displacement and bi-directional application) and cup disks (for high resistance against abrasion and long distance application). The guide disks, as always, provide pig stability, alignment and, more importantly, displacement of debris.

An important decision made here was to avoid running brush pigs in this pipeline. The reason why is that it was believed the pipeline with its disastrous operating history is severely corroded and has a large deal of loose debris and high roughness inner wall. It means no matter how many runs of brush pigs are propelled through the pipeline, receiving corrosion products will not finish. That is because in a highly corroded pipeline the more you scrap the inner wall, the more debris will be produced and there is no end to it. Hence, it is very important to treat these kinds of pipelines gently.

During all pig running operations, accurate data measuring was performed and required data for evaluation of the situation were collected. This includes both pipeline pressure and volume of injected water. These information help the pigging operator to estimate the pig location based on injected volume of water and also evaluate the pigging condition based on pipeline pressure so that he can adjust the equipment accordingly. The summary of recorded data during degassing and

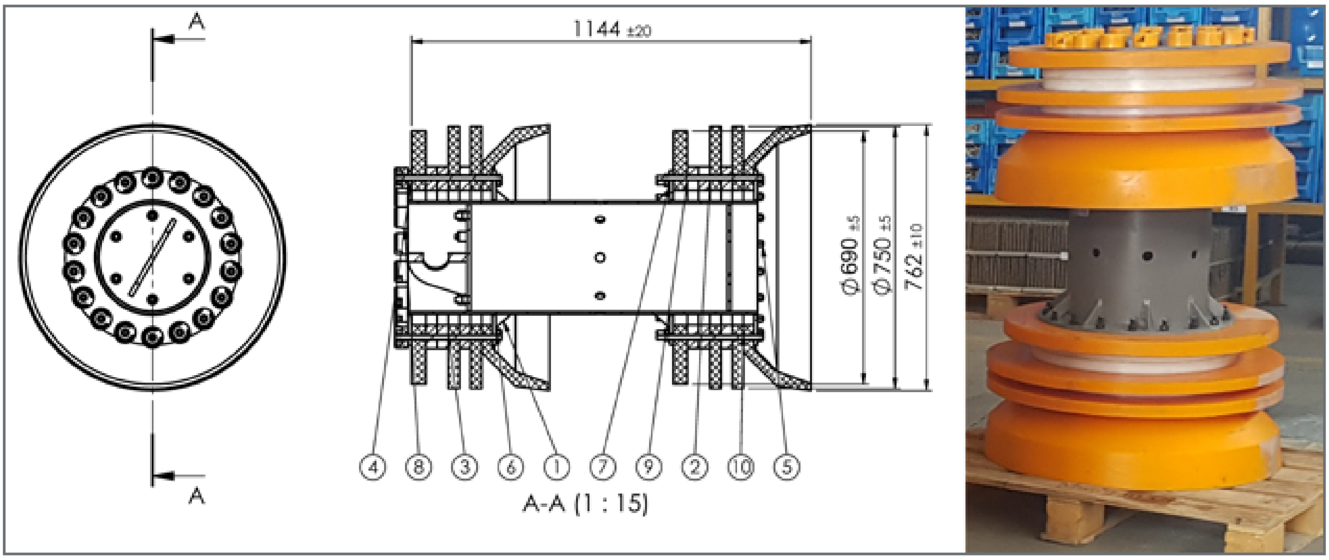

Figure 4: Drawing of Bi-Di/Cup Combination Pig [5]

cleaning operations are illustrated in following figures. It should be noted that since water is incompressible, the pig location in these graphs is calculated according to the measured water volume behind the pigs divided by the cross sectional area of the pipeline.

As it can be seen in above diagram, during first cleaning operation, a pig stuck condition occurred around KP35 from platform leading to pressure increase up to maximum available pressure of flooding pumps. In this case, a plunger pump (so called as test pump) was utilized in order to pressurize the pig back pressure up to 40 bar. At this pressure, the pig was released and the rest of the operation was continued.

As it can be seen in both above figures, the more cleaning pigs have been propelled through the pipeline sections, the softer has become the running of next pigs. Each pig is being run with lesser pressure requirement than its previous pig.

When performing pig running operations in such a challenging pipeline, reliable pumping equipment are vital. Usually, multi-stage centrifugal pumps are utilized for running the pigs with water. Proper pumps shall be selected carefully, and more importantly in offshore operations, it is recommended that diesel engine driven pumps be mobilized. In addition to that, it is very crucial that one should always consider spare pumps when working on offshore platforms and vessels.

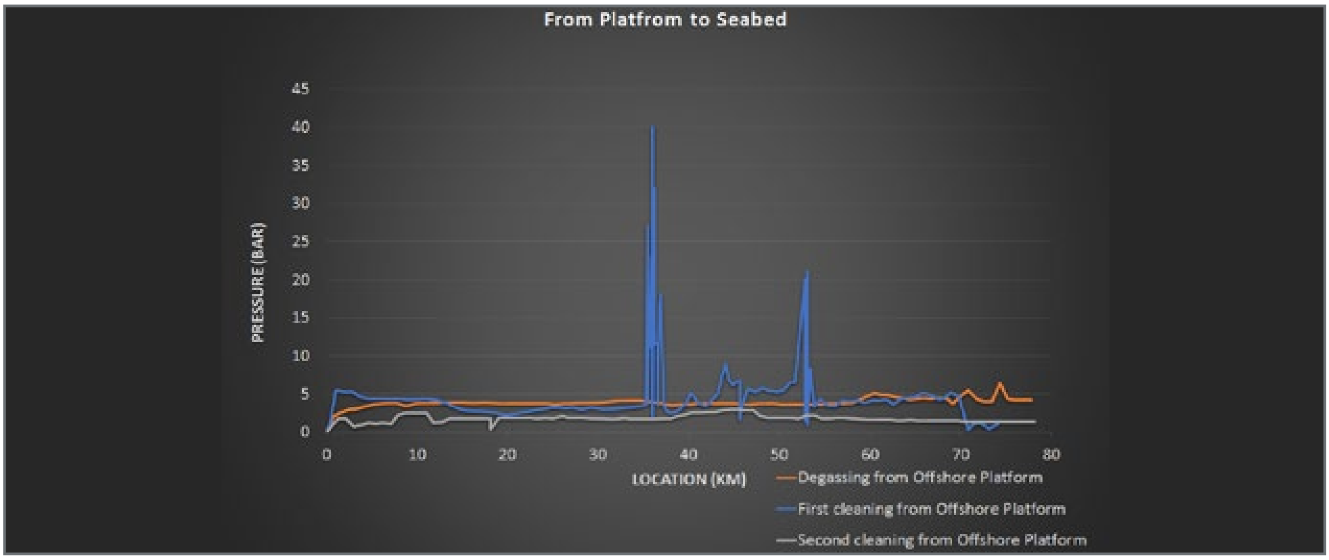

Figure 5: Pipeline Pressure vs. Estimated Pig Location during Pigging Operations from Offshore Platform to Rupture Point [5]

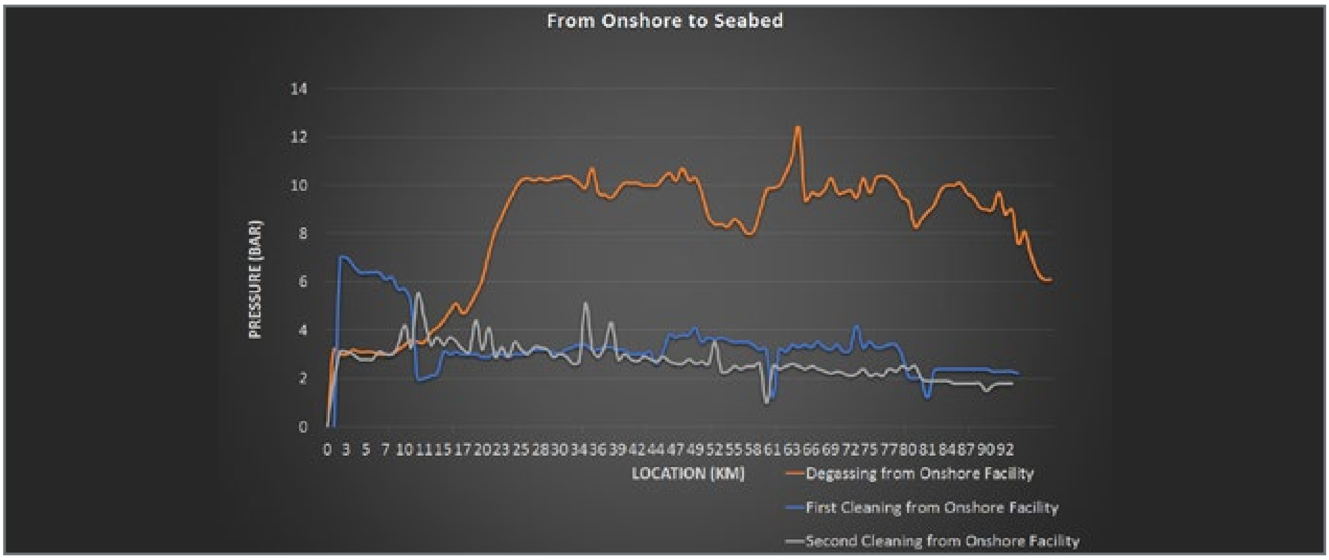

Figure 6: Pipeline Pressure vs. Estimated Pig Location during Pigging Operations from Onshore Facility to Rupture Point [5]

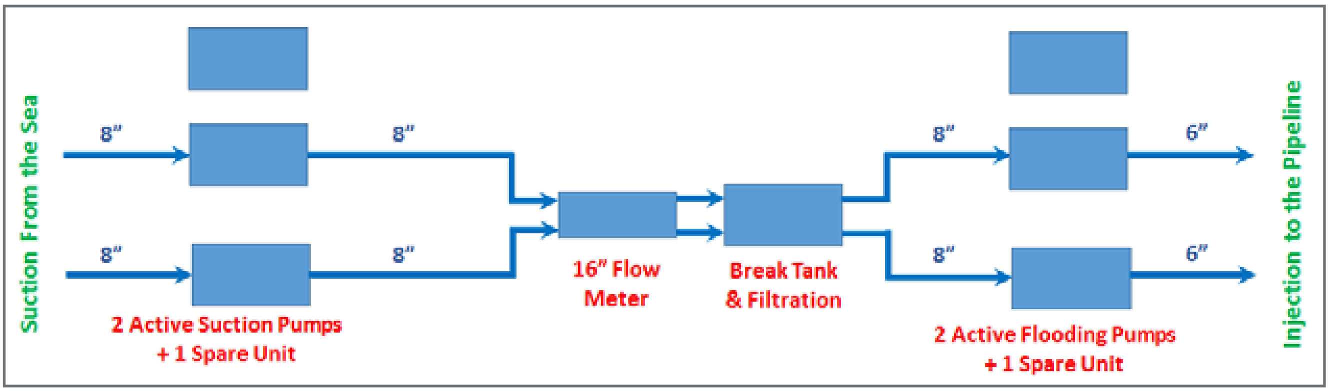

Figure 7: Schematic Arrangement of Water Injection Equipment

Furthermore, when such an operation is required to be performed from platform side, a suitable vessel shall be selected. A vessel that not only provides enough deck space for placing the pumping equipment and consumable materials, but also has the ability to withstand its stability during weather conditions in order to maintain the continuity of pigging operations besides platform.

The utilized equipment in this project are described and illustrated in Figure 7 and Table 2.

All below equipment along with all consumables (pigs and chemical barrels) and all operating personnel were mobilized onboard an offshore vessel during the pigging operations from platform which is shown in following Figure 8.

6. Smart Flange and Spool Piece Installation

After completion of cleaning operations, the two sections of the pipeline are ready to be integrated. The selected method here for this purpose is installation of smart flanges. Among different techniques to mitigate

Suction/Feeding Pumps		Flooding/Filling Pumps	
			
Model	WP 200/80	**Model**	WKL 150-6
Type	Centrifugal self-priming	**Type**	6 stages with mechanical seal
Maximum Capacity	550 m^3/hr	**Maximum Capacity**	440 m^3/hr
Maximum Head	30 m	**Maximum Head**	308 m
Vacuum Lift	8.8 m	**Suction**	8"
Suction & Discharge	8"	**Discharge**	6"
Engine	DEUTZ F4L 912	**Engine**	VOLVO TAD1642VE
Maximum Power	46 kW @ 2000 rpm Air Cooled	**Maximum Power**	494 kW @ 1800 rpm 478 kW @ 1450 rpm

Table 2: Technical Specifications of Suction Pumps and Flooding Pumps [5]

Figure 8: All Equipment onboard Offshore Vessel besides the Platform [5]

the damaged section of pipeline, using smart flanges is a fast and applicable approach which is of interest for offshore industry. The product offers pipeline and riser repairs without the need for hyperbaric welding and can be installed in driverless applications. It should be noted that subsea smart flange installation and pipeline repair is fast and easy if performed right. On the other hand, special cares have to be paid during installation and operation to put the integrity of pipeline in safe side [3].

After installation of two sets of smart flanges at both pipeline ends at rupture point which are already cut, spool piece(s) shall be installed. Here, the 72 meter spool which consists of two spool pieces, has been manufactured earlier at onshore factory and transferred to the offshore installation location. The spool pieces shall be manufactured based on metrology which has been performed earlier at seabed. Once the smart flanges and spool pieces are aligned and adjusted, all bolts shall be tightened so that the smart flanges are activated.

Another critical challenge that happened during this project was presence and troubles of Sulphuric contents at seabed. To be more specific, once the pipeline contaminations were expelled by pigging operations at seabed and due to high Sulphur content of the gas reservoir, Sulphuric contaminations were spread at seabed around the rupture area. This led to huge troubles for divers working on smart flange and spool installation. The contamination caused the divers with body burns and scalds on their feet due to acidity of the expelled debris. Finally, the divers had to use high resisting clothing to clean the whole area by means of mud lift operation. Approximately 5000 m² of seabed was cleared by mud lift before starting the smart flange and spool installation job.

7. Leak Test

Any pipeline repair process includes a kind of testing in order to make sure there are no other leaks or damages present and the pipeline integrity is ensured. Most importantly, here and in such subsea repair projects, it is essential to make sure that smart flanges and spool pieces (which are new objects recently installed on the

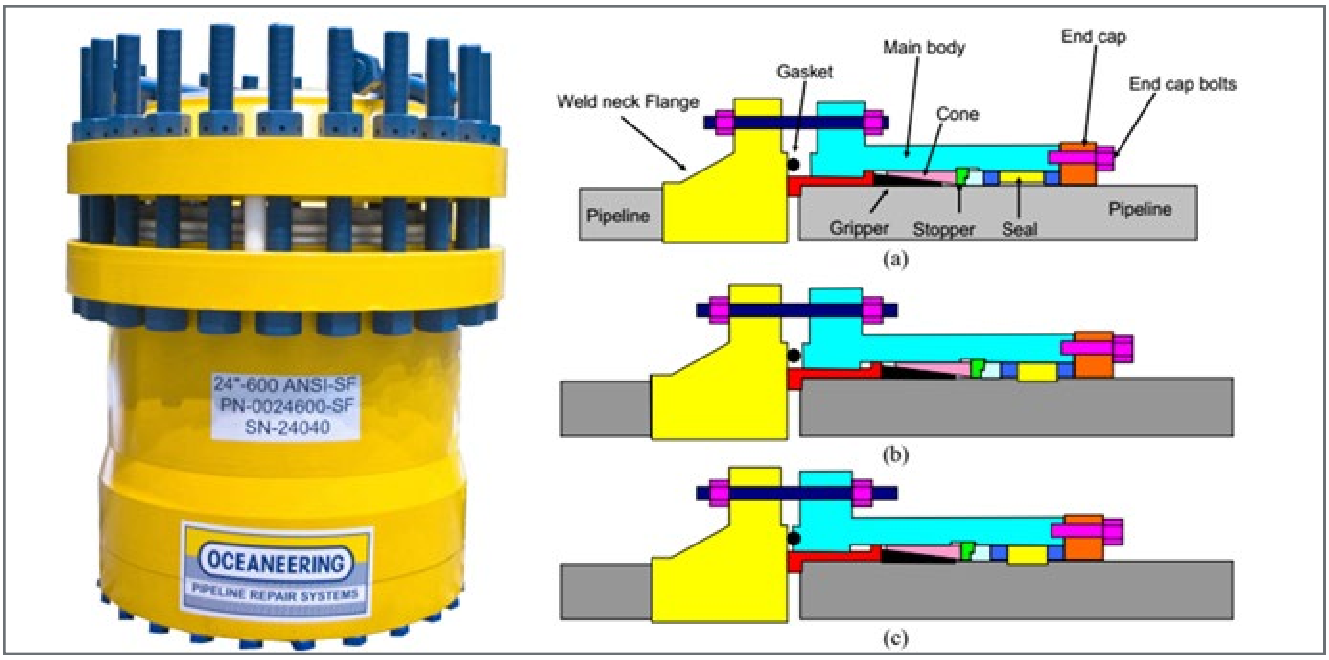

Figure 9: Left: A Typical Smart Flange, Right: (a) Internal mechanism of smart flange, (b) Sealing energized and (c) Gripping activated [3]

pipeline system) are free from leaks. For this purpose, a leak test operation was considered. Yet, the major issue was how to select a proper test pressure. As it was mentioned earlier, the pipeline had a catastrophic background and since no In-Line inspection operation had been performed on the pipeline recently, and thus, no FFS or FFP was available, selecting a proper test pressure was quite challenging. Normally, what goes through these situations is as follows [4]:

1. A Fitness-For-Service report be prepared according to the latest ILI operation;
2. Pipeline MAOP be adjusted according to FFS report;
3. Leak test pressure be selected according to MAOP.

Despite the mentioned steps, since no late ILI report had been available on this pipeline and also due to the fact that the pipeline rupture had been occurred at a pressure lower than pipeline MAOP, rather conservative considerations led to selecting of 60 bar pressure value as leak test pressure.

The leak test operation was completed successfully and the pipeline proved its integrity for withstanding the pressure of 60 bar and was ready for dewatering operation which was expected to be the most challenging operation in whole project.

8. Dewatering

As it was mentioned earlier, the dewatering operation in this project was expected to be the most challenging step of the job. The reasons for that can be summarized as follows:

1. According to pipeline history, the pipeline inner wall is believed to have high roughness;
2. The long length of pipeline (150km) along with its roughness provides a severe abrasive circumstance for pigs` polyurethane disks;
3. The pipeline profile (figure 1) includes intensive high and low fluctuations which impose additional risks to the pigging operation;
4. The pipeline after integration (150km) has not been pigged and earlier pigging operations were performed in shorter lengths (70km and 77km). It means that the piggability of the pipeline is not ensured yet.

According to pipeline condition, it was decided to run four pigs in dewatering train. The first two pigs carry a batch of fresh water to desalt the inner wall of the pipeline which has been in full contact with sea water. The amount of fresh water equals to 2% pipeline length [1]. The next pigs push the train and remaining water after the first pig to be expelled out of the pipeline. The selected type of pigs were the same Bi-Di/Cup Combination pig (figure 4) which proved to be successful during the previous pigging steps. The Figure 10 shows the arrangement of the dewatering train.

The pigs were propelled by means of oil free compressor station with capacity of maximum 4190 cfm which were mobilized on the vessel deck alongside of the platform. In order to estimate the pig train location, a theoretical calculation was being done. Since air is compressible, the pig location is calculated according to the following equation.

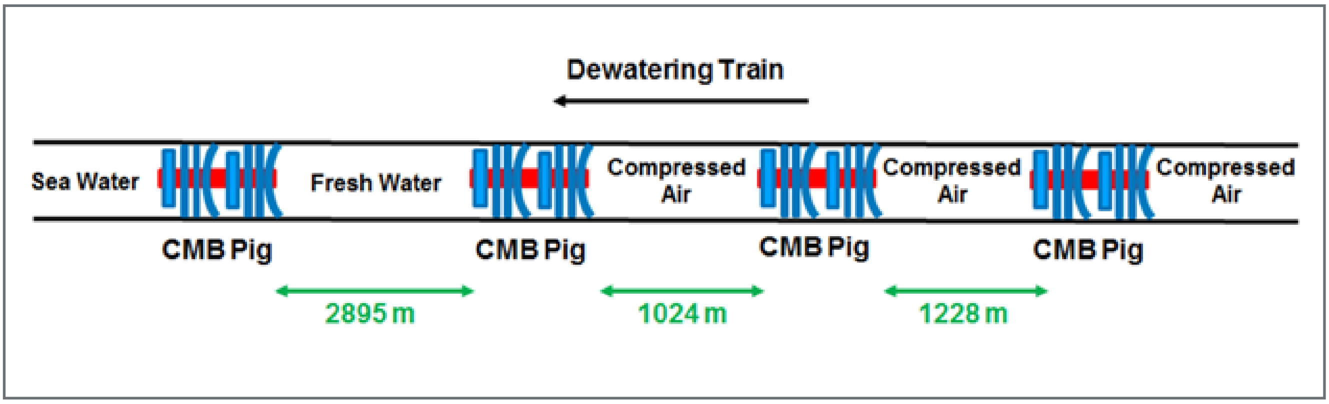

Figure 10: Arrangement of the Dewatering train as performed [5]

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Where:

P_1: Atmospheric pressure

V_1: Injected volume of air at atmospheric pressure (compressor station intake)

T_1: Ambient air temperature

P_2: Pipeline pigging pressure

V_2: Injected volume of air at pipeline pressure (compressor station discharge)

T_2: Injected air temperature (compressor station discharge)

Thus, the pig location will be calculated with dividing V_2 by pipeline cross sectional area.

During the dewatering operation, all above mentioned parameters were recorded and pig location calculation was being done continuously. Also, water discharge at receiving location at onshore was being simultaneously monitored. Yet, some challenges came along

Date and Time	Flow Rate (cfm)	Pressure Range at Platform (bar)	Remarks / Outlet Condition at Onshore
2:10 on 7 Aug. to 20:30 on 7 Aug.	1600	1.5 ~ 9.0	Launching the four pigs one by one
22:30 on 7 Aug. to 4:00 on 10 Aug.	2240	Fluctuating from 7.5 ~ 8.7	Continuous water discharge through 2 x 6" pipes. Pressure range: 1 ~ 2 bar
4:00 on 10 Aug. to 16:00 on 10 Aug.	2240	Pressure rise from 8.5 to 10	4:00 ~ 8:40, no water discharge 8:40 ~ 10:15, full discharge 2 x 6" 10:15 ~ 11:30, small discharge 2" 11:30 ~ 16:00, no water discharge
16:00 on 10 Aug. to 14:30 on 11 Aug.	2240	Pressure decrease from 10 to 9.1	16:00 ~ 2:00, 1 x 6" discharge 2:00 ~ 14:30, full discharge 2 x 6" 14:30 ~ 15:30, no water discharge 15:30 ~ 9:00, full discharge 2 x 6"
14:30 on 11 Aug. to 15:30 on 11 Aug.	2240	Small pressure rise 9.1 to 9.2	No water discharge.
15:30 on 11 Aug. to 9:00 on 12 Aug.	2240	Pressure decrease from 9.2 ~ 8.6	Full water discharge 2 x 6"
9:00 on 12 Aug. to 15:40 on 12 Aug.	4190 *(Compressors Added)*	Slight pressure increase 8.6 ~ 9	Full water discharge 2 x 6"
15:40 on 12 Aug. to 15:30 on 15 Aug.	4190	Pressure rise from 9.0 ~ 16.5	Sudden discharge stoppage. No water discharge.
15:30 on 15 Aug. to 18:45 on 15 Aug.	4190	Pressure drop from 16.5 ~ 15.7	Sudden water discharge 2 x 6" full. Sudden pressure rise to 10 bar. Pressure range: 7 ~ 6 bar. At 18:45, discharge stoppage.
18:45 on 15 Aug. to 11:30 on 16 Aug.	4190	Pressure rise from 15.7 ~ 16.9	No water discharge.
11:30 on 16 Aug. to 12:00 on 16 Aug.	4190	Pressure steady at 16.9	Sudden water discharge 2 x 6" full. Decrease in water discharge. At 12:00, discharge stoppage.
12:00 on 16 Aug. to 23:00 on 16 Aug.	4190	Pressure rise from 16.9 ~ 17.5	No water discharge.
23:00 on 16 Aug. to 23:59 on 16 Aug.	4190	Pressure steady at 17.5	Full water discharge 2 x 6" for 10 minutes. Then, 1 x 6" water discharge. At 23:59, discharge stoppage.
00:01 on 17 Aug. to 14:00 on 17 Aug.	4190	Pressure rise from 17.5 ~ 18.3	00:45 ~ 2:45, small discharge 3" 3:30 ~ 6:20, small discharge 3"
14:00 on 17 Aug. to 12:00 on 18 Aug.	4190	Pressure rise from 18.3 ~ 19.4	No water discharge.
12:00 on 18 Aug. to 11:00 on 20 Aug.	4190	Pressure rise from 19.4 ~ 22.0	Inserting shocks. Stopping all compressors.

Table 3: The pressure recordings during hours of the dewatering operation

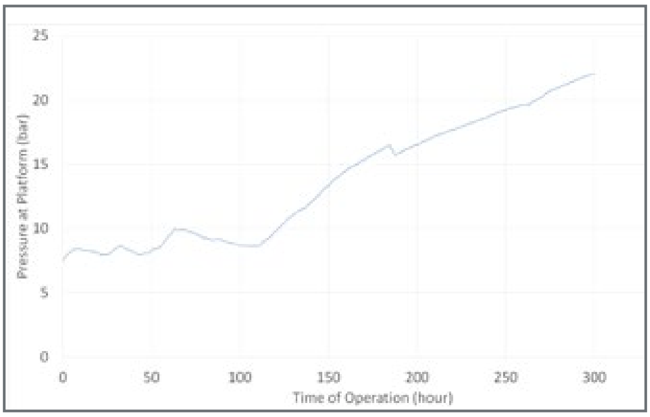

Figure 11: Pressure Recordings during Hours of the Dewatering Operation [5]

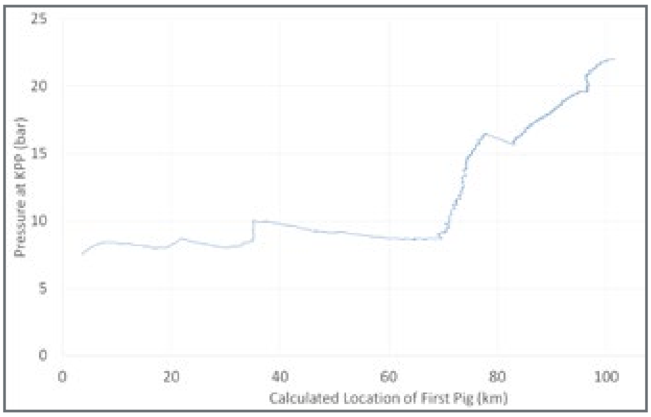

Figure 12: Calculated Location of the First Pig of Dewatering Operation [5]

which faced the operation with critical problems. The water discharge was stopped and it was perceived that the pig train is stuck. The pipeline pressure (which was around 8 to 10 bar during the operation) started to rise sharply and increased up to 22 bar. Several observations were made during all undesirable happenings which can be seen in related graphs.

The pressure recordings during hours of the dewatering operation listed in Table 3 is illustrated in Figure 11.

Based on earlier-explained equations, the hours of air injection can be correlated to pig location. It means that by multiplying air injection rate by hours of injection, one can obtain the accumulated amount of injected air which will be used to calculate an estimated location for the pig train. It should be noted that since air is compressible, the calculated location of the pigs is highly dependent to pipeline pressure. This fact adds some miscalculations and contradictions in illustrated graph which might be incoherent and not real. Yet, the total perspective and big picture shall be taken into view.

As it can be seen in Figure 12, the water discharge stoppage and pipeline pressure increase has been occurred at around KP 102 of the pipeline. It can be concluded that from that moment (water discharge stoppage) the pig train has not moved. Thus, the calculated location after that point is calculation error due to compressible nature of air. In addition to that, once the pigs get stuck, some bypass flow forms around their disks. The amount of this bypass flow cannot be known without knowing the geometrical position of the pigs. But, since it is known that pigs` location is fixed and pigs are not moving, the amount of this bypass flow may be guessingly calculated by performing some numerical adjustments on the above graph. Also, it can be presumed that the amount of hypothetical bypass flow may differ at different stages with different diagram slope. After performing some numerical calculations for adjusting the diagram, following results were derived.

The indicated areas in the above figure are to be described

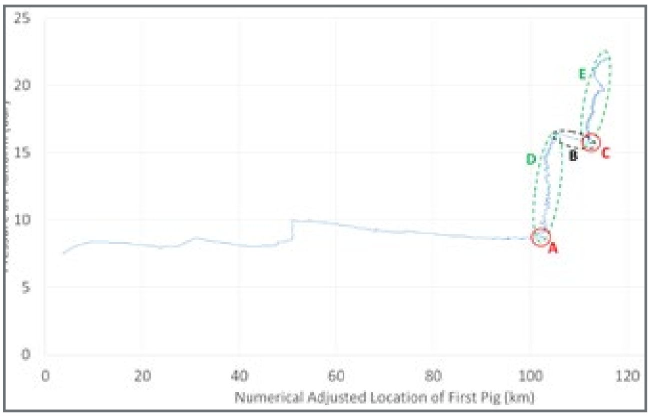

Figure 13: Calculated Location of the First Pig of Dewatering Operation after Numerical Adjustments and Reduction of Hypothetical Bypass Flow [5]

as below:

A. Sharp pressure rise once the first pig gets stuck at KP 102 and water discharge at onshore is stopped.

B. Pressure decrease as the first and second pigs are released temporarily and water discharge is being received at onshore.

C. Sharp pressure rise once the third and fourth pigs are stuck at KP 102 and water discharge is stopped again.

D. This area still includes numerical error which makes the diagram not very clear. It is known that the pig is not moving since no water is discharged at onshore. The amount of bypass flow which had to be deducted in this area is numerically calculated to be around 1100 m^3/hr.

E. This area still includes numerical error which makes the diagram not very clear. It is known that the pig is not moving since no water is discharged at onshore. The amount of bypass flow which had to be deducted in this area is numerically calculated to be around 2500 m^3/hr.

After the pigs got stuck, different actions were made leading to inserting shocks from receiving side. This was not finally successful since the pipeline pressure at launcher side reached to 22 bar which was the maximum available pressure of compressor station. Inserting shocks from receiving end did not result in any more water discharge and pigs movement. Thus, the operation was held on standby so that further decisions will be made accordingly. Nevertheless, an unexpected event occurred.

9. Second Damage

On 23 August, the pipeline pressure at platform (launcher side) unexpectedly started to drop sharply. It dropped from 22 bar down to 6.7 bar without any actions being made on the pipeline and stayed steady even with compressor station working. This event was concluded to be a new damage on the pipeline due to two major reasons:

1. This amount of sharp pressure drop could not be correlated to any other phenomena.

2. The 6.7 bar steady pressure could easily be correlated to the depth of pipeline at KP 102 (pig stuck location).

Consequently, an ROV survey was planned to be performed around suspicious area. The result is presented in Figure 14 which shows a wide rupture at KP 102 with stuck pigs being visible.

Just like the repair process for the first damage, the second damage was also went under similar repair process. Cleaning from both sides, pipeline cutting, smart

Figure 14: ROV Result on Second Damage of the Pipeline [5]

Figure 15: Recovered Stuck Pigs from Damaged Location (Third and Fourth pigs of first Dewatering Operation) [5]

flange and spool piece installation.

The strange witnessing during the second repair was when the cut section of the pipeline was recovered and the stuck pigs were removed. As it was mentioned in earlier sections, the third and fourth pigs of dewatering operation were remaining stuck at damage location. These pigs were recovered after cutting the damage area of the pipeline are shown in Figure 15.

The imposed damages on the pigs are extraordinary. There were no disks left on the pigs which was such a rare thing to be observed in any pigging operation. Thus, the pipeline is going through another flooding, repair and dewatering operation accordingly.

10. Conclusion

Based on the discussed matters in this paper, following conclusions and recommendations can be presented.

1. Historical bad operating of the pipeline and unnecessary keeping of water inside pipeline has made it highly corroded and almost un-repairable.

2. Huge amount of Sulphur content has severely made corrosion process faster and more disastrous, making it hardly operable.

3. During repairing process and pre-commissioning of such corroded pipelines:

   a. It is better to clean the pipeline before repair process and not after it.

   b. It is recommended to start cleaning process with softer pigs and progressing towards harder and metal body pigs.

   c. It is highly required that cleaning pigs be run one by one and not in a pig train.

   d. Using of brush pigs is not recommended in such corroded pipelines as it scrapes the pipe wall to its end.

   e. It is easier to expel the pipeline debris at seabed, yet consideration on acidity content at seabed shall be made.

   f. Before starting the repair process of such ruptured pipeline, it is recommended to perform a full ROV survey on the pipeline in order to look for further probable and potential damages.

   g. During all steps of the project, fast access to ROV survey is an important privilege for appropriate decision makings.

   h. For dewatering operation, it is recommended that pig train be divided into smaller trains and even better to run pigs one by one.

All in all, in such offshore projects and subsea pipeline repair and pre-commissioning operations, all necessary arrangements and equipment shall be provided and all possible probabilities shall be taken into considerations before starting the job. The repair team shall be ready for any possible and undesirable events.

11. Acknowledgment

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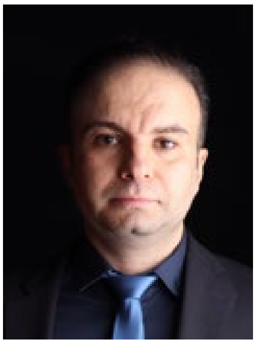

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In-pipe Ultrasonic Inspections of Mud and Tailing Lines: how to manage difficult to remove Scaling, provide quality and accurate Defect Assessments of steel and HDPE

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Abstract

Rio Tinto Yarwun Aluminium Refinery (RTY) is expanding its pipeline integrity assessment technologies. As part of this effort, RTY has been working with Intero Integrity Services (Intero) to introduce Intero's Pipeline Surveyor services, a free-swimming pipe inspection tool.

Rio Tinto is one of the world's largest mining companies, operating in 25 countries with a portfolio that includes iron ore, copper, aluminum, lithium, and other materials needed for everyday life. The Yarwun Aluminum Refinery located in Gladstone, Australia is operating since 2004. Australia is a country with very strict regulations and a tight social license to operate.

There is a need to provide it's owners with suitable technologies and methods to offer inspection technologies not only to detect pipeline defects, but also to evaluate the integrity and safety of their pipelines.

RTY has been working since 2019 to introduce Intero's Pipeline Surveyor as inspection technology for difficult-to-inspect mud, slurry, and caustic pipelines. In 2021 an inspection was carried out on an 8kms steel mud line of DN750.

This paper will provide an overview of the Pipeline Surveyor technology and information on the evaluation of inspections conducted for its application in Australia.

1. Introduction

RTY's has an in-house department for asset integrity with expertise in pipeline integrity assessment technologies. This chapter presents the background of this initiative and the technologies that RTY currently possessed.

1.1 Background

The total length of mud and slurry pipelines at Rio Tinto worldwide will be hundreds of kilometers. This can be broken down between steel and HDPE pipelines. All pipelines in Australia are constructed in accordance with AS2885 and take in consideration these lines can be in some very remote areas.

Due to asset aging, environmental changes, as well as government regulations, emphasis is beginning to be placed on pipeline maintenance and management, and interest in integrity assessment technologies is growing. In response to these changes, Rio Tinto has begun to expand integrity assessment technologies.

1.2 Integrity Assessment methodology of RTY

RTY has proprietary methodologies for pipeline maintenance and integrity assessment. RTY did not have a technology to assess the integrity of the pipe body. Therefore, this aspect needed to be expanded.

There are many mud and tailing pipelines in Australia. In addition, since there are many pipelines with complex alignments that weave through gaps in other infrastructure, there are many "unpiggable" pipelines in Australia. Therefore, RTY has been working with Intero since 2019 to apply Intero's free swimming, Pipeline Surveyor, in Australia.

1.3 Pipeline Surveyor

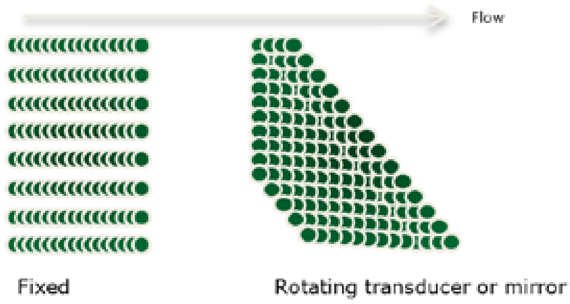
For maximum flexibility, the system applies a contact-free ultrasonic measuring head that is able to scan the full surface of the pipe wall. Dual diameter, mitered bends, full-bore unbarred tee pieces, and single-entry configurations are well within the capabilities of our system and can be inspected utilizing regular, high, and ultra-high resolutions. The pipeline Surveyor aims for unpiggable pipelines ranging from 2" to 64" and located from subsea offshore to remote areas anywhere in the world.

Matrix

- Multiple transducers evenly distributed over the tool's circumference
- High speed

Helix

- Rotating mirror covering entire pipe wall
- Flexibility to increase resolution and/or measurement grid



2. Preparation

Mud and tailing lines tend to have thick layers of scaling which requires a tailored cleaning program.

2.1 Selecting the right inspection method

Although the pipe characteristics allowed for a Magnetic Flux Leakage (MFL) inspection, the anticipated amount of scaling had the potential to result in a blockage. A combination of pipe geometry factors, such as back-to-back bends, multiple wall thicknesses, as well as a very tight receiving area too small to receive an MFL tool, resulted in Intero's Pipeline Surveyor being selected for the job. The biggest challenge using an UT ILI tool was getting the pipeline sufficiently clean.

2.2 Launching and receiving

For launching the permanent installed equipment was to be used. The launcher was, however, likely designed for MFL operations. To launch the single body Surveyor correctly a special push rod was designed to safely push it into position.

The mudlines are open ended during normal operations. A challenge was the receiving area which has very limited space, hence a tailored receiver was built for the job with sufficient capacity to release scaling.

Figure 1: A combined effort Rio Tinto, Contract Resources and Intero

Figure 2: Launcher location during launch of gauging bidi

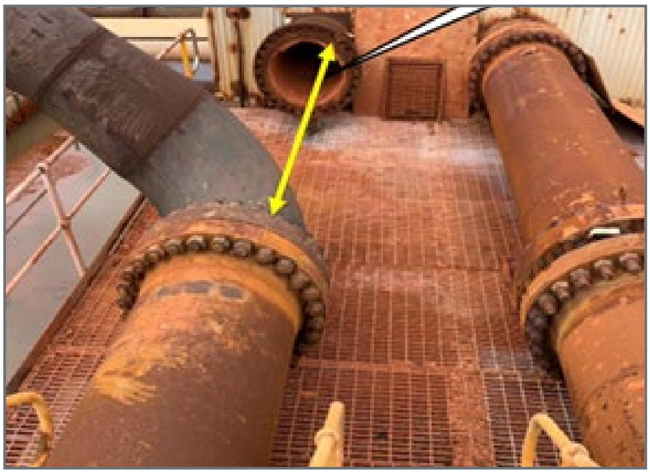


Figure 3: Tight receiver location

3. Execution

In September 2021 the pipeline inspection was executed. The overview and results of the inspection are presented in this chapter.

3.1 Purpose of the Inspection

RTY had indications, based on manual Ultrasonic Thickness Testing results, that areas of the pipeline were close to minimum allowable thickness. This was particularly the case around the 6 o'clock position due to erosion corrosion. Since the pipeline had underground sections a fit for purpose inspection was required which meant a full 100% coverage inspection was required.

Key pipeline characteristics:

Diameter: DN750

Length: 7945m

Wall Thicknesses: 9.5 mm, 12.7 mm and 15.9 mm

3.2 Cleaning

In consultation between RTY, Contract resources and Intero a progressive cleaning program was determined. The challenge was to remove the hard scaling, so it was clean enough for ultrasonic inspection and not too aggressive to damage the pipe wall.

After a flush, a few foam poly pig runs and a few brush pig total wire runs, the line was isolated from the supply tank. Since the cleaning runs were executed with an open-end pipeline there was hard scale noted on the inner wall, most notably at the 06:00 position in the last few meters of the pipeline. The scale on the other clock positions was notably softer. It took some force from a shovel to remove the scale. It was estimated to be 5-7mm thick in spots.

As a result of the initial assessment another 8 total wire cleaning runs were performed.

3.3 Bidi Results

The results of the cleaning runs were not entirely

Figure 4: Scaling at 6 o'clock position

Figure 5: Scaling 5-7mm

satisfactory as scaling remained visible. However, there was no guarantee this was the case over the entire pipeline. In consultation with all 3 parties, it was decided that more cleaning runs would not make a difference in achieving perfect cleanliness.

The bidi run had another important role of obtaining valuable data to prepare for the ILI. The pipeline geometry, elevation differences and enormous pump capacity was a challenge to run an ILI tool in the 20m/min range.

The bidi run had two unexpected results. First one was that the receiver was seriously challenged to deal with a huge amount of scaling the bidi had removed and secondly because the bidi gauging plate was damaged beyond what would have been acceptable. The other challenge was that it was very difficult to control the speed of the tool.

The damage of the bidi was deemed to be a result of hitting an air pocket while navigating a section of back-to-back bends leading to an underground section. Consequently, based on the first run parameters it was decided to perform a second bidi run, with the aim to simulate the optimum for the ILI run. The results of the second bidi were within the set conditions with no damage to the gauge plate. With some minor changes at the launching, it was also possible to control the inspection speed. Finally, the amount of scaling was much less this second run.

3.4 Ultrasonic Results

With two bidi runs to prepare the ILI tool ran around the calculated optimum speed of 19m/min. At evaluation of the UT data, it showed there were still areas where no UT data was obtained, but mostly outside the critical 6 o'clock area.

The inspection data showed erosion was present at the 6 o'clock positions over a multitude of standard pipe lengths, however not gradual over the entire pipeline length.

Figure 6: Damaged gauging plate

3.5 RTY Remaining Life Assessment

A remaining life assessment was completed in-house by Rio Tinto engineers. The ILI data clearly showed internal erosion along the bottom of the pipeline, this is consistent with sliding bed erosion, which is typical in slurry pipelines. Although the pipelines were not fully cleaned, there was sufficient data to obtain a very good assessment of the bottom section along the entire length of the pipeline.

Continuous erosion along the bottom of the pipe in effect creates a continuous groove along the pipeline. From a pipe design point of view, this is very similar to a global erosion case, and the assessment was based on basic hoop stress calculations. It is noted previous assessments had been completed on the pipeline in relation to self-weight, seismic and wind. These all showed that pressure was the governing design case.

The ILI data had been provided in tabulated format, which included the minimum measured value in each pipe segment (approximately 12.5m lengths between each weld) and the chainage along the pipeline. This data was then overlayed with the pipeline elevation data.

In total following data was compiled and overlayed in a single chart which is shown in Figure 7:

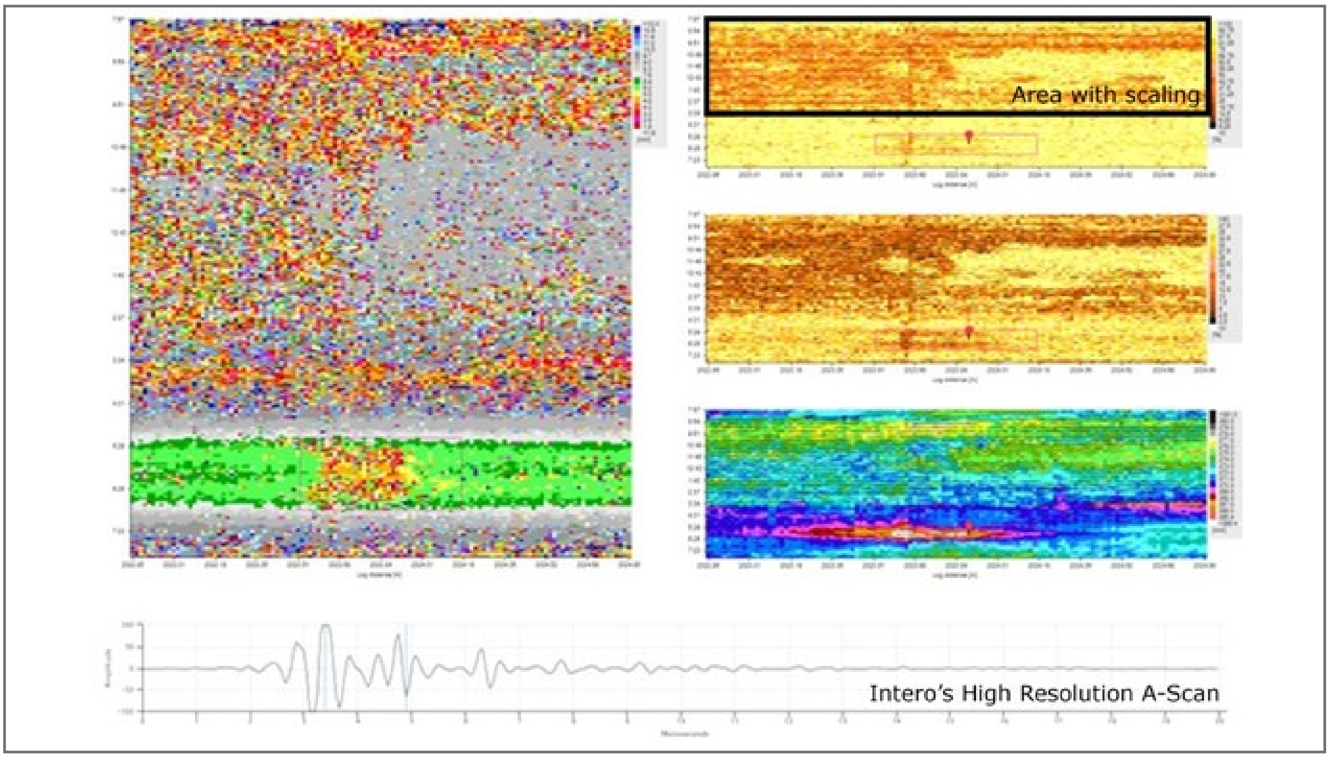


Figure 7: UT data presentation showing effect of scaling presence

- Pipeline elevation vs chainage
- Original nominal pipe thickness
- Measure thickness from ILI data
- 3x Required thickness lines (see below for explanation)
- Underground areas highlighted.

Note that the pipeline flows from left to right on the graph. Pumps are located on the left and pump the slurry about 100 meters vertically over the 9km length of pipeline.

The data showed significant loss of material along the entire pipeline. However, it also showed some areas with higher losses than others. These were in sections of higher "up-hill" gradient. It is unknown why the up-hill gradients show much higher material loss than similar downhill gradients. Ultimately given that it is not practical to change the pipeline gradient, no further investigation was conducted. The minimum required pipe thickness was calculated based on the original pipeline design standard B31.11. This is based on the basic hoop stress calculations provided in that standard. As discussed earlier the nature of the material loss results in this being a suitable assessment method. There is no need to perform a local area loss analysis. This calculation was completed 3 times with slight variations, the reason being to understand how sensitive the design is to some variable.

- T(mm) 3 pumps

This is a basic hoops stress calculation form B31.11, using a fixed elevation at the discharge of the pumps, which is almost the lowest elevation along the pipeline. This number is what was used to communicated to a wider audience when asked "what is the minimum required thickness". Is much easier to people to understand a single number, rather than having to refer to a graph every time.

- T(mm) 3 Pumps & Elevation

The same calculation was performed again, this time using the specific pipeline elevation to modify the pressure. As a result higher elevation sections of the pipeline have a lower required thickness. This is the "true" minimum required thickness for any section of the pipeline.

- T(mm) 3 Pumps & Elevation & Materials Certs

The material certificates for the pipeline were reviewed, and the material with the lowest yield stress was selected. A method specified in AS1210 (Australian standard for pressure vessel design) adapted and then used to calculate a new SMYS for the pipeline. Refer AS1210 Appendix A. The same hoops stress calculations were completed using this revised material yield strength data. This line represents the "absolute lowest" minimum required thickness, and is provided to give a feeling of the sensitivity of the analysis. It was not used for formal decision making.

A second graph was produced based to show the "end of life" data along the pipeline. For each datapoint, the measured thickness was compared to the original thickness and a yearly wear rate determined based on linear trend. This was then used to calculated time to reach the required minimum thickness "t(mm) 3 Pumps + Elevation". A further calculation was conducted to determine the date at which this would occur. The results of this are shown in Figure 9.

The make the data a easier to comprehend, a line was manually drawn to the show the "lower bound life estimate" on the data (shown as red-dashed).

This graph is what was presented to the company management to allow for decisions to be made on a replacement / rectification schedule. The power of this approach is a simple graph shows at what date the given section of pipeline must be either rectified or removed from service. From a Pipeline Operators point of view this is the exact data they need to be able to make informed decisions.

- Rectification Strategy

The pipeline was re-designed in preparation for replaced using a much high corrosion allowance based on the expected life of the facility and the more recent design standard B31.4. This resulted in DN750 Schedule 30 pipe being specified, with a corrosion allowance of 10mm.

A combination of pipeline replacement and pipeline rotation is included in the rectification strategy, based on input from piping contractors of what is most feasible in each section of pipeline.

The overall timing of the rectification is staggered based on the End-of-Life graph. This allows cost of rectification to the spread over several years, without creating an increase in risk of pipeline failure.

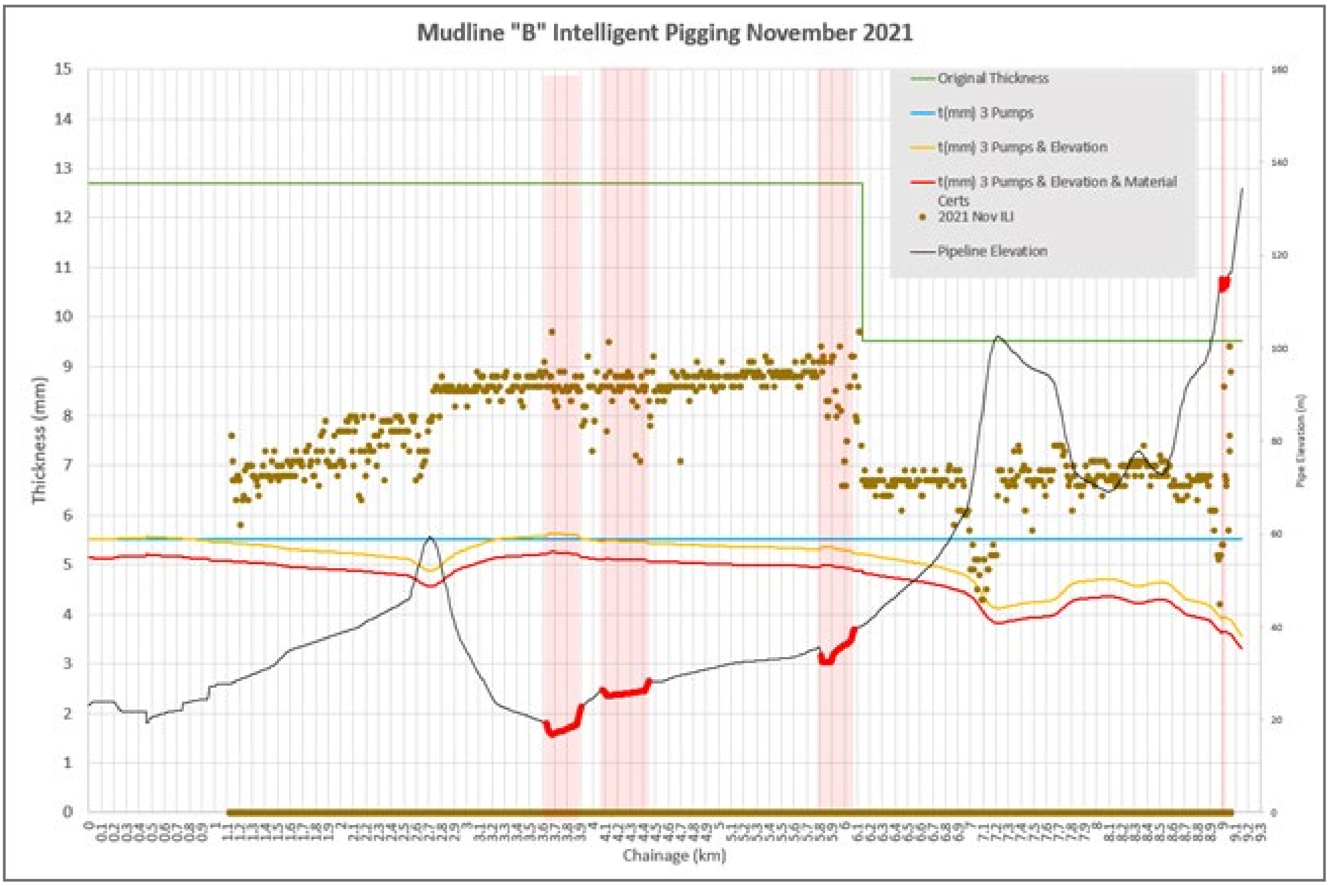


Figure 8: Graph with various overlay data showing minimum pipe thickness

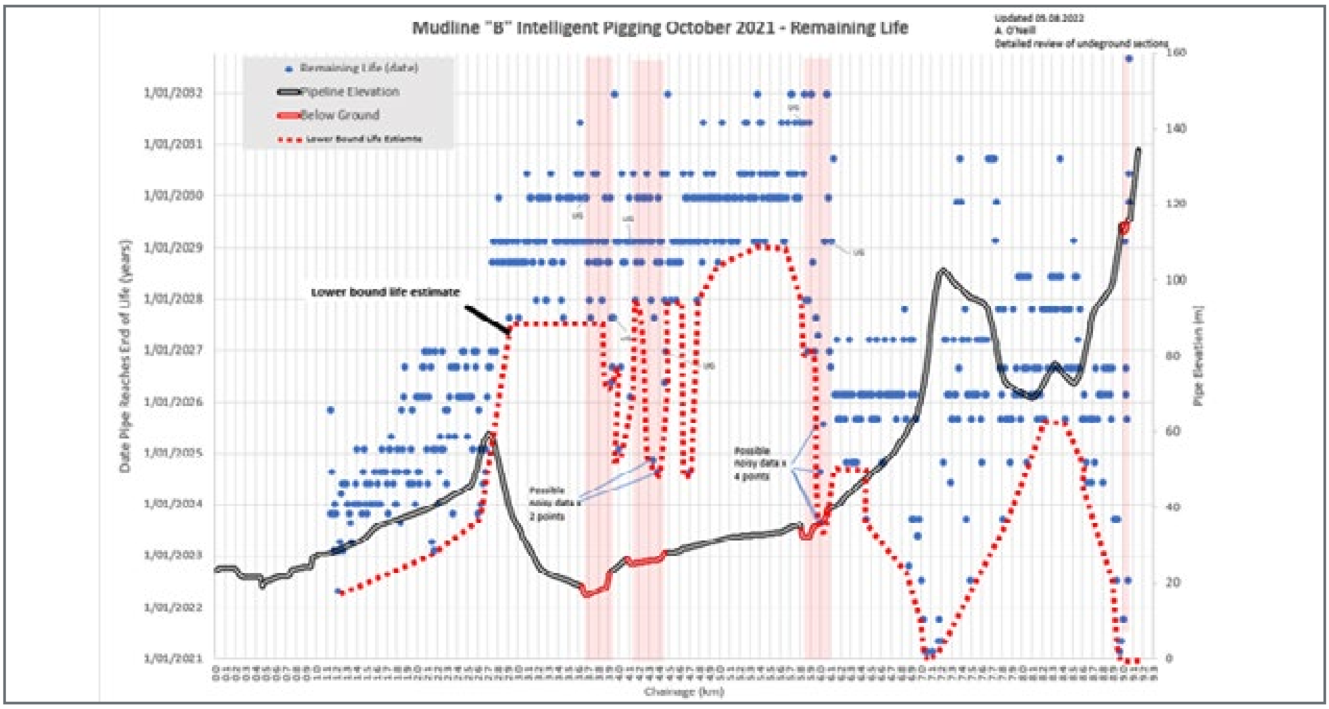


Figure 9: Graph showing "End of Life" date

4. Conclusion

Mud and tailing lines are critical assets for Rio Tinto. The inspection showed that although 100% cleanliness was not achieved the inspection data allowed Rio Tinto to make a well-informed assessment of the integrity of the pipeline.

As a result of the ILI inspection and remaining life assessment RTY was able to make informed decision to spread the rectification work over several years without increasing the risk of pipeline failure occurring. A key mechanism for this to occur was the presentation of the data in a simple graph that showed a prediction of when each section of the pipeline would reach End of Life.

RTY, Contract Resources and Intero will continue to work for the expansion of these inspection technologies for the integrity assessment of pipelines within the Rio Tinto organization.

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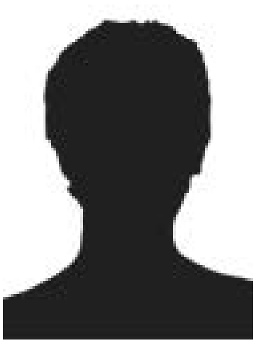
1. B31.11 - Slurry Transportation Piping Systems
2. B31.4 – Pipeline Transportation Systems for Liquids and Slurries
3. AS1210 – Pressure Vessels

AUTHORS



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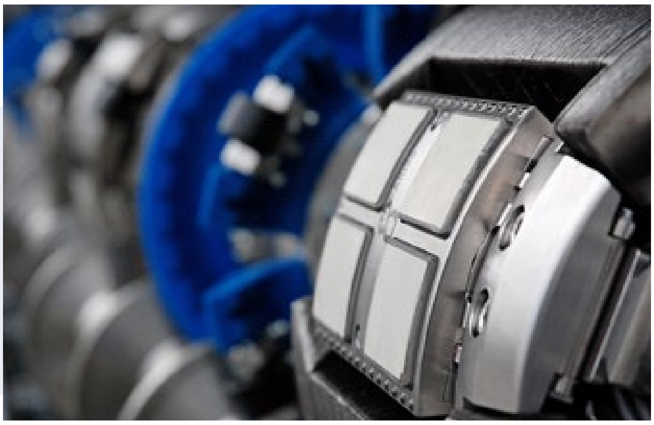
Ask the Experts



Safety & Inspection

Q1) What are the current best practices for managing and preventing corrosion in pipelines?

Rodolphe: Preventing corrosion relies on establishing a set of prevention barriers. While significant progress has been made in the engineering domain (Corrosion coupons, ER Probes, Pigging, etc.), other crucial barriers, such as the human factor and the management system factor, play equally important roles.

Some typical points for consideration include:

- Is the system effectively consolidating corrosion-related data to extract valuable insights?
- Are corrosion and integrity teams collaborating efficiently and effectively?
- Is the sharing and integration of lessons learned effectively taking place within the organization?

These questions underscore the multifaceted nature of corrosion prevention. Therefore, alongside advancements in engineering, the current best practices for managing and preventing corrosion in pipelines include maintaining an efficient management system, competent personnel, and a robust safety culture within the organization. State-of-the-art pipeline integrity management software solutions, such as Synergi Pipeline, provide advanced analytics, such as corrosion growth modelling features, making it easier to monitor, manage and prevent corrosion growth. They also offer improved communication with their capability to seamlessly connect to Corrosion monitoring systems.

Q2) How can the uncertainties and challenges associated with complex pipeline geometries, materials, and operating conditions be managed?

Troy: Managing uncertainties and challenges associated with complex gas and oil pipeline geometries, materials, and operating conditions requires a combination of effective monitoring, risk assessment, leak detection, and mitigation strategies. Operators can face a wide range of issues with these situations, including failures such as cracks, leaks, corrosion, and material failure. Remote Telemetry Units (RTUs) can be useful by continuously monitoring for changes in conditions and managing remote automation. Probabilistic risk models should be utilized where uncertainties can influence decision-making and drive continuous improvement in data collection, as they quantify the likelihood and consequences of various scenarios, aiding in informed decision-making. Companies can better prepare for risks by identifying credible threats, assessing their impact, and developing a plan to mitigate them.

Rodolphe: Effectively managing uncertainties requires the implementation of a comprehensive risk assessment, enabling the prioritization of mitigation actions. The usual risk assessment approaches often fail when multiple threats interact (especially if some data is missing), and probabilistic approaches are able to account for data uncertainty but not modeling uncertainties. A new approach is using Bayesian Networks, a form of machine learning, to construct mechanistic and probabilistic risk models. These networks excel in handling both types of uncertainties and offer adaptability in scenarios with missing data. For over a decade, DNV has been using this approach to aggregate information from various sources to address threats like corrosion, stress corrosion cracking, third-party damage, illegal tapping etc. Just take a simple example: an external pipeline corrosion model should not depend only on corrosion but also on other mechanisms such as cathodic protection, coating degradation, vegetation and even weather patterns. This approach allows the creation of truly comprehensive risk models.

Q3) In what scenarios is direct assessment preferable to inline inspection for pipeline safety, and what are the trade-offs between these two approaches?

Troy: Industry and regulatory changes often favour ILI over Direct assessment (DA). That said, DA methods can be preferable to inline inspection (ILI) tools in certain scenarios. DA is typically used when ILI is not feasible due to unpiggable pipeline parameters or conditions such as diameter, flow, and other restrictions or difficult to inspect.

The trade-offs between these two approaches are:

- *Cost:* DA is generally less expensive than ILI and even more so when internal resources are used.
- *Accuracy:* ILI is more accurate than DA when higher-resolution tools are used
- *Time:* DA can take longer to complete than ILI when scheduling external vendors and multiple surveys are required.
- *Data Volume:* DA generates a large amount of data, which can be difficult to manage and analyze.

Rodolphe: While ILI offers unparalleled value by providing vital information about the type, location, and size of anomalies, it falls short in explaining the underlying mechanism causing the defect. This is where the Direct Assessment process becomes invaluable as it addresses the "Why?" question, offering insights into the occurring mechanism and facilitating preventive measures. Ideally, a synergistic approach is recommended where In-Line Inspection and direct assessment complement each other, ensuring a comprehensive evaluation of pipeline safety.

Q4) How can data from multiple sources and technologies be integrated to improve the accuracy and reliability of pipeline defect detection and assessment?

Troy: Data from multiple sources and technologies can easily be integrated with proper software tools that support rich analytics from data managed in a standardized format in a common storage repository. Information crucial for pipeline defect integrity assessment is sourced from various channels like pipeline inspection tools, field measurements, sensors, testing, and GIS.

However, the journey of data consolidation introduces challenges, such as issues with diverse formats, alignment variations, and accuracy levels. Extracting meaningful insights from integrated datasets is complex, and ensuring the reliability of integrated data requires robust quality assurance processes. Fortunately, software solutions like DNV's Synergi Pipeline can serve as a key ally in overcoming these challenges:

- *Efficient Integration:* The software seamlessly incorporates diverse formats, overcomes alignment variations, and ensures accuracy through standardized protocols.
- *Insightful Analysis:* Leveraging advanced data analytics techniques becomes streamlined with software, employing machine learning algorithms, statistical analysis, and data visualization tools to extract meaningful insights from integrated datasets. This analytical approach enhances defect detection and assessment accuracy.
- *Reliable Data Quality:* Software plays a pivotal role in ensuring data reliability through robust quality assurance processes. Procedures such as data cleansing, validation, and verification identify and rectify inconsistencies and inaccuracies within datasets, maintaining high data quality standards.

Q5) How can the frequency and scope of inline inspections be optimized to reduce costs and risks?

Troy: The use of in-line inspection is expanding among pipeline operators. The development of new technologies and innovative techniques has helped to improve accuracy, efficiency, and lower costs. The use of software which supports and integrates detailed defect assessment, anomaly lifecycle management, and risk/condition-based inspection scheduling to understand and evaluate mitigation strategies will help reduce costs and risks.

Rodolphe: To optimize inline inspection (ILI) frequency and scope for cost and risk reduction, it's crucial to design a tailored ILI system following API 1163 recommendations for each pipeline's unique challenges. Clearly defining inspection objectives is essential—answering questions like credible mechanisms and expected defects aids in selecting appropriate technologies for valuable results, ultimately leading to cost savings and risk reduction. A comprehensive Threat Assessment is crucial in fine-tuning the ILI system to target and mitigate specific risks, enhancing the efficiency and cost-effectiveness of the inline inspection strategy.

Q6) How have recent innovations in pipeline inspection techniques improved the detection and management of potential safety hazards?

Troy: Recent innovations in natural gas and oil pipeline inspection techniques have significantly improved the detection and management of potential safety hazards. Non-destructive testing (NDT) technologies are helping oil and gas producers across all market sectors. Some of the most effective techniques include:

- ***Ultrasonic Testing (UT):*** UT instruments facilitate faster setup, reduce inspection time, have none of the health risks associated with radiation, and ensure the full volume of a weld is covered.
- ***UAVs and Drones:*** UAVs equipped with sensors are more efficient and cost-effective than traditional methods, simultaneously reducing the risk of human injury.
- ***Sensors:*** Optical and other sensors play a pivotal role in detecting leaks, strain, fatigue, and ground movement.

These techniques have enhanced the accuracy, efficiency, cost-effectiveness and safety of pipeline inspections.

Rodolphe: Historically, corrosion was the main focus of the industry's innovations, which explains the current maturity levels of Metal Loss inspection techniques. Now, other damage mechanisms, such as Stress Corrosion Cracking (SCC) and Geohazards, are responsible for many high-consequence failures. As outlined by Troy, the industry has diversified its focus and implemented advanced techniques, with notable advances in:

- ***Crack Anomalies:*** The detection of cracks in gas pipelines has substantially advanced with the recent developments in EMAT (Electromagnetic Acoustic Transducer) ILI technology. Ultrasonic tools have also considerably evolved, making these innovations indispensable for the accurate detection, identification, and sizing of crack anomalies in liquid & gas pipelines.
- ***Material Properties:*** Challenges like lost pipeline records, non-compliance with as-built records, and changes during the pipeline's lifespan can now be addressed through advancements in ILI tools in identifying hard spots and Pipe Grades, allowing accurate fitness for service of pipelines.
- ***Pipeline Strain and Movement:*** Real-time Strain Gauges and High-Resolution ILI Geometry tools provide crucial insights into bending strains and pipeline movement, allowing for proactive measures to mitigate potential risks.

As the industry continues to advance in pipeline inspection, questions arise regarding other critical aspects of pipeline integrity management. Addressing issues such as data errors, overcomplex processes, lack of safety culture, and potential loss of competencies may hold the key to making a more impactful change in reducing pipeline incidents.

Q7) What are the key challenges in assessing and mitigating risks associated with pipeline integrity?

Troy: Some of the challenges in assessing and mitigating risks associated with natural gas and oil pipeline integrity include accurate prediction and assessment of internal and external corrosion, construction issues, operational practices, and third-party damage. Many companies also struggle with data quality and the impact that unknown and incorrect data have on risk assessment accuracy.

The US regulatory body, PHMSA, has conducted multiple risk workshops with pipeline operators and has identified general weaknesses in some of the more basic risk models used in the industry. The report provides an overview of methods and tools for improved pipeline risk modelling, including the use of more advanced quantitative and probabilistic models with monetized risk, consideration for data uncertainty, and the identification of mitigative measures.

Rodolphe: Addressing and mitigating risks associated with pipeline integrity involves navigating several significant challenges:

1. ***Tailoring the right model for your system:*** Tailoring models to the specific characteristics of the pipeline operators' system and data enhances the accuracy of risk predictions beyond 'off the shelf' models.
2. ***Data Quality Issues:*** Inconsistent, incomplete, or inaccurate data is a major obstacle to conducting reliable risk assessments. Robust data quality assurance processes, including thorough validation and cleansing procedures, are vital.
3. ***Dealing with Missing Data:*** The absence of data often has a significant impact on the final risk results. Employing effective strategies to address

missing data, such as probabilistic approaches like DNV's PRA model or tapping into alternative data sources, is crucial for conducting comprehensive risk evaluations.

4. *Black Box Models:* Black box models, where it is unclear why a certain risk is high, present challenges in identifying targeted risk mitigation strategies. It is crucial to ensure a transparent understanding of risk factors and facilitate effective risk mitigation.
5. *Understanding Risk Results (Aggregation):* Aggregating risk results necessitates careful consideration, as overlooking nuances in aggregated data may lead to inaccurate risk prioritization. Defining clear Risk acceptance criteria helps avoid oversights in the evaluation process.

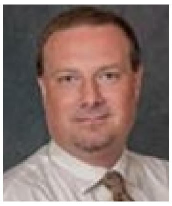
Q8) In what ways does digital transformation enhance the effectiveness of integrity management?

Rodolphe: In contrast to traditional approaches, digital platforms introduce capabilities that were previously unattainable. They elevate integrity management across multiple dimensions:

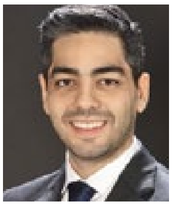
- *Control:* Provide greater control over the integrity of pipelines, empowering operators to stay on top of their priorities.
- *Accessibility:* Offer a single source of truth, making information and resources easily accessible to all stakeholders, thereby improving transparency and collaboration.
- *Efficiency:* Streamline processes, speed up commodity tasks and reduce redundant actions, resulting in significant time and cost savings across the organization.
- *Intelligence:* Harness advanced data analytics to derive valuable insights, enabling data-driven decision-making and predicting future trends and opportunities.
- *Communication:* Enhance internal and external communication through integrated tools and regular updates, fostering better collaboration and information sharing.
- *Judgment:* Enable better-informed decision-making by providing stakeholders with comprehensive data and analysis, allowing for more accurate and well-considered judgments.

Find more of your questions answered here: www.pipeline-journal.net/news/ask-experts

This issue's experts



Troy Weyant, Product Manager - Pipeline Product Line, DNV
Troy joined DNV in 1994 and is currently responsible for the pipeline risk & integrity management software strategy and roadmap to meet the needs of the global integrity management market. Before this role, Troy held the position of Principal Integrity Solutions Consultant responsible for the implementation of projects based upon DNV's Asset Integrity Management suite of products. He has also been responsible for the development of DNV's MAOP management solution and has served as a Synergi Pipeline technical lead for large integrity and GIS implementation projects in the US and abroad.



Rodolphe Jamo, Regional Sales Manager - Digital Solutions, DNV
Rodolphe joined DNV in 2022 and has 15 years of experience in the Pipeline Integrity Management field. He holds an MSc in GIS and started his career as a Pipeline Risk Engineer and then moved to Project Management responsible for the implementation of multiple PIM Solutions across the globe. In his role as Senior Key Account Manager, he was also responsible for the provision of tailored integrity and inspection solutions to major gas operators. Rodolphe's current focus is on supporting operators in their Digital journey via DNV's suite of Digital Solutions.

With each issue of the journal, the "Ask the Experts" section focuses on a new topic of particular relevance to the pipeline industry. People from the international pipeline community are invited to send in their questions which will afterwards be answered publicly by selected experts from the respective field.

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