Enhancing Pipeline Assessments: Answering the Challenge of Unpiggable Liquid Assets with Self-Propelled Solutions

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Abstract

In response to pipeline restrictions that prevent the use of common free-swimming in-line inspection equipment, self-propelled inspection solutions have emerged as a transformative alternative. Leveraging robotics, automation, and advanced sensing, these solutions can autonomously navigate complex pipelines without the requirement for conventional access points or product flow. The adoption of self-propelled systems enables operators to conduct comprehensive inspections in pipelines previously considered inaccessible. This paper outlines the utilization of a self-propelled tether approach supported by case studies. The paper will outline in detail the workings of the inspection tool, particularly: the ridged ring UT sensor unit, the modifications and testing to ensure the system could pass features in the line, and the electrically driven propulsion system

The first case study introduces a self-propelled robotic Ultrasonic Wall Measurement (UTWM) solution deployed in a 16”/20” pipeline. While the focus of this case study is the deployment of this inspection solution in the 20” section, it will also compare a previous operational attempt with running a free-swimming 16”/20” tool in this line. The case study will outline not only how this solution helped verify the integrity of the line itself, but also how its execution reduced operational requirements while still collecting high-quality in-line inspection (ILI) data.

Case Study two addresses the challenge of offshore pipelines situated in remote and rugged terrains. This case study presents a tethered self-propelled inspection device equipped with ultrasonic sensors. What was of particular interest was the tools ability to navigate over 11 complex bends. The study showcases the device's technical abilities in conducting real-time assessments and overcoming access limitations inherent in such locations. Further the case study highlights the extensive testing required to be able safely complete such inspections.

Case study #1

Asset overview

Imperial Oil’s underground lateral line between the Regina fuel distribution terminal and 3rd party main pipeline operator is used to supply multiple storage tanks with distillate and gasoline product. This line has a dual diameter segment that runs within the 3rd party facility land and can be accessed from aboveground risers with tool launching and receiving infrastructure.

Pipeline Information

Table 1. Pipeline Details

Description	Measure
Diameter	NPS 16/20
Length	~1,411ft/430m (~1,138ft/347m 20”/ ~272ft/83m 16”)
Minimum Bend radius	90° (assumed 1.5D)
Wall thickness (nominal)	0.25”/6.35mm
Pipeline product	Distillate and Gasoline
Description	Measure
Diameter	NPS 20/16

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Figure 1. Pipeline Overview.

The technical challenges in the case of the NPS 16/20 line included:

1. Despite launcher and receiver capabilities, the line was not designed for conventional pigging
2. Operating in-service conditions did not allow for a conventional ILI tool inspection.
3. Limited space available to setup temporary pumping equipment for standard pigging operation on 16” end.
4. Staging of temporary equipment for conventional pigging (flowback tanks and pump) could pose risks to the environment.
5. 16”/20” transition located at bend (Figure 2).


Figure 2. 16”/20” transition with affixed bend

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Previous Inspection Background

This dual diameter pipeline segment was inspected in 2022 using a UTWM free-swimming in-line inspection tool. Due to the pipeline operation set points and its connection with a 3rd party interprovincial pipeline, the execution team used temporary equipment to complete the tool run and eliminate the risk of interrupting mainline operation. As a result, the dual diameter line inspection required a product supply outage for a couple days, flowback tanks and temporary pumps at the tool sender and receiver locations to enable tool displacement. Because of challenges encountered while navigating the 16”/20” transition area, the tool failed to gather data that met Imperial Oil's requirements, necessitating the need for an alternate approach for the 20” section.

Preplanning

Before initiating the tool selection process, boundary conditions were established in consultation with Imperial Oil. These conditions served as the parameters that any viable solution must adhere to. The established boundary conditions for the inspections were as follows:

1. The inspection was to be conducted during a planned shutdown window.
2. High-resolution corrosion measurement performance was a mandatory requirement.
3. Activities, modifications, or equipment were to be minimized whenever possible.

While these boundary conditions formed the foundation for the solution, the challenging nature of asset inspection often necessitates compromise. Therefore, fostering open and transparent discussions between the inspection vendor and the operator during the decision-making process is essential. This approach ensures that, if compromise is inevitable, the outcome remains positive for both parties involved.

When creating a solution, various critical factors must be taken into account. These encompass the identification of propulsion components, the selection of the most suitable measurement technology for the asset, and the incorporation of robust failsafe mechanisms for the inspection tool itself. Given that the inspected line contained a relatively clean oil, which facilitates the propagation of ultrasonic signals, it was mutually agreed that UTWM would be a suitable measurement technology for the inspection. Generally preferred for its low drag and versatile application, UTWM is often the technology of choice for inspections of unpiggable pipelines, attributes that align well with the activities outlined in this paper.

While the selection of measurement technology is pivotal for acquiring accurate data, the application methods of these technologies vary and play a crucial role in the overall effectiveness of the inspection. Several methods were considered for this line, and although a few were technically feasible, not all met the agreed-upon boundary conditions and some added additional risks.

Similar to the previous inspection, there was potential to utilize diesel as a propellant for a free-swimming solution. In this scenario, the tool would be inserted at the tank farm in the 16” section. To facilitate tool propulsion, pumps would be essential, drawing product either directly from the storage tanks or via temporary tanks/tucks positioned at the tanks farm. Modifications at the tank farm end would be necessary to establish temporary launching facilities, and temporary receiving facilities would be required at the 20” entry point. The displaced product during pigging operations could be collected at the receiving end with temporary tanks, allowing for contingency cleaning activities if required, although the likelihood of such need was considered low given the nature of

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the product. Further, there was an expectation that the line would be adequately clean following the deployment of multiple cleaning pigs during the attempted inspection conducted one year prior.

While this proposed solution was technically feasible, it necessitated additional modifications and the provision of supporting equipment at the congested tank end. Consequently, this method fell short of addressing all the challenges mentioned earlier.

In the exploration of alternative solutions, it was determined that a self-propelled tethered inspection tool provides the distinct advantage of autonomously traversing the dual diameter line without the need for liquid or gas propellants. The tool could be deployed at the 20" entry point, removing the requirement for modifications at the tank farm end. It could then navigate through the line, reaching the 16"/20" transition point where it could be paused and subsequently retrieved using a winch system positioned at the entry point, eliminating the need for supporting pumping equipment at each end. This method avoids the necessity to evacuate product from the line and circumvents any operational interventions at the tank farm end, effectively mitigating potential environmental or safety risks. Furthermore, this solution ensures data quality on par with or exceeding alternative options, without compromising the integrity of the inspection process.

Tethered UTWM technology overview

The Tethered Tractor Self-Propelled Inspection System includes a UTWM module, the propulsion / tractor unit, the umbilical winch, and a computer system responsible for communication with and control of the inspection vehicle, Figure 3.

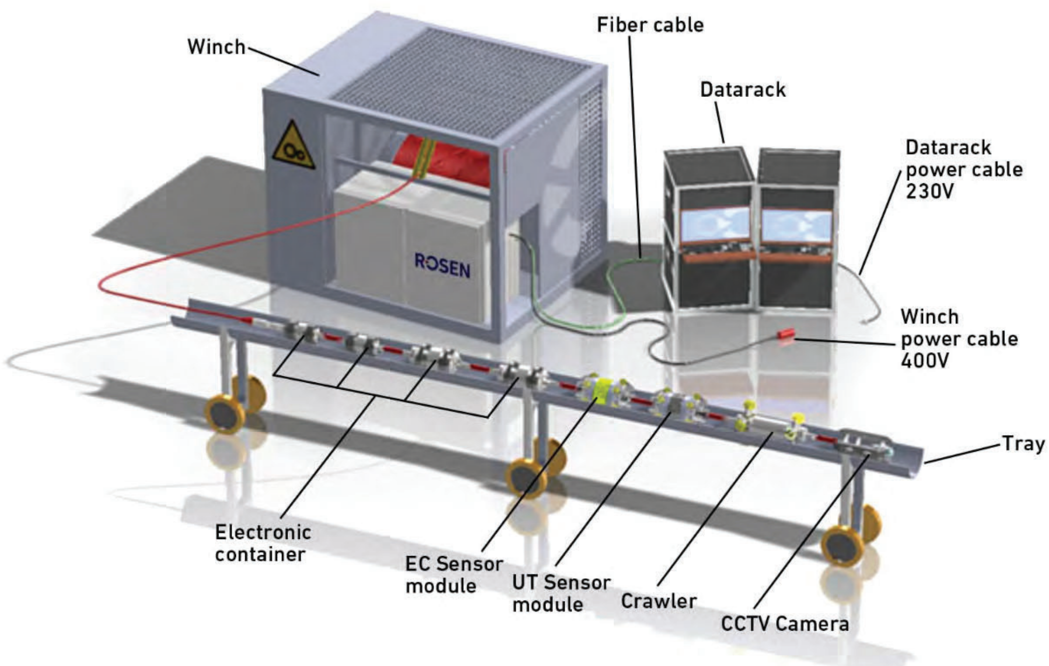

Figure 3. Typical tool train setup

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Measurement technology

The systems ultrasound inspection is performed by sending pulses of high-frequency sound waves into the pipe wall via ultrasonic transducers and then measuring the echo, or reflection, back at the same transducer. The strength of the echo and the time it takes to arrive can provide an impression of the pipe's condition. For wall thickness measurements, the probes are directed perpendicular to the pipe wall. The application of this method allows for the detection and sizing of internal and external metal loss such as corrosion anomalies. By measuring the stand-off and wall thickness, detection, and sizing of deformations such as ovality and dents in the pipeline is also possible when utilizing a tool-centralized sensor ring.

The fluid in the pipeline (oil, water, etc.), act as a coupling medium between the probes and the pipe wall (air has relatively poor sound conducting characteristics and cannot be used as coupling medium) allowing the ultrasonic pulse to travel into the pipe wall.

The UT sensor carrier ring contains narrow focused beam UTWM sensors which are mounted in a rigid ring that had a diameter, which allowed the tool to negotiate 1.5D back-to-back bend that included a 10% restriction. In the event that known restrictions were in the line which were outside of the 10% threshold, the system can be further adapted.

During the inspection, the odometers that measure the axial position of the tool also trigger the probe excitations and associated data collection.

The reading includes the full length of the UT signal. This means that the excitation signal, the internal echo, and rear wall echo are recorded. Additionally the tool was set up also to record several rear wall echoes.

Since the distance between the probe and the pipe wall is fixed, it is easy to distinguish between internal and external wall loss. While the fixed UT measurement ring allows the tool to measure small deviations in internal diameter that is caused by ovalities or dents. In general, the tool is very well suited for such geometric measurements, and as long as the 10% constriction threshold is not exceeded.

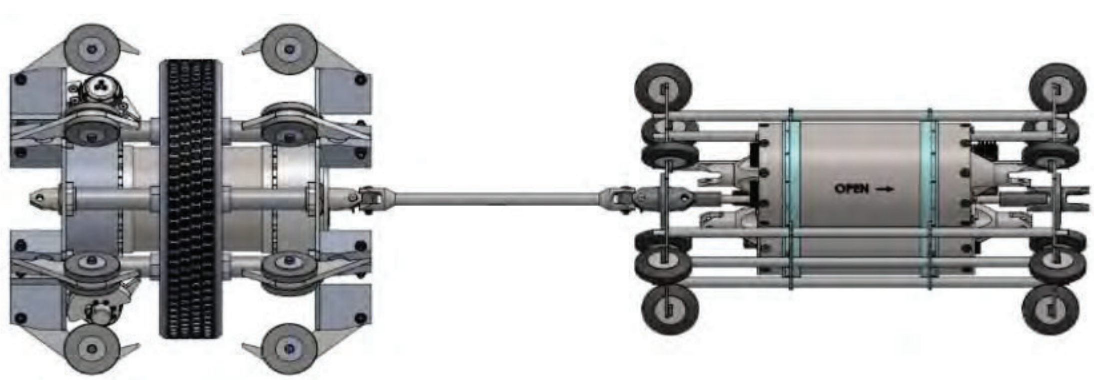

Figure 4. 20" TUM (Tethered UT Wall Measurement) train with supporting electronic modules

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Supporting equipment

The comprehensive inspection system incorporates a tailored computer system designed for various functions, including:

UTWM Data Collection:

1. Communicates with the UTWM data module
2. Facilitates online inspection data visualization
3. Stores data files downloaded from the tool for later analysis, with simultaneous storage on the tool during the inspection.

Motion Control Computer:

1. Controls speed and direction of the electro-hydraulic tractors
2. Monitors operational data of the tractor
3. Stores the tractor operational data (logs).

Throughout the inspection process, the collected data is accessible in real-time, enabling onsite analysts to make adjustments, such as modifying sensor gain to enhance data quality. Moreover, analysts have the capability to conduct additional passes on areas of concern, providing a dynamic and adaptable approach to the inspection procedure.

A pivotal element of the inspection system is the umbilical, accompanied by its corresponding winch unit, which fulfils the following key functions:

1. **Cable Management:** Organizes and manages the umbilical cable effectively.
2. **Power Interface:** Interfaces external power to the copper wires within the umbilical.
3. **Communication Interface:** Provides communication interface for the fibre cables within the umbilical.
4. **Pull-Back Capabilities (Normal Use):** Facilitates pulling back the tool under normal operating conditions.
5. **Pull-Back Capabilities (Higher Pull Force):** Enables pulling back the tool with increased force if encountering unknown obstacles impeding its momentum.

The umbilical plays a critical role in ensuring proper power supply and communication. Functionally linking the tool to the winch, the umbilical incorporates:

1. **Data Communication and Power Support:** Utilizes both fibre and copper wires to support data communication and power.
2. **Neutral Buoyancy:** Maintains neutral buoyancy in liquids, minimizing the weight of the tool.
3. **High Breaking Forces:** Exhibits strong breaking forces of up to 3.5 tons.

The proposed system faces limitations in its distance capabilities, influenced by various factors, including:

1. **Cable Length:** The maximum length the cable can extend.
2. **Cable Weight:** The weight of the cable itself.
3. **Tool Weight:** The weight of the inspection tool.
4. **Friction:** The resistance encountered, particularly in the presence of bends or elevation changes.

During tethered inspections, the tractor unit is tasked with pulling the cable throughout the inspection process. Even in straight pipe sections, the tractor unit encounters challenges in pulling a cable over significant distances due to the constant increase in overall payload. This challenge intensifies when bends or elevation gains are introduced into the pipeline.

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Elevation gains contribute to an increased weight that the tractor must pull. Additionally, bends introduce friction between the tether and the pipe. The friction resulting from bends is proportional to the deflection angle and, to a lesser extent, the bending radius, which minimally affects friction. Known as the Capstan effect, this friction force is often regarded as the predominant factor limiting the range of a tethered vehicle in a pipeline.

The determination of this force is calculated prior to preparation and often involves trials, considering factors such as tool weight and the resistance between the tool and the pipe wall. To mitigate the impact of the Capstan effect, the tool's components are optimized. All inspection tools are constructed from titanium to minimize weight, the tether is neutrally buoyant in water, and the friction coefficient between the umbilical and the pipe is kept low.

To mitigate the impact of bends, tool weight, and friction, the tool was operated with the line filled with a liquid medium. Combining the elements described above with the incorporation of buoyancy elements into the inspection tool itself enabled the tool to navigate various bends over the entire distance without experiencing significant tether payload.

The stuffing box, which is connected to a launcher spool, allows for variability in friction, as it can be adjusted as needed.

Propulsion

For the 20” diameter pipe, the tethering inspection systems employ an electro-hydraulic tractor module to propel the tool, as depicted below. This design eliminates the need for flow or pressure in the line during inspection, thereby avoiding the requirement for auxiliary pumping to propel the tool.

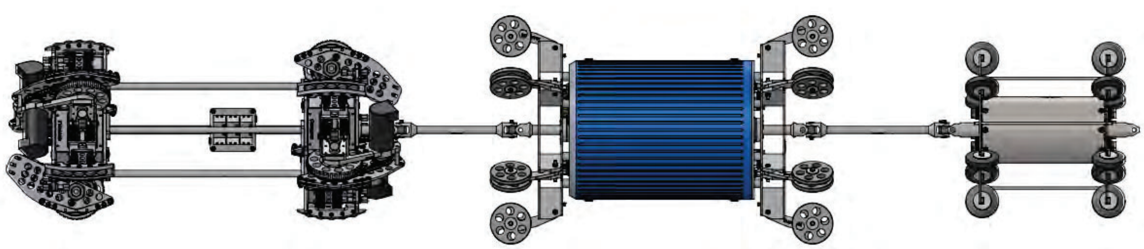

Figure 5. 20” self-propelling tractor unit

The 20” – 24” hydraulic tractor unit is comprised of three modules as shown in figure 5 and listed below from left to right:

1. Centralizer and drive module
2. Hydraulic power module
3. Tractor power supply module

The front drive/centralization unit features both front and rear centralizers, each equipped with three hydraulically driven wheel arms. Friction against the pipe wall is facilitated by hydraulic actuated arms on each drive wheel, which are powered through a chain drive mechanism connected to the hydraulic motor. To enhance centralization during the tool's retraction when the drive arms are in a collapsed position, a set of free wheels are mounted on the centralizer ring. The regulation of the collapse function can be independently controlled for the front and rear wheel centralizers, managed by the tool operator.

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During operation, continuous monitoring of power consumption serves as a safety feature, preventing motor current drain from exceeding specified maximum thresholds. While the operator visually monitors current drain throughout the inspection, software-based monitoring ensures automatic tool shutdown if specified current drain thresholds are exceeded, preventing potential damage. Notably, power consumption is a crucial parameter to monitor as it also reflects the actual payload experienced by the tool at any given time.

Pre-inspection Testing

Utilizing the pipelines technical specifications provided by Imperial Oil, a comprehensive design requirement review was undertaken in collaboration with the in-house design team. The tool design was then tailored to align with the specific application, considering the actual geometry and installations of the line. Following a comprehensive review of all available options and the development of an initial solution, the subsequent phase entailed the assembly and testing.

The assembled inspection tool train shown in Figure 6 measured approximately 6000mm in length and weighed 280kg. As illustrated below, the tool train comprised the following modules arranged from left to right.

1. Centralizer/drive module and hydraulic power module.
2. Universal Joint.
3. Tractor power supply module.
4. 20'' sensor carrier – containing; 320 Pulsed Echo UT probes.
5. Bundle – Containing; front-end modules and UT Back-end module.
6. Interface module.
7. Transformer module.

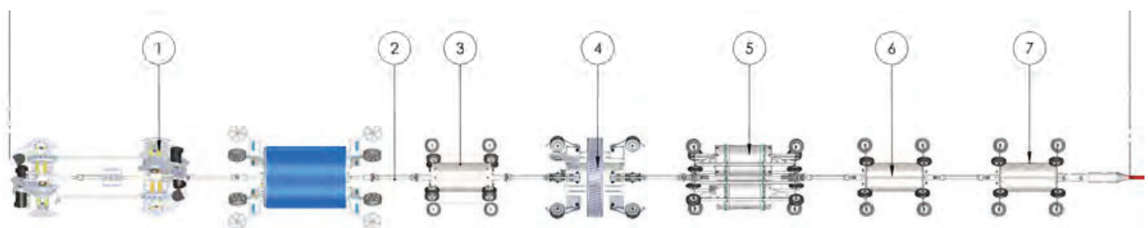

Figure 6. Complete 20" TUM (Tethered UT Wall Measurement) train with all supporting modules

To validate the system's capability to traverse the proposed line, two separate stages of preparation and testing were undertaken. The initial stage encompassed the assembly and validation of the tool post-setup, while the second stage involved the functional testing of the system post-mobilization.

The Factory Acceptance Testing (FAT) conducted after the tool trains assembly at the ROSEN Norway facility is comprehensive, covering:

1. **Tool Train Measurement:** Measure the distance between all modules, verify that the tool train is constructed in accordance with the drawing, and sign off on the drawing.
2. **Tractor testing:** The entire tool train is driven into a 20" test line that replicates critical features present in the subject line, in this instance a 1.5D bend. Numerous measurements are captured throughout the testing process and subsequently validated against models and tool tolerances.

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3. **Pull Back Measurements:** Eight pullback measurements were executed on the full tool train tool within the dry 20" line and the 1.5D bend. The pullback forces were quantified using a load cell and cross-validated against the simulation model. In the event of any deviations, the simulation model would be re-evaluated to confirm the tool's capability to navigate through bends with current tool design and the selected supporting equipment, addressing any concerns.
4. **System test of UTWM system:** While immersed in a liquid-filled 20" pipe spool, tests validate the precise configuration of the UTWM system to ensure accurate collection of wall thickness (WT) data and stand-off (sensor to pipe wall) information. The acquired data is typically presented to the client after collection and analysis. Furthermore, operational assessments of the ODO system and additional tractor testing were conducted to verify functionality.

Following the completion of the testing, all components were meticulously prepared, packed, and mobilized.

Site works

Upon the tool's arrival, additional redundancy functional testing was undertaken to verify that no damage had occured during transit. These tests encompassed:

1. **Assembly Check:** Visual mechanical inspection of all modules and supporting equipment.
2. **UTWM Tests (also performed during the FAT):**
   a. Upload correct parameter settings to the tool.
   b. Sensor alignment test and verification.
   c. Tool orientation test (pendulum).
   d. Odometer rotation test.
   e. Centralizing wheel and odometer adjustments according to ID.
3. **Tractor Tests (also performed during the FAT):**
   a. Confirmation of the direction of wheel assemblies.
   b. Verification of motor run and measurement of current drain.
   c. Verification of tractor wheel retraction

Pipeline preparation

To ensure the line was adequately prepared for inspection, various measures were reviewed and implemented. Notably, considering the absence of standard pigging facilities for introducing the tool train, a temporary launcher spool was connected to the topside valve, as depicted below. Specifically, a 20"/24" barrel with a length of ~22' (6.71m) was utilized from the previous campaign as the launcher spool for this purpose.

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Figure 7. Topside valve and entrance point

The inspection is within a "closed system," where a stuffing box flange is affixed to the pipeline entry flange. This stuffing box flange, a modified ASME 16.5 – 24" – 150# flange, features a central aperture for the passage of the inspection tool and threaded flat-bottom holes for connecting the stuffing box. The installation of the stuffing box is facilitated by feeding the umbilical through the flange.

Upon feeding the umbilical through the stuffing box flange, the stuffing box can be securely installed. An adjustable sealing and a torqued gland are employed to create a seal around the umbilical, enhancing its sealing capabilities. While the stuffing box can achieve complete sealing during tool standstill when over tightened, this may not be optimal during inspection, as it could impede the forward movement of the tool train by holding back the umbilical. Thus, it is adjusted as required throughout the system to balance seal and friction on the umbilical.

Figure 8. Stuffing box and flange assembly

Preceding the inspection, onsite staging of equipment was conducted for execution. The following equipment was positioned at the launcher area for the inspection activities:

1. Computer workstation (mobile van unit)
2. Power generator
3. Winch
4. Inspection tool and launch tray

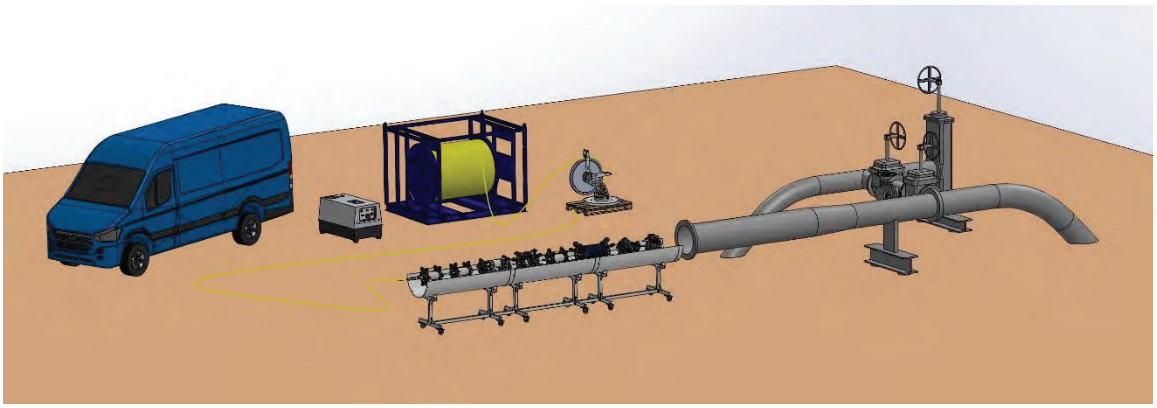

Figure 9. Visualization of site setup

The winch, serving as the mechanical and electrical connection to the tool, was aligned near the entry point and launch spool set up by Imperial. The umbilical was deflection via a pully on the launcher spool to bring the cable back to the winch.

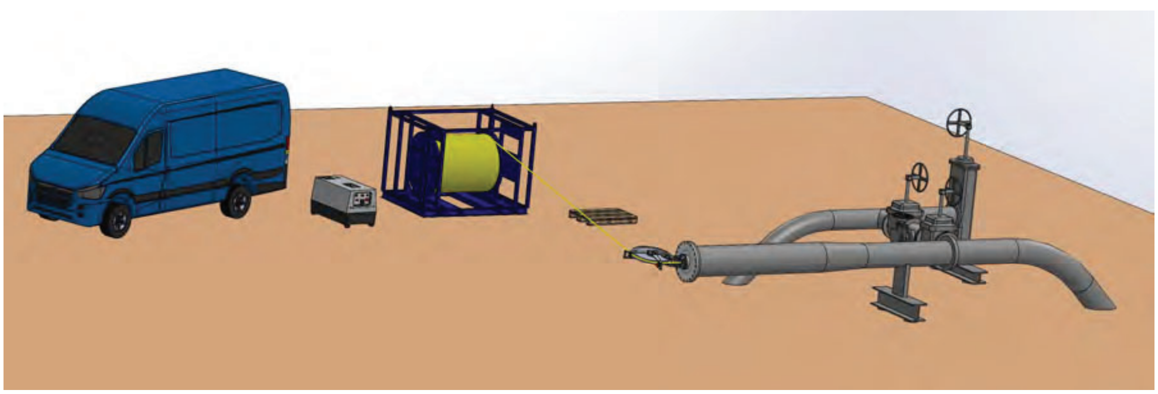

Figure 10. Visualization of site setup during the inspection

The tool was situated on the launching tray, and the umbilical was connected to the tool. A final check of the tool's functionality, encompassing all components and systems, was conducted as outlined above to ensure proper operation.

The workstation was established adjacent to the winch to facilitate clear communication during inspection activities, while the generator was positioned just outside the working area.

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Figure 11. Site setup

Inspection

As the inspection was being executed while the line was shutdown, a defined inspection window was outlined by Imperial Oil.

Table 2. Inspection execution schedule

Day	Description	Measure
1	Preparation of line access	Imperial Oil
	Setup of ROSEN equipment incl. winch, computer workstation, launch tray	Imperial Oil/ROSEN
	Inspection tool onsite testing	ROSEN
2	Inspection execution and take down	ROSEN
3	Demobilization	Imperial Oil/ROSEN

Day 1

The first day of the execution consisted primarily of setup and testing activities, including:

1. Safety induction.
2. Equipment placed at location.
3. Winch and computer workstation connected.
4. Functional tests all equipment.
5. Pre-launch tests and check lists completed.

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Day 2

The second of the execution consisted of a tool run execution, which included:

1. Tool train loaded into launcher and inward inspection run started at 09:30 am.
2. Tool train travelled and reached end location (396 meters / 1300 ft.) at 10:30 am.
3. Return inspection run started at 12:00 pm. and tool train was back in launcher at 01:00 pm.
4. Tool train removed from launcher, dismantled and all equipment was packed up for demobilization.

Data

The comprehensive data package provided to Imperial comprised the following elements:

1. A field data quality statement provided within 72 hours of the inspection
2. Preliminary report issued within 30 days of the inspection
3. Final report issued within 60 days of the inspection

The inspection data exhibited no reduction in data quality attributed to sensor loss, air pockets, or velocity excursions. The later does not occur with self-propelled systems.

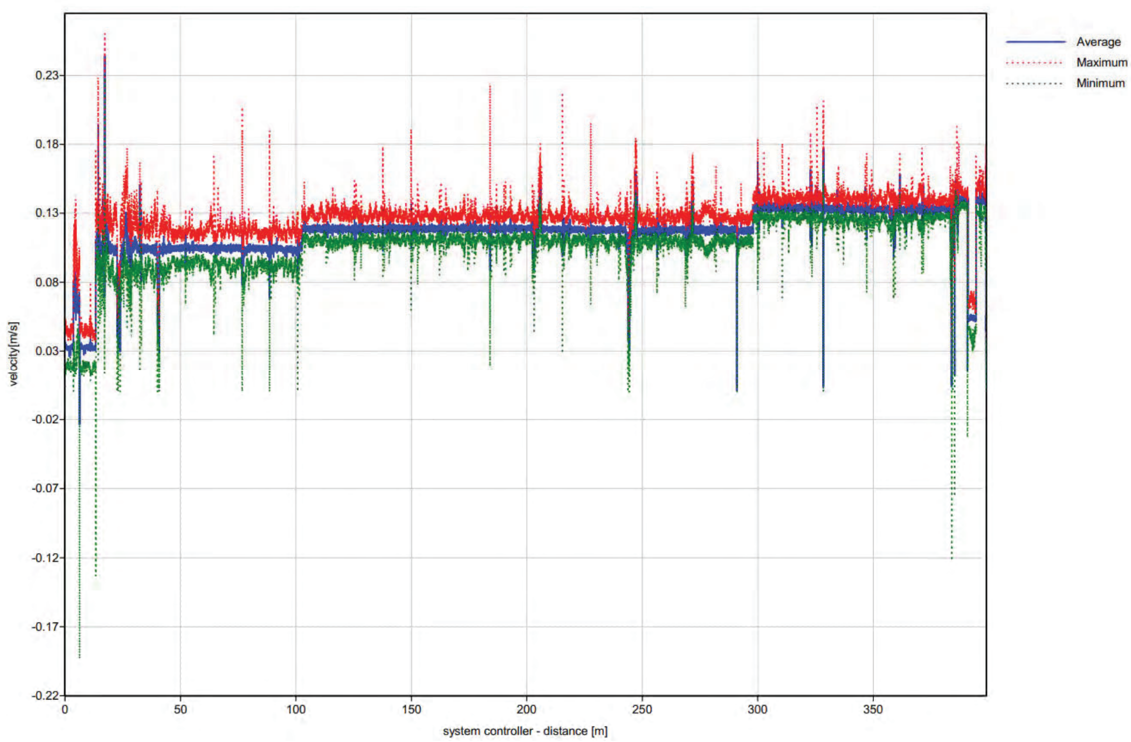

Figure 12. Inspection velocity graph

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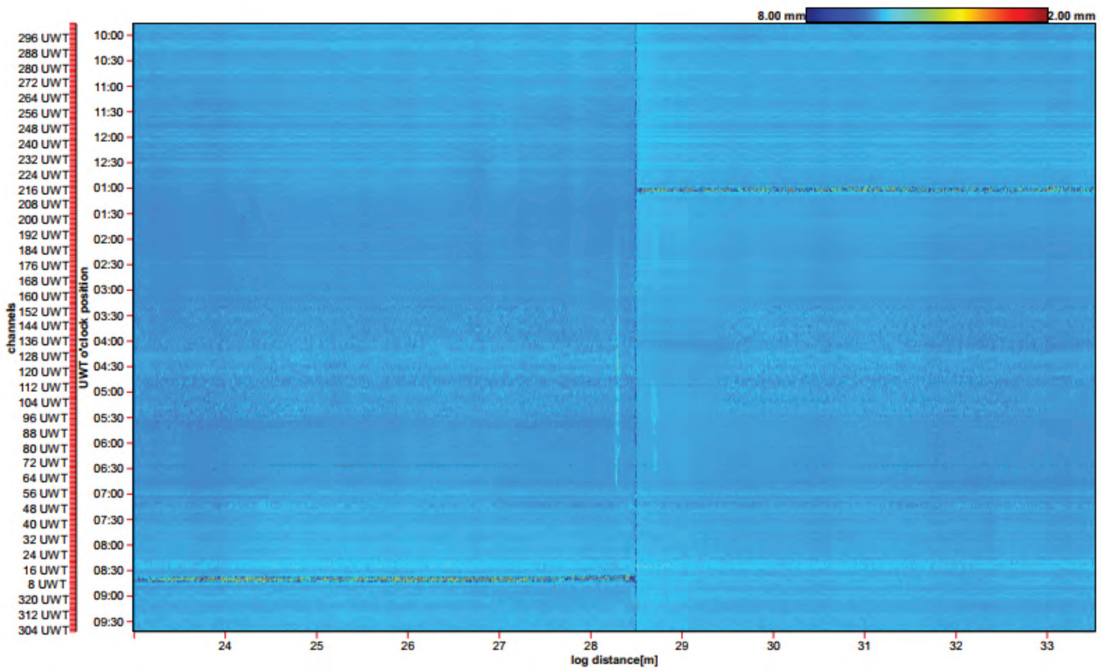

Figure 13. Data screenshot sample #1 collected from the inspection run

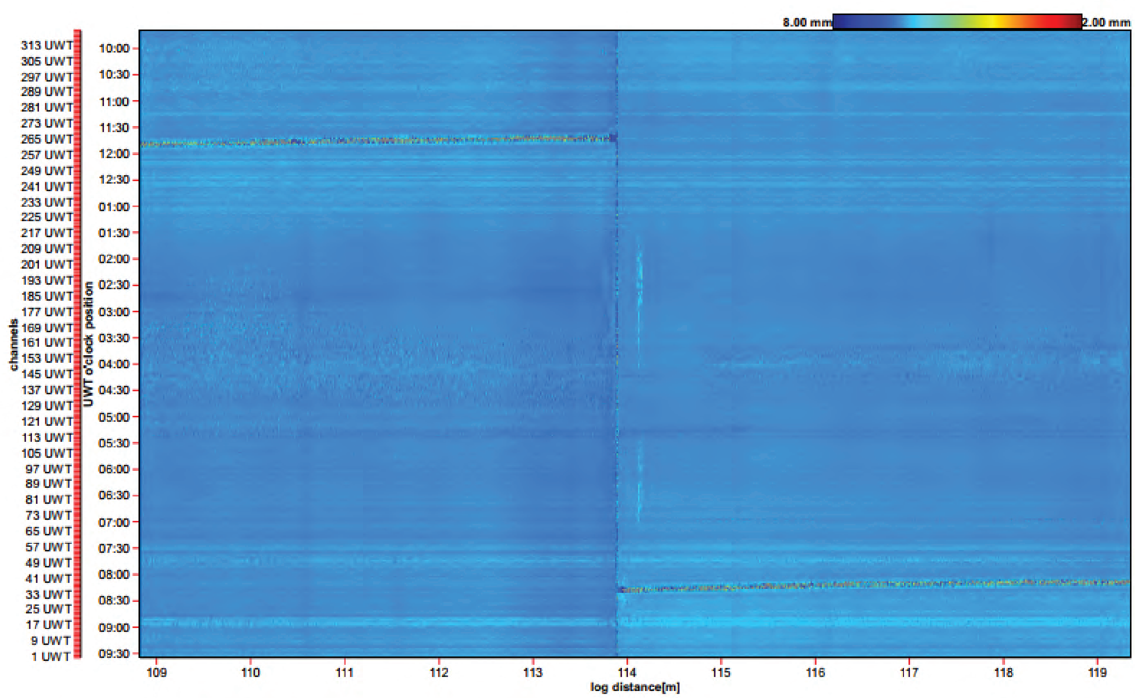

Figure 14. Data screenshot sample #2 collected from the inspection run

As of today, Imperial has not needed to conduct any verifications or repairs based on the inspection data gathered.

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Case Study #2

Asset overview

The pipeline for Case #2 was a riser that was part of an offshore platform in the North Sea. It was designed for launching pigs from the topsides and receiving them at a subsea receiver. However, this procedure was not preferred by the operator because of the operational risks and costs associated with subsea receiving. The primary pipeline integrity threat the operator was concerned with was external corrosion in the splash zone. Pipeline details are included in the Table 3. An isometric drawing of the riser is included in Figure 15.

Pipeline Information

Table 2. Pipeline Details

Description	Measure
Diameter	NPS 10
Length	Pipeline length ~ 10.4 miles (16.8km) Inspection length (riser) ~1030' (314m)
Water Depth	456' (139 m)
Minimum Bend radius	5D
Bends during inspection	13 x 90° bends, 5 x 45° bends
Wall thickness (nominal)	0.629-0.709" (16-18mm)
Pipeline product	Crude Oil
Inspection Medium	Diesel at topsides, Crude in riser

The primary inspection challenges in the case of the 10" riser included:

1. Conventional pig launching and receiving were not possible because of the pipeline design.
2. Multiple bends were present in the riser, which created challenges for tethered solutions
3. The offshore environment created additional operational risks, for example space constraints and limited intervention options in the event of a stuck pig

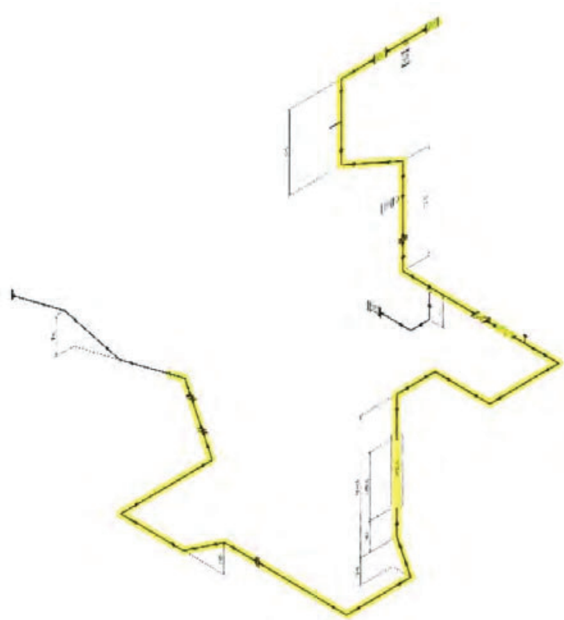

Figure 15. Riser isometric

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Previous Inspection Background

Rosen had inspected portions of the riser in 2014 and 2016 using a tethered self-propelled bi-directional UT solution. However, this inspected sections were limited in length and had fewer bends, though testing was performed through mock bends to confirm the tool would be able to safely navigate the riser. For the third inspection, the operator requested advancing further into the pipeline and through additional bends, which brought the total to 18 bends. For tethered inspections, the amount and angle of bends are in most cases a limiting factor, as each additional bend creates friction on the tether. This results in higher required pulling forces for the tractors and the pullback forces for the winch during the return. Typically, similar solutions can manage between three and four 90° bends, so 18 presented a significant challenge.

Solution

For the inspection, ROSEN suggested the implementation of its self-propelled bi-directional ultrasonic testing (UT) solution. This technology aligns with the base tethered technology previously detailed in Case #1. ROSEN made additional modifications to enhance the solution. These included a dual propulsion system, which featured two crawler units in tandem. This created more power so that the tool could travel further into the pipeline and around all 18 bends. In lieu of the aforementioned tractor drive system, this particular setup utilized an electro helix crawler. The propulsion for the crawler is achieved by the rotation of both front and rear wheels in a radial manner. However, owing to the angled wheels, a helical movement is induced. The freely moving wheels are set at a positive angle in the direction of the desired tool movement. At the center of the crawler, two electric motors are positioned—one linked to the front wheel arms and the other to the rear wheel arms—to supply power to the drive wheel arms. Each arm is equipped with a spring-loading mechanism to ensure sufficient pressure on the wheel against the pipe wall, enabling effective traction.

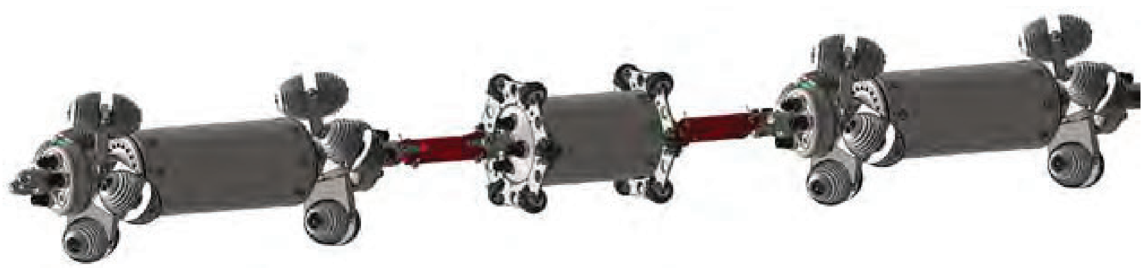

Figure 16. 10” Electro helix crawler system

Two additional technology modifications included fitting a sonar system, in order to see a blocked pipeline (closed valve or any other obstacle), as well as a time-of-flight diffraction (TOFD) crack measurement scanner. The purpose of the TOFD scanner is to aid in the evaluation of pitting, as well as sizing of any potential cracks in the girth welds. Two tool trains were configured, one of them had the sonar module and a UT wall measurement module. The second tool train featured the TOFD scanner and a secondary UT wall measurement module. Most of the tool components were used in both configurations so technicians had to modify the tool between runs so that both configurations would be covered.

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Sonar with UT module tool train shown below with components listed.

1. Transformer module.
2. 10'' sensor carrier – containing; 160 Pulsed Echo UT probes.
3. Crawler modules.
4. Crawler power supply module.
5. Sonar module.
6. Front-end modules.
7. Data module.
8. Interface module.
9. Cable Termination.

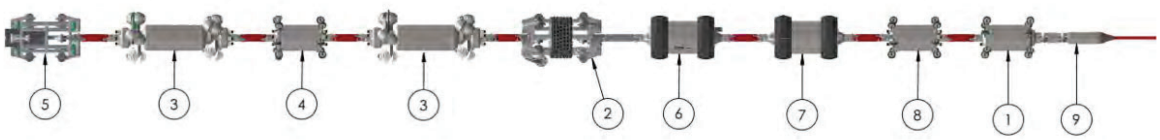

Figure 17. 10" UT train with Sonar module

TOFD with UT module tool train shown below with components listed.

1. 10" TOFD weld scanner module.
2. Transformer module.
3. Crawler modules.
4. Crawler power supply module.
5. Front-end modules.
6. Data module.
7. 10'' sensor carrier – containing; 160 Pulsed Echo UT probes.
8. Cable termination.
9. Pocket scan module.
10. Interface module.

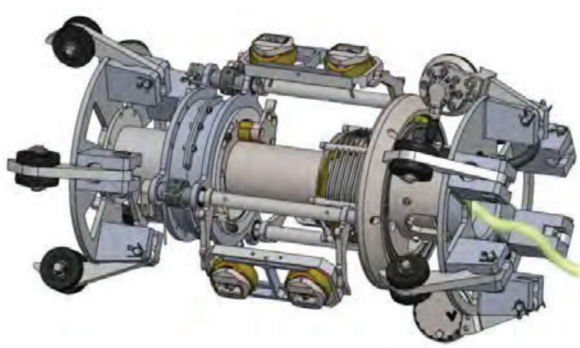

Figure 18. 10" TOFD module

The support equipment that was chosen for the inspection was a 0.75 mile (1.2km) tether with breaking load of 4400lbf (2000kg) and normal pulling force of 2200lbf (1000kg). The winch was certified for ATEX zone 2. A certified launcher/receiver spool was used for inserting and retrieving the tool at the riser. A customized stuffing box flange with cable feeder and hydraulic closing clamp was designed to seal off the end of the launch spool. It was manufactured and tested with 1450psi (100 bars) for this asset during the initial inspections in 2014. The cable feeder was designed to reduce cable friction at the stuffing box location. Meanwhile, the hydraulic closing clamp was designed to maintain the stuffing box seal in the event of a sudden pressure surge in the pipeline.

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This system was used for the second and third inspection campaign. An image of it is included in Figure 20.

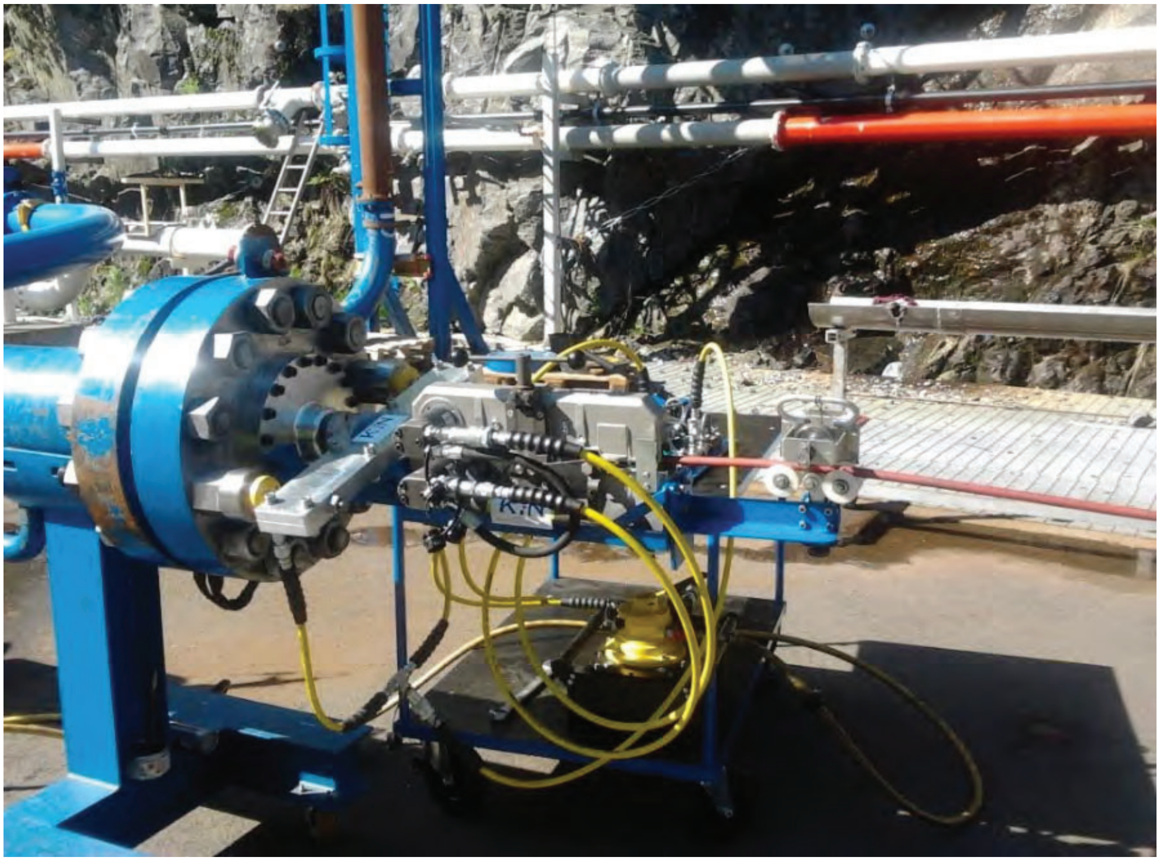

Figure 19. Temporary launch spool and stuffing box flange, during testing

Pre-inspection Testing

For the pre-inspection testing for this third inspection campaign, ROSEN performed the following tests to confirm suitability of this solution for the riser inspection:

1. Functionality tests of the sonar system.
2. Functionality of the wall thickness and TOFD measurement systems.
3. Pressure tests of the temporary launch spool and the stuffing box flange system, certified for at least 1450psi (100 bar).
4. Mechanical tests of the winch and tool configurations to ensure the tool could pass the 18 bends, and that it could be retrieved with the winch in the event of a propulsion failure.

For the test program, ROSEN built a test pipeline with bends that simulated the actual bends present on the offshore riser. The test pipeline was filled with water and ROSEN performed numerous tests to ensure that the tool could physically navigate the 18 bends and overcome the friction caused by the interaction between the tether and the bends. This involved crawling the tool backwards and forward through each bend multiple times. Pull-back tests were also performed to ensure that, in the event of a mechanical failure of the crawler, the winch would still be able to pull the tool through the 18 bends and back to the temporary launch spool. These were also performed multiple times at each bend location. A drawing of the test loop can be found in Figure 20 with an image of the test loop is shown in Figure 21.

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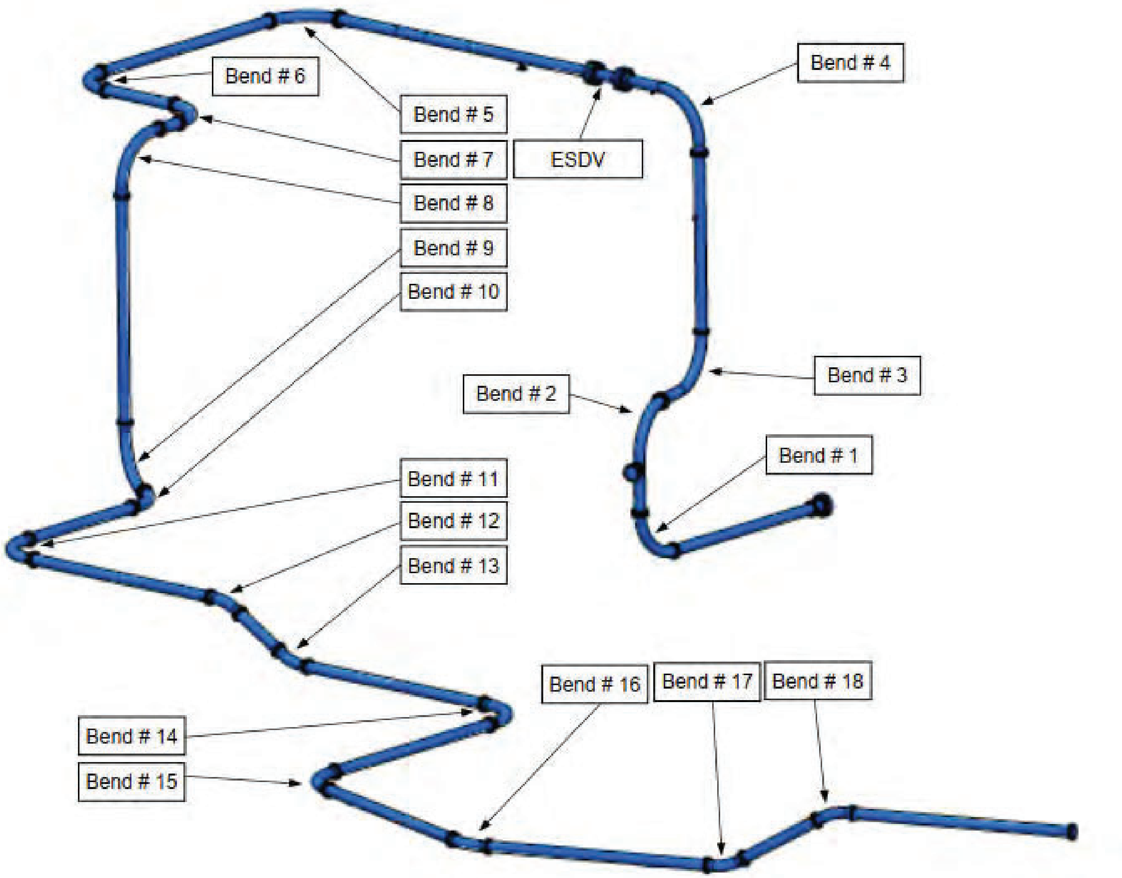

Figure 20. Test pipeline drawing from ROSEN facilities

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Figure 21. Test pipeline at ROSEN facilities

Site works

The team mobilized to the platform in May 2021 and began the operations by setting up the winch and the temporary launch spool. After the pipeline was shut down and the preparations were completed ROSEN inserted the tool configuration that utilized the sonar system and the wall thickness measurement system. ROSEN drove the tool through the complete 314m, collecting high-quality wall thickness data on the forward and return run. No closed valves or other restrictions were detected by the sonar system. During the inspection, many pull and pull-back force measurements were done on preselected distances in order to calculate the friction coefficient of the riser and to be sure to be able to return in even the worst-case scenario. Two operators were on deck operating the

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winch and tether reeling activities. Two operators were stationed in an enclosed environment habitat so they could operate the computers for propulsion and measurement technologies.

After retrieval, the tool was modified from the wall thickness measurement and sonar configuration to the second configuration, which swapped the sonar system for a TOFD scanner. The outward launch of the tool was successful. On the return ROSEN stopped the tool in the splash zone area to do full circumferential TOFD scans at pre-selected girth welds and at any locations in the pipe body in any areas that had corrosion features that the TOFD tool could aid with the evaluation of. The tool was received in good condition and the inspection operations were completed. The whole process from shutting the pipeline down to completing all of the inspections took approximately 11 days.

After presenting a site report, which included the most severe defects, the equipment and the team were demobilized. The data evaluation team was provided with four data sets for wall thickness (2x forward + 2x return runs) and two data sets for the TOFD crack analysis. The full length and circumference of the targeted pipe section was successfully inspected and the collected data were of high quality, meeting the required specification.

The conclusive report was provided in September 2021, meeting the operator's expectations. The project adhered to the planned timeline, and no incidents or accidents occurred. The precise UT and TOFD data provided enabled a thorough fitness-for-purpose assessment, ensuring the ongoing safe functionality of the riser. This case study illustrates that such a solution can be used as an alternative to subsea launching or receiving when inspecting a riser, which in this case proved to be safer and more economical for the operator.

Data

The comprehensive data package provided to the customer comprised the following elements:

1. A field data quality statement.
2. Preliminary report.
3. Final report.

The inspection data exhibited no reduction in data quality attributed to sensor loss, air pockets, or velocity excursions. The later does not occur with self-propelled systems.

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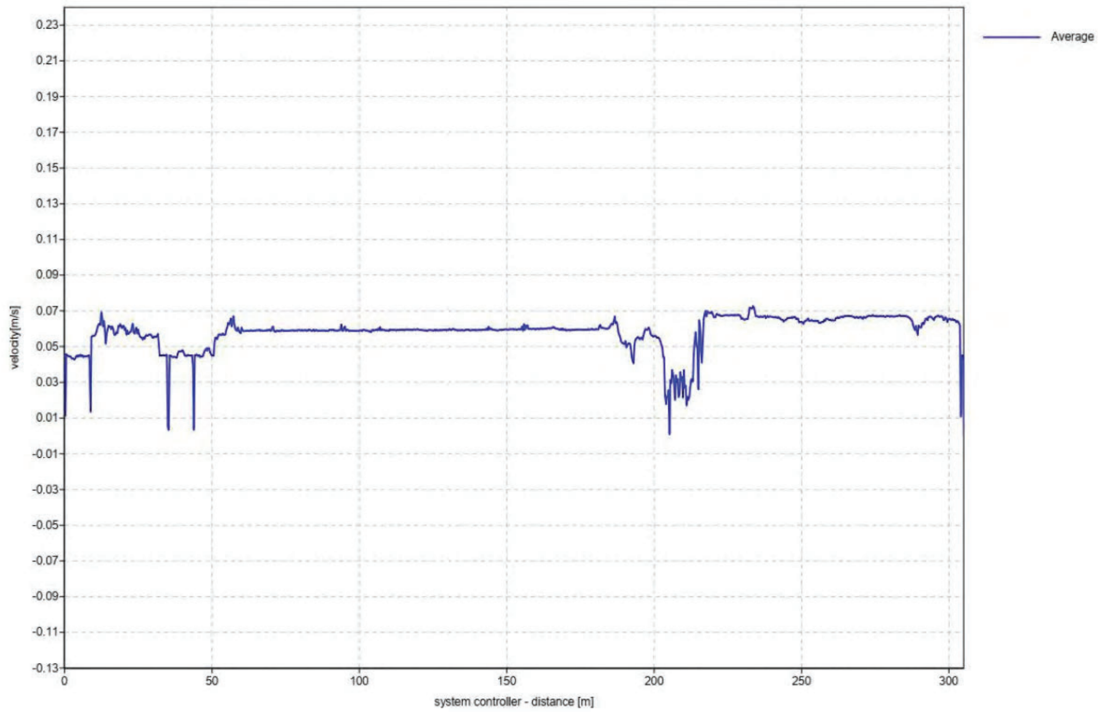

Figure 22. Inspection velocity graph

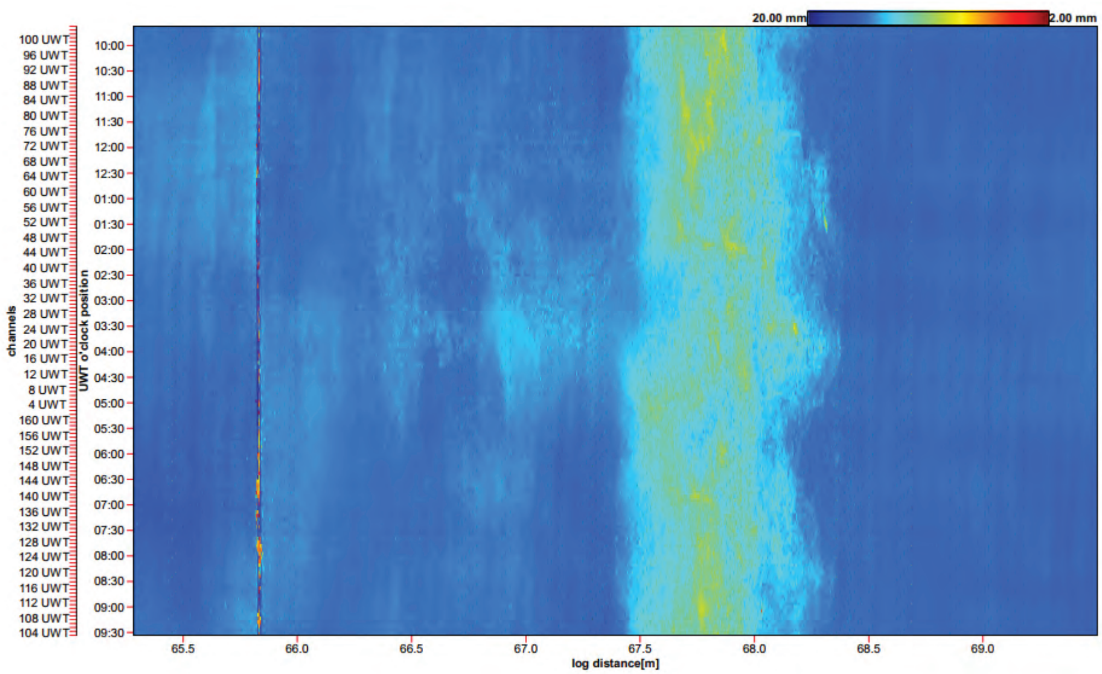

Figure 23. UTWM data screenshot #1 collected from the inspection run

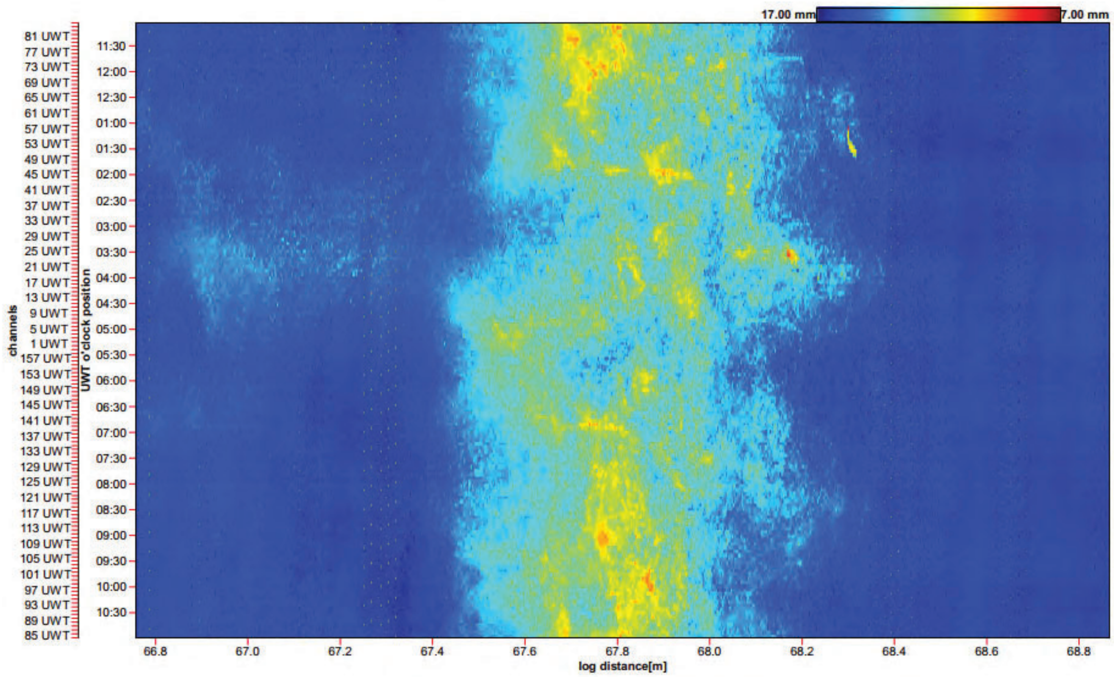

Figure 24. UTWM data screenshot #2 collected from the inspection run

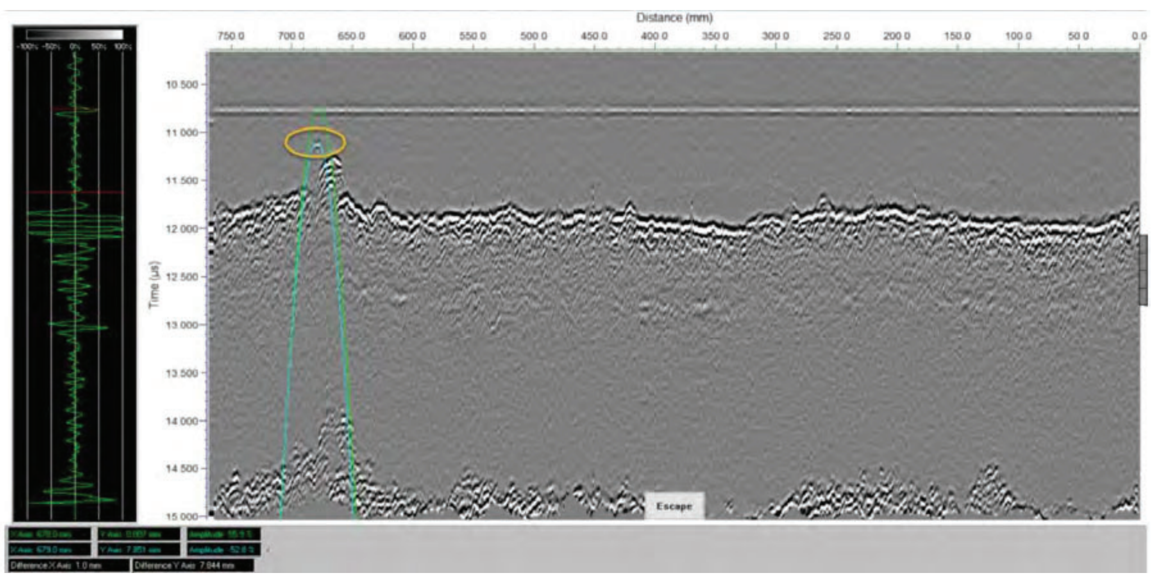

Figure 25. TOFD data screenshot #2 collected from the inspection run

As of today, the operator has not reported any verifications or repairs based on the inspection data gathered.

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Conclusion

The provided case studies outline the diverse challenges associated with inspecting non-piggable pipelines. They underscore the critical role of meticulous engineering, exhaustive testing, and collaborative client engagement in the successful inspection of challenging pipelines, showcasing the adaptability and robustness of self-propelled tethered UT technologies.

The range of challenges outlined in these cases provide a demonstration of the comprehensive capabilities inherent in the outlined inspection systems. Case #1 represents a straightforward deployment of a UT crawler inspection vehicle for unpiggable scenarios, while Case #2 highlights the complexity of an offshore deployment featuring a multi-measurement technology-based solution. These instances underscore the self-propelled UT technology's versatility and proficiency in navigating a field of intricate scenarios.

While the technology deployment represents the end solution, it is crucial to recognize that the foundation of these solutions relies heavily on the meticulous application of advanced engineering principles. Additionally, sustained collaboration with clients throughout the project remains integral to ensuring the success of these inspection systems in diverse and challenging environments.

Acknowledgments

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