DEEPWATER PIPELINE INLINE INSPECTION – A TOOL BOX APPROACH

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Abstract
To ensure continuity of hydrocarbon supply, opportunities are sought by Exploration & Production companies in continually increasing water depths. A range of pipeline technologies and manufacture methods are generally employed to increase the technical feasibility of Deepwater developments. While a combination of pipeline types facilitates high pressure and high flow production, it also brings challenges for internal inspection techniques due to an amalgamation of demanding inspection criteria such as: heavy wall thickness, high temperature and pressure, flexible riser transit, trap constraints and internal diameter reductions.

To address these challenges, ROSEN is able to provide a holistic approach to inspection, whereby a portfolio of solutions can be considered, offering maximum flexibility to pipeline designers, with an aim to deliver optimum integrity data while also mitigating risk. This paper will discuss ROSENs toolbox approach to Deepwater pipeline inspection through presentation of case studies.

Introduction

Subsea pipeline systems pose numerous unique challenges for In Line Inspection (ILI), distinct from those encountered with onshore pipelines. These challenges stem from both the difficult access to underwater facilities and their connection to structures above the water's surface

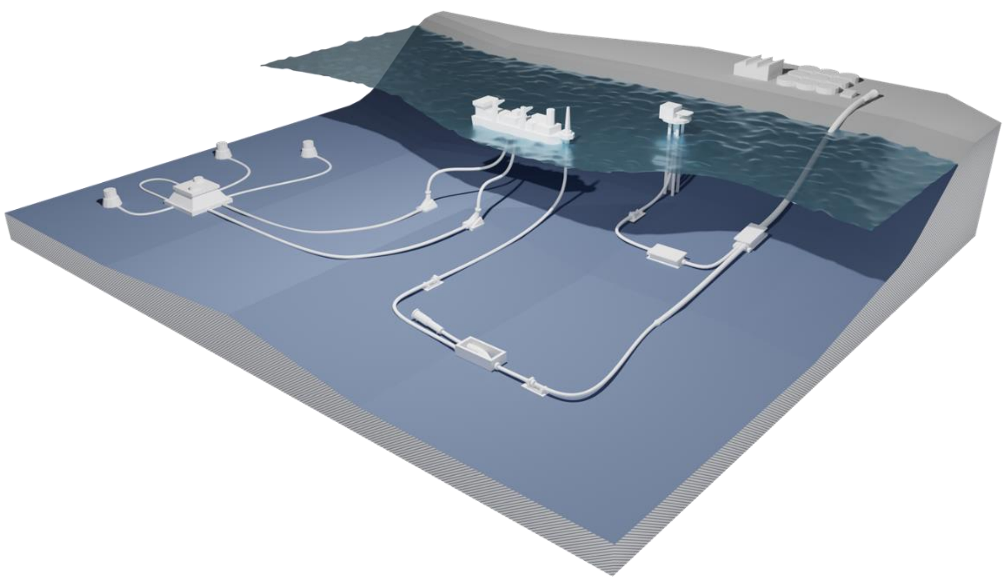

Figure 1: Example of a Deepwater Field Layout

Starting with the launching process, the inherent complexities become apparent, as the usual flow direction is from wells and production lines through manifolds and flow lines to the platform or FPSO. In most cases, pigging of the production lines is not feasible because neither the wellheads nor the manifolds are designed for such operations. For the flow lines, launchers are situated on a platform, vessel, or sometimes temporarily subsea. Given the intricacy of subsea launching operations, looped systems are often employed. Looped layouts consist of two parallel lines of the same diameter running between the manifold and the topside facility, with the possibility of a connected loop at the manifold. This arrangement allows both lines to be inspected in a single inspection run with the launcher and receiver at the same location, minimizing subsea activities (except for valve operations). When this option is unavailable along with restricted subsea launch and receive facilities, flow lines can be inspected using bidirectional tools, self-propelled umbilical tools or tethered tools.

The transportation of the medium presents its own set of challenges. Typically, a platform gathers flow from multiple flow lines, leading to an increase in overall volume for export, necessitating larger pipeline diameters. However, larger installations are costly, and riser pipelines are limited in maximum diameter. Consequently, dual or multi-diameter pipeline systems are often used. Additionally, platforms and production vessels experience movement due to waves, wind, currents, and tides, requiring flexibility in the respective pipeline segment (riser). To address this, various solutions are available, such as flexible risers, steel catenary risers, and lazy wave rigid risers. All of these can pose additional challenges for inline inspection (ILI).

Export pipelines typically run straight for long distances until they reach an onshore facility or the next platform. However, these systems often expand due to the declining production of old wells and the addition of production from new wells and platforms. This expansion usually involves the use of tie-ins, often realized with wye pieces. Moreover, the flow from the original pipeline may be very low and only increase after the new tie-ins, which can also present challenges for ILI tool velocity. Inspecting these systems through the new tie-ins often involves different pipeline diameters and navigating the passage of a wye typically with side flow.

Typically, subsea installations (wyes, manifolds, jumpers, tie-in spools) are compatible for pigging, particularly when considered in isolation, however these geometrical complexities may assume critical significance, particularly when situated in proximity to other installations like subsea connectors, valves, and tees. All of these challenges are compounded by operational conditions characterized by high flow velocities and high pressure. Considering the potentially severe consequences of issues during an ILI inspection of a subsea pipeline, it becomes evident how crucial and complex the preparation for such projects is, and why testing is sometimes key.

In response to the challenges raised by Deepwater environments, ROSEN is able to deliver flexible and customized inspection solutions, whereby tools are developed, manufactured and tested in-house. To identify the optimal solution the “ROSEN Toolbox” approach is employed. ROSEN is able to provide a holistic approach to inspection, whereby a portfolio of solutions can be considered, offering maximum flexibility to pipeline designers, with an aim to deliver optimum integrity data while also mitigating risk.

This technical paper examines the multifaceted challenges associated with Deepwater pipelines in the context of pigging and will discuss three case studies, highlighting the individual challenges and successful ROSEN solutions:

- Case Study 1: Safe passage of Magnetic Flux Leakage (MFL-A) tools in flexible pipes
- Case Study 2: A Deepwater Multi-diameter Gas Pipeline
- Service Overview: Deepwater high pressure riser inspection with self-propelled tethered tools

Case Study 1: Safe passage of Magnetic Flux Leakage (MFL-A) tools in flexible pipes

Challenge

In general, use of flexible pipes for jumpers, risers and flowlines is prevalent in Deepwater fields and is usually combined with rigid pipelines to facilitate transportation of fluids from the well to a floating vessel (FSO, FPSO), or tension Leg Platform.

Typically, these systems are designed to accommodate passage of pigs, however the type and design of pigs that can be used are often constrained due to operator requirements to protect the riser from unwanted pigging damage. Due to the complex construction of a flexible, the available testing and monitoring techniques for integrity management are generally less sophisticated than those available for a rigid pipeline, ultimately making smaller defects (such as metal loss) harder to detect and monitor.

Figure 2: Typical flexible construction (source Technip FMC & ROSEN)

Since integrity management of a flexible is more difficult, it is simpler for an operator to mitigate against damage mechanisms, such as those linked with pigging activities. According to API 17B Table 30 'recommended Practice for Flexible Pipe' [1], only two potential pipe defects/failure mechanisms apply to the carcass layer, both of which could theoretically be caused by pig passage:

- Hole, crevice, pitting, thinning – leading to reduced collapse resistance and reduced tension capacity
- Unlocking deformation – locally reduced collapse resistance and tension capacity

Historical data for failure and damage of flexible pipelines as presented in the SureFlex JIP report [2] indicates that carcass failure accounts for less than 10% of the total failures of flexibles. Of these failures, it is unlikely that pigging damage is the primary cause of all carcass failures since it covers only 1 out of 14 possible causes as listed in Table 30 of API 17B [1]. However, pigging damage cannot be entirely excluded as a failure cause, particularly where ill-suited or badly designed pigs have been utilised.

Even though the likelihood of carcass failures due to pigging is relatively low, operators may prefer to take a conservative approach, sometimes requiring pig designs to avoid metal-to-metal contact of the carcass surface. By specifying such a requirement, the following designs elements are usually adopted:

- Tools supported by PU and/or nylon wheels

- Non-aggressive cleaning tools, composed of plastic cleaning elements only (ruling out the use of metallic brushes, descaler cups and lamellar sheets)
- Wheeled magnetisers for MFL technologies

Although pigging vendors are able to adapt tools and comply with the no metal-to-metal contact requirement, disadvantages are then introduced for other parts of the project, these include:

- Ineffective cleaning of wax and scale type debris in rigid pipeline sections where inspection is required
- Insufficient magnetisation of heavy wall rigid pipeline due to standoff created by magnetiser wheels
- Risk of loose parts due to fatigue, mainly concerning wheeled magnetisers over long pipeline lengths
- Risk of pipeline damage due sharp edges resulting from blocking wheels

In order to address the above limitations and also provide a compatible tool, ROSEN has completed a series of pull tests to assess the impact of ROSEN MFL-A tools on the inner carcass of flexible pipes.

Solution

The main objective of the testing was to demonstrate the compatibility of standard ROSEN MFL-A tools for passage through flexible pipes without causing damage. Since the defect/failure mechanisms discussed above do not have any guidance on acceptable defect sizes, ROSENs ultimate aim was to not create any visible damage to the carcass surface when performing the pull tests.

Pull testing was performed to qualify ROSENs smaller diameter tools for use in flexible assets, with emphasis placed on compatibility for Deepwater gas pipeline systems where flexible riser lengths tend to be long and rigid pipelines tend to be heavier wall, standard MFL tools would provide significant advantages in these systems for both data retrieval and run conditions. The results from the testing are expected to be representative across a range of tool diameters due to analogous design.

Figure 3: ROSEN standard 8” MFL-A tool with wear resistant steel brushes

Magnetiser Optimisation

To close the magnetic contact between the magnetic yokes of the MFL tool and the pipeline, the magnetic flux has to be transferred through magnetisable contact elements, so called brushes. Depending on tool size and application ROSEN uses different types of brushes:

1. Lamellar brushes – typically used for larger tool diameters
2. Wear resistant steel brushes – typically used for smaller tool diameters
3. Wheeled Wear resistant steel brushes – for use in smaller diameter low pressure pipelines, the wheels reduce friction at the magnetiser by creating a small ‘stand-off’

As Deepwater flexible risers are typically constructed in smaller diameters, lamellar brushes are not a solution. At first choice, wheeled brushes seem to be most applicable, however the following disadvantages should be noted:

- Wheels create a localized contact pressure at the edge of the carcass link
- Wheels can be susceptible to blockage from debris, preventing rotation and encouraging uneven wear and eventually creating sharp edges
- The air gap reduces the wall thickness capability of the tool, potentially making it less suitable for thick wall rigid pipeline inspection.

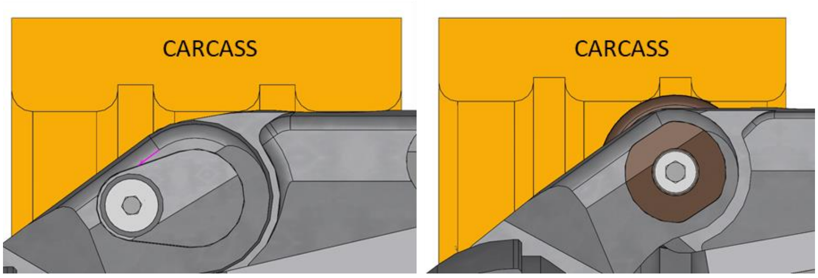

Figure 4: Comparison of wear resistant brush (left) and brushes on wheels (right)

Based upon the above, a wear resistant brush is the preferred option. Although historical ROSEN testing has shown negligible risk of using a standard wear resistant brush, modifications were adopted to optimize the brush to the internal curvature of the flexible. As shown in Figure 5, the existing chamfer has been removed and rounded.

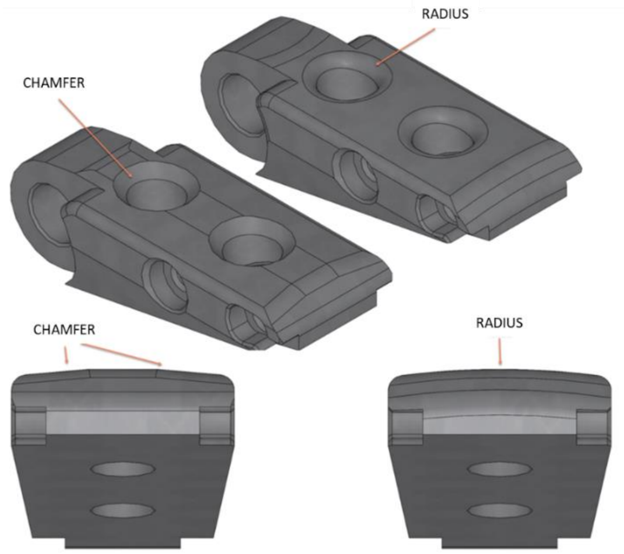

Figure 5: Curvature of wear resistant brush adapted to the internal curvature of the test riser (LHS: standard brush, RHS adapted brush)

The brushes are the main contact point between the magnetiser and the pipeline, however as part of standard design, yokes and sensors are spring loaded to prevent high contact forces and distribute the load of the magnetiser evenly. The maximum pre-tension of the yoke system on the inner wall of the carcass is 126 N per yoke (for a completely compressed magnet unit). This results in a worst case surface pressure of 0.24 N/mm^2 per brush, this is demonstrated in figure 6.

Figure 6: Flexible support of sensors and yoke

Even if the magnetic forces due to the magnetic parts of the pressure and tensile amours are added (expected to be low because of the large gap between the brushes and the magnetisable parts in the riser) the actual load of the brushes to the carcass will be very low. In combination with the rounded geometry of the brushes and yoke brackets this minimizes the impact on the inner carcass.

Testing

The pull test string composed of both a 35 m rigid spool and 20 m 8” nominal ID rough bore unbonded flexible (including termination heads). The pull rig utilises wire rope which is used for standard pull through tests, to avoid damaging the flexible with the steel wire, an intermediary Dyneema® rope was utilised to ensure no damage to the carcass was caused by the pull rope.

Figure 7: View along the installed flexible (yellow Dyneema® rope ready for pull)

A colour marking technique was employed to aid in visual inspection of the carcass surface after each pull test. To enable a comparison between runs, the same location in the flexible needed to be compared. Therefore, several locations were marked with a paint spot to verify the respective position (distance along sample and o’clock position, Figure 8).

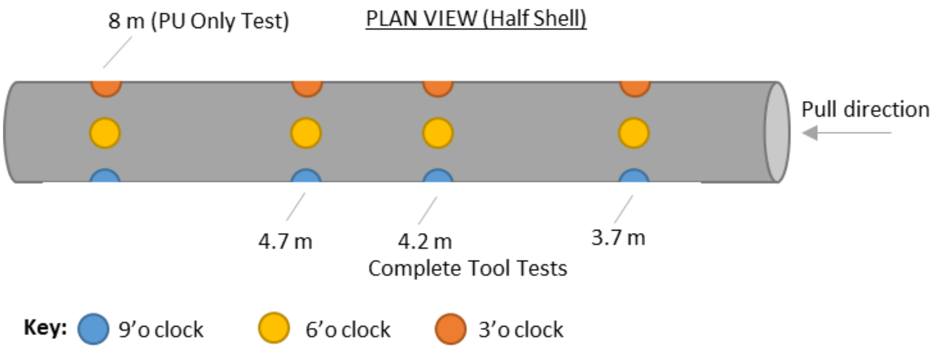

Figure 8: Flexible Marking Example

Before and after the respective pull tests, photos were taken of each paint spot. Additionally video recordings were made by pulling a camera through the flexible, orientated suitably for each o' clock marking.

Using a fully configured 8" MFL-A tool, initially four pull tests were performed to investigate the effect of the tool on the inner surface of the carcass. The tests were executed at the following pull speeds: 0.2 m/s, 0.5 m/s, 1.5 m/s and 3.0 m/s.

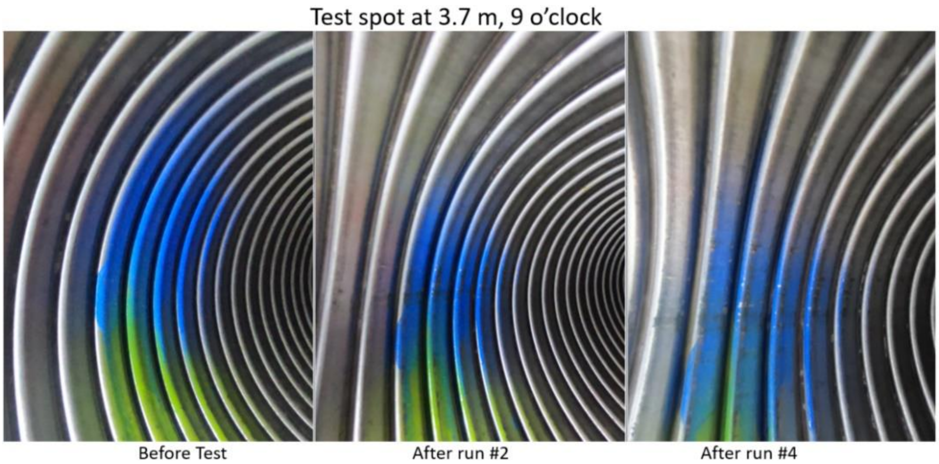

Figure 9: 9 o' clock test spot @ 3.7m (left: before test, middle: after run 2, right: after run 4)

Based on initial results, an additional seven pull tests were performed to isolate the effect of only cup contact with the carcass, this was facilitated by removing the magnet and odometer unit. These tests were performed to compare the effect of only PU with the effect of the complete tool including the magnet unit. Both soft 75A (full red cups) and hard 85A cups (full blue cups) were tested on individual runs, with new paint spots applied to exclude any effect of the magnetiser.

Conclusions

The paint markings resulted in two observations:

- The respective location (distance and orientation) can be identified.
- The condition of the paint gives an additional indication of the effect of the tool passage.

Overall, it can be stated that the observed effects to the paint and carcass are similar for all positions and o' clock orientations. Minimal abrasion of the paint can be seen between runs, with even less changes (if at all) noted to the carcass surface.

The area most specifically effected by the pull tests is located at the leading edge of each carcass link as indicated in Figure 10.

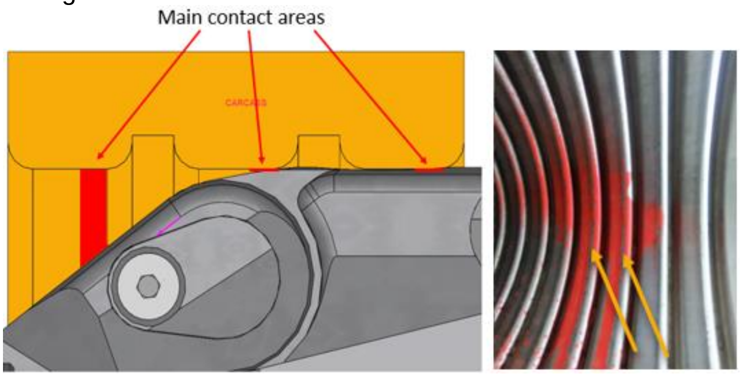

Figure 10: Main contact areas with carcass as per photo analysis

Paint removal is likely driven by a few factors rather than PU or brush contact alone. Dust, rust and inconsistent paint application will contribute invariably to the changes seen in the paint between runs.
Although paint removal has been observed, it should be emphasized no deformation or damage to the underlying carcass could be noted.

When comparing the different parameters such as tool setup and velocity, no damage mechanism due to velocity can be observed. In contrast, the difference in tool setup has a greater impact (albeit still insignificant) on the paint markings, Figure 10 shows the difference between the complete tool, red cups and finally blue cups.

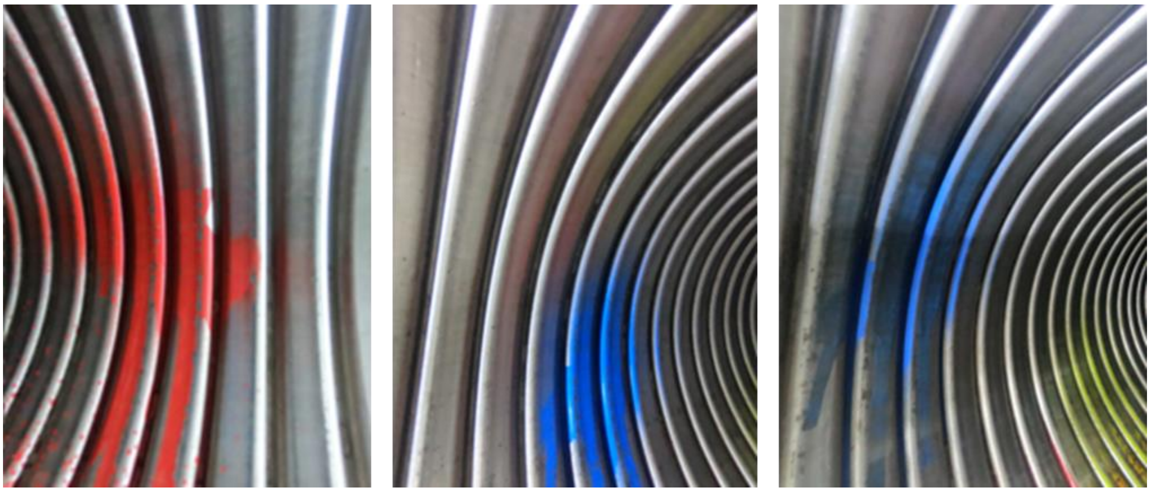

Figure 11: LHS: Complete tool last run, Middle: Red cups last run, RHS: Blue cups last run

It can be observed that there is little difference in the effect to the paint removal and carcass when comparing the complete tool and the two module tool fitted with red 75A cups. The largest difference can be noted when comparing the last 85A blue cup run with either the complete tool or tool fitted with 75A red cups. The volume of paint removed by the 85A blue cups is much greater than either of the previous setups. Therefore it can be deduced that the harder 85A blue cups effect the paint integrity more than the magnet unit which has metal to metal contact.

Although removal of paint is noticeable in all three test series, the amount of paint removed and the effect to the carcass underneath is negligible, similarly the surrounding carcass is also unaffected and shows no signs of scratches or deformations

Based upon the completed test series, ROSEN can conclude:

- Overall, no damage was induced by any of the tool setups (complete tool, red cups or blue cups).
- An adapted and optimized magnet unit has a lower impact on the carcass than a standard PU **c**up.
- ROSEN wear resistant brushes have been proven suitable for passage through flexible pipe
- Furthermore, no mechanical damage or scratches could be observed.

While the aim of the test was to qualify a standard ROSEN MFL tool for safe passage through a flexible, many other benefits are also realised from this tool design:

- Greater wall thickness inspection capability is possible due to the direct contact to the rigid pipe wall
- A more robust tool design can be utilised, distributing the overall magnetizer force over a greater surface area, eliminating contact point loading and encouraging even wear
- Greater resiliency to mechanical fatigue (due to the lack of moving parts such as wheels)
- Larger tolerance for pipeline debris and cleanliness
    - better tolerance to speed effects and lift off due to debris
    - More resilient against debris clogging tool parts. Wheeled magnetisers are susceptible to becoming blocked with debris, consequently preventing the wheels from rotating, causing uneven wear and the creation of sharp edges due to worn parts

Case Study 2: A Deepwater Multi-Diameter Gas Pipeline

Even when a solid magnetiser brings improvements to wall thickness capability, some pipelines are just too thick for inspection with MFL. Even if magnet strength can be increased, often this has compromises to the tool passage for both straight pipes and bends. In certain circumstances, an internal specification may still be maintained, this can be further improved by combining MFL technology with Internal Eddy Current (IEC). IEC can be provided as a combined or standalone solution and often compliments pipelines which have a combination of constraints: heavy wall, multi-diameter, gaseous medium and ID restrictions. Case Study 2 showcases ROSENs ability to provide a solution which can navigate a complex pipeline system, reduce risk to as low as possible and provide comprehensive integrity data.

The Challenge

ROSEN was tasked with the development of a multi-diameter 16”/22” ILI tools for the cleaning and inspection of an offshore pipeline system containing many of the typical deep-water installations and features such as: Y and T-pieces, jumpers, flexibles and valves. High operating pressure, high flow and heavy-wall design posed additional challenges. Early involvement of ROSEN, already in the design phase of the pipeline, provided the operator’s engineers with crucial input regarding the possibilities and limitations of ILI technology. Team effort and cooperation contributed greatly to the success of this project. The final main parameters of the pipeline system are shown below:

Maximum water depth:	2,230 m
Design pressure:	335 bar (33.5 MPa)
Maximum wall thickness:	36.8 mm.
Maximum ID range:	14.70 – 21.75 in./15.40 – 22.30 in.
Maximum length:	452 km

The Solution

Multi-Diameter Pull Unit

The pull unit is a crucial unit of ILI and cleaning tools. ROSEN developed a new multi-diameter pull unit, which can operate in an ID range from 340mm to 610mm. In order to ensure optimal sealing in such a wide range, so-called “umbrella cups” were employed on the pull segments. Due to the modular design of the pull unit, the number of sealing segments can be adapted easily depending on the requirements. In this case the 4-segment design provides a large sealing length, sufficient for the passage of different installations such as T- and Y-pieces. To improve the stabilization of the sealing segments, spring-stiffened cardan joints were used in between. All 4 segments were designed to carry battery packs. If desired, a high-pressure transmitter can be installed in the first pull unit module. A general sketch of the 16”/24” pull unit is shown in Figure 12.

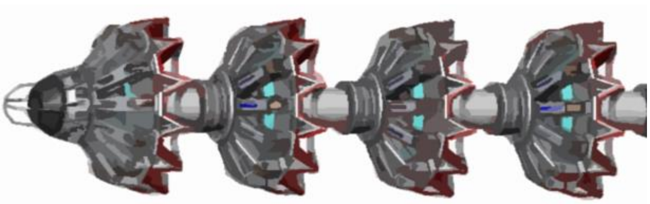

Figure 12: 16"/24" pull unit

Multi-Diameter Cleaning tool

ROSEN developed a new multi-diameter cleaning tool with nylon brushes and magnet rings. The 16"/24" cleaning tool equipped with a gauge plate is shown in Figure 13.

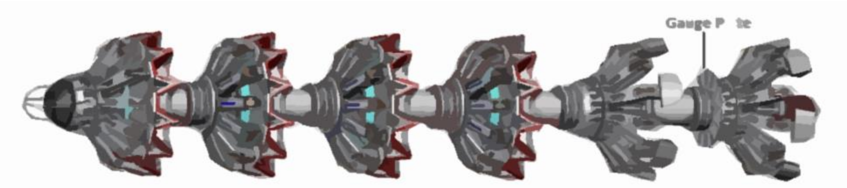

Figure 13: 16"/24" cleaning tool with gauge plate

The design of the cleaning tool consists of 6 segments guided by 4 umbrella cups and 2 spring-loaded brush segments. Brush segments provide full coverage within the entire operating range to ensure optimal cleaning performance, it is worth mentioning that the pull unit itself has excellent cleaning properties. All segments are connected with spring-stiffened cardan joints. To verify the internal diameter of a specific pipeline, the tool can be equipped with a gauge plate between the first and second brush segment. The type of gauge plate and its position is the result of ROSEN's long-time experience with gauging surveys. The specifications of the 16"/24" cleaning tool are shown in Table 1.

Tool parameter	Tool value
Tool length	3,202 mm
No. of segments	6
Min. ID passage in straight pipe (designed/tested)	340 mm/344 mm
Min. ID bend passage (2.5D in 16″) (designed/tested)	345 mm/356 mm
Max. operating pressure	300 bar (30.0 MPa)
Min. product temperature	0°C
Max. product temperature	65°C
Max. tool run velocity	5 m/s
Recommended tool run velocity	1 – 2 m/s
Operational weight	580 kg
Gauging plate outside diameter	372 mm

Table 1: Specifications of the 16"/24" cleaning tool

Multi-Diameter IEC geometry tool

To tackle all of the above-mentioned challenges the IEC (internal eddy current) technology was selected as it can be used on a high-resolution geometry tool and is capable of internal metal loss inspection, which is a primary threat for offshore gas pipelines. Contrary to MFL technology, measurement performance of IEC is speed independent and the tool design is less bulky compared to a MFL tool offering better passage capabilities. Furthermore, IEC geometry tools have significantly lower friction than MFL tools which results in a better run behaviour. The combination of multi-diameter and heavy wall thickness poses a particular challenge for a MFL tool – forcing a multi-segment design with extremely strong magnetic circuits, which negatively influences the tool's run behaviour and passage capabilities. Because of the above, an IEC tool reduces the overall operational risk during an inspection. The ILI tool consists of the multi-diameter pull unit, the measurement and the odometer units (Figure 14).

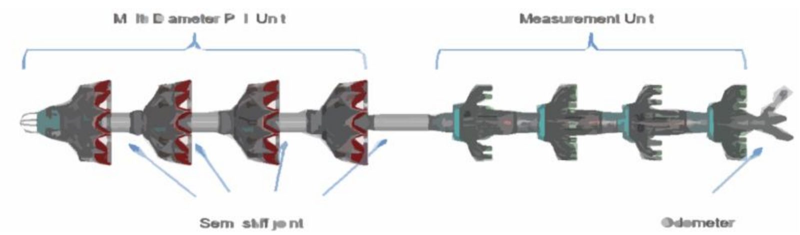

Figure 14: IEC tool assembly

The measurement unit was designed to measure internal corrosion and pipeline geometry in a multi-diameter pipeline. There are 4 measurement modules with multiple sensor arms each in order to achieve full coverage in the maximum ID. The sensor arms are spring-loaded, which ensures that all arms always follow the pipeline wall. Each sensor arm consists of 2 sensors: 1 for the diameter change measurement (measures the angle of the sensor arm) and 1 for the measurement of the internal corrosion and the distance to the pipe wall. Outer support wheels on each sensor arm decrease friction. The measurement unit is equipped with a high-resolution gyro. The specifications of the IEC tool are shown in Table 2.

Description	**Value**	**Corresponding pipeline value**
Tool length	4,500 mm	4,769 mm (min. launcher length)
Tool weight	760 kg	
Min. bend radius	2.5D in 16”	2.66D
Min. ID in straight pipe	340 mm	370 mm
Min. ID in bend	350 mm	393 mm
Max. ID in straight pipe	570 mm	565 mm
Battery capacity	95 hours (+ 10% safety margin)	82 hours

Table 2: Specifications of the IEC tool

Testing

After detailed design, manufacturing and assembly, the tools underwent an extensive testing program including:

- Bypass test under low and high differential pressures
- 6 pump tests (Figure 15)
- 30 pull tests in 5 different diameters (16”/18”/20”/22”/24”) in order to verify the tool specifications

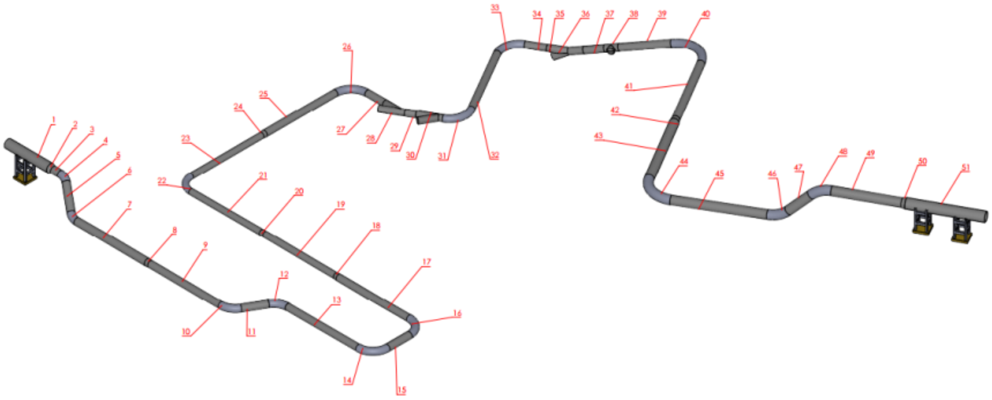

Figure 15: Pump test loop sketch

The test loop consisted of 51 elements including pipes in a wide ID range, bends, T-Piece but also an original 10-tonne offshore Y-piece combination, all in order to prove passage, proper run behaviour and acceptable differential pressure levels in the most challenging combinations of installations. All test were successful and confirmed the tools fitness for use.

Gauging And Inspection Runs

The first line for gauging and inspection runs had the following challenges:

- Length of 384km
- ID range from 391.1mm to 552.4mm

- High flow up to 5m/s
- Passage through flexibles/flow coating
- Challenging combinations of installations: Y-pieces, bends, T-pieces, jumpers, valves
- High pressure up to 280 bar
- Subsea pig detection

Both the cleaning/gauging and the ILI tools were equipped with an ITX 804 HP ROSEN's transmitter designed to withstand pressures up to 300 bar and a radioactive isotope supplied by a third-party provider to ensure emergency pig detection.
The ILI run was completed within the estimated time, and the recorded geometry, metal loss and XYZ data were of good quality, providing 100% coverage. After traveling 384 km and passing complex installations, the IEC tool was received in very good condition.

Benefit

The initial participation of the engineering team led to substantial cost reductions for the client during the construction of the pipeline. Through the creation of a customized solution, ROSEN assisted the client in maintaining pipeline integrity, complying with local regulations, minimizing operational impact on flows, and ensuring the safe usability of the pipeline for gas transportation.

Deepwater high pressure riser inspection with self-propelled tethered tools

Introduction

ROSEN Norway (former KTN AS) as part of the ROSEN GROUP is a technology company specialized in self-propelled tethered tool inspection technology.

For Deep water pipeline inspection the tethered crawler solution can be applied (as part of the ROSEN toolbox) in case:

- The line cannot be looped or is risky to loop for example because it’s unknown if subsea valve can be fully opened.
- Conventional Bi-Di ILI pigging is not possible because flow cannot be reversed.

Different types of technologies, including ultrasonic wall thickness (vertical beam pulse echo) and crack measurement (angular beam pulse echo, Time of Flight Diffraction and Phased Array), Eddy Current, video camera and sonar are available on the tethered crawler tool train. Low friction MFL is in development phase.

Different types of propulsion elements, including bi-directional self-propelled (crawlers/tractors) and pumped modules, are also available for the specialized tethered ILI tools.

The system is capable to measure geometry, wall thickness/corrosion, crack depth and crack profile quantitatively, data is collected on the way in and out and the results are visible in real-time. Tethered technologies are capable of inspecting pipelines with a 6" (4” on request) or larger diameter. Pipelines up to 12 km in length were successfully inspected, however, distances up to 24 km are also possible.

Principle of Tethered Tool

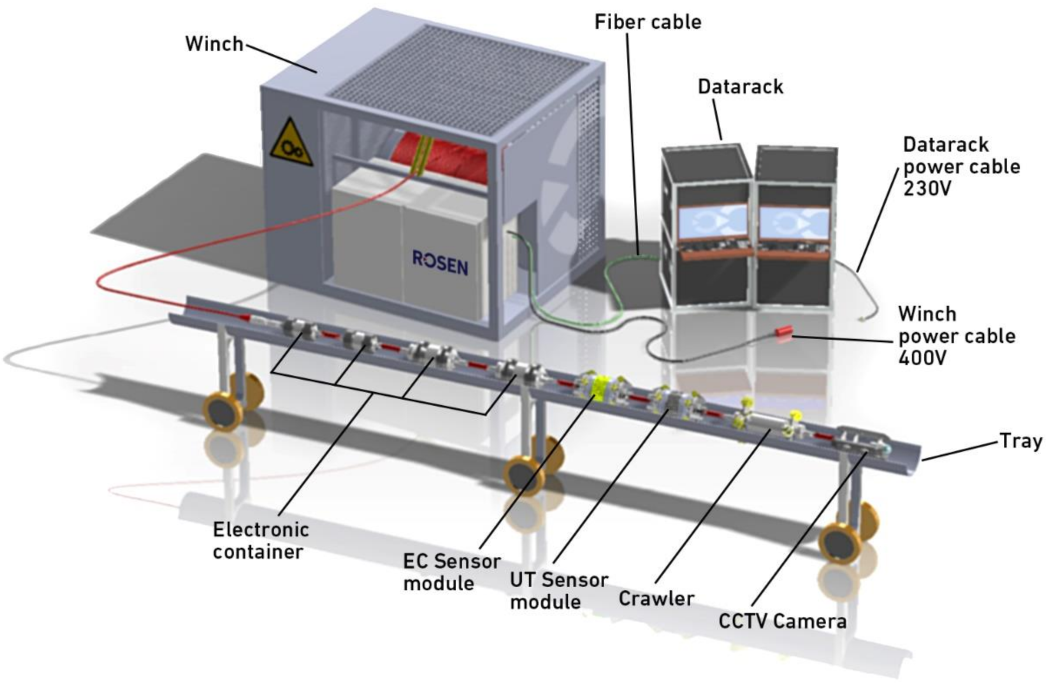

Figure 16: TUM principle

Although the TUM, which stands for Tethered Ultrasonic Measurement, is typically tailor-made for a special project, the typical composition consists of the following:

- One or two crawlers in the front – depending on the pull forces required – will pull the complete tool into the pipeline and push it back on the return run. Propulsion method with crawler is either with rotating wheels or build in self-propelled pump unit.
- The pulling/pushing modules are followed by project-specific modules:
    - For UT geometry and wall thickness with pulse echo vertical beam technology.
    - Standard UT for Carbon steel and high resolution UT for CRA cladded Catenary risers
    - For geometrical anomalies as dents, ovalities and further restrictions, and for metal loss and wall thickness defects as pitting, all kind of metal loss, wall thinning and lamination,
    - For crack detection with shear wave technology,
    - And/or for crack detection and seizing with TOFD (Time of Flight Diffraction),
    - For corrosion or crack inspection with eddy current technologies.
- Modules for data storage are also part of the tool train.
- If the tool is inspecting a pipeline within a clear product as water, a camera can also be installed in the front of the tool.
- For very special tasks even a grinding tool can be added for grinding out internal girth weld penetrations and internal cracks.
- The tool is connected via a cable coming from a winch with the control unit. The cable has four functions: to bring the energy to the tool (the tool does not have a battery pack), to transfer the data in real time to the control unit, to control the movement of the crawler, and last but not least as a safety line. If the crawler cannot move anymore and the tool would get stuck, it can be pulled back with up to, for example, 10 tons.

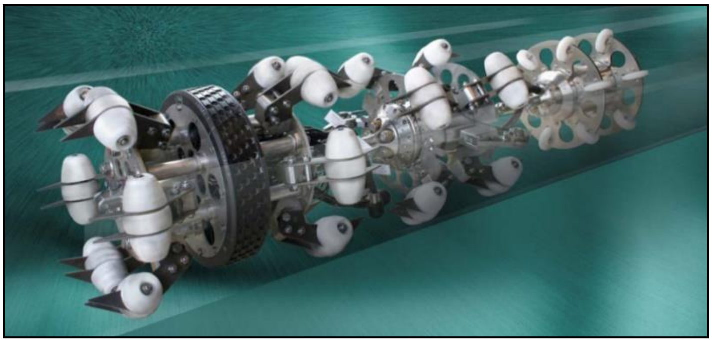

Figure 17: TUM module

The ROSEN TUM tool has a lot of bypass compared with conventional ILI tools which is a great advantage because a small amount of debris will not be "bulldozered" in front of the tool. The sensor carrier module is typically flexible to negotiate bends. It is extremely lightweight, made of titanium. The main purpose of the lightweight tool is to require only very little pulling forces and almost no friction in order to be able to inspect longer sections even through many bends. Furthermore, softer crawler wheels can be utilized if there is concern for inner carcass damage of a flexible riser.

Another differentiation compared with conventional tools is that winches are required to carry out the inspection. Inspection of up to 12 km have been completed successfully, with up to 24 km the total possible length, however possible inspection length is dictated by the number bends and pipeline configuration.

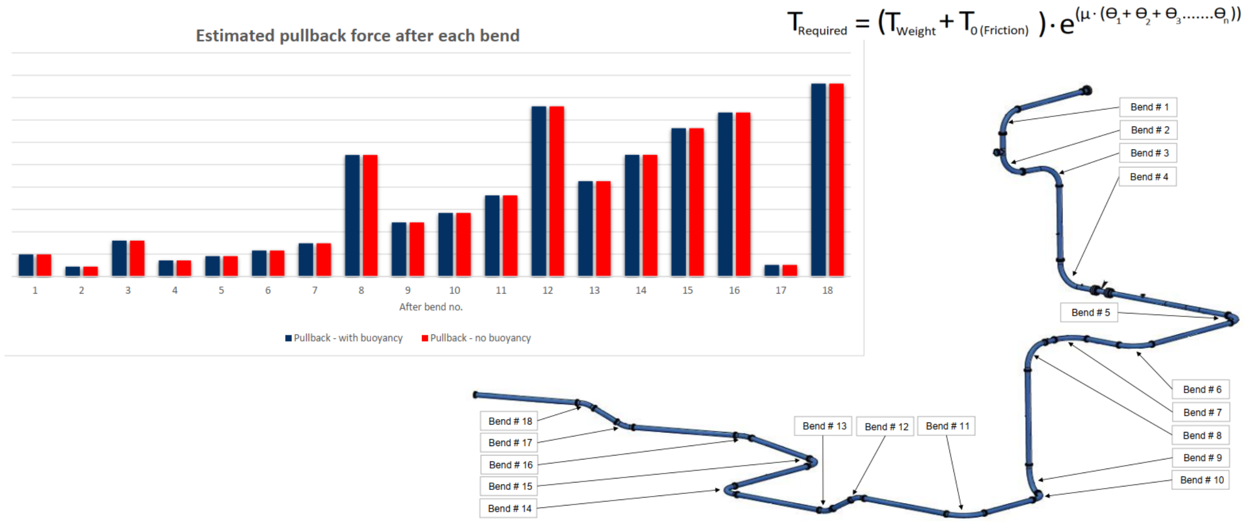

Figure 18: Challenging offshore riser with many bends

For deep water riser inspections, a point of attention is the pull-back force of the tool. In case a tethered crawler tool is losing power, the tool needs to be pulled back via the winch. The pulling force of 10" crawlers are approximately 200 kg each and not the limiting factor for the inspection of a deep sea pipeline.

In order to confirm that the passage and retrieval through multiple bends is feasible, a tool will be tested in a test loop in ROSENs facility in Bergen, Norway. The main purpose of these tests is to demonstrate that the tool could be retrieved by the umbilical. Based on the friction profile from the test loop (the pullback forces as function of tool position in the loop), we are able correlate the figures with the riser configuration. This way, ROSEN are able to obtain a figure for the required pullback forces in case the tool loses power within the riser system.

Figure 19: Test loop in Bergen

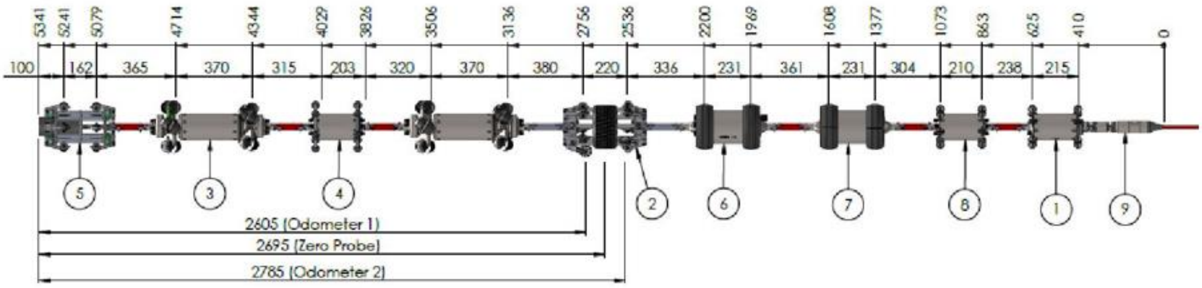

Figure 20: Typical Inspection tool train – TUM-WT-Sonar

Specific tool train configurations can be used, for example: wall thickness measurements and sonar (UTWM + Sonar), see figure 22.

In order to see a blocked pipeline (closed valve or similar), a sonar will be mounted in the front of the tool. Sonar is used as a method for locating objects in space and under water by means of emitted sound pulses.

Two electrical crawlers will run in tandem configuration. This configuration has been designed for increased pulling force to ensure that the tool can negotiate through difficult to pass pipeline components like slippery valves, tees etc. An ultrasonic sensor carrier with 4 rotating UT probes for pipe diameter 6” to 8” and 160 fixed UT probes for pipe diameter 10” to 18” will be used, along with two odometers measuring the travelled distance and tool velocity. The movement of the odometers triggers the data collection.

During the run, pull-back force measurements can be carried out on preselected distances in order to calculate the friction coefficient and to be sure to be able to return in even the worst case. Throughout the testing and the actual inspection activities, two operators are on deck operating the umbilical winch, tool train and umbilical etc. and two operators in the habitat are in charge or operating the computers: Propulsion & UT/Sonar.

During an additional run with a TOFD module, the tool can be stopped at some pre-selected locations (like girth welds) to make TOFD scans, which will enhance the accuracy of WT readings and provide additionally crack detecting and seizing.

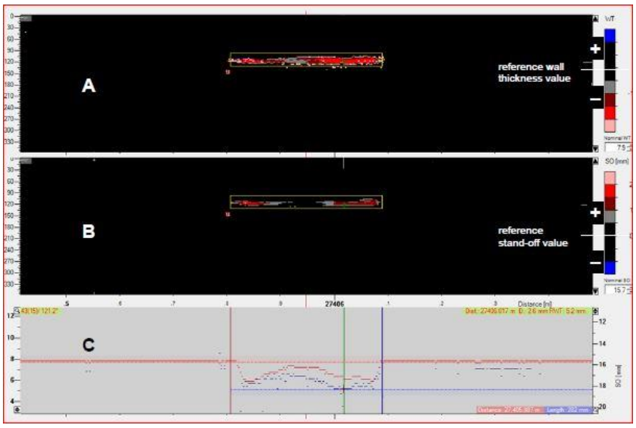

Figure 21: Experts control tool movement and record data real time.

A site report can be provided showing the most severe detected defects while the crew is still offshore because data will be recorded real time, see figure 23, and analysis of severe defects can be made at site. At a later stage the final report will be submitted.

Highly accurate UT and TOFD data allowed for a fitness-for-purpose evaluation, specific decision making and the continued safe operation of the riser.

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