Cleaning and ILI of a Heavy Wall Subsea Pipeline with Improved Differentiation Between Debris and Corrosion

Johannes Keuter
3P Services GmbH & Co. KG, Germany

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Abstract

An 18", North Sea, heavy wall, offshore wet gas flowline with known debris interference, had to be inspected. The total length is circa 300km with up to 27.3mm nominal wall thickness. Potential corrosion had been detected in a previous 3rd party in-line inspection. However, the POI was limited and no clear differentiation between corrosion and debris was possible. Hence, the previous inspections were not fully successful, and the data couldn't be used for a full evaluation of the clients' problems. 3P Services was asked to perform a metal loss inline inspection of the pipeline as soon as possible. Following on from a specific cleaning program, 3P proposed an 18" GEO/MFL/DMR combo tool. This tool combines a heavy wall magnetizer with a geometry measurement segment and special DMR sensors, wall guided as well as in a stand-off configuration. The combination of these different sensor technologies allows an optimized differentiation between debris, internal corrosion, or internal corrosion with debris. This information was used to improve the POI and anomaly sizing. The challenges and solutions of this outstanding project are explained in this paper.

Introduction

The integrity plan of any asset is an integral part of a safe hydrocarbon producing facility. This applies in particular to pipelines that run through areas that require special protection, such as any sub-marine pipeline system. The internal condition of a pipeline is to be monitored to enable an understanding of the environment and confirm longevity of the asset.

The offshore pipelines relevant in this paper transport gas. The subject gas field is in the North Sea in 600m water depth, Northwest of the Shetland Islands. The pipelines carry wet gas and were inspected through a pigging loop which connects the two pipelines. Hence, the launcher and receiver were located next to each other.

3P Services has been contracted to perform the in-line inspection of these two 18" gas import pipelines. The pipelines in question were built post 2010 and had been MFL inspected in 2020 by another inline inspection (ILI) company, but their interpretations were compromised by sensor lift-off believed to be caused by pipeline debris.

The inspection scope of 3P Services included several cleaning tool runs and an ILI tool run. With this information, 3P Services was approached to design and assemble an ILI tool that would safely pass through the pipeline and record inspection data of the entire pipeline to provide a status of the current integrity of the pipeline. To counter the known POI challenge, an ILI tool was developed with four different sensor types and these four different data sets available were to accurately analyse these known problematic areas. The special designed ILI tool was equipped with MFL and GEO sensors as well as wall-guided and stand-off magnetic sensors to inspect the pipeline for internal and external metal loss, geometric discontinuities, and other features. Cleaning runs were performed with export gas as the propelling medium. The initial cleaning pig runs removed the well product, wet gas and other liquids. The ILI Tool was run in gaseous environment only. The inspection execution was planned to begin in April 2023.

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The challenges

The pipeline design, layout, and condition combine several factors which made a successful inline inspection challenging such as:

- Pipeline length, wear on tool components, battery life.
- Cleanliness, vibration and stand-off problems degrading data quality.
- Wall thickness, beyond the magnetization of most MFL tools in the market.
- Schedule, a very challenging timeline.

Firstly, the length of the pipeline is circa 300 kilometers which requires a low-wear ILI tool design, because such a length in a gas pipeline can cause significant wear of the cups, sensor arms and magnetizer. The cup wear could be unequally distributed and could cause an asymmetrical tool position with potential tool sagging, which could influence the data quality. The wear on the sensor arms and magnetizer could damage the sensor and lead to data loss. A 3rd party dewatering campaign during pipeline pre-commissioning showed significant wear issues on multiple pigs, heavy scoring, and portions of polyurethane (PU) missing.

In addition to the risk of wear, battery lifetime is an issue. The run time was anticipated to be three (3) days. Hence, the ILI tool needed to be equipped with sufficient battery power that provided enough energy to record four times the pipeline length, one for each data set. The number of batteries needed more space and hence, additional tool segments were required. The additional segments complicated the tool transportation and handling. Detailed planning of the transportation and onsite tool handling, in close cooperation between the 3P Services and the client, was necessary.

The pipelines had several cleanliness challenges. There have been several pigging operations between 2016 and 2020 in which dewaxing pigs and debris mapping tools were used. However, the data from the debris mapping tool and debris observed after cleaning did not assist with the decision to run a 3rd party MFL inspection, nor help interpret the compromised data received. The probability of identification (POI) was limited and no clear differentiation between corrosion and debris was possible. Hence, the previous inspections were not fully successful, and the data couldn't be used for a full evaluation of the clients' problems.

Figure 1-2. Examples of previously removed debris.

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The pipelines are classified as having “heavy wall”. The nominal wall thicknesses of 25.4mm and 27.3mm are a measurement challenge for MFL, especially in an 18" pipeline as a proper magnetization level must be achieved for a good measurement performance. A previous 3rd party ultrasonic inspection (UT) was unsuccessful in retrieving data across the whole line, because of significant wear issues on sensor carrier and PU components on the ILI tool and pig train. In this case the batching couplant was lost and gas impacted the sensors. Because of this experience, the uncertainties of the cleanliness, UT was not considered a viable option.

Due to previous unsuccessful 3rd party ILI runs 3P Services were challenged to develop a heavy wall MFL magnetizer which could magnetize the wall thicknesses, cope with additional debris, and associated vibration and ensure correct reporting specifications would be met.

In addition to technical challenges the project also had schedule challenges. The schedule challenges refer to the lead time between contract award and onsite activities to build a unique inspection tool as well as the accelerated time for analyzing 4 data sets to produce the final report. Accelerated reporting times posed a double challenge, because the pipeline length is above a normal inspection and there were four data sets to be evaluated. Due to the high-profile nature of this inspection the client required weekly data analysis updates. For this reason, the 3P Services project team worked on project preparation, tool design, assembly, testing, shipment, project execution and reporting under elevated levels of time pressure.

The Solution

In order to tackle this very challenging inspection 3P services had to include several solutions in its overall inspection concept, including:

- Low friction and extended run components
- Extended run time
- Multiple sensors allowing discrimination of pipe-wall from debris
- Detailed testing and factory acceptance
- The cleaning program

The mechanical concept of the ILI tool was developed at the very beginning of the project. It was required to have a detailed assessment of wear reduction for each ILI tool segment. First, the weights of each segment were estimated, and optimum polyurethane cups were designed. The number of cups, the position and the dimension were defined. Each cup got several ceramic pins included which limit the wear significantly, because the abrasion resistance is higher than the abrasion resistance of polyurethane. This solution increases the maximum inspection length significantly.

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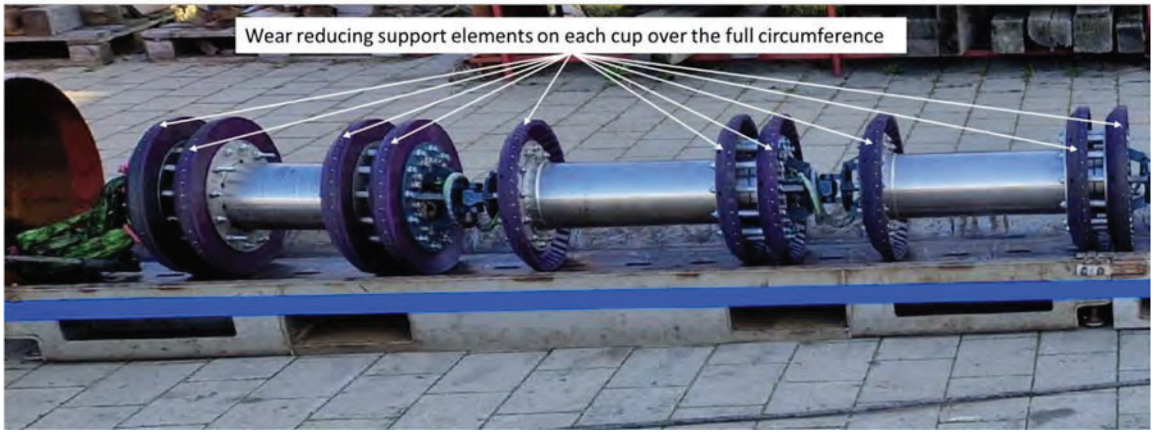

Figure 3. Wear reducing elements on the cups.

Furthermore, the geometry measurement segment which carries additionally the wall-guided magnetic sensor was redesigned. The sensor arms were equipped with wheels which guided the arms. This design allows rolling friction instead of sliding friction. This reduced the abrasion significantly. However, a redesign of the sensor housing of the wall-guided magnetic sensors was also carried out in order to increase protection against abrasion.

Unlike most ILI service companies, 3P Services uses wheels to support its magnetic flux leakage (MFL) magnetizer as standard. It was a clear choice to use this successful wheel design for this extremely long gas pipeline. As an added benefit the wheel design will not compromise any internal coatings adversely. Nevertheless, there was the need to strengthen the magnetization capabilities of the yokes to magnetize up to 27.3mm nominal wall thickness. A combination of bespoke yoke design and exceptionally strong magnets solved this challenge. 3P Services has a long history of heavy wall MFL inspection in the past, these experiences were used to find the ideal balance between wear limitation, yoke volume, magnetic strength, and pipeline magnetization.

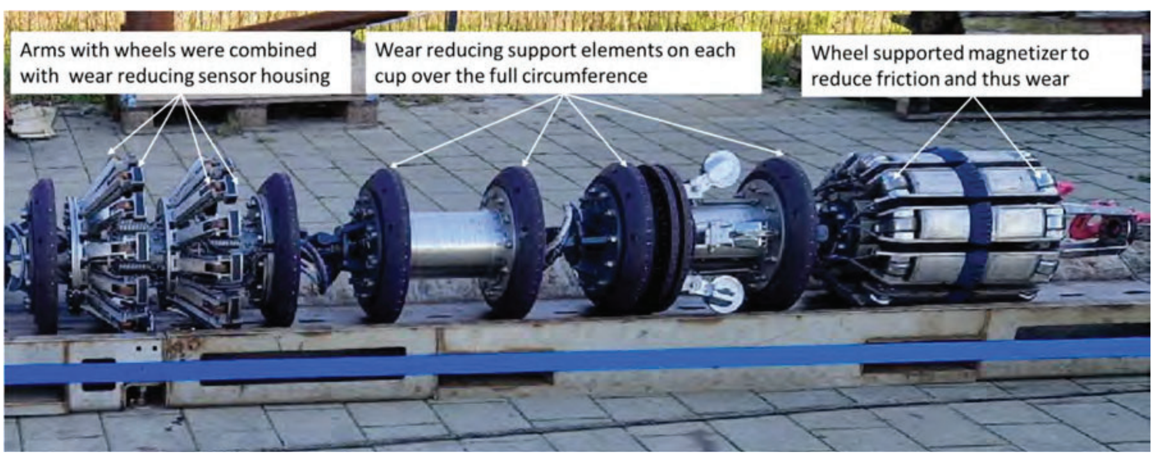

Figure 4. Wear reducing design optimizations on the different ILI tool segments.

A circa 300km long pipeline with a run time of three (3) days using multi-sensor-technology combo-ILI tool will require enormous energy consumption. Three additional battery segments were needed to carry sufficient battery power to ensure a successful inspection. The battery segments were used as pulling segments to limit the tool lengths and combine two functions.

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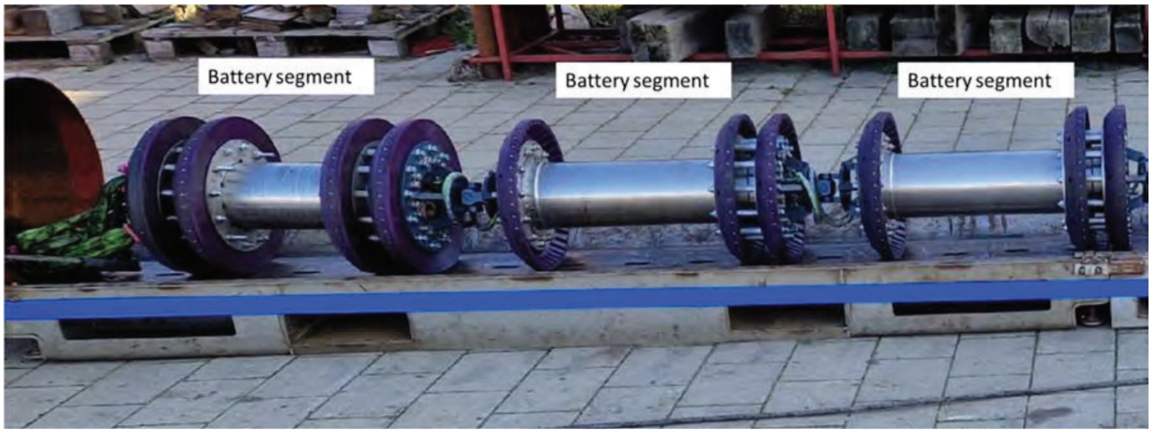

Figure 5. Three battery segments to carry sufficient power for a three (3) days ILI run.

An important part of the preparation of the pipeline inspection is the pre-ILI cleaning of the pipeline. Considering the history of the pipelines previous inspections, special attention was given to the cleaning program. 3P Services assessed the cleaning program, including the clients existing cleaning tools. After collaboration, suggestions to enhance the overall cleaning program were made by adding some 3rd party equipment and 3P Services own most aggressive cleaning tools. In total seven (7) cleaning tools were mobilized to be able to flexibly adapt to the cleaning plan as necessary.

It was decided to use a 3rd party debris assessment tool in-between the last cleaning run and the intelligent tool run. The reported debris thicknesses in combination with the results of the first cleaning tool runs, were used to decide if the line is clean enough or if further cleaning tool runs follow.

Nonetheless, the focus remained on inspecting and collecting complete, good, and unequivocal data from the intelligent tool to avoid a limited probability of identification (POI) and to avoid issues with the clear differentiation between corrosion and debris.

3P Services developed an advanced approach of combining several measurement technologies on one combo-ILI tool. The following measurement technologies were combined:

- Magnetic flux leakage (MFL).
- Geometry (caliper).
- Wall guided magnetic sensors.
- Stand-off magnetic sensors.

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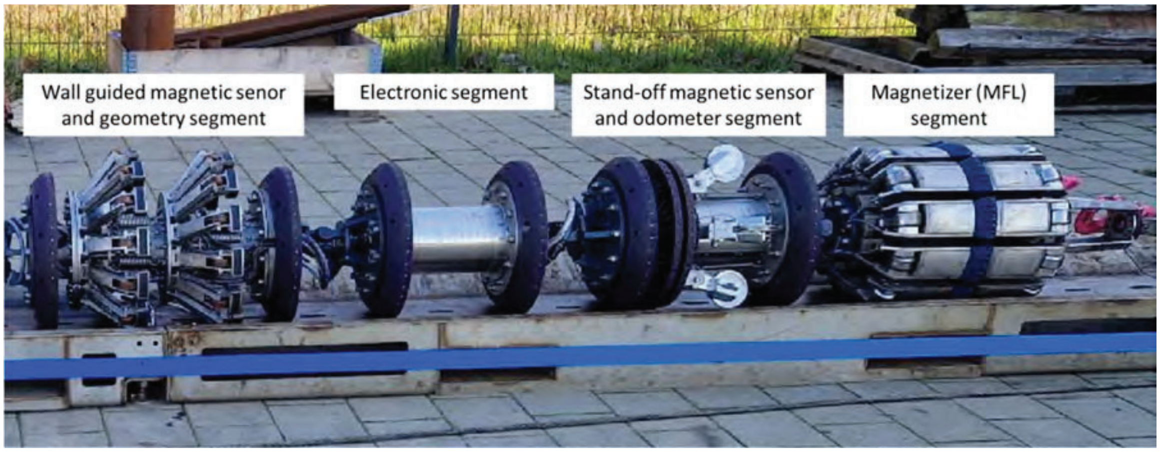

Figure 6. Combination of multiple measurement technologies on one (1) combo ILI tool.

The combination of four (4) different measurement technologies or sensor arrays, respectively, allowed a differentiation of various debris/metal loss situations based on the collected ILI data. The geometric sensors (GEO) measure the internal diameter (ID) and any internal deformations. The wall-guided magnetic sensors were used to measure the distance between each sensor and the next ferritic surface, typically the inner pipe wall. The wall-guided magnetic sensors (WG) move with the movement of the geometric sensor arms. In contrast to that, the stand-off magnetic sensors (SO) don't move with the movement of the geometric sensor arms. But they also measure the distance between each sensor and the next ferritic surface. Finally, the MFL sensors were used to measure the magnetic field in the pipe wall and detect internal as well as external metal loss.

The following schematic shows four different situations (A-D) and the effect of those onto the four (4) different sensor measurements. From top to bottom the effects on each technique can be seen.

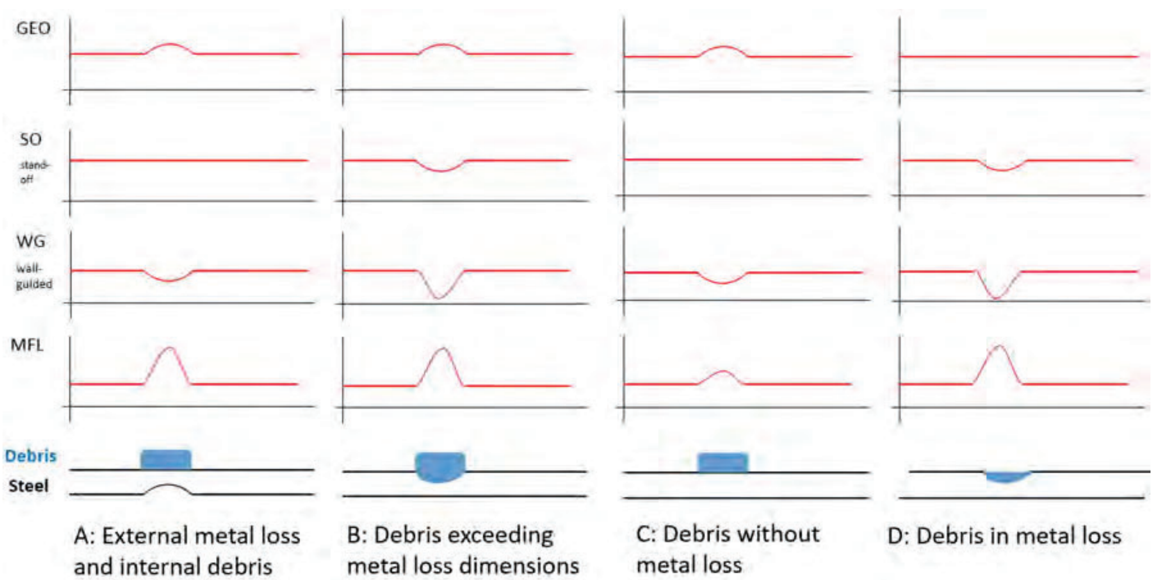

Figure 7. Effect of different Situation (A-D) on multiple measurement technologies.

Situation "A" shows external metal loss and internal debris. The geometry sensors (GEO) show a corresponding ID reduction. The stand-off magnetic sensors are not in touch with the debris and consequently don't show any change in signal. Whereas the wall-guided magnetic-sensors show a weak signal caused by the increased distance of themselves to the inner pipe wall due to the arm movement. The MFL sensors show a strong signal caused by the external metal loss.

Situation “B” shows internal metal loss with internal debris thicker than the internal metal loss depth. Consequently, the geometry sensors (GEO) show an ID reduction. In contrast to Situation “A”, the stand-off magnetic sensors are still not in touch with the debris but show a signal change due to the internal metal loss. The wall-guided magnetic-sensors show a strong signal caused by internal metal loss and the MFL sensors show also a strong signal caused by the internal metal loss.

In situation “C” there is no metal loss but internal debris. Hence, the geometry sensors (GEO) show an ID reduction. The stand-off magnetic sensors are not in touch with the debris and there is no internal metal loss and consequently they don’t show any change in signal. Whereas the wall-guided magnetic-sensors show a weak signal caused by the increased distance of themselves to the inner pipe wall due to the arm movement. The MFL sensors show a weak signal caused by the minor sensor movement which is possible in case of hard scale debris. There is a risk of misinterpreting this weak signal as metal loss, which probably caused compromised data interpretations in the 2020 3rd party MFL inspection.

A similar situation is visualized in situation “D” in which internal metal loss is filled with debris. In this case the geometry sensors (GEO) show no ID reduction. The stand-off magnetic sensors are again not in touch with the debris but show a signal change due to the internal metal loss. The wall-guided magnetic-sensors show a strong signal caused by internal metal loss and the MFL sensors show also a strong signal caused by the internal metal loss.

In conclusion, the combination of the four (4) different measurement technologies or sensor arrays, respectively, allowed a differentiation of various debris/metal loss situations. Because each situation causes different reactions of each technology. The combination of the data set of each technology shows a unique picture and allows a significantly improved identification of debris and metal loss or debris with metal loss. This leads to a clear improvement of the probability of identification (POI).

It was decided between the client and 3P Services to test the above-described system and to include a challenging spool piece with internal metal loss and debris into the standard pull-test program. A 600mm long piece of pipe was used to machine two internal metal loss anomalies with 28mm axial length and 556mm circumferential width. The first anomaly had a depth of 47.4% and the second had a depth of 53.1%. Both anomalies were filled with artificial debris. The spool piece was flanged to further calibration spool pieces, used in the calibration pull-through tests.

The characteristics of this spool piece were used to reflect situation “D” as part of the large-scale tool testing. The combined ILI tool was pulled several times through the pull test line and data sets of the introduced four (4) different measurement technologies were recorded. The first data screenshot below shows the geometric (GEO) data of the ILI tool. Each line represents a sensor. The debris within the internal metal loss didn’t exceed the inner pipe wall and didn’t cause any ID reduction. Accordingly, the GEO sensors don’t show any reaction and show no ID reduction. Instead, they show a constant ID. The location of the anomaly is marked with a blue rectangle.

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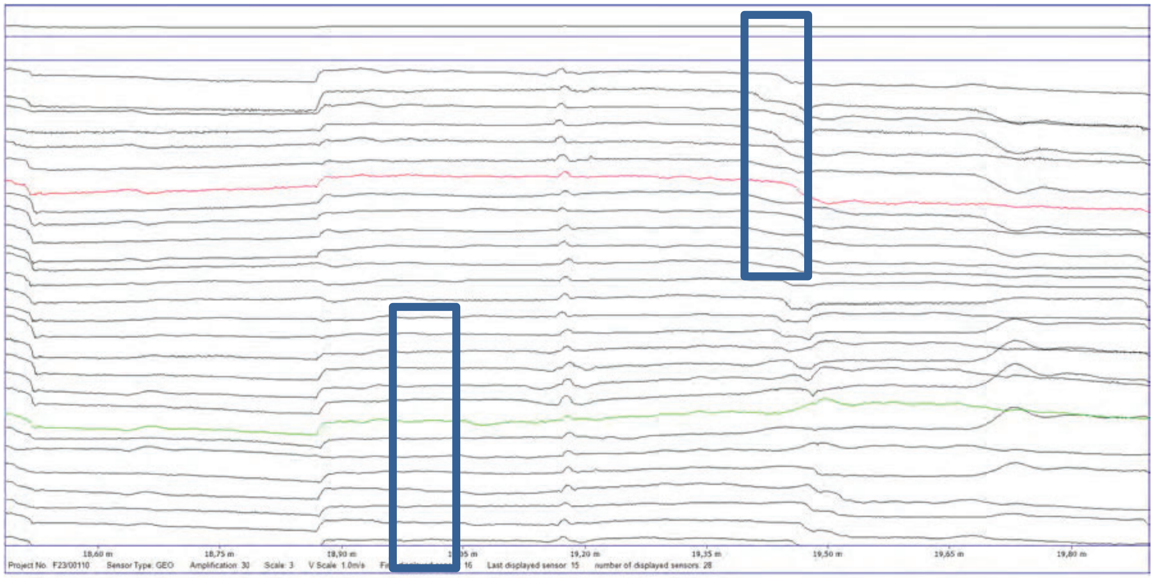

Figure 8. GEO data – blue rectangle shows anomaly location (red/green sensors = 12h/6h).

In contrast to the GEO sensors show the wall-guided magnetic sensors clearly the internal metal loss. These sensors measure through the artificial debris.

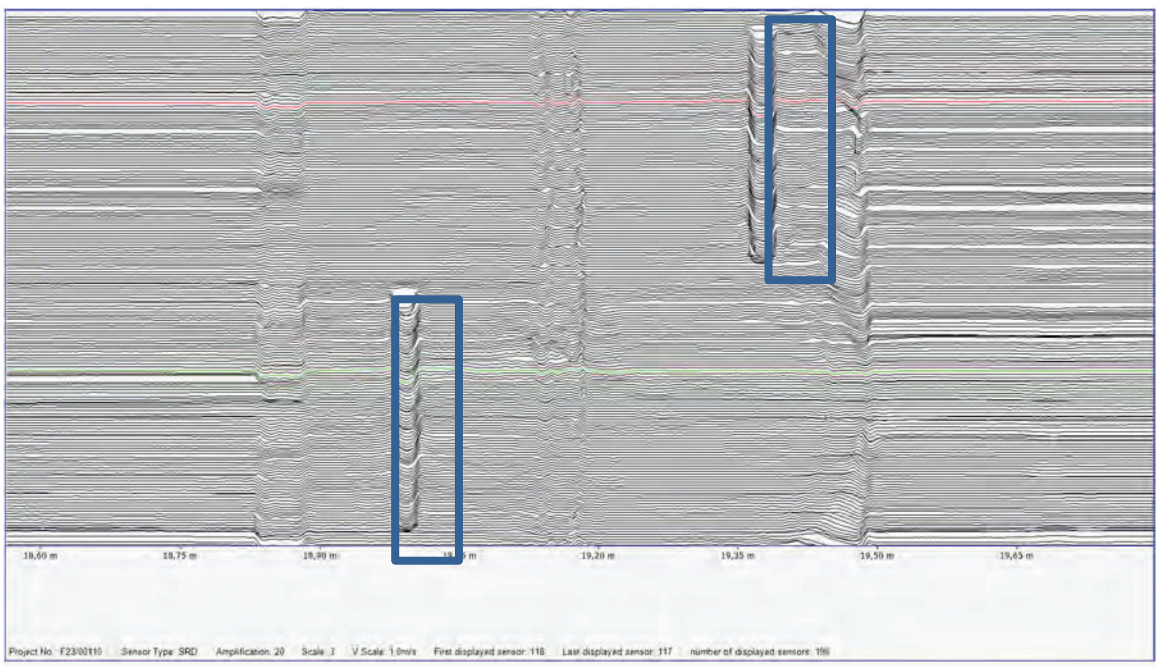

Figure 9. Wall-guided magnetic sensors data – blue rectangle shows anomaly location (red/green sensors = 12h/6h).

The same behavior can be observed on the stand-off magnetic sensors. These sensors ignore the debris and measure clearly the internal metal loss.

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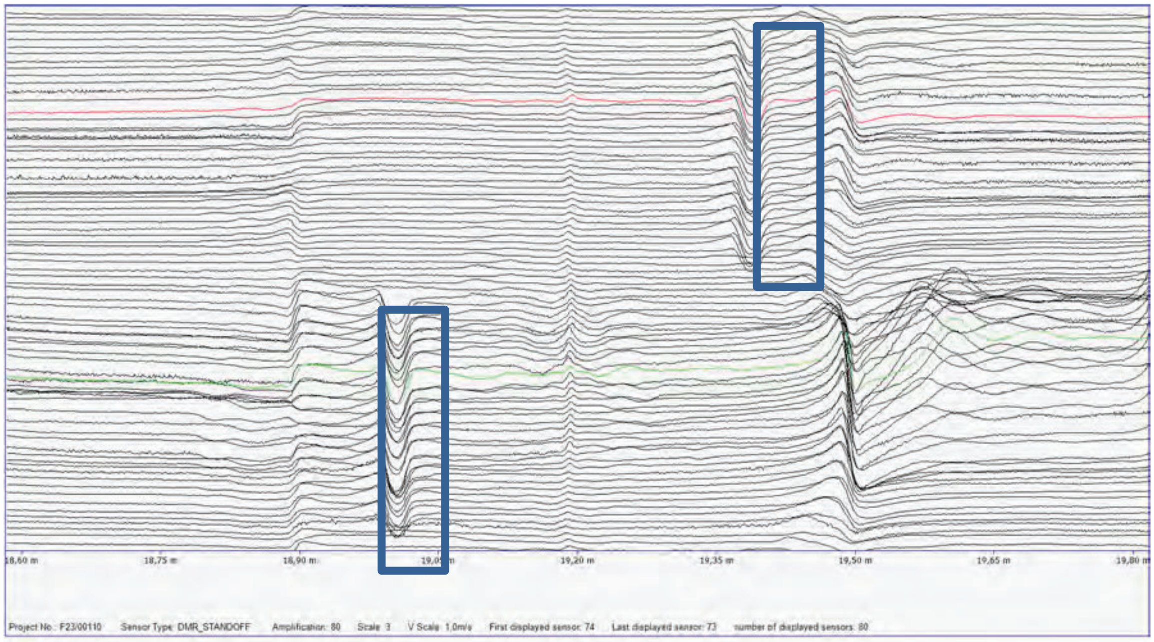

Figure 10. Stand-off magnetic sensors data – blue rectangle shows anomaly location (red/green sensors = 12h/6h).

The heavy wall MFL magnetizer was able to magnetize the 27.3mm wall thickness and clearly detect and size the internal metal loss anomalies. The internal debris did not influence the magnetic field and the sizing of the metal loss worked according to performance specifications.

Table 1. As-built vs. ILI results.

AS BUILT				ILI RESULTS		
No.	Axial length	Circ. width	Depth	Axial length	Circ. width	Depth
1	28mm	556mm	47,4%	34mm	545mm	50%
2	28mm	556mm	43,1%	34mm	558mm	49%

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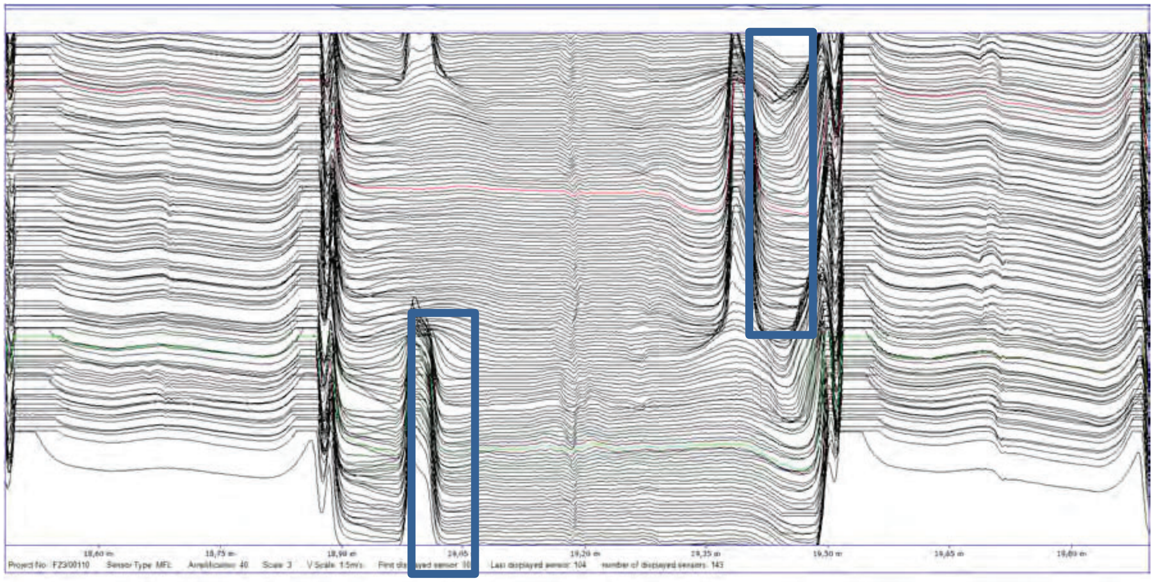

Figure 11. MFL sensors data – blue rectangle shows anomaly location (red/green sensors = 12h/6h).

The above data from the large-scale pull-through tests confirmed that the combination of the four (4) different measurement technologies enables a significant improvement of the probability of identifying (POI) and hence, an improved differentiation between debris and corrosion. The client did witness the factory acceptance tests (FAT) and the test results were documented with a FAT report and approved from the operator prior to ship the tools and equipment onsite.

The cleaning and inspection campaign

Prior to the start of the cleaning campaign 3P Services and the client discussed about the types and sequence of the cleaning tool runs. Current schedules and operational circumstances were taken into consideration to choose the ideal cleaning tools and cleaning tools sequence.

Due to time pressure, and in collaboration with all parties, two 3rd party cleaning tools were launched one after the other. The first medium aggression cleaning tool with brushes, magnets, and discs brought 4800m3 on liquid, no wax, and minor debris out of the line. The second high aggression cleaning tool brought 300m^3 of liquid, no wax, and minor debris.

Afterwards 3P Services' scraper tool was prepared for launch. This tool uses special scraper arms to remove scale from the inner pipe wall and is more aggressive than the previous two 3rd party cleaning tools. With the 3P services tool an additional 350m^3 of liquid was received, but again no wax and minor debris only.

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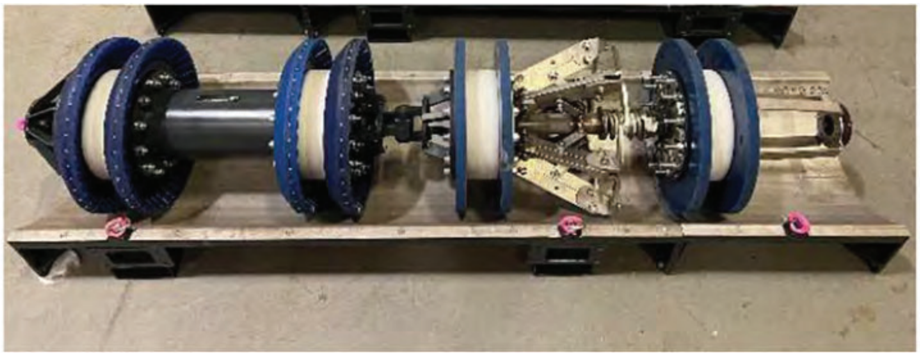

Fig 12. 3P Services' scraper tool (3rd).

To get as much information as possible regarding the cleanliness, 3P Services and the client decided to use a third-party debris mapping tool prior to launching the intelligent tool. The same tool was used in this pipeline in previous unsuccessful inspection campaigns. A graph showed the debris histogram comparison between the previous debris mapping tool run and the recent debris mapping tool run. A comparison of the two histograms showed a narrower distribution in the run 2023. This comparison indicated a cleaner pipeline compared to the previous run from 2016.

The type and quantity of debris removed from the pipeline during the three cleaning tool runs in combination with the debris mapping tool results, was used to decide that the line is clean enough for the intelligent tool run.

The cleaning and inspection campaign

The intelligent combo tool was installed into the launcher trap and launched with gas according to plan. The overall travel time was 62 hours with an average tool speed of 1.3m/s. After receipt, the tool was removed from the receiver trap. Firstly, onsite field technicians checked the completeness of the data of the four (4) sensor sets. The entire pipeline length was recorded. A special analysis of potential debris influence was made, and it was confirmed that there were no indications of debris influence in the data. The upload of the data to 3P Services' server was completed on the next day. An operations report according to pipeline operator forum (POF) was issued 48 hours after data receipt and the data analysis department started work.

Prior to the project an extended preliminary reporting time of four weeks was agreed, which was recommended due to the size of gathered ILI data. The preliminary report was sent accordingly and fourteen (14) metal loss indications equal to or above 60% were reported. Correspondingly to the operations report, the preliminary report re-confirmed that there is no debris-based influence on the data.

The operator required to get weekly updates about the data analysis progress which 3P Services delivered accordingly. A weekly update was shared with the client between the preliminary report und the final report. Eight (8) weeks after the receipt of the data, 3P Services submitted the final report. The final report contains the list of all reported findings, the pipe book and 3P Services' software to visualize the inspection data. The distribution of metal loss over the pipeline length and circumference was visualized with the following graph.

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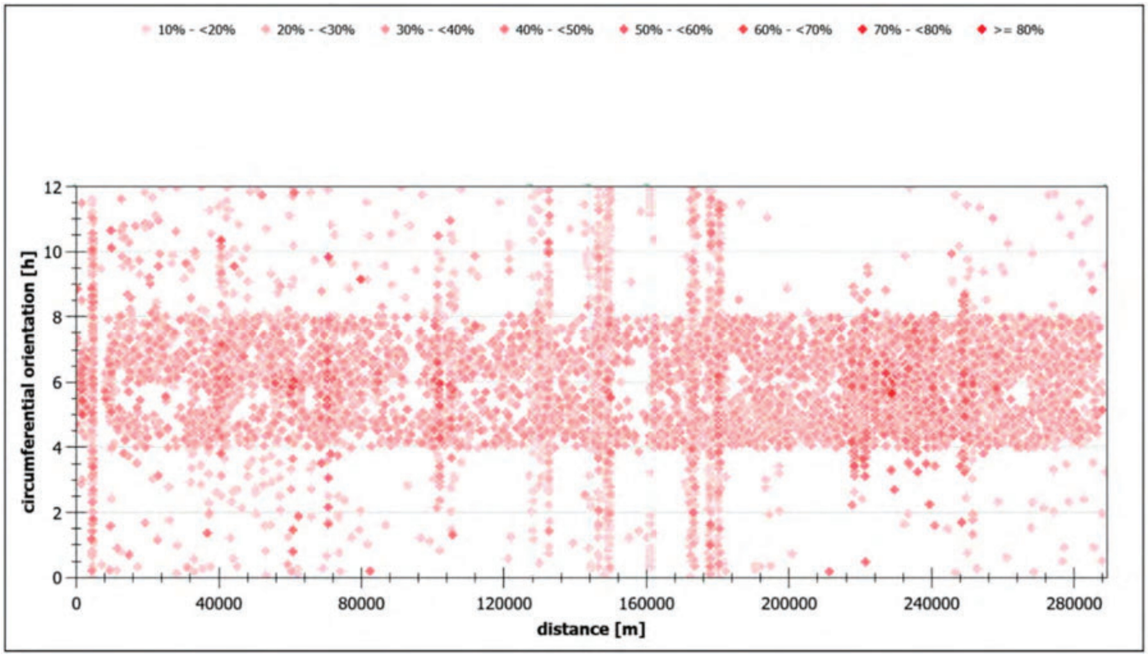

Figure 13. Distribution of metal loss over the pipeline length and circumference.

A typical 6 o'clock pattern of internal metal loss anomalies over the pipeline length and circumference can be seen. 3P Services did additionally perform an estimated repair factor (ERF) calculation according to ASME B31.G to provide the operator further data for their integrity assessment. These results are visualized below.

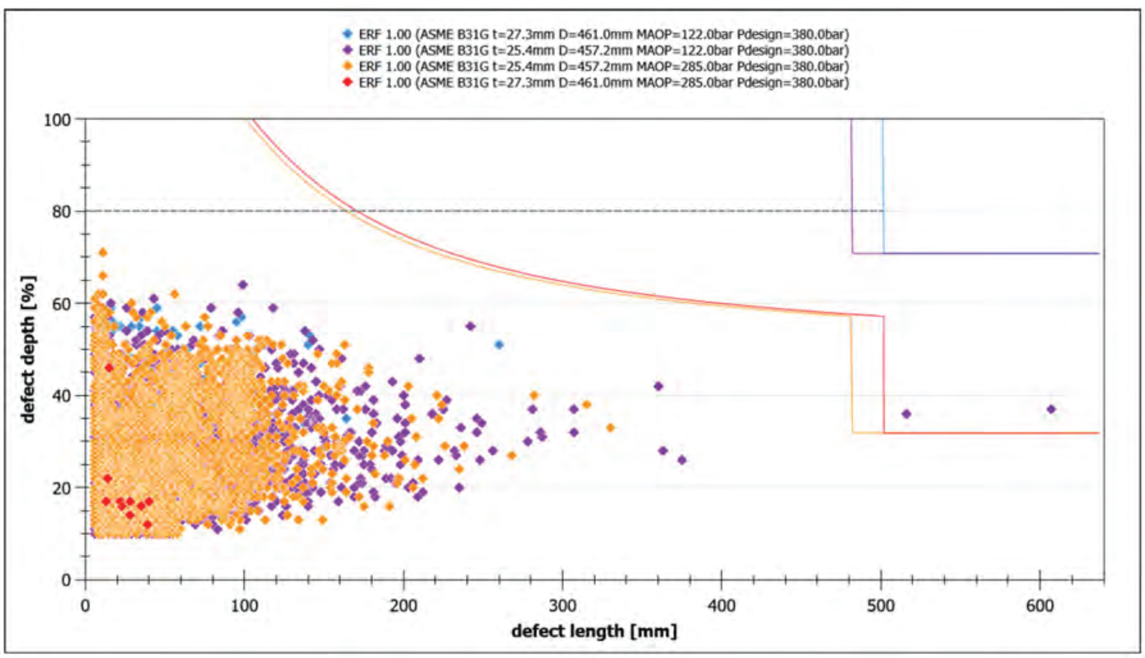

Figure 14. ERF sentenced plot.

The execution of the inline inspection with 3P Services' ILI tool allowed the operator to perform a full integrity management of his asset and take measures to operate the pipeline safely. A possible verification of reported indications is currently being assessed by the operator.

Conclusion

Any investment in the integrity of a pipeline is weighed by the results. To obtain value for these pipelines it was vital to overcome the data degradation that had occurred in previous inspection campaigns.

3P services approach to challenging pipeline inspections was vital to the success of this project. Custom designing a tool specifically for this pipeline inspection allowed us to select superior materials, create a unique magnetizer, a flexible cleaning program and incorporate multiple inspection sensors. All these factors allowed a superior level of probability of identification (POI) which enabled the client to efficiently design the remainder of their integrity program.

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