A Pipeline Inspection Case Study:
Design Improvements on a New Generation UT In-line Inspection Crack Tool

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ABSTRACT
For over 20 years, ultrasonic in-line inspection (ILI) tools have played a crucial role in helping operators manage pipeline integrity threats. The predominant ILI applications utilizing ultrasonic technology have been for wall loss and crack inspection.

Despite the high success rate experienced with ultrasonic ILI tools, there are still technological improvements needed to help operators manage the integrity of an aging pipeline infrastructure. Among the improvements needed are at a higher confidence level in the Probability of Detection (POD), improving detection reliability under different pipeline conditions, increased ranges for pipeline operating parameters and leveraging synergies from a Combo WM-CD in a single run.
In 2010, Weatherford Pipeline and Specialty Services (P&SS) commissioned its new generation fleet of ultrasonic wall measurement and crack detection tools. One of the design objectives was to address some of the ILI tool limitations identified above.

This paper focuses on reviewing the latest design improvements for the new generation tools and presenting a case study on a recent survey conducted on the Adria-Wien Pipeline (AWP). The pipeline sections inspected were the 30” x 4 kilometer and 18” by 420 kilometer pipeline. This is a joint collaboration between AWP (represented by Michael Huss) and Weatherford Pipeline &Specialty Services.

**Project Scope**

The Adria–Wien Pipeline GmbH operates a crude oil pipeline, which connects the Transalpine Pipeline from Würmlach at the Italian-Austrian border with the Schwechat Refinery near Vienna, Austria. It allows oil supplies to Austria from the Italian oil terminal in Trieste.

The length of the pipeline is 416 kilometres. The diameter of the main pipeline is 18 inches (460 mm), divided into 3 section, and there is a section of 30” x 4 kilometre pipeline which connects the main pipeline with the TAL system.

The pipeline was constructed in 1970 of seam welded pipe material conforming to API 5L Grade X52. The nominal wall thickness was 6.35 mm to 9.52 mm. The pipeline has external DANSO-3-Bandsystem coating.

Several in-line inspection surveys were performed in 1991, 2000 and 2006 using geometry and MFL tools to determine the condition of the pipeline and identify any potential threats to pipeline integrity.

In 2010 Weatherford were awarded a contract to inspect 4 sections of the AWP pipeline using the latest generation of angled beam ultrasonic crack detection technology tools. The pipeline reference names are:

- PS -1 to PS06 18” x 169 km
- PS06 to PS09 18” x 121,5 km
- PS 09 to US02 18” x 123 km
- TAZ1 to PS01 30” x 4 km

The project scope called for identification of axial cracks, crack-like anomalies in welded seams, and parent material. Following the crack detection survey the vendor also performed a crack assessment in accordance with API 579.
Summary of Crack Inspection Field Operations

It should be noted that the marker locations were provided by AWP from previous run data. In addition, a geometry survey was performed prior to mobilization. Weatherford have mobilized its crew from an ILI base in Germany to provide the turnkey service. This service included:

- Pre-inspection cleaning by magnetic and brush scrapers
- A Gauge Pig run
- UT-CD inspection runs

After demobilization from site it was determined the UT-CD tool accurately recorded the locations, crack sizes and crack-like anomalies. Features also recorded were axially-oriented manufacturing anomalies.

Because pipeline integrity operations are comprised of several stages it was important to meet AWP’s planned schedule. All 4 sections were completed within scheduling parameters.

After completion of the field inspection work Weatherford performed analysis of the recorded data and provided AWP with a preliminary report. The preliminary report included also reportable cracks, crack-like and axially-oriented anomalies. Based on analysis of the preliminary report AWP selected 4 locations in order to verify the accuracy of the defect sizing and location. The 4 features excavated are comprised of two crack, one crack-like and I seamweld anomaly.

During the verification process Weatherford provided a verification specialist to aid AWP personnel in locating, classifying and identifying the dimensions of the selected anomalies. All of the 4 verified locations confirmed the ILI predicted measurements were within stated tolerance. The probability of detection and probability of classification specifications were also confirmed as adhering to stated specification tolerances.

In addition to the ILI analysis, an API 579 assessment was performed which enabled the operator to confidently continue to operate the asset with an understanding of Remaining Strength Factors and Maximum Allowable Operating Pressure pursuant to industry standards. This also provided detailed sizing information to enable the operator to monitor defect growth following future inspections.

ILI tool Technology Characteristics

The latest generation of UT ILI pigs was introduced to the market in 2009 – 2010 after having utilized the previous generation since 2003. The latest generation of UT-CD pigs are better adapted for challenging pipeline conditions. For example, this generation has improved the bend passing capability (1st generation 3D versus 2nd
generation 1.5D bend capability), the probability of detection (POD), defect sizing, and improved performance in challenging pipeline environments.

![Figure 1: Latest generation UT-CD tool used on this project.]

In order to achieve a successful operation in challenging pipeline environments, much attention has been paid to addressing issues associated with rough internal pipe walls, increasing temperature ranges (now @ -20°C - +70°C) and pressure (now up to 120 bar) ranges, product velocity, bore restrictions and product deposits (wax or scale).

During the design phase of the tool development special emphasis was also applied to the development of a Combo WM CD tool inspection capability for a single run. All WM and CD tools ≥ 14” are now capable of a WM CD Combo tool configuration.

Some of design parameters of the new generation Combo WM CD tool are identified below. Requirements for some parameters are as follows:

- Wall thickness measurement resolution: < 0.06 mm
- Minimum detectable depth for general metal loss: < 0.3 mm
- WT measurement range: 3 mm to 60 mm
- Minimum crack-like defect length: 30 mm
- Minimum crack-like defect depth: 1 mm
- Probability of detection (POD): > 90%
- Maximum inspection speed at 3 mm axial resolution: up to 2.2 m/s
- Bend passing: up to 1.5D x 90°
- Maximum pressure: 120Bar
Improved Ultrasonic Transducers

A lot of combo ultrasonic immersion-type transducers have been investigated in order to ensure appropriate characteristics for the UT ILI pigs.

The type of ultrasonic transducers that was selected for this technology has the following key attributes and advantages:

- High sensitivity (transducer signal is 15-20 dB greater than transducers of the previous generation, allowing for increased sensor density and better signal to noise ratio)

- Improved transducer (Photo located in Figure 2) focusing based on new design providing the following advantages:
  - less sensitive to medium acoustical properties
  - Reduction in signal losses from transducer to medium transition

- Higher resolution due to shortened pulse width and customized signal processing

- Improved operation parameters:
  - Improved operating pressure up to 200 bar
  - A temperature range of -20°C to 120°C
Data acquisition system

Specifications of New Generation UT ILI pigs are primarily based on the data acquisition system features, including an echo-signals processing chain. The data acquisition system was designed to meet the capacity requirement up-to-date digital signal processing algorithms and ensure recording of inspection data.

This new data acquisition system is based on a 32-channel processing board (Fig. 3.), providing scalability from 6” WM UT ILI tool (64 channels) up to 36” Combo CD&WM UT ILI tool (1024 channels).

To minimize echo-loss, the received pulses are processed using a high selectivity matched digital filter, with individual parameters preset for each particular sensor. Filter criteria is chosen in the course of the UT system testing and calibration before the pig run. Filter criteria can be individually calibrated for each transducer if required.

In addition, a special digital rectifier which sharpens max signals peaks is used in the detector of the reflected echo signals. A wide dynamic range of the receive path (72dB) prevents signal saturation and ensures maximum possible signal-to-noise ratio.
Confirmation of Latest Generation UT ILI Specification

Numerous laboratory, bench, and pull-through tests (containing artificial and natural defects) have been performed to validate the design specifications\(^1\),\(^2\) of the new UT ILI tools. In addition, subsequent customer inspection surveys (including this case study project) have further validated the published specifications for this technology. Photos of lab and field trials are located below [Figure 5, 6]

![Figure 4: Illustration of noisy weak echo signals with onboard digital filtering process followed by rectification process for improved detecting and recording](image)

![Figure 5: Sensor lab test for surface roughness capability](image)

![Figure 6: Mechanical field tests for new generation UT](image)
Data Processing Software

The existing data processing software has been upgraded to improve accuracy of inspection data obtained by the new Gen UT ILI pigs.

Fig. 8 shows depth sizing accuracy for cracks. In accordance with accepted standards\(^3,4\) the field trials confirmed that quality of data obtained by the new Generation UT ILI pigs is improved from previous Generation ILI tools\(^5\) for challenging pipelines having the following features: increased internal surface roughness, heavy oil with high content of wax in pumping medium, inner coating.

Capability of the new Generation UT ILI tool to operate properly in various products i.e., unstable condensate, sea water have been confirmed.

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**Figure 7:** Sizing accuracy tests based on echoes’ time evaluation
(illustration on the right)
Figure 8: WM sensor echoes comparison: 1mm hard wax deposit blue and clean internal surface (magenta)

Figure 9: WM echoes with 1 mm hard wax deposit (zoomed), measurement capability is maintained
Summary of Data Analysis

Below are the results of the ultrasonic crack inspection of the 30” and 18” TAZ1 – US01 pipeline with the total length 418 km.

<table>
<thead>
<tr>
<th>ILI Predicted</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILI</td>
<td>Def. #</td>
</tr>
<tr>
<td>18” PS01 – PS06, 169 km</td>
<td>31</td>
</tr>
<tr>
<td>18” PS06 – PS09, 121.5 km</td>
<td>2149</td>
</tr>
<tr>
<td>18” PS06 – PS09, 121.5 km</td>
<td>2148</td>
</tr>
<tr>
<td>18” PS09 – US02, 123 km</td>
<td>2348</td>
</tr>
</tbody>
</table>

Table 1 Feature Summary

<table>
<thead>
<tr>
<th>ILI</th>
<th>Cracks</th>
<th>Notches</th>
<th>LW Anomaly</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>30” TAZ1 - PS01, 4 km</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18” PS01 – PS06, 169 km</td>
<td>25</td>
<td>297</td>
<td>12</td>
<td>334</td>
</tr>
<tr>
<td>18” PS06 – PS09, 121.5 km</td>
<td>34</td>
<td>228</td>
<td>4</td>
<td>266</td>
</tr>
<tr>
<td>18” PS09 – US02, 123 km</td>
<td>20</td>
<td>258</td>
<td>2</td>
<td>280</td>
</tr>
</tbody>
</table>

Grand Total of Anomalies 880

Table 2 Verification Detail Summary
Excavation Results

Detailed results from the excavation are shown below. The first two tables highlight the predicted versus actual results from 2 anomalies identified on the same joint of pipe. Below the tables is the corresponding software screenshot of the anomalies and a photo of the excavated joint of pipe.

<table>
<thead>
<tr>
<th>Defect Parameters</th>
<th>Ili Results</th>
<th>Dig verification results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>Possible crack</td>
<td>Laminations and crack</td>
</tr>
<tr>
<td>Orientation</td>
<td>204°</td>
<td>210°</td>
</tr>
<tr>
<td>Length mm</td>
<td>281</td>
<td>55</td>
</tr>
<tr>
<td>Width mm</td>
<td>44</td>
<td>55</td>
</tr>
<tr>
<td>Nominal wt in feature area</td>
<td>7.1</td>
<td>7.3</td>
</tr>
<tr>
<td>Maximum depth mm</td>
<td>1.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 3 Actual Versus Predicted - Anomaly 2148

<table>
<thead>
<tr>
<th>Defect Parameters</th>
<th>Ili Results</th>
<th>Dig verification results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>Crack</td>
<td>Laminations and surface cracks</td>
</tr>
<tr>
<td>Orientation</td>
<td>191°</td>
<td>195°</td>
</tr>
<tr>
<td>Length mm</td>
<td>507</td>
<td>500</td>
</tr>
<tr>
<td>Width mm</td>
<td>36</td>
<td>75</td>
</tr>
<tr>
<td>Nominal wt in feature area</td>
<td>7.1</td>
<td>7.3</td>
</tr>
<tr>
<td>Maximum depth mm</td>
<td>2.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Table 4 Actual Versus Predicted - Anomaly 2149

Figure 10: IView Screenshot of Anomalies 2148 and 2149
The actual versus predicted results of Feature no 31 and Feature no 2348 are outlined in tables 5 and 6 below.

### Table 5 Actual vs Predicted - Anomaly 31

<table>
<thead>
<tr>
<th>Defect Parameters</th>
<th>I LI Results</th>
<th>Dig verification results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>Crack</td>
<td>Crack</td>
</tr>
<tr>
<td>Orientation</td>
<td>69°</td>
<td>68°</td>
</tr>
<tr>
<td>Length mm</td>
<td>156</td>
<td>160</td>
</tr>
<tr>
<td>Width mm</td>
<td>32</td>
<td>25</td>
</tr>
<tr>
<td>Nominal wt in feature area</td>
<td>6.3</td>
<td>6.3</td>
</tr>
<tr>
<td>Maximum depth mm</td>
<td>2.0</td>
<td>1.9</td>
</tr>
</tbody>
</table>

### Figure 11: Photo of pipe joint - Anomalies 2148 and 2149
Crack Assessment

To assess the cracks calculations were performed in accordance with API 579\textsuperscript{6} methodology (LEVEL 2). Below is an example of a Failure Assessment Diagram (FAD) highlighting defects in red that fall outside the acceptable size for the pipeline section. The defects in red represent defects that are $>1$ for the defect acceptability factor (DAF) described in API 579.

<table>
<thead>
<tr>
<th>Defect Parameters</th>
<th>ILI Results</th>
<th>Dig verification results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>Possible long weld anomaly</td>
<td>linear slag edges</td>
</tr>
<tr>
<td>Orientation</td>
<td>23°</td>
<td>26°</td>
</tr>
<tr>
<td>Length mm</td>
<td>275</td>
<td>330</td>
</tr>
<tr>
<td>Width mm</td>
<td>64</td>
<td>-</td>
</tr>
<tr>
<td>Nominal wt in feature area</td>
<td>6.3</td>
<td>6.4</td>
</tr>
<tr>
<td>Maximum depth mm</td>
<td>2.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Table 6 Actual vs Predicted - Anomaly 2348
Conclusion

The project preparation and planning, tool technology, and positive client-vendor collaboration contributed to a successful project. In accordance with the vendor’s internal project management performance indicators, the scope was delivered on time, within budget forecast and to the client’s satisfaction. Also, from the vendor’s perspective, this was a very successful and important project, successfully introducing the newest generation UT-CD tool to the European market.

References

1. Weatherford of Mexico SA de CV; *ILI inspections run between January and April 2009*


3. Pipeline Operators Forum- *Specifications and Requirements for Intelligent Pig Inspection of Pipelines, Version 2009*

