High Resolution Ultrasonic In-Line Inspection for Non-Scrapable Pipelines

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Abstract

Internal inspection of non-scrapable pipelines is a major challenge in the oil and gas industry. With the aging pipeline infrastructure and increasing economic and regulatory constraints for pipeline operators, pipeline integrity issues are an area of increasing relevance. For this reason, the Inspection Department (ID) at Saudi Aramco introduced several initiatives to address this challenge and evaluated several NDT techniques. Among the validated technologies were several in-line inspection (ILI) tools that the ID implemented as an effective methodology to maintain pipeline integrity.

Saudi Aramco successfully inspected one 14-inch and six 10-inch flow lines in a producing facility using an ultrasonic-based ILI tool called “InVista.” The data collected by InVista identified corrosion at several locations along the flow lines. Selected locations were later excavated, and field verification using conventional inspection techniques confirmed the accuracy of the inspection results. The inspection data was then utilized as the input for a fitness-for-service (FFS) assessment of the pipelines. In this paper, the results of ILI inspection in this producing facility will be reported and its findings will be shared.
Introduction

It is generally accepted that pipelines provide one of the safest means of transporting large quantities of oil and natural gas. However, pipelines are susceptible to various environmental and operational conditions that affect their integrity; as a result, flaws can appear and grow. Hence, the integrity of pipelines should be monitored closely in order to detect and size flaws before they reach a critical dimension, which can eventually lead to a failure.

Specialized inspection tools, known as in-line inspection (ILI) tools or intelligent pigs, were introduced nearly 40 years ago and used mainly to detect and locate pipeline anomalies such as dents and metal losses. Advances in ILI tools and other inspection technologies have made these tools more refined and sophisticated, incorporating better defect detection capabilities and achieving better sensitivity and accuracy levels [1-3].

Today’s ILI tools not only give the operators the capability of collecting large amounts of inspection data, but they also improve the quality and resolution levels of the inspection data magnificently. Such high resolution inspection data provides inspectors and engineers with the capability to accurately size the length and depth of an anomaly, which if coupled with the appropriate ILI tool and supporting software, will enable them to go beyond traditional assessment methodologies and run advanced Level 2 (effective area) assessments on areas of metal loss or even to build a finite element model of individual dents in order to assess fitness-for-service (see Appendix I for further discussion on FFS). The advantages of inspecting a difficult-to-pig pipeline with high resolution ILI technology are demonstrated in the following case study [4].

Case Study

A total of 7 pipelines, one 14-inch and six 10-inch lines, with a suggested combined length of 38,577 meters were inspected using InVista. The trunk lines/flow lines have various challenges including...
diameter telescoping, sand/wax deposition and water limitations. The UT inspection data obtained by InVista was utilized as the input for an FFS assessment of the pipelines. We will discuss the inspection and assessment activities performed on one of the seven sour crude oil well flow lines, referred to as the “SCOWFL” line.

The SCOWFL line is constructed of a 10-inch (254mm) pipe with multiple schedules and material changes throughout the line. The pipe is made of carbon steel produced according to the API 5L Grades X42 and Grade B. The nominal wall thicknesses of the pipe are 6.4mm (0.250 inch) and 12.7mm (0.500 inch) and it runs for a distance of 3135.0 m (10,291.0 ft) between the wellhead and gas oil separation plant (GOSP). These nominal wall thickness values of record were validated with the direct, ultrasonic measurements of the InVista tool.

Prior to inspection, the line was initially flushed and pre-cleaned several times, and six above grade markers (AGMs) were placed at strategic locations to track the progress of InVista inside the line. InVista was then hand carried and inserted through the temporary launcher/receiver facility at the wellhead and propelled with a low pressure pump in water (temperature ~ 26°C) at a flow rate of 550 gpm to achieve an average scanning rate of 0.6 m/s.

Upon the arrival of InVista at the receiver site, the UT inspection data was downloaded and prepared for analysis. However, large quantities of soft wax were attached to the pig after the run, which affected the resolution and quality of inspection data. For this reason, bi-directional cleaning scrapers were used to apply a diesel oil batch in an attempt to remove the wax deposits more efficiently. The InVista tool did not experience any further damage that would have affected the quality of the inspection data, and it was able to be immediately re-run after the additional cleaning work was performed.
Once the field inspection data collection was completed successfully, data analysis and an FFS assessment to the API 579-1/ASME FFS-1 2007 standards were performed to demonstrate the structural integrity of the SCOWFL line.

<table>
<thead>
<tr>
<th>Pipeline Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Sour Crude Oil Well Flow Line</td>
</tr>
<tr>
<td>Material</td>
<td>API 5L Grade X42 and Grade B, Carbon Steel</td>
</tr>
<tr>
<td>Design Code</td>
<td>ASME B31.4</td>
</tr>
<tr>
<td>Specified Minimum Yield Strength</td>
<td>290.0 MPa (42,000 psi)</td>
</tr>
<tr>
<td></td>
<td>241.0 MPa (35,000 psi)</td>
</tr>
<tr>
<td>Maximum Allowable Operating Pressure</td>
<td>8.76 MPa (1,270 psig)</td>
</tr>
<tr>
<td>Nominal OD</td>
<td>273.1mm (10.750 in.)</td>
</tr>
<tr>
<td>Nominal ID</td>
<td>260.4mm (10.250 in.)</td>
</tr>
<tr>
<td></td>
<td>247.7mm (9.750 in.)</td>
</tr>
<tr>
<td>Nominal Thickness</td>
<td>6.4mm (0.250 in.)</td>
</tr>
<tr>
<td></td>
<td>12.7mm (0.500 in.)</td>
</tr>
<tr>
<td>Total Length</td>
<td>3135.0m (10,291 ft.)</td>
</tr>
</tbody>
</table>

Table 1: SCOWFL Pipeline Details

**Inspection Summary**

Initial data analysis was performed on the raw UT measurements collected by the InVista tool to qualify the data and identify pipeline features. Qualified data refers to those UT measurements that were captured by the sensors with sufficient signal strength and shape, as judged by the data analyst. It is worth mentioning that only qualified data points will be considered and analyzed during the assessment calculations. The quality of the data acquired corresponds to the cleanliness of the pipe, air bubbles in
the line, and tool alignment passing through piping fittings such as bends, tees, and valves. A quantitative measurement of data quality is obtained by taking the ratio of the qualified data points to the total number of data measurements (Table 2).

<table>
<thead>
<tr>
<th>Pipeline Segment</th>
<th>% of Sensor Data Captured</th>
<th>% of Valid Data (Inner Profile)</th>
<th>% of Valid Data (Thickness)</th>
<th>Total Thickness Readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCOWFL</td>
<td>100%</td>
<td>99.4%</td>
<td>87.7%</td>
<td>70 million</td>
</tr>
</tbody>
</table>

Table 2: Quality of SCOWFL Inspection Data

Inspection Results

The analysis of the inspection data collected by the InVista tool revealed the following findings:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Number</th>
<th>Max. % Wall Loss</th>
<th>RSF (min)</th>
<th>Min. MAOPr (MPa)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Metal Loss</td>
<td>62</td>
<td>81.6%</td>
<td>0.477</td>
<td>5.14</td>
<td>1</td>
</tr>
<tr>
<td>Internal Metal Loss</td>
<td>4</td>
<td>24.0%</td>
<td>0.778</td>
<td>9.04</td>
<td>2</td>
</tr>
<tr>
<td>Dents</td>
<td>48</td>
<td>3.63% of OD</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Repair Sleeves</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Girth Welds</td>
<td>338</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bends</td>
<td>23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Valves/Taps/Tees and Takeoffs</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3: SCOWFL Inspection Results
External Metal Loss
Located near Girth Weld #790 with a depth of 81.6% of the nominal wall thickness.

Figure 1: 2D and 3D Views of External Metal Loss near Girth Weld #790

Internal Metal Loss Located near Girth Weld #2480 with a depth of 24.0% of the wall thickness.

Figure 2: 2D and 3D Views of Internal Metal Loss near Girth Weld #2480
To further measure the accuracy of data collected by the InVista tool, a verification study was performed. In this study, 27 feature locations on the SCOWFL line were excavated to confirm the presence of corrosions and the remaining wall thicknesses. The features at all the 27 locations were successfully verified. Furthermore, it was verified that the tool is capable of measuring the remaining wall thickness accurately.

**Assessment of Inspection Data**

The qualified inspection data was assessed using specially developed software to determine the Remaining Strength Factor (RSF) and Reduced Maximum Allowable Operating Pressure (MAOPr) for
the pipeline. This assessment is based on the longitudinal extent of thinning found in the pipeline and in accordance with a Level 2 Assessment found in Part 5 of the API 579 standard [6]. The API 579 Level 2 assessment is recognized as a Level 2 assessment in ASME B31G-2009.

Based on the assessment performed by the software and considering the operating conditions and material properties stipulated in Table 1, the pipeline does not satisfy the API 579 Part 5 Level 2 Fitness-for-Service criteria for the listed maximum allowable operating pressure of 8.76 MPa (1270 psig). The pipeline does not satisfy the API 579 criteria due to the extent of local thinning which results in the Reduced Maximum Allowable Operating Pressure of 5.14 MPa being below the Maximum Allowable Operating Pressure (MAOP) of 8.76 MPa (1270 psig) established for the line.

Four of the areas of concern (with the lowest RSF, MAOPr below the MAOP on record, and minimum measured wall thickness values), are in areas of previous repairs where the external metal loss has been covered by an external repair sleeves. These previous repairs were validated and found to be sound, so that the pipeline then satisfied the API 579 Part 5 Level 2 Fitness-For-Service criteria for any MAOP below 6.26 MPa (907.9 psig). Note that this remained a reduction in MAOP from the MAOP of 8.76 MPa (1270 psig) provided for this line.

**Conclusion**

The results of this trial demonstrated promising results for using ILI tool data as input for FFS assessment. The inspected pipeline was inspected and based on the API 579 Level 2 Fitness-for-Service criteria was found to be in need for a repair action to maintain its structural integrity. The tool was able to produce location and sizing data for a high percentage of actual defects to reliable accuracies and guide the operator to the correct locations to make the pipeline repairs as efficiently as possible.
References


   http://www.questintegrity.com/articles/Ultrasonic-In-line-Inspection-Technology-and-Fitness-for-Service-Assessment-for-Non-Traditional-Pipeline-Inspection-Applications


APPENDIX I

Fitness-For-Service (FFS) assessments are quantitative engineering evaluations which are performed to demonstrate the structural integrity of an in-service component that contain flaws or are otherwise damaged. There are three possible assessment levels for each damage mechanism and these levels are sequentially increasing in complexity to verify the integrity of the component and ensure safe operation of equipment. Level 1 is the most conservative. It is devised to be utilized with a minimum amount of inspection or component information. Level 2 may utilize the same amount of inspection information as in Level 1 but it employs more detailed calculations. Level 3 requires more detailed inspection and information, and uses extensive experimental or validated numerical stress analysis. Depending on the type of flaw or damage the methodologies used in each of the three assessment levels may utilize one or more acceptance criteria: allowable stress, remaining strength factor (RSF), or the failure assessment diagram (FAD) [6].

In our FFS assessment, Level 2 RSF methodology was adopted as we expected metal losses in the inspected pipes to be contributed mainly by corrosion or erosion damage mechanisms. The RSF approach considers the ratio between the limit or plastic collapse loads of damaged and undamaged components. After obtaining thickness data from InVista, the software computes the RSF value for each possible segment of the pipe to find the minimum RSF value using formula (1) and then ranks the corrosion damage over the various segments. Finally, the rerated maximum allowable working pressure is obtained using formula (2) and all the above calculations are used to make the decision on the structural integrity of the component.
Figure 2: Thickness Data from InVista

Figure 5: RSF Calculation for Pipe Segments

\[
RSF^i = \frac{1 - \left( \frac{A_i^l}{A_o^l} \right)}{1 - \frac{1}{M_t} \left( \frac{A_i^l}{A_o^l} \right)} \tag{1}
\]

\[
MAOP_r = MAOP \left( \frac{RSF}{RSF_a} \right) \text{ for } RSF < RSF_a \tag{2}
\]
Where:

RSF$^i$ = RSF at Segment $i$

MAOP$^r$ = Rerated Maximum Allowable Operating Pressure

MAOP = Original MAOP