Development of a Long Duration, Free Swimming, Inline Acoustic Leak Detection Inspection Tool

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Abstract: Acoustic leak detection inspection tools have become a common technique to identify minute pipeline leakage before the leak and the defect producing it can become a larger problem or even a rupture level event. While these inspection tools only identify small defects once they reach the through wall stage and result in leakage, they can be an effective means of demonstrating the pressure tightness of a pipeline and ruling out the presence of through wall defects that are below the detection threshold of other ILI inspection tools; in so doing finding a way into both the leak detection and pipeline integrity toolboxes.

Enbridge Pipelines owns and operates a 12” pipeline that transports crude oil over 870KM. A majority of the line resides in permafrost conditions in a remote region, thus the window for inspections or work to be done on the pipeline is limited. Additionally the pipeline consists of long segment lengths between traps, which traverse multiple water crossings and experiences large changes in elevation. Therefore, availability, scheduling, and transport of inspection equipment are critical. The SmartBall was selected for a twofold purpose: to test the technology’s capabilities, and to inspect the line specifically for any leaks.

Inspection of 3 segments of the 12” pipeline provides some unique challenges to inspection providers, requiring tools with up to 12 days of operational run-time capability and the ability to operate in product temperatures as low as -15 degrees Celsius. The generation of SmartBall tools at the time did not have the run time and data capacity required to inspect the entire length of each of the pipeline segments. As a result, Enbridge and Pure Technologies collaborated on the development of a custom, long duration, high data capacity, SmartBall acoustic leak detection tool specifically for the 12” pipeline application.

Background: Enbridge’s 12” Pipeline

The 12” steel pipeline transfers light sweet crude from over a total length of 870 km, which is divided into 3 unequal segments, the longest being 336 km. In addition to the long segment lengths, the pipeline has limited access due to its location in a remote region. As a result of its remote location, the window for running inspection tools and completing excavations is limited to certain times of the year. Furthermore, most of the pipeline resides in permafrost conditions, has multiple water crossings, and experiences large elevation changes, which can add to the challenges in completing an inspection run.

A trailing pig was used for each inspection with the intention to push out the SmartBall in the event it got hung up in a valve or fitting. A lead pig, which was used to mildly clean the line, was also used on all 3 of the inspection runs.
Safety is one of Enbridge’s core values, and ensuring the integrity and safe operation of our pipelines through new technology and tools is one of our goals. In addition to evaluating the tool, the inspections would also provide proactive feedback on whether there were any leaks (or through wall defects) in the inspected line; addressing areas where other tools may be limited, such as detecting through wall pinhole defects.

**Background: SmartBall Inline Acoustic Leak Detection**

**Design/Operation:**
SmartBall is an acoustic-based inline inspection technology that detects anomalous acoustic activity associated with leaks in pressurized pipeline. The SmartBall is composed of an aluminum alloy core containing a power supply, electronic components and instrumentation (including an acoustic sensor, tri-axial accelerometer, tri-axial magnetometer, GPS synchronized ultrasonic transmitter, and temperature/pressure sensor). There are two modes of deployment for the SmartBall, both using existing pig launch and receive fittings. In the first, the aluminum core is encapsulated inside a protective outer foam shell, which allows the device to be propelled through the pipeline by creating a larger surface area for the product flow to make contact with. This method is typically used for pipelines of 16” diameter and larger. In the second design, the aluminum core is encapsulated in a polyurethane coating and is suitable for deployment into pipelines ranging from 4” to 14” in diameter. Both the outer foam shell and polyurethane coating also help to reduce low frequency ambient noise that is typically present in the pipeline.

It is important to note that the SmartBall tool is not a pig and does not seal against the inside wall of the pipe, nor rely on differential pressure for propulsion. The SmartBall tool is designed to be of a smaller diameter than the ID of a pipe, and physically rolls through the pipeline, propelled by the flow of that product in the pipeline.

The SmartBall tool is deployed into the flow of a pipeline, traverses the pipeline, and is captured at a downstream receiver. During the inspection, the SmartBall’s location is tracked at known bench marked locations along the pipeline to correlate the inspection data with position along the pipeline.
Tracking: Tracking the position of the SmartBall in the pipeline is critical for locating important acoustic anomalies such as leaks. The on-board accelerometer records the rotation of the SmartBall which is used to determine the angular velocity of the SmartBall, which is then used to determine a velocity profile of the device as it travels the entire length of the pipeline.

This data is aligned with the acoustic recordings to give a precise location of any recorded anomaly. To correlate the accelerometer data to an absolute position and time a reference point is required. Tracking the position of the SmartBall via SmartBall Receivers (SBRs) and above ground markers (AGMs) provides a time and position to be stamped on the velocity profile resulting in a position versus time relationship for the entire run of the device that is used to
report the location of acoustic anomalies. The use of SBRs and the methodology for leak
detection is detailed in the following sections.

1) **SmartBall Receivers**: SBRs, which detect the ultrasonic pulses emitted from the
SmartBall, are positioned along the pipeline to track the position of the device as it
traverses the pipeline. The SBR devices measure the time it takes for the pulse to travel
from the SmartBall to the SBR and calculates an approximate location of the ball. More
importantly, as the SmartBall passes the SBR it provides a discrete point where the
location of the ball is known at a moment in time, which is correlated to the acoustic data
and used in locating leaks. Figure 5 shows an acoustic sensor, which is adhered to the
pipe or pipeline appurtenance and is attached to the SmartBall Receiver via coaxial
cable. SBRs can be used anywhere the pipeline is accessible to mount a sensor, e.g.
above ground sections, pump stations, underground chambers, etc.

2) **Above Ground Markers**: Commercially available 22HZ benchmarking devices can also
be used with the SmartBall inspection tool. The AGMs are placed on the ground, directly
above the pipeline and log the inspection tool GPS passage time by measuring the 22Hz
signal emitted from the SmartBall. In so doing AGMs provide fixed reference points to
be used in the data analysis to aid in locating leaks or other anomalous signals.

3) **Locating Leaks**: Once a suspected leak is identified during the data analysis, the
positional data for SmartBall is reviewed to determine its location. The methodology
used to locate leaks involves creating a velocity profile from the accelerometer data on-
board the SmartBall, which is used to best-fit a curve between the discrete points from
when the ball passed an SBR or AGM. This provides an accurate plot of distance versus
time that is used to report the location of leaks. Absolute position reference points
obtained from the SBR are then applied to time stamped data.

![Figure 5 - SBR and Acoustic Sensor adhered to pipeline](image)
**Acoustic Leak Detection:** A leak inside a pressurized pipeline produces an acoustic signal. This acoustic signal is created as the pressurized product inside the pipeline escapes into the lower pressure atmosphere outside the pipe. While the SmartBall traverses the pipeline it continuously records this acoustic data, which is analyzed after tool extraction to identify acoustic activity associated with leaks along the pipeline. As the SmartBall is rolling along the bottom of the pipeline, it will always pass within one pipe diameter of the leak, allowing for extremely high detection sensitivity.

As the SmartBall approaches a leak the acoustic signal detected by the SmartBall will increase. The acoustic signal will peak at the point at which the SmartBall passes the origin point of the leak and will then diminish as the SmartBall continues away from the leak. This is demonstrated in Figure 6 below showing a typical acoustic signature resulting from a leak.

![Figure 6 – Leak detected in Analysis Software](image)

**Custom SmartBall Development:**
The particular challenges posed by Enbridge’s 12” pipeline required the development of a longer duration inspection tool, combined with a significant increase in the onboard flash memory capacity required for storage of the additional inspection data. Table 1 below illustrates the nominal run times and memory capacities of the existing SmartBall tools prior to development of the new tool.
Scaling up the size of the aluminum core of the largest existing SmartBall tool allowed the internal space to accommodate a significantly larger power supply to satisfy the energy requirements of a longer run duration tool. In addition, recent commercial advancements in the speed and capacity of flash memory modules allowed for provision of sufficient data storage space without having to sacrifice any resolution in the data by resorting to lower sample rates.

The changes made for the new long duration SmartBall allowed for inspection run times up to 18 days in length. With 128GB of onboard flash memory, the tool was also able to maintain its full 40 KHz acoustic sample rate for the entire 18 day run time.

Table 2 below demonstrates the current SmartBall tool specifications with the inclusion of the new long duration tool.

**Table 1 – SmartBall Tool Specifications Prior to Re-development**

<table>
<thead>
<tr>
<th>OilBall Tool Size</th>
<th>Polyurethane Coating</th>
<th>Suitable Pipeline Diameter</th>
<th>Maximum Pressure (psi)</th>
<th>Maximum Temperature (°F)</th>
<th>Pressure Transducer</th>
<th>Temperature Transducer</th>
<th>SBR Finger</th>
<th>22Hz EM Transmitter</th>
<th>Magnetometer</th>
<th>Run Time (days)</th>
<th>Memory Capacity</th>
<th>Sample Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4”</td>
<td>Y</td>
<td>4”</td>
<td>2000</td>
<td>170</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>0.5</td>
<td>4 GB</td>
<td>40 KHz</td>
</tr>
<tr>
<td>6”</td>
<td>Y</td>
<td>6”</td>
<td>2000</td>
<td>170</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>2.2</td>
<td>32 GB</td>
<td>40 KHz</td>
</tr>
<tr>
<td>8”</td>
<td>Y</td>
<td>8”</td>
<td>2000</td>
<td>170</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>4.25</td>
<td>32 GB</td>
<td>40 KHz</td>
</tr>
<tr>
<td>10”</td>
<td>Y</td>
<td>10”–12”</td>
<td>2000</td>
<td>170</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>4.25</td>
<td>32 GB</td>
<td>40 KHz</td>
</tr>
<tr>
<td>10”</td>
<td>N</td>
<td>16” and greater</td>
<td>2000</td>
<td>170</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>4.25</td>
<td>32 GB</td>
<td>40 KHz</td>
</tr>
</tbody>
</table>

**Table 2 – Current SmartBall Tool Specifications**

**Project Success and Challenges**

All 3 inspected segments of the pipeline were successfully completed in 2012 with the new custom SmartBall tool. The inspections were not without challenge. As anticipated by Enbridge and Pure, the check valves on the pipeline in many cases managed to hang up the SmartBall and prevent passage through the valve without other means of assistance. Expecting this situation, a trailing cleaner pig was launched several hours behind the SmartBall tool on all 3 inspections. The intent of the trailing cleaner pig was to push the SmartBall tool through any check valves where it may have been hung up. The cause for the hang up was never confirmed, but could be a
result of a variety of factors, such as the tight tolerance between the tool and pipe ID, the flow rate during the time of inspection, or other reasons. While the cleaner pigs were able to ensure the SmartBall had no issue traveling the pipelines, they did introduce a level of acoustic contamination into the SmartBall data proportional to its proximity to the tool. The result was that for short sections of the pipeline, usually where the cleaner pig was required to push the SmartBall through the valve, the trailing pig contaminated the acoustic data thereby reducing the leak detection sensitivity of the tool in those particular areas.

In an attempt to gauge the effect of the acoustic contamination due to the proximity of the pig, a comprehensive data quality assessment of the SmartBall inspections were performed. The result of the data quality assessment for the most recent inspection – several more runs were performed on the same line since the initial 3 inspections – is in Figure 7 below; demonstrating that over 97% of the data still allowed for detection of leak rates less than 2 litres per minute and 88% of the data allowing for detection of rates as low as 0.14 litres per minute, in spite of the influence of noise from the trailing cleaner pig.

![Minimum Leak Threshold (LPM) as a % of Inspection Length](image)

**Figure 7 – Chart of minimum leak detection threshold**

Refinements of the outside diameter of the SmartBall shell as well as configuration of the trailing pig should allow for further improvement in data quality. A different type of trailing pig was utilized in each of the 3 inspection runs, but all 3 inspections experienced noise contamination and an increase in the minimum detection thresholds for portions of the run.

Further feedback from Enbridge personnel involved in the inspections stated the tool was easy to launch and receive – less labor and equipment was required in comparison to other inspection tools. Also the results of the inspection were straightforward and unambiguous – either a leak was found or not – and did not require extensive analysis of the inspection data.
Some challenges faced for the inspection was that of limited access to the pipeline, which prevented creating simulated leaks along the pipeline. Instead the simulated leaks were produced while the SmartBall was in the sending trap, and were more of a calibration leak.

Conclusions
The SmartBall was selected for a twofold purpose: to evaluate the technology’s capabilities, and to inspect the pipeline for any leaks – particularly through wall pinhole size defects that may be below the capabilities of published specifications of other ILI tools. Due to the long segment lengths of pipeline to inspect, the SmartBall was redeveloped to extend the duration of the inspection tool, along with increasing the onboard flash memory capacity required for storage of the additional inspection data. Challenges with respect to noise contamination from the trailing pigs were encountered on each inspection run, and have yet to be fully resolved. However, overall the 3 inspection runs were considered a success as for most of the inspection run the minimum leak detection threshold was at 0.14 LPM.