Review of Lessons Learned from 10 Years of Ultrasonic Inspections in Gas Pipelines

Willem Vos, Jan Ove Toskedal, Gary Dye
NDT Global AS

Pipeline Pigging and Integrity Management Conference

February 12-16, 2024

Organized by
Clarion Technical Conferences

Abstract

In the early 21st century, a team of researchers in DNV (Norway) developed an ultrasonic technology for the inline inspection of gas pipelines without liquid batch. The dry-ultrasound technology has subsequently been used to inspect more than 10,000 miles of operational gas and liquid pipelines around the world.

The authors present lessons learned during the deployment of this new technology and reflect on the advantages and limitations.

Several different use cases are considered; one being deployment of acoustic resonance ILI for the base line inspection of newly constructed gas pipelines. In particular, the others will highlight a number of long-distance gas transmission pipelines that have been inspected using acoustic resonance ILI, and highlight the benefits of ultrasonic baseline for pipelines.

Furthermore, the tools have shown notable flexibility in the field of difficult-to-inspect gas and liquid pipelines. Notably, large diameter variations have been traversed, and bidirectional inspections have been performed, as well as extremely long duration runs.

A summary of completed work will be of value to all pipeline operators of challenging pipelines, in particular offshore, demonstrating challenging pipeline inspection projects which have been completed successfully.

Background

A decade after the successful qualification of Acoustic Resonance Technology (ART) for inline inspection, the authors reflect on the achievements. Major milestones include:

a. Inline Inspection in excess of 10,000 miles of pipeline
b. The longest ultrasonic ILI run ever (over 600 miles in one run)
c. Deployment in operational pipelines sizes 10" to 48"

The authors present a description of the technology, and a summary of achievements. This is followed by an overview of feature detection and identification capabilities. Finally, the authors will demonstrate how the tool can manage varying pigging and inspection challenges, and share lessons learned on pipeline medium.

Historical Background

In the age of analog electronics, Acoustic Resonance Technology (ART) was the standard method for wall thickness measurement. Following the introduction of digital electronics and low-cost digital timers, it become more cost-effective to measure time-of-flight in signals than resonances. As a result, many of our great engineering achievements were completed with the support of acoustic resonance NDE equipment, such as the Vidigage shown in Figure 1, page 9.

Acoustic resonance technology inline inspection technology was developed by DNV, following the development of a shallow seismic technology for shipwreck inspection. The application for inspection of pipelines was pursued once it was confirmed that compressed gas can be a suitable coupling medium for ART, avoiding the need for a liquid medium in gas lines.

The acoustic resonance technology was deployed on an inline inspection tool and validated through in-service qualification runs. The first ART Scan^{TM} tool was successfully qualified in 2014, allowing the authors to reflect on 10 years of deployment, lessons learned, and a summary of achievements.

Technology Description

The first step of acoustic resonance measurement of wall thickness is the emission of a wide-band acoustic waveform towards the target, as shown in Figure 2 (page 9) to the left. The waveform excites numerous standing compressional waves between two surfaces of the pipe wall. All oscillations can be characterized by the integer number of half wavelengths per plate. For the fundamental, or first oscillation, the plate thickness corresponds to one half wavelength. [1],[2],[3]

The second step in the process is the detection of the returning signal. This returning acoustic energy signal is generated by the standing compressional waves inside the pipe wall, which acts as a source of acoustic energy after the initial wide-band waveform has passed. The resonance pattern emitted from the pipe wall as seen in Figure 2, center, is referred to as the resonance tail.

Recording the entire resonance tail allows for identification of the resonance frequencies, see Figure 2, right. Through the estimated compressional speed of sound in the pipe material, the half wave resonance frequency provides an accurate measurement of local pipe wall thickness. Furthermore, additional higher order harmonics of the half-wave resonance frequency provide additional confidence in the initial measurement.

In the ILI application, the ART transducers are positioned away from the pipe wall, sending a wavefront using pressurized gas as a coupling medium. Amplification of the signal inside the pipe wall (as result of the resonance phenomenon) allows for sufficient signal strength to use ultrasound with gas without a liquid coupling medium.

Capabilities Of Acoustic Resonance Technology

The clearest advantage of acoustic resonance in the pipeline is accuracy. The accuracy of the wall thickness measurement is ± 0.4 mm (at 90% confidence), which is the same accuracy achieved with typical ultrasonic ILI tools in liquid pipelines.

When compared to typical MFL specification (assumed depth sizing ± 10%), it should be noted that ART is significantly more accurate in higher wall thickness pipelines, such as common offshore pipelines. The below chart shows a comparison in accuracy.

Wall Thickness	20 mm	25 mm	35 mm	40 mm
MFL Depth Sizing Accuracy (10% WT)	± 2.0 mm	± 2.5 mm	± 3.5 mm	± 4.0 mm
ART Depth Sizing Accuracy	± 0.4 mm	± 0.4 mm	± 0.4 mm	± 0.4 mm

The accuracy of feature depth sizing is beneficial to estimate corrosion growth rates, leading to improved pipeline safety, and increased intervals between inspections.

ART Feature Detection

Buckle

ART inspections deliver a time-of-flight component that is used to analyse the geometry of the pipeline. This can be used to detect dents and other geometry related features.

The feature shown in Figure 3, page 10, is a buckle detected in an offshore pipeline. The buckle likely occurred during pipeline installation. Clearly visible are two areas protruding inwards (in blue), contrasted with the dark red area, where the pipe wall folds outward.

The capabilities of ultrasonic geometry measurement are quite apparent in this example. The data accurately represents the geometrical shape of the feature. The accurate and undistorted shape of the buckle allows for Finite Element Analysis (FEA) of the feature to assess the long-term integrity of the buckle, and provide guidance on remediation activities.

Mid-wall Features / Laminations

Besides the improved accuracy of ultrasonic wall thickness measurement, ART detects mid-wall features which are not visible to MFL tools. These include laminations, which are attracting increased attention in relation of gas pipeline integrity, especially with regards to emerging fuels.

Figure 4 on page 10 shows c-scan data of wall thickness where the indicated area shows (sloping) laminations. The wall thickness reading indicates the offset between inner pipe surface and the location of the lamination. The c-scan shows a very abrupt change in wall thickness, being typical for laminations, and not common for corrosion features. Of the three features, a change in wall thickness readings can be observed (from left to right), indicating these laminations are sloping.

Positive identification of lamination features is possible through analysis of attenuation of resonances, which is much lower in the case of laminations. A clear example of this identification is shown in Figure 5, page 10. The lamination shown includes 2 screenshots. The above c-scan shows wall thickness, the lower c-scan shows signal attenuation. Clearly seen in the feature area is a reduction in attenuation, which is typical for laminations.

This characteristic is very distinctive for laminations and used to positively classify laminations from other features.

Paraffin and Wax

ART Scan tools are often used to inspect crude oil pipelines, particularly those that have a high wax-content. The advantage of ART can be explained by looking at the absorption spectrum of sound in the ultrasonic frequency range, see Figure 6, page 11.

The red bars indicate the operational range of Acoustic Resonance Technology, from 400 kHz to 1.2 MHz. Sound attenuation in paraffin is very low in this frequency range. As a result, ART Scan tools can record wall thickness even through layers of paraffin (wax) on the inside of the pipe wall. The images in Figure 7 show a test piece with 3 machined features, covered in a layer of paraffin. The deepest feature is covered with 17 mm of paraffin (wax). As shown in Figure 8, feature depth sizing continues throughout the covered test piece.

Multiple inspections have been completed in crude oil lines with various levels of paraffin (wax) deposition on the pipe wall. These inspections have shown that ART Scan tools can read wall thickness with some level of wax on the inside of the pipe wall. A screenshot from collected data is included in Figure 9, page 12. As seen in the screenshot data, wall thickness data is collected through a layer of deposits (bottom c-scan) shown in blue. Note that the ART tool has detected corrosion under this wax deposit (shown in the red oval).

Pigging Challenges

Pipelines are typically designed and constructed with pigging in mind, although exceptions occur, and some pipelines are very challenging to navigate for an ILI tool. Fortunately, acoustic resonance ILI tools can overcome many of the pigging challenges due to a combination of superior bore passing and low tool drag.

Challenging Pipeline Features

Features such as wye's, tee's and non-return valves have all been successfully navigated with ART Scan. The technology has also been applied in multi-diameter pipelines (20x24, 24x30, 18x26, 16x24 and more). In multi-diameter pipelines, maintaining drive in all sections is more challenging. For this reason, the tools are designed with centralizing wheel sets, as shown in Figure 10.

The wheels support the weight of the tool, minimizing wear on the polyurethane package, and allowing the PU package to be optimized for sealing and drive, as opposed to a compromised configuration that also has to support the weight of the tool. In order to provide drive throughout the larger diameter sections, care must be taken for the over-size discs not to wear excessively in the smaller bore sections, and buckle inducers are used for this purpose. Pump trials confirm the ability to collapse and seal throughout the line. An example of a pump-trial setup is included in Figure 11. Pump trials are completed for all challenging pig runs, including multi-diameter pigging and wye crossings, as well as bidirectional runs.

Managing Polyurethane Wear

Running the tools on wheels enables very long-distance ILI runs. The photograph in Figure 12 shows an acoustic resonance ILI tool at the receiver site, after completing a 600 mile run. The overall wear on the discs is extremely low.

The rotation helps to manage wear, since discs are likely to wear more at the 6 o-clock position, even with centralizing wheels. To achieve constant rotation, the wheels are mounted on the tool at an angle, resulting in constant rotation as the tool passes through the line. This rotation is recorded with the IMU and reviewed to prove functionality of this design. A rotation chart is included (Figure 13, page13) where the tool completes about 7 full rotations per travelled mile.

Managing Elevation Changes

Low differential pressure and drag also help obtain constant velocity when passing elevation changes. In one ART Scan run, the tool passed under 3 very deep waterways, shown in the elevation chart (see

Figure 14, page 14). These so-called fjords are quite deep, so each of the fjord crossings represent an elevation change of about 1,200 ft in a 40% slope. The third and lowest chart shows the ILI tool speed during this entire crossing which remains nearly constant at 2 m/s or about 4½ mph. The same tool run behaviour is seen in mountainous terrain (absence of excursions) as well as offshore inspections when passing up or down risers.

Pipeline Medium

Pipeline medium properties are essential parameters for all ultrasonic ILI tools, and acoustic resonance tools form no exception to this rule. ART can overcome the large acoustic impedance mismatch between the pipeline medium and pipe wall, but the tools are not exempt from medium influences.

Several parameters are reviewed to confirm pipelines are within the operational envelope of the ART Scan tools. Gas pressure is the leading parameter. As a guideline, a minimum pressure of 750 PSI is needed to couple acoustic energy into the pipe wall. Tools are rated to 3,600 PSI operating pressure by default, some tools have been modified to run in higher pressures up to 7,500 PSI.

Gas composition is carefully analysed during the assessment of each project. In this assessment balance between lighter (C1) and heavier molecules (C2, C3, C4) is a key factor, and trace elements of all components are also included in the assessment.

Internal flow coating improves the acoustic coupling. Typical modern pipeline coatings (3LPP, 3LPE, CWC) are ideal for ART Scan, as they show very low levels of signal attenuation.
Sour service can be managed by ART Scan, as most tools are qualified to H2S levels of 5% (50,000 PPM).

Conclusions

In the first ten years of operations, ART Scan has become the established ILI technology for inspection of long-distance offshore gas transmission pipelines, an application for which the technology was initially developed.

Operators of these gas pipelines have consistently selected ART Scan for baseline services as well as in-service inspections.

We further note the tools have been adopted by operators of multi-diameter pipelines, especially for offshore applications. Simple navigation of diameter changes, wyes, and the ability to inspect through paraffin (wax) proves ART is the preferred and low-risk option for these lines.

In Europe and North America, we see many inspections performed at underground gas storage facilities. These lines are exposed to the maximum reservoir pressure, resulting in high wall thickness, and pushing them beyond the operational envelope of magnetic technologies.

Given this wide range of applications, it can be concluded that ART Scan has grown to be the key technology for challenging in-line inspections in gas and liquid lines. This technology has earned a place in the market in the first 10 years of operations and will continue to deliver value to operators in future.

References

[1] Ward D. RUMMEL, “The Changing Face of NDT In the USA Over the Past 50 Years”, 18th World Conference on Non-destructive Testing 16-20 April 2010, Durban, South Africa

[2] Krautkramer, J., Krautkramer, H., “Ultrasonic Testing of Materials”, 3rd edition, Springer-Verlag

[3] Jostein Jacobsen, “New Technology for Resonance Thickness Measurements”, 10th Annual International Marine Surveying forum, 3 – 4 April 2000.

[4] Vos et al, "Application of Wide-Band Ultrasound for the Detection of Angled Crack Features in Oil and Gas Pipelines", IPC 2018, Calgary, Canada

Figures

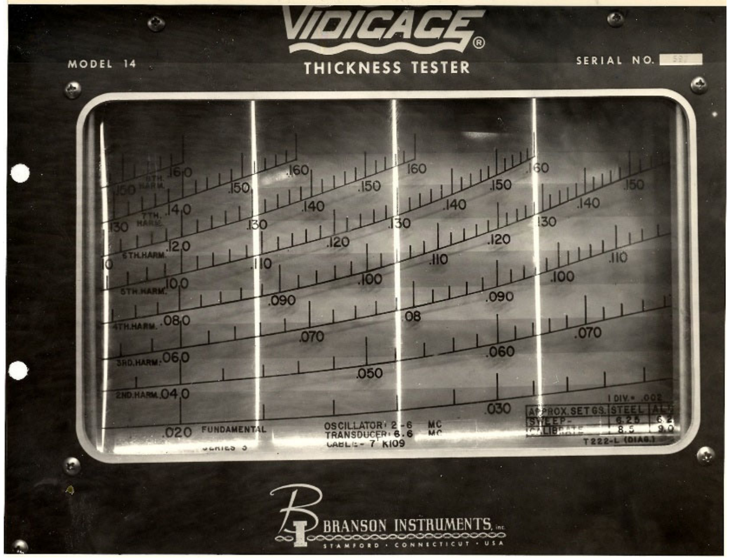

Figure 1. Photograph of Vidigage instrument from Branson. Please note four distinct resonance peaks.

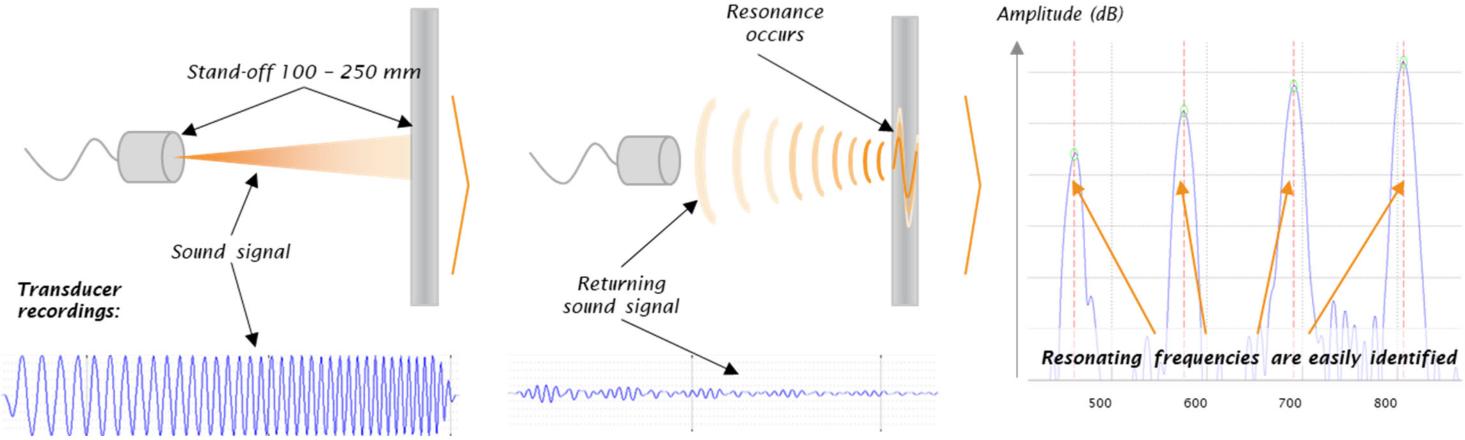

Figure 2. Acoustic Resonance Technology explained through the steps of, A. Emitting (left), B. Listening (middle), C. Interpreting (right)

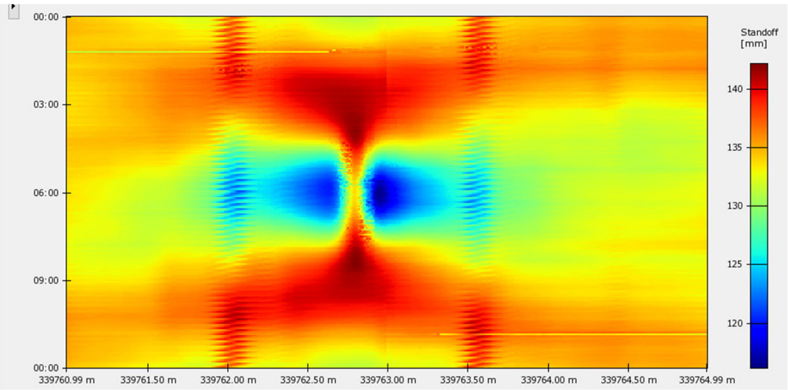

Figure 3. C-scan showing 6 'O-Clock Buckle in offshore pipeline

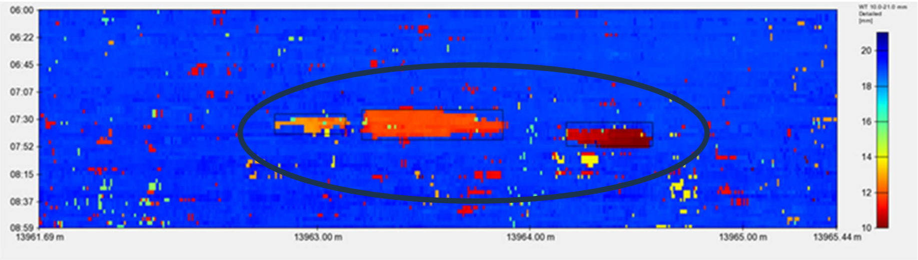

Figure 4. C-scan showing example A of mid-wall lamination

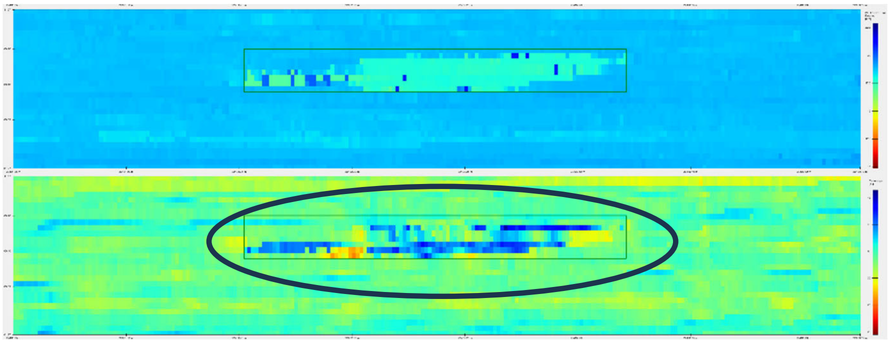

Figure 5. C-scan showing example B of mid-wall lamination including the attenuation plot.

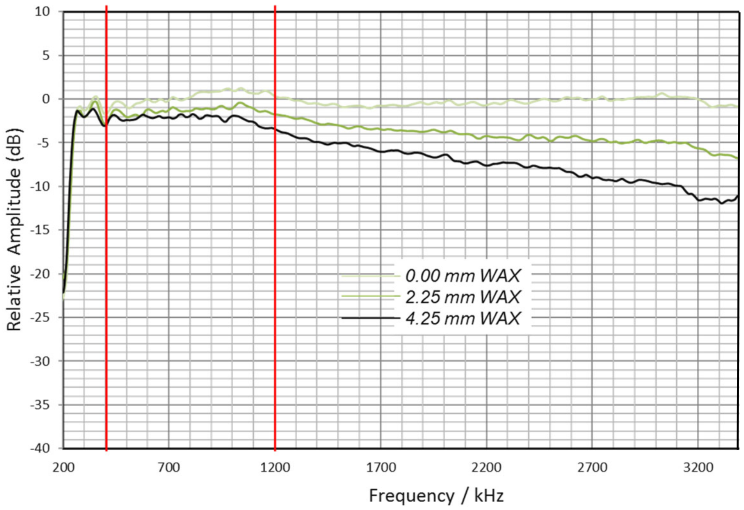

Figure 6. Chart showing absorption spectrum of ultrasound in paraffin.

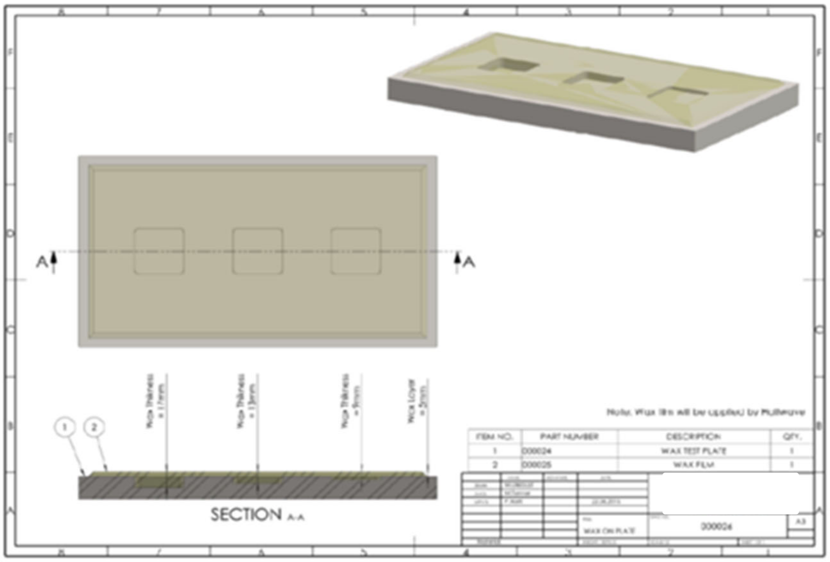

Figure 7. Test Plate with Paraffin Layer Applied

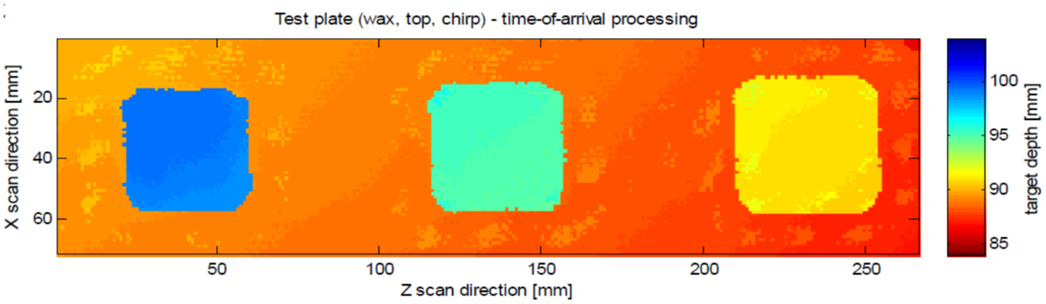

Figure 8. Feature Depth Sizing through layer of Paraffin

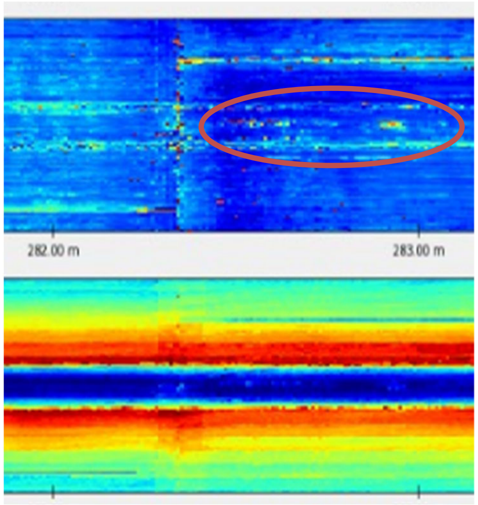

Figure 9. C-scan of wall thickness (top) and depositions (bottom)

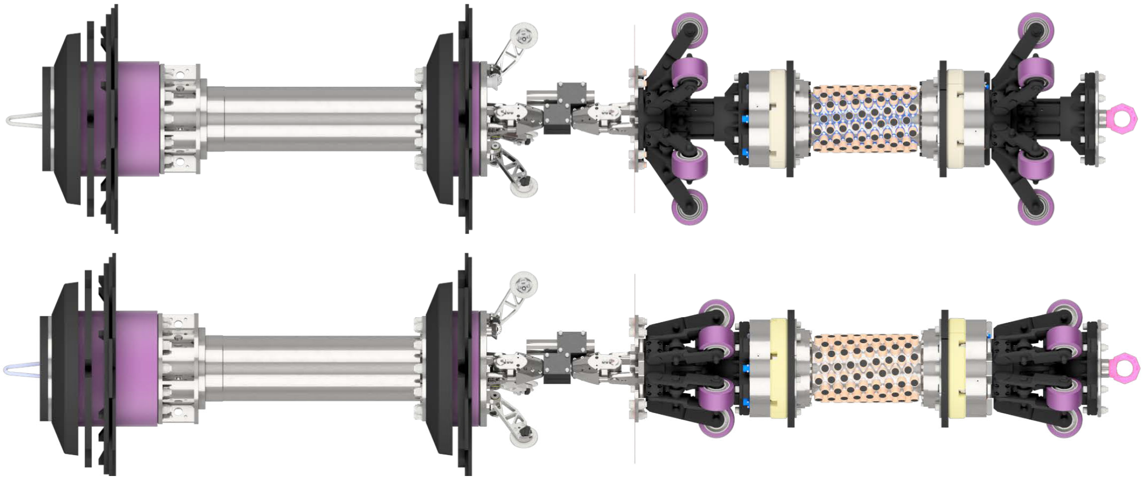

Figure 10. ART Wheels on sensor carrier shown in 24" (top) and 18" (bottom) position

Figure 11. Pump trial setup including diameter change and Wye passage

Figure 12. ART tool at receiver after 600+ mile run

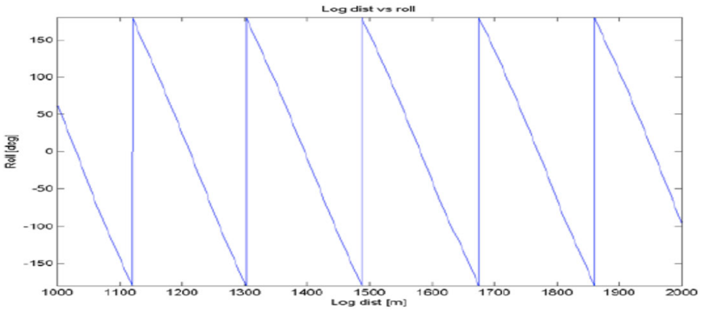

Figure 13. Tool Rotation Chart, showing about 7 rotations per mile

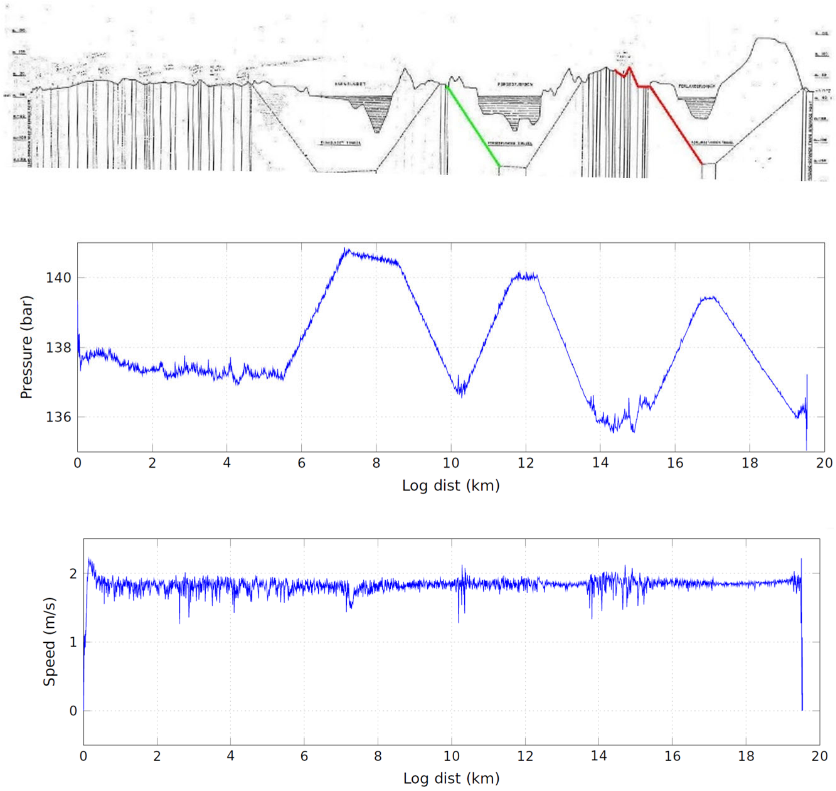

Figure 14. Elevation changes and speed profile