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White Paper

Crack Diagnosis in Natural Gas Liquids Pipelines

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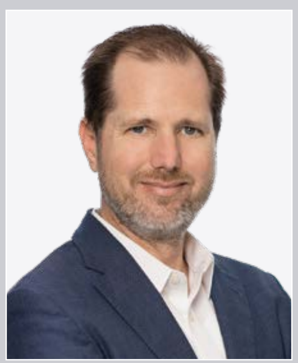
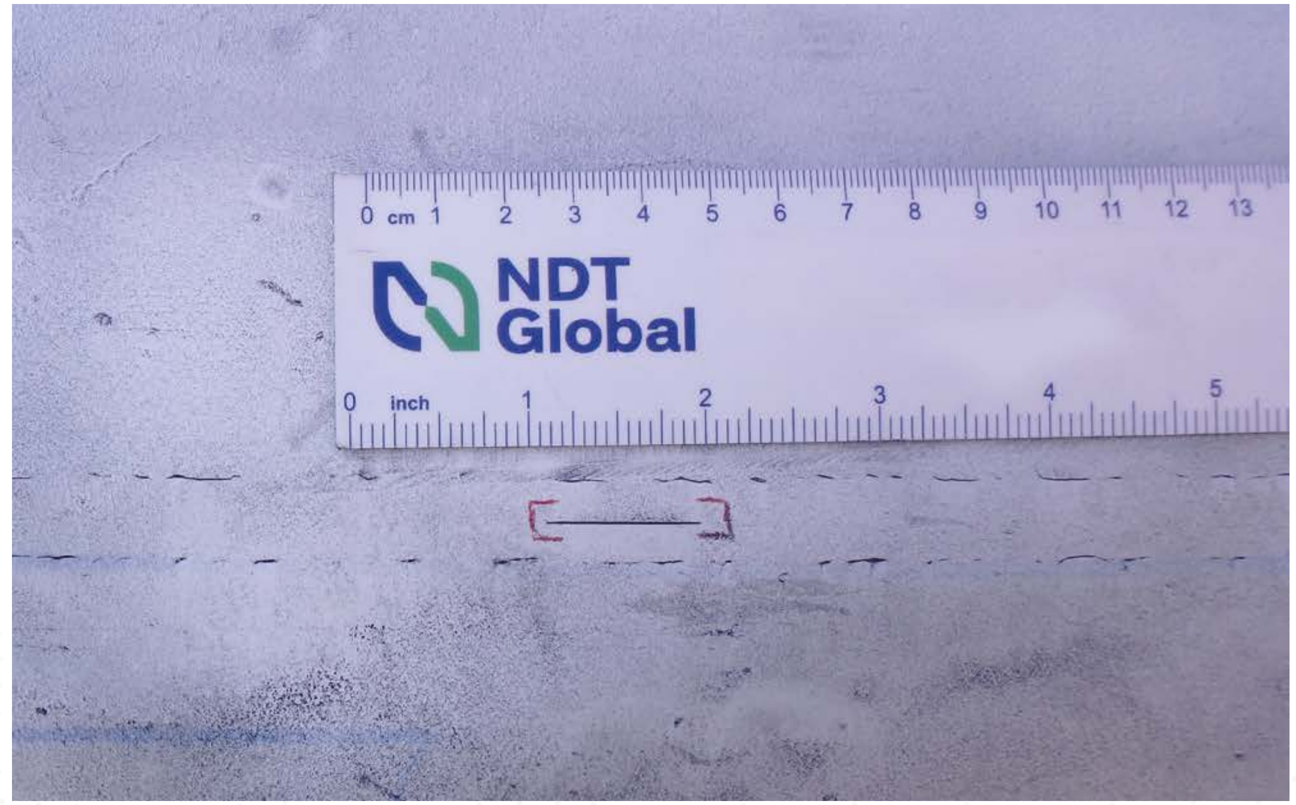
Authors



Nathan Leslie
Vice President - Product Management and Marketing

Sayan Pipatpan
Manager, Field Verification

Andreina Guedez
Product Analyst



Abstract

Natural Gas Liquids (NGL) are a group of hydrocarbons that are a by-product of natural gas processing and refining including ethane, propane, normal butane, isobutane, and pentanes plus also known as natural gasoline. As the infrastructure to aid in the exportation of NGLs has grown so have the requirements to safeguard the assets that are used to transport these liquids by utilizing inline inspection technologies.

This case study will focus on the deployment of an ultrasonic inline inspection (ILI) technology in an NGL line as well as a comparison of crack data analysis from the tool and Non-destructive Examination (NDE) data from field verifications. The service was deployed for a North American operator to diagnose the potential for axial cracks, including hook cracks, in their 18" pipeline.

The main challenge to overcome was configuring a service to properly diagnose potential cracks in the pipeline given that the medium for this inspection differed significantly from typical liquid inspection mediums regarding sound velocity and attenuation.

Results from data analysis from the ILI service showed accurate detection and identification of crack-like features and were validated with NDE phased array UT measurements which characterized these complex crack geometries.

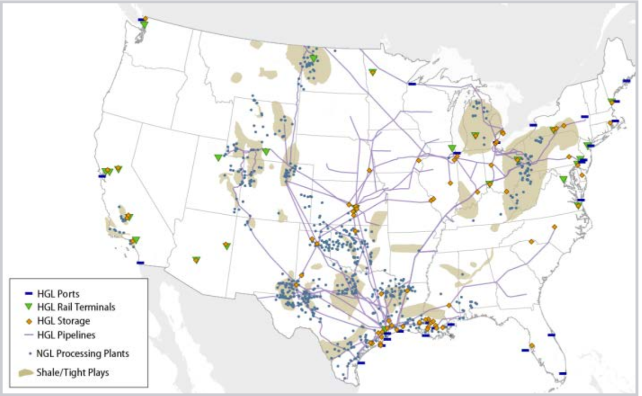


Figure 1 – Map of Selected NGL Infrastructure and Production Sources (Congressional Research Service)

Introduction

Natural Gas Liquids are a group of hydrocarbons that are by-products of natural gas processing and refining such as ethane, propane, butane, isobutane, and pentanes plus or natural gasoline. They differentiate from one another by the number of carbon atoms in their molecular chain. NGLs are extracted from natural gas and are preserved in a liquid state for storage, shipping, and consumption. These can be used for industrial, residential, commercial, and transportation purposes; especially, for enhancing oil recovery in oil wells, as raw materials for refineries or petrochemical plants, and as a source of energy.

Over 54,000 miles of NGL pipelines are in the United States with more than 6,600 miles for direct purity products. Figure 1 shows the location of NGL processing plants and pipelines for transporting NGLs within the United States (Congressional Research Service, 2018). Figure 2 shows the production of NGLs in the world in thousands of barrels per day (IndexMundi). The top 3 countries producing NGLs are the United States, Saudi Arabia, and Canada.

The demand for Natural Gas Liquids is increasing significantly as more and more refineries and petrochemical plants require NGLs to produce ethane and other products. Likewise, the high demand for energy and transportation, as well as climate change concerns, are propelling the usage of NGLs. Allied Market Research estimated the global NGL market at $16.9 billion in 2020 and is projected to reach $28.5 billion by 2030 (Mohd, A., Yerukola, P., 2022).

According to the U.S. Energy Information Administration (EIA), in 2020 and 2021, more than 2,000 miles of new liquid pipelines were put into service, with some of them dedicated to transporting NGLs. The expansion of new pipelines to transport NGL has helped expedite the processing of natural gas as well as reducing costs. Two active areas have been the Permian Basin and Southeast New Mexico, where in the past two years, more than 800,000 barrels of NGL have been transported per day in new pipelines (Figure 3). Moreover, the U.S. Energy Information Administration (EIA) indicates that NGL production for Texas and New Mexico grew by 19%.

According to the Pipeline and Hazardous Materials Safety Administration (PHMSA), there were approximately 11% of incidents reported in the US for 2021 related to corrosion for NGL pipelines. Furthermore, 68% of the reported incidents in the US in 2021 were related to material, weld, and equipment failure for NGL pipelines (Figure 4).

Similar to gas pipelines, NGL lines are susceptible to cracks and crack-like features including fatigue cracks, tilted cracks, stress corrosion cracking, and lack of fusion. These cracks can and have led to failures on NGL pipelines.

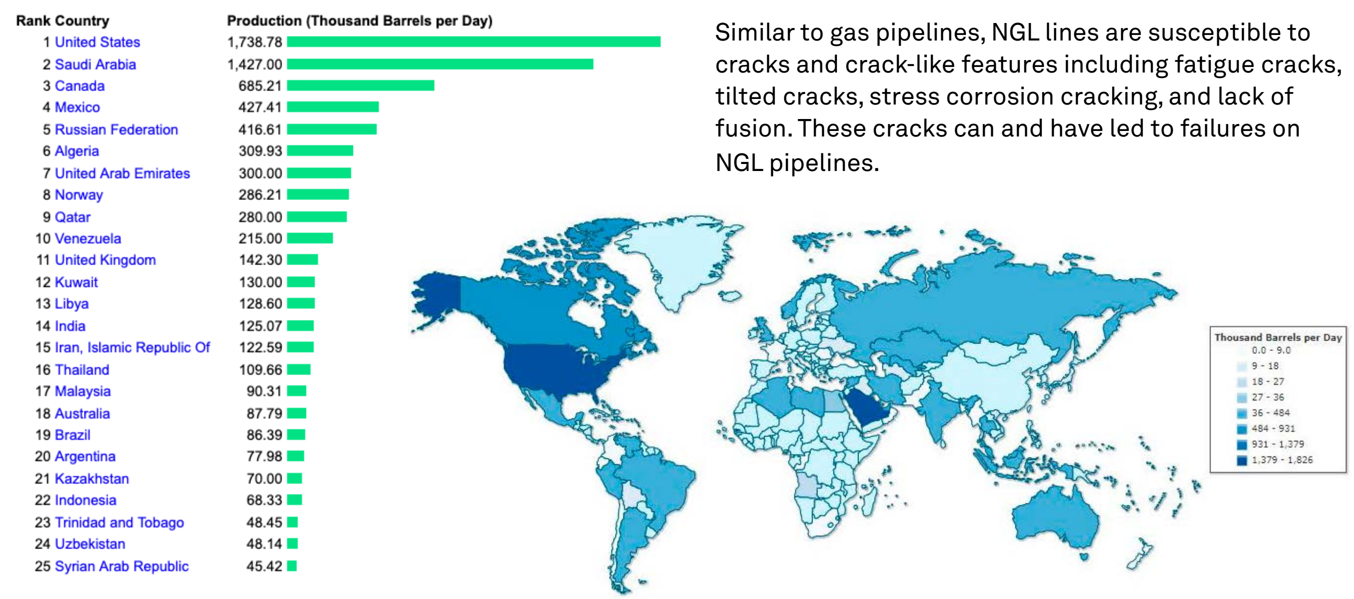


Figure 2 – Production of NGL's by country (United States Energy Information Administration / IndexMundi)

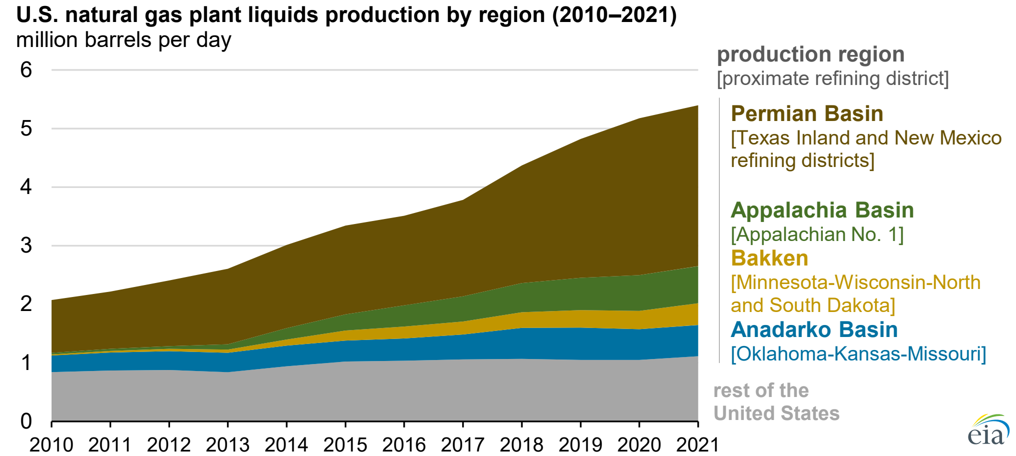


Figure 3 – U.S natural gas liquids production by region from 2010 – 2021 (Energy Information Administration)

Ultrasonic Inline Inspections for Crack Diagnosis

Ultrasonic crack inspections require a liquid coupling medium like oil, water, or refined products and use shear waves in a pulse-echo (PE) configuration (Guajardo and Hennig, 2019). The emitted signal travels at a specific angle through the liquid medium and is refracted at the internal pipe wall. The optimum angle of refraction for crack inspections is 45°. Once the sound velocities in the steel and the medium are known, the angle of incidence (α) is calculated. Then, the refracted shear wave travels through the pipe wall at a 45° angle. After transmitting the signal pulse, the transmitting sensor is used to record any echoes to be analyzed as A-scans, showing amplitude vs. travel time. In other words, the same sensor is used as the transmitter and receiver.

If there is no defect, the wave will propagate continuously and without any interruptions through the steel, zigzagging between the inner and outer pipe walls and the A-scan will show only a surface echo signal. On the contrary, if there is a discontinuity (for example, an internal or external crack), part of the energy will be reflected when hitting the flaw, and the A-scan will show a surface echo and a crack signal (Figure 5).

Unfortunately, the PE technique has limitations when it comes to sizing tilted features. EVO Eclipse UCx was developed in 2019 to accurately size tilted and skewed features (i.e., those that have radial misalignment like hook cracks or misalignment from the pipe axis, respectively). EVO Eclipse UCx includes the traditional PE technique plus an additional pitch and catch measurement (Guajardo et al., 2022). The pitch and catch technique arranges the ultrasonic probes where a pair face each other: one clockwise facing and the other counter-clockwise. In addition to the PE technique, the transmitted signal is additionally received by the paired sensor. This doubles the number of feature measurements and allows for sizing of skewed and titled features. For more information on EVO Eclipse UCx technology refer (Guajardo and Hennig, 2019).

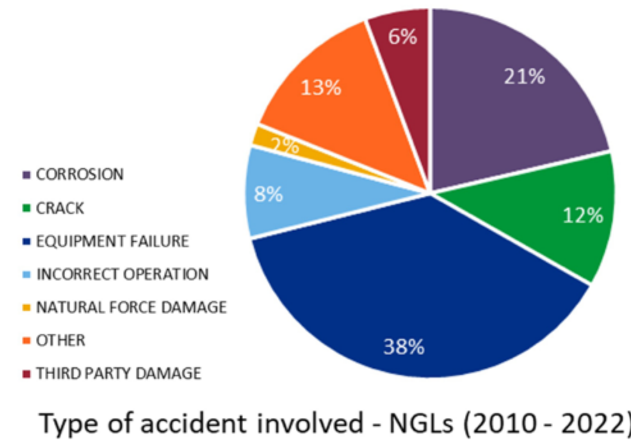


Figure 4 – All reported incidents by type for 2021 (US DOT Pipeline and Hazardous Materials Safety Administration)

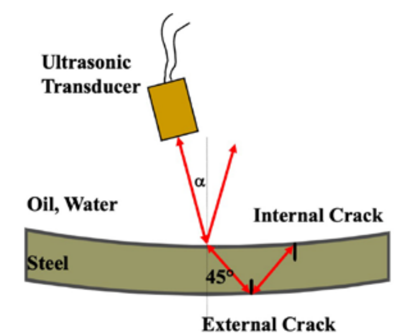


Figure 5 – Ultrasonic pulse echo technique for crack diagnosis

Ultrasonic Inline Inspections for Crack Diagnosis in Natural Gas Liquids

Natural Gas Liquids are more challenging for ultrasonic inspections compared to crude oil, diesel, and water as temperature and pressure have a significant impact on the ultrasonic characteristics relative to the speed of sound, density, and attenuation. For instance, Hennig et. al. (2018), presented an example of the effect of pressure and temperature on sound velocity for pure propane. It was observed that, at a constant temperature, the sound velocity of the propane increases with increasing pressure, but decreases with increasing temperature.

To adequately perform an ultrasonic crack inspection in these challenging mediums there are certain parameters that must be well understood. The biggest challenge is determining the sound velocity in the medium because changes in the speed of sound affect ultrasound propagation angles which can lead to measurement degradation. An important consideration is the angle of incidence (AOI) of the propagated acoustic energy and the refracted angle of the acoustic energy entering the steel, both of which depend on the medium's sound velocity. The optimum refracted angle for a crack inspection is 45°. Given that the sound velocity in steel is known, and knowing the sound velocity in the medium, the AOI for the acoustic wave can be calculated. With this information, the acoustic sensors on the ILI tool can be mechanically adjusted for the AOI to provide the best measurement results. In short, to obtain the speed of sound for various mediums requires extensive testing and experience. Figure 6 depicts the medium sound velocities for various hydrocarbon liquids, gas, and water. These velocities are approximations and are influenced by the product's pressure and temperature. In essence, the lower the carbon molecules, the lower the sound velocity. Therefore, mediums with slower speeds of sound require smaller AOI to achieve a 45° refracted angle in the steel.

The optimum refracted angle for a crack inspection is 45°

Until now, PE ultrasonic ILI has been successfully performing crack diagnosis surveys for "pure" NGLs, i.e., propane and butane. However, blended NGLs have been more problematic given the variances in the speed of sound due to the unique composition of each product. Because of this, operators have been unable to confidently assess the condition of their pipeline assets relative to cracks as other inspection technologies do not provide the performance levels required by operators to meet their needs. At times, this has left operators to utilize hydrostatic testing to manage their blended NGL pipeline assets. While hydrostatic testing is effective in identifying crack features that fail during the test, they do not provide insights or information on the remaining features in the pipeline. Without these critical insights, operators cannot optimize their integrity management plan for the safety of the pipeline asset.

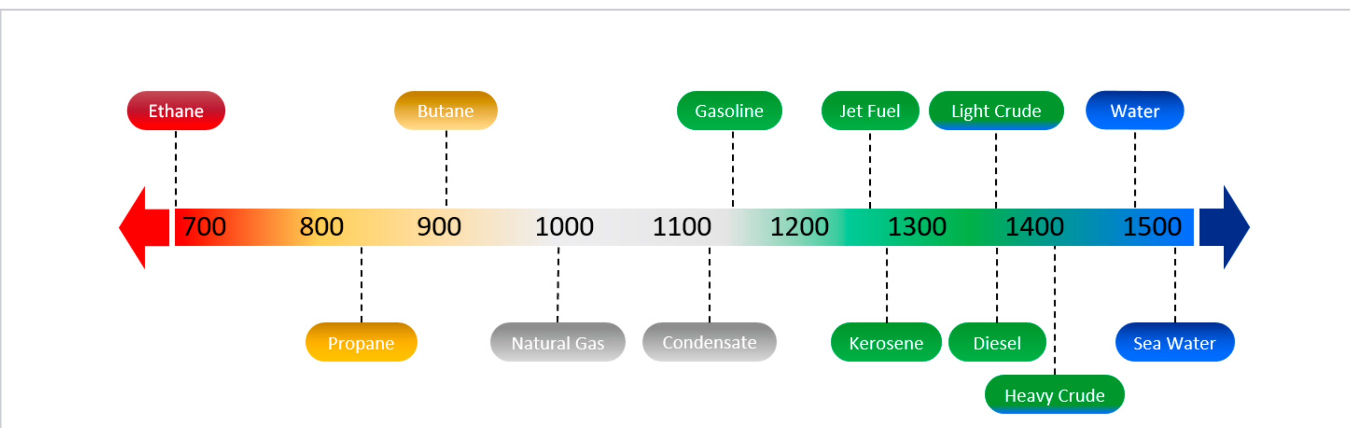


Figure 6 – Approximate speed of sound for various liquid hydrocarbons in m/s

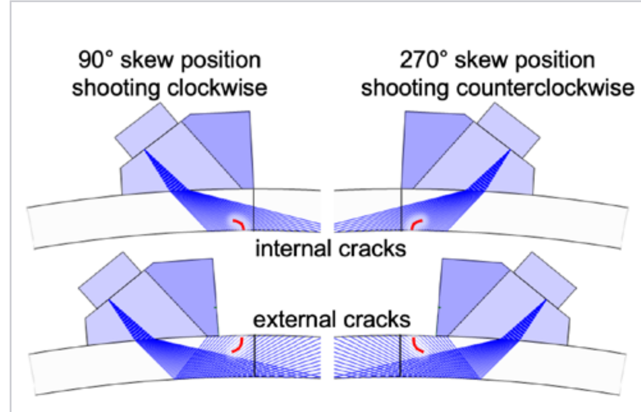


Figure 7 – PAUT scan positions with the probe shooting clockwise (90° position, blue) and counter-clockwise (270° position, green)

NDE Phased Array UT Inspection for Crack Assessment

Phased array UT (PAUT) probes can be used to steer the ultrasonic beam and electronically control the AOI and the focus of the beam (Figure 7). While the ILI tool utilizes hundreds of sensors with the same AOI of 45° to cover the pipe circumference including the seam weld, PAUT often allows covering the weld volume with only one pass. By default, every scan has to be performed with probes facing both clockwise and counter-clockwise.

Detecting hook cracks in the field is not an easy task. PAUT signal amplitudes may be low, they may be visible from one side only, and the signal is hard to interpret and requires experienced technicians to do so. In some cases, the best results are obtained by a combination of PAUT with manual UT measurements (Torres et al., 2018). Detection or reporting criteria based on amplitudes require low thresholds for embedded hook cracks, depending on their orientation.

Case Study

A North American operator contracted NDT Global in 2021 to inspect a blended NGL pipeline with a nominal pipe size (NPS) of 18" for cracks, including problematic hook cracks.

Unique to this line, the medium was challenging as it was a blend of NGLs, and determining the correct speed of sound is critical. When a challenging medium is presented, the common procedure would be to deploy the inspection tool in a diesel batch as no previous ultrasonic technologies have successfully inspected in this medium. A batch is a method of deploying an ultrasonic technology in a liquid couplant with known acoustic properties, e.g., diesel.

The diesel, together with the UT crack tool, is isolated from the NGL in the pipeline via a series of sealing pigs and together is deployed through the pipeline for a crack inspection and diagnosis survey. However, batching is not always possible. In this instance, the operator was looking for a solution that could be deployed directly in the NGL product, avoiding the need for a batching procedure. Instead of using a batch process for the inspection, the EVO Eclipse UCx tool was deployed directly in the NGL. The EVO Eclipse UCx service is an advanced NDT Global crack detection technology allowing operators to size and diagnose complex features, such as hook, tilted, and skewed cracks in their assets. Utilizing the NGL chemical composition from samples provided by the customer as input, the NDT Global team of engineers followed a sophisticated medium assessment process to determine the speed of sound and attenuation of the NGL. With this information, it was determined that an assessment run would need to be performed to fully validate the ideal AOI to achieve the best data quality. So, the team constructed a set of sensor plates for the inspection system with varying AOIs. After completing the assessment run and reviewing the results from the Data Quality Assessment, the ideal AOI was confirmed. The inspection system was quickly configured to the ideal AOI, and the NDT Global team proceeded with the inspection survey. The inline inspection was successful as the stated performance specification was achieved for the entirety of the pipeline.

Results

After the completion of the full data analysis process by the NDT Global team, a final report was prepared and delivered to the operator. Several complex crack-like features were identified, sized, and reported including several possible hook cracks. The ILI data was validated using NDE measurements by an independent third-party contractor and NDT Global's field verification team which characterized the complex crack geometries with PAUT. Since the anomalies in question could be located anywhere in or near the weld, as well as possibly titled, a second pass was performed with a different spacing between the seam weld and probe. The outcome was one dataset optimized for internal anomalies, and another optimized for external anomalies. The NDE validation matched the ILI results and demonstrated the excellent ILI data quality as evidenced in the unity plot below (Figure 8).

A typical example of a hook crack is shown in Figure 9, showing PAUT sectorial scans from either side of the seam weld. The crack originates near the external surface (orange cross-hairs) and seems to extend downwards for the probe facing clockwise, but upward for the probe facing counter-clockwise, ending at the blue cross-hairs. The reason is that the sound hits the tilted crack in different legs due to its angle, as illustrated in Figure 10. The hook-shaped nature of the crack was furthermore confirmed through manual 0° UT measurements, which detected a horizontal component (Figure 11). This anomaly was not detected externally by magnetic particle testing.

Of the 19 verified anomalies, NDE identified:

- 10 as lack of fusion
- 3 as cracks
- 5 as hook cracks, and
- 1 could not be confirmed by NDE

The outcome was one dataset optimized for internal anomalies, and another optimized for external anomalies

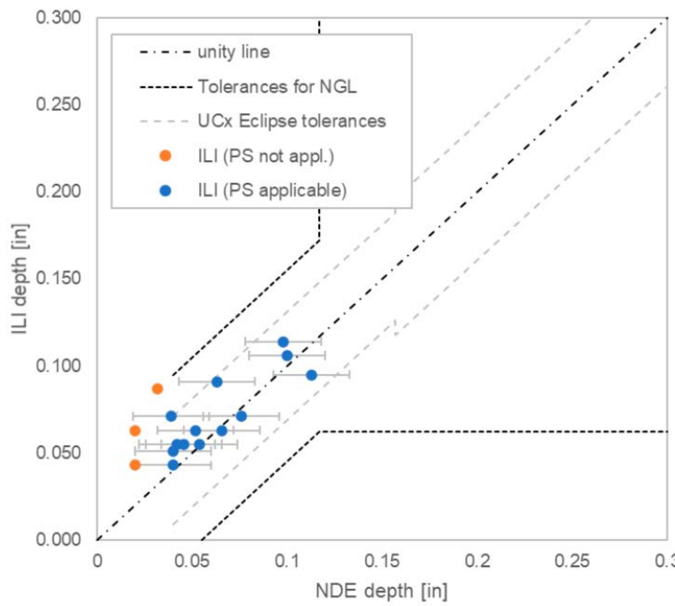


Figure 8 – Unity Plot where ILI performance specification is and is not applicable.

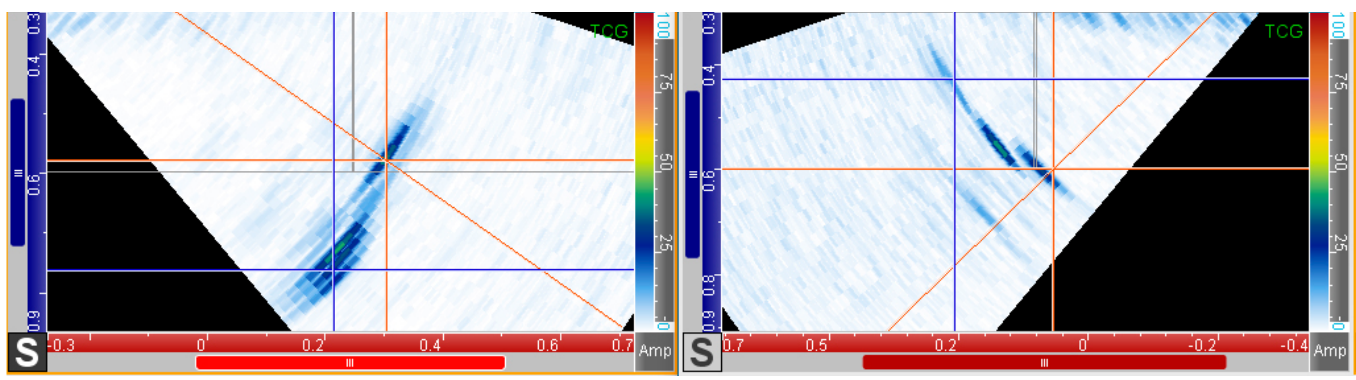


Figure 9 – PAUT sector scans with the probe shooting clockwise (left) and counter-clockwise (right)

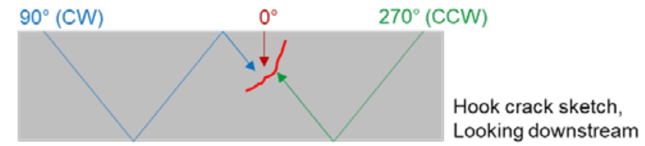


Figure 10 – Sketch of the shear wave sound paths for a tilted crack and the probe shooting clockwise (blue) and counter-clockwise (green), as well as 0° UT (red). Notice, that the main echo has its origin in the third leg on the clockwise but in the second leg on the counter-clockwise leg.

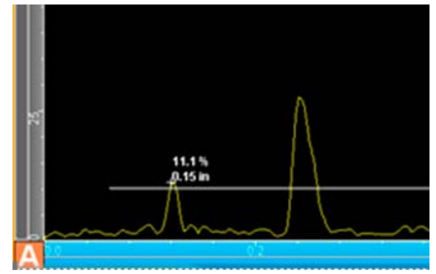


Figure 11 – 0° UT A-scan, showing an echo from the anomaly at 0.150" from OD and the back wall at 0.300"

Figure 12 shows the corresponding ILI data for the anomaly above. The anomaly is visible from both sides and displays the typical characteristics of a crack-like feature. Similar to the PAUT data, we see secondary signals, but occurring on different sides of the main sensor (Figure 13). The maximum amplitudes differ significantly between the data from either side of the anomaly. These signal characteristics are typical for hook cracks.

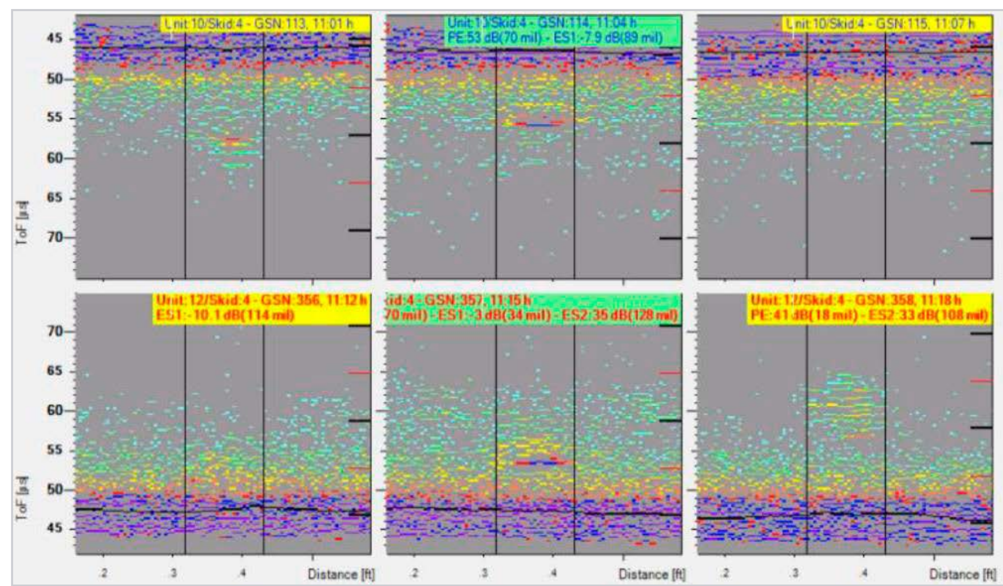


Figure 12 – EVO Eclipse UCx B-scans for three consecutive sensors facing clockwise (top) and three consecutive sensors facing counter-clockwise (bottom)

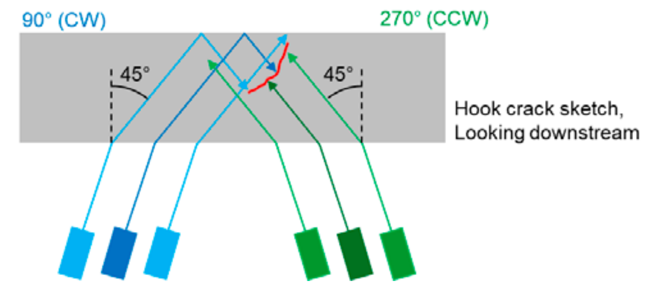


Figure 13 – Schematic of ILI sensor positions, relative to the anomaly

Axial Cracks
Circumferential Cracks
Metal Loss
Geometry Ovalities
Mapping

Conclusion

While operators have been able to assess the condition of their propane and butane pipelines with regard to crack anomalies, they have been challenged to do the same with blended NGL assets. However, recent advancements in ultrasonic ILI techniques and experience have overcome this challenge, providing operators with a reliable crack diagnosis solution – specifically, the sophisticated medium assessment process, consisting of accurate measurements of the sound velocity for blended NGLs, as well as an assessment run to test and validate the ideal tool setup. This information provides the necessary input to establish the ideal angle of incidence for both pulse-echo and pitch and catch ultrasonic techniques for a specific inspection.

As evidenced in this case study, these advancements have yielded highly accurate detection and sizing results, for challenging crack-like features including hook cracks. This advancement potentially provides operators with an alternative to costly hydrostatic testing and improves the holistic insights on the truest condition of their pipeline asset.

This paper was published at the 2023 Pipeline Pigging and Integrity Management conference.

Learn More

For more information about NDT Global and our inline diagnostics solutions, visit www.ndt-global.com