

MEASURING CRACK DEFECTS WITH SUB-MILLIMETER ACCURACY

WHITE PAPER



INTRODUCTION

Ultrasonic crack technology, using piezoelectric transducers, is a proven and widely used solution for crack and crack-like defect detection in liquid pipelines. Over the past 20 years, only minor developments and improvements in this area were offered to pipeline operators. The most significant enhancement was a move from bucket sizing to absolute depth sizing. After two decades of incremental improvements, technology-related limitations still prevent accurate sizing of defects.

Recent technical developments at NDT Global have successfully overcome several of these limitations. Higher-resolution tools, specialized sensors and measurement configurations address major flaw-measurement challenges: depth-sizing accuracies, extended maximum crack depth sizing beyond the formerly known maximum crack depth of typically 4 mm (0.16 in), through wall defects, and measurement capabilities less susceptible to skew and tilt.

NDT Global's Evo Eclipse technology is a combination of high-resolution crack robots (UCx) and new analysis methodologies. Together, these technologies enable new inline inspection robots with a circumferential resolution of 5.0 mm (0.2 in).

High-resolution robots offer increased crack depth-sizing accuracy and repeatability. More importantly, they are an enabler for Enhanced Sizing methodology, allowing new ways to analyze data, which successfully overcomes existing depth-sizing limitations.

Evo Eclipse sizing technology results in accurate depth values for many flaws, typically below 0.8 mm (31 mil) tolerance. A combination of different datasets, characteristics, and sizing methodologies allows highly accurate inspection, with greatly reduced tolerances. Sub-millimeter accuracy for the entire range of flaws, including hook cracks, is now possible.

Introduction

Limitations of conventional pulse echo technology

High-resolution UCx technology

Meeting the challenge of skewed and tilted cracks

Conclusion

References



LIMITATIONS OF CONVENTIONAL PULSE ECHO TECHNOLOGY

Widely used for crack detection and sizing, 45° pulse echo (PE) shear wave technology is based on an ultrasound sender/receiver configuration in which the sender and receiver comprise a single element. An ultrasonic pulse is transmitted from the sensor in a liquid coupling medium (e.g. oil, water, diesel). The signal travels through the medium and continues the sound path in the pipe wall. The system is mechanically setup to generate a 45° angle of sound path in the specimen.

Deviations from the optimum 45° angle affect the amplitude of the recorded signal and, as a result, the depth-sizing accuracy of flaws. The emitted signal could be reflected by an external or internal flaw. The reflected signal’s time of flight (TOF) or travel distance provides information about the location of the flaw: early signals represent external defects; late signals represent internal defects. The recorded amplitude of this corner echo (CE) contains information about the depth or severity of a defect. Figure 1 depicts the described setup. Figure 2 depicts a typical sizing model for pulse echo technology. The chart clearly illustrates a flattening effect of the recorded signal from a depth of approximately 4.0 mm (160 mil) onwards. This effect limits the conventional pulse echo technology in depth sizing above 4.0 mm (160 mil).

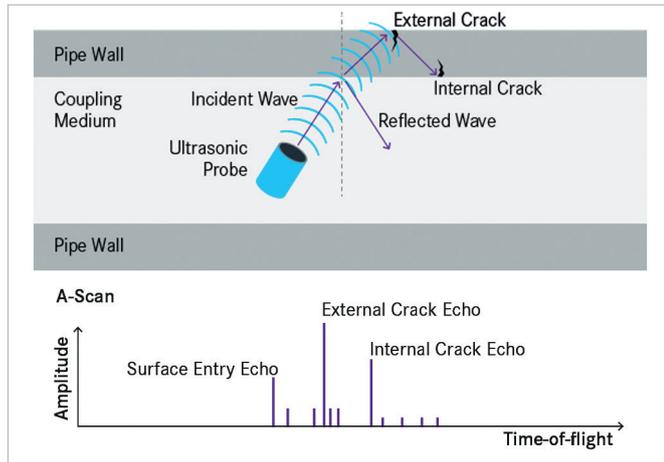


Figure 1 – Schematic of 45° shear wave, describing the angle of incidence (α) and the 45° reflected shear wave detecting an external and internal crack. The recorded signals are represented in an A-Scan

HIGH-RESOLUTION UCx TECHNOLOGY

The path leading to Evo Eclipse technology began in 2016, with the development of high-resolution crack robots (UCx) and new analysis methodologies. Together, these technologies enabled robots with a circumferential resolution of 5.0 mm (0.2 in). Circumferential resolution on its own is a significant enhancement to any crack inspection.

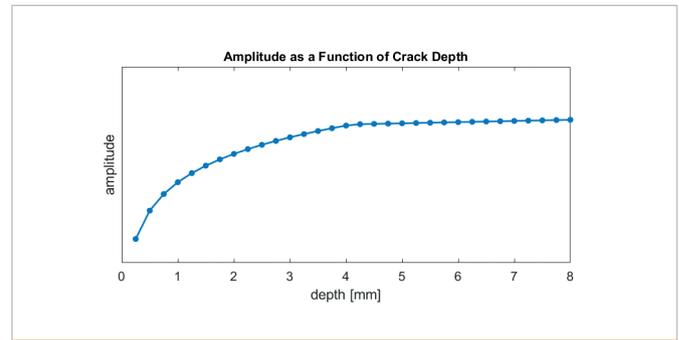


Figure 2 – Logarithmic signal response vs. flaw depth. The curve shows a flattening around 4.0 mm (160 mil) limiting depth-sizing capabilities above this threshold

By at least doubling the number of sensors emitting and receiving signals, several aspects are enhanced (Table 1).

Characteristic	Enhancement
Sizing accuracy	collect relevant amplitudes for sizing the defect
Sizing accuracy	detect/size deepest point of defect
Sizing accuracy	high-density crack depth profile
Identification (POI)	more sensors provide a better representation of the feature allowing better identification, e.g. notch vs. crack vs. hook crack
Coverage	> 200% compared to conventional robots
Robustness of entire service	failure of a single sensor does not compromise the entire ILI as many other sensors still cover the feature

Table 1 – Enhanced aspects

Significant improvements in four areas helped to drive the technical evolution leading to the development and successful commercialization of Evo Eclipse technology: greater sensor density (with more channels); greater onboard processing power; greater onboard data storage capacity; and improvements in analysis methodologies, partly as the result of the availability of more and better data produced by the high-resolution robots.

CIRCUMFERENTIAL RESOLUTION ON ITS OWN IS A SIGNIFICANT ENHANCEMENT TO ANY CRACK INSPECTION

High-resolution robots already offer a certain increase in crack depth-sizing accuracy and repeatability. More importantly, they act as an enabler for Enhanced Sizing methodology, and they allow for a new way to analyze data and overcome the existing limitations in depth sizing.

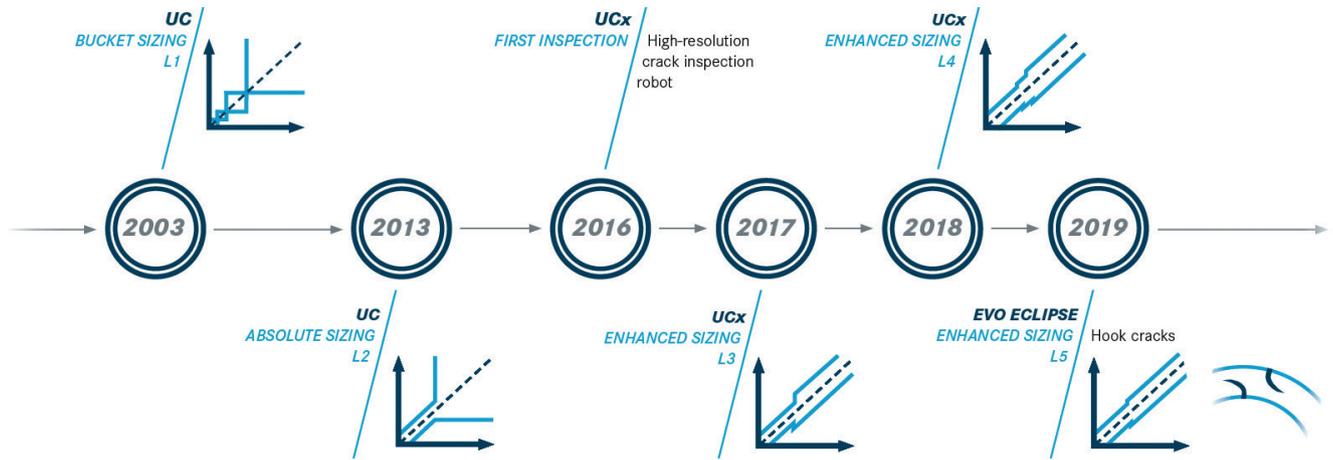


Figure 3 – Major achievements introduced to crack inspection services by NDT Global since 2003

MEETING THE CHALLENGE OF SKEWED AND TILTED CRACKS

Although the industry has seen dramatic improvements in ILI technology and capability since first introduced, it has lacked the ability to accurately measure tilted cracks, e.g. hook cracks or cracks following the level of a DSAW. In general, detecting these types of cracks with current technology is possible, but accurately sizing them is not.

Within the last year, NDT Global has overcome these remaining challenges in liquid crack detection technologies.

To address tilted and hooked cracks, a modified sensor arrangement was introduced to the fleet of robots. Instead of arranging clockwise and counter-clockwise sensors independently from each other, the new arrangement always combines a clockwise and a counter-clockwise sensor as a pair. This allows recording a third type of signal, in addition to the conventional pulse echo and Enhanced Sizing information.

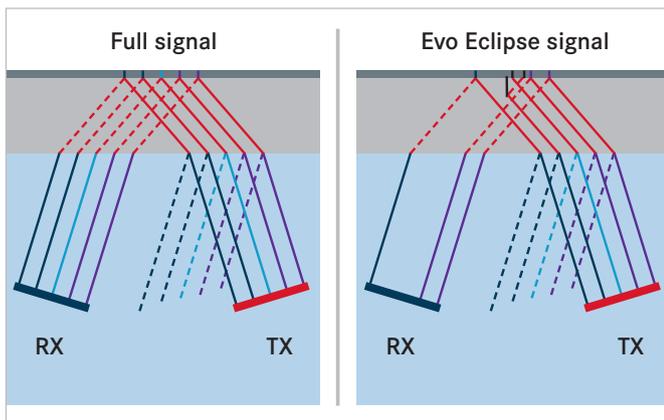


Figure 4 – Schematic for an Evo Eclipse configuration

Figure 4 depicts the general sensor arrangement. The left-hand plot shows the situation for a pipe without any flaw. The emitted signal from the TX sensor is traveling in the liquid and pipe wall, reflected at the outer wall and recorded by the RX sensor. When no obstacle, e.g. a crack, blocks or partly blocks the signal path, the maximum reflected amplitude is recorded. A crack, e.g. at the external pipe wall, causes a portion of the signal to be blocked or shaded, and the recorded amplitude is reduced. The technology is invariant to tilt angles. Even branched cracks are accurately sized, because they also shade the signal and block the sound path.

Category A	Category B
Category C	Category D

Table 2 – Cross-sections of real cracks and simplified geometrical representation for simulation

During development of Evo Eclipse technology, systematic simulations were performed to investigate sensitivity, amplitude behavior, and depth-sizing capabilities of this arrangement for different crack types and morphologies. Four categories were defined with different crack morphologies (Table 2). Cross-sections and selected, simplified geometric models are both shown. Figure 5 and Figure 6 show the result of different depth-sizing results based on conventional pulse echo and Evo Eclipse technology.

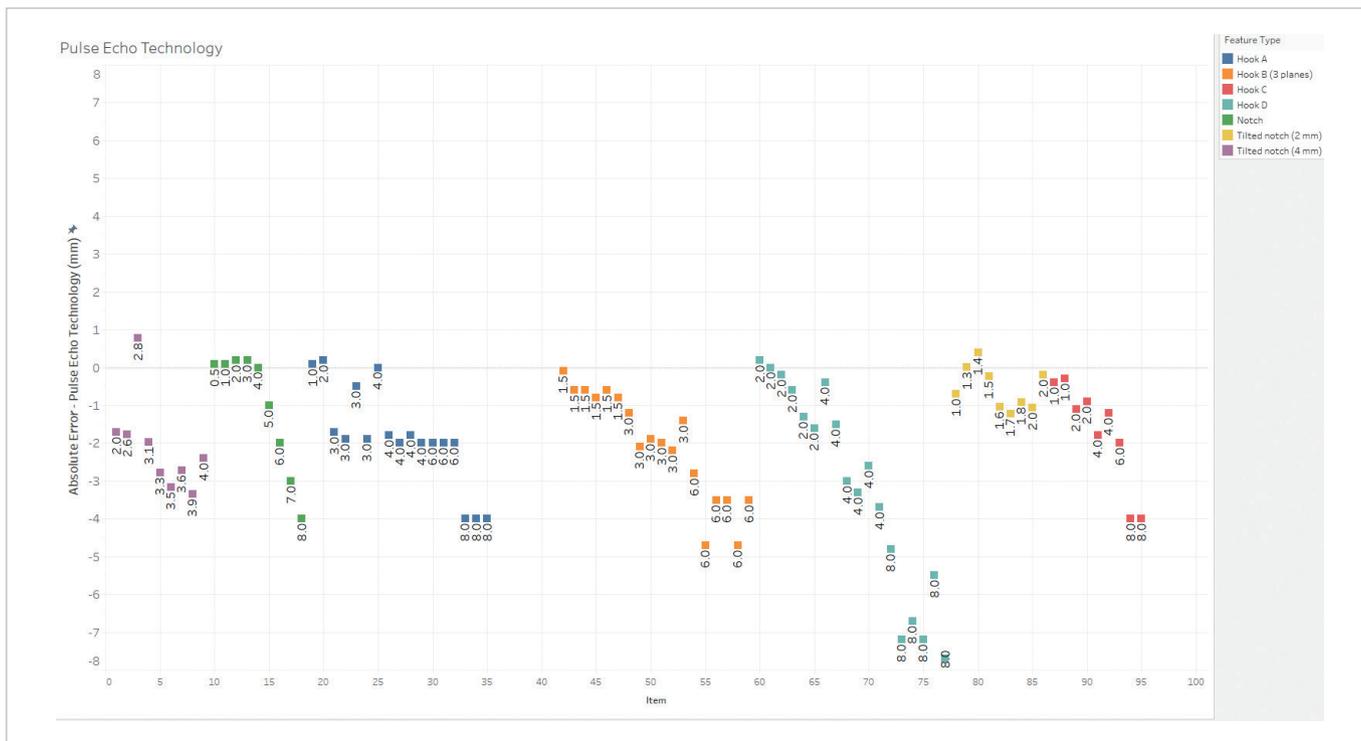


Figure 5 – Pulse echo sizing deviation from design depth for tilted and challenging flaws, numbers represent design depth in mm

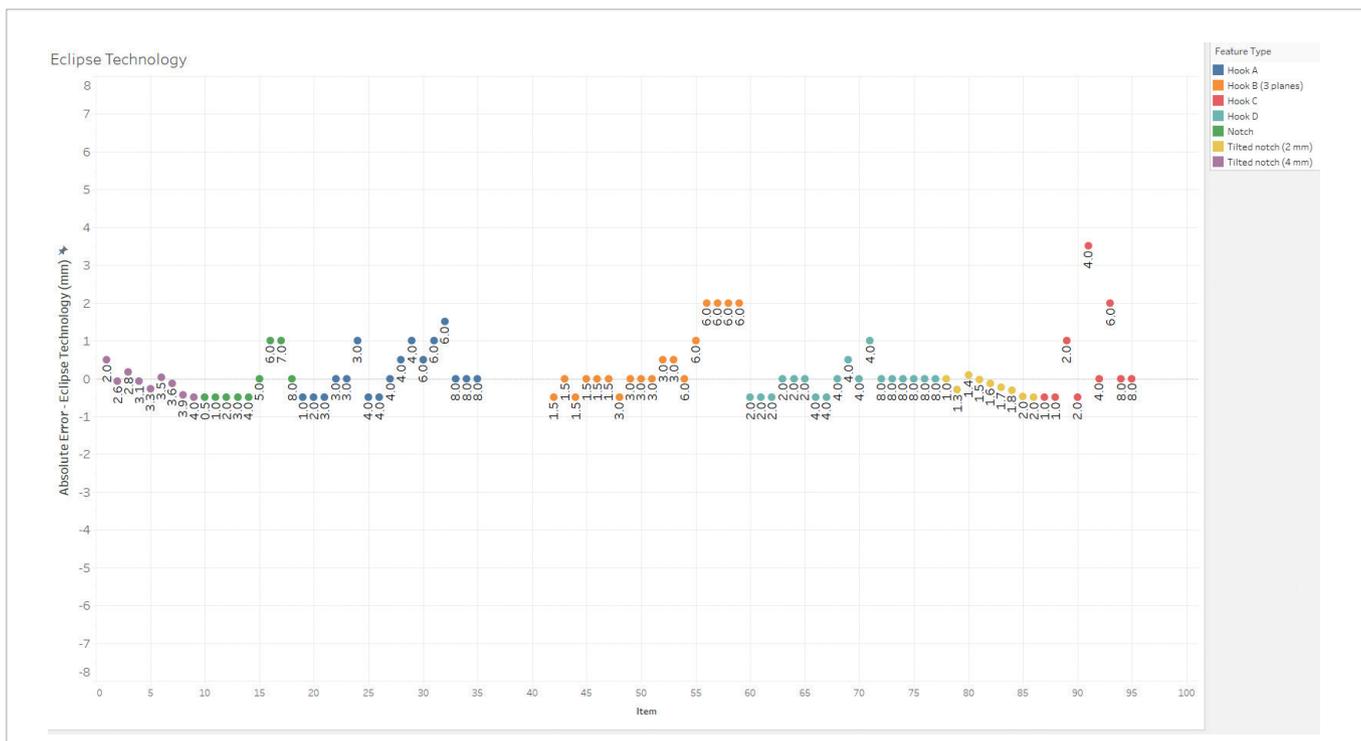


Figure 6 – Evo Eclipse sizing deviation from design depth for tilted and challenging flaws, numbers represent design depth in mm

The abscissa shows different crack types with an increasing tilt angle in each group. On the ordinate, the absolute depth-sizing error is plotted. Oversizing is reflected by positive values, under sizing by negative values. Pulse echo results are represented by squares. Circles indicate the result of the Evo Eclipse sizing methodology. For each color/category, the design crack depth

values from left to right are increasing. The number next to the symbol indicates design depth.

As expected, the error in crack depth for conventional pulse echo technology is low for notches < 4.0 mm (160 mil) and Type A cracks with radial main component and a small

hook only. As soon as the main component is not oriented in radial direction and/or combined with a longer 2nd crack component, the sizing capabilities are significantly reduced. Typically, this leads to an under sizing of flaws.

In comparison, Evo Eclipse sizing results in accurate depth values for many flaws, typically below 0.8 mm (31 mil) tolerance. A few outliers show oversizing of depth. The selected geometries of those features represent Category C cracks. For all these features, the axial component is significant compared to the radial. Some of these defects are closer to a lamination than a conventional crack. These findings led to the definition of a diamond or rhomb. Cracks, whose tips are within the indicated rhomb area – starting at the OD or ID intersection with the diamond – can be detected and accurately sized (Figure 7).

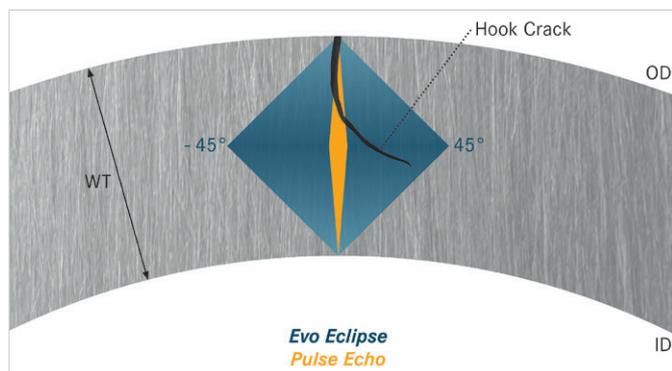


Figure 7 – Diamond (blue) defining the working range for crack detection by Evo Eclipse and reduced area (orange) for conventional UC technology

Figure 8 depicts two sample unity plots for skewed (left) and tilted (right) flaws, sized with conventional technology and Evo Eclipse. The skewed flaw population on the left-hand side shows in general a good match, but even for those flaws an enhancement, especially for the deeper flaws is visible when

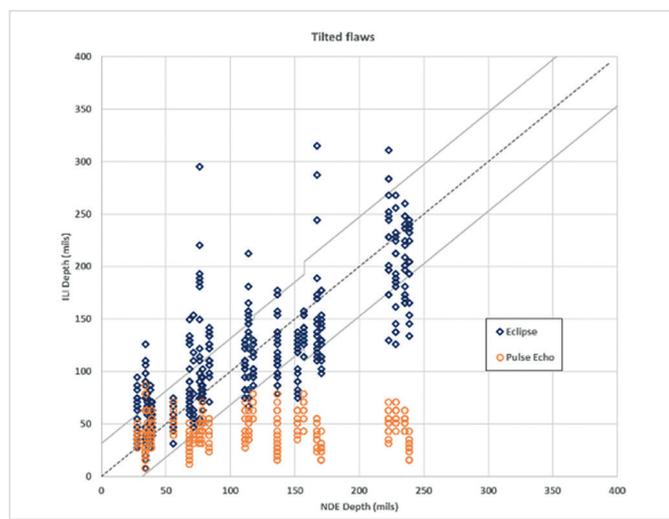


Figure 8 – Unity plot for radial flaws (left) and tilted flaws (right), both showing results for pulse echo (orange) and Evo Eclipse (blue) sizing methodologies

applying the Evo Eclipse methodology. Like the simulations a significant under sizing is visible for tilted flaws based on pulse echo technology (right hand plot). Based on Evo Eclipse signals, most flaws are accurately sized within a small tolerance band.

An extensive test program with hundreds of flaws and several repetitions led to a new performance specification (in accordance with API 1163). For this specification, the entire test results, and hundreds of NDE results gathered from commercial crack inspections and pipeline operators, were considered. A combination of analysis and sizing methodologies, as indicated in Figure 9, allow for an increase in depth-sizing accuracy. Especially for the deeper feature range, Evo Eclipse technology sharpens the tolerances.

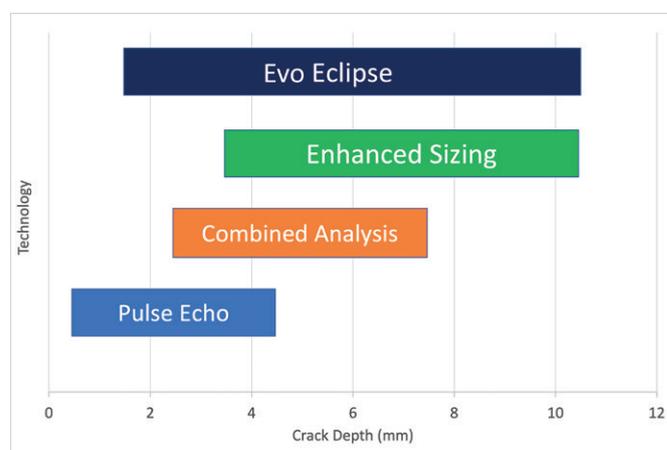


Figure 9 – Depth-sizing methodologies applied for different depth ranges

CONCLUSION

As Figure 3 illustrates, the development of ultrasonic crack detection technology and capability has been fast-paced and substantial. Along the way, gaps and limitations have been addressed and overcome with high-resolution robots, new analysis methodologies, and today, a special inspection solution: Evo Eclipse. A combination of different datasets, characteristics, and sizing methodologies allow a highly accurate inspection service, with greatly reduced tolerances. Sub-millimeter accuracy for the entire range of flaws, including hook cracks, is now possible.

A twenty-plus year development path, on which some of the ILI industry’s greatest technical achievements were reached, leads directly to Evo Eclipse technology. Pipeline operators can now get a far more accurate understanding of their pipeline condition, without assuming the costs and risks of hydrostatic test inspection.

AUTHORS



Dr. Thomas Hennig
Technology Advisor

NDT Global Corporate Ltd,
Dublin, Ireland



Rogelio Jesus Guajardo,
Global Manager
Data Analysis UC

NDT Global GmbH & Co KG,
Stutensee, Germany



Dr. Michael Haas
Physicist

NDT Global GmbH & Co KG,
Stutensee, Germany

REFERENCES

- [1] Anderson, T. & Thorwald, G. (2016): Finite Element Procedure to Model the Effect of Hydrostatic Testing on Subsequent Fatigue Crack Growth. International Pipeline Conference, Proceedings, 64563, Calgary, Canada, September 26-30
- [2] Brimacombe, M., Hennig, T., Wargacki, C. (2016): Circumferential Crack Detection: Challenges, Solutions and Results. International Pipeline Conference, Proceedings, 64111, Calgary, Canada, September 26-30
- [3] Guajardo, R. & Hennig, T. (2019): High-Resolution Inspections for Crack Detection: The next level of Accuracy. Pipeline Pigging and Integrity Management Conference, Proceedings, Houston, USA, February 18-22
- [4] Hennig, T., Guajardo, R., Suarez, E., Haro, V. and Haberl, P. (2018): Exceeding limitations – ultrasonic crack inspections become feasible for liquid natural gases. International Pipeline Conference, Proceedings, 78573, Calgary, Canada, September 24-28
- [5] Kiefner, J. F., Maxey, W. A., and Eiber, R. J., (1980): A Study of the Causes of Failure of Defects That Have Survived a Prior Hydrostatic Test., Pipeline Research Committee, American Gas Association, NG-18 Report No. 111, November 3.
- [6] Leis, B. N. & Brust, F.W. (1990): Hydrotesting effects-1 model predicts crack growth and material behavior. Oil and Gas Journal.
- [7] Pipatpan, S. (2019): Operator - Vendor Cooperation for Optimum Benefits from Field Verifications. Pipeline Technology Conference, Berlin
- [8] Willems, H., Kopp, G., & Haro, V. (2017). Sizing Crack Indications from Ultrasonic ILI: Challenges and Options. Pipeline Technology Conference, Berlin
- [9] In-line Inspection Systems Qualification. API Standard 1163, 2nd Ed. April 2013

LEARN MORE

For more information about NDT Global and their inspection services, visit www.ndt-global.com