# THROUGH A ROBOT'S EYES

**Dr. Thomas Hennig, NDT Global Corporate Ltd, Ireland, describes how high-resolution robots and new analysis methodologies can overcome crack sizing limitations.**

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 have become available to pipeline operators. The most significant enhancement was a move from bucket to absolute depth sizing. After two decades of incremental improvements by the inspection industry, technical limitations still prevented accurate sizing of defects, especially if tilted, skewed or hooked.

However, recent technical developments have overcome several of these limitations. Higher-resolution inspection systems, specialised sensors, and measurement configurations address major flaw-measurement challenges: depth sizing accuracies, extended maximum crack depth sizing beyond the formerly known depth of 4.0 mm (0.16 in.), through-wall defects, and measurement capabilities less susceptible to skew and tilt. NDT Global's Eclipse UCx technology is a combination of high-resolution crack robots and new analysis methodologies. Together, these technologies are designed to enable reduced sizing tolerances for the entire depth range.

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 analyse data, which overcomes existing depth sizing limitations.

Eclipse UCx sizing technology results in accurate depth values for many flaws, typically below 0.8 mm (0.031 in.) tolerance. A

combination of different data sets, characteristics, and sizing methodologies allows for accurate inspection, with reduced tolerances. Sub-millimetre accuracy for the entire range of flaws, including hook cracks, is now possible.

## Limitations of conventional 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 set up 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 can 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 set-up. Figure 2 depicts a typical sizing model for PE technology. The chart clearly illustrates a flattening effect of the recorded signal from a depth of approximately 4 mm (0.16 in.) onwards. This effect limits conventional PE technology in depth sizing above 4 mm.

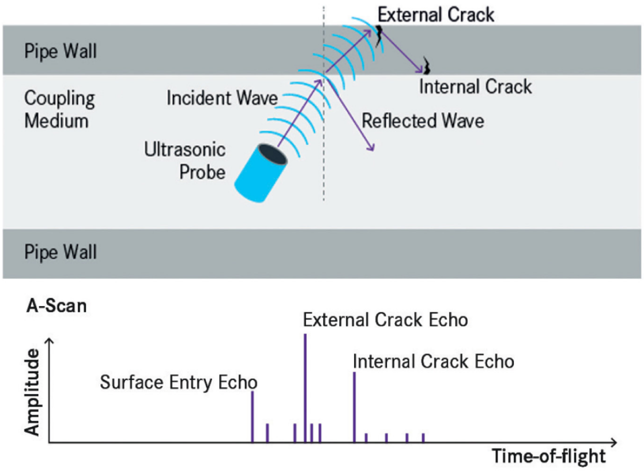


**Figure 1.** Schematic of 45˚ shear wave, describing the angle of incidence (α) and the 45˚ reflected shear wave detecting an external and internal crack. The recorded signals are represented in an A-scan.

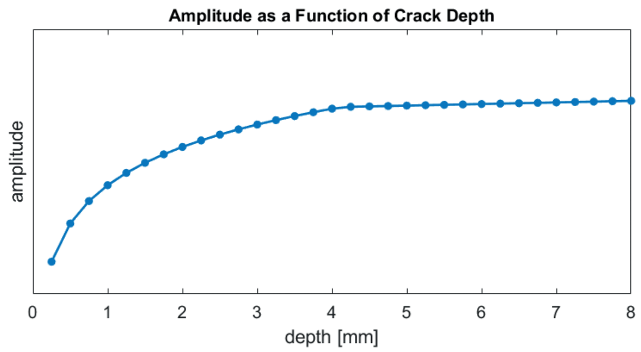


**Figure 2.** Logarithmic signal response vs flaw depth. The curve shows a flattening around 4 mm (0.16 in.), limiting depth sizing capabilities above this threshold.

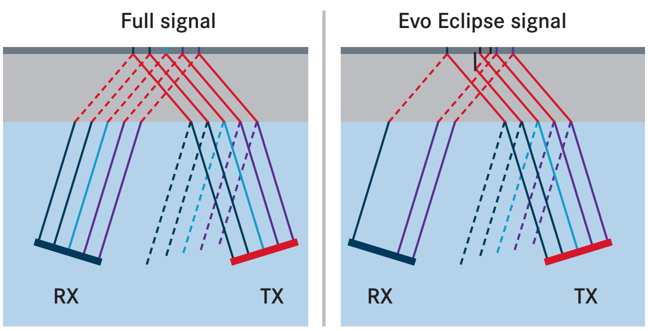


**Figure 3.** Schematic for an Evo Eclipse UCx configuration.

## High-resolution technology

Beginning in 2016, significant improvements in four areas helped to drive the technical evolution leading to the development of Eclipse UCx 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 high-resolution robots. Together, these technologies enable the current UCx robots with a circumferential resolution of 5 mm (0.2 in.). It should also be noted that 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 – the company's proprietary technology that removes the existing depth sizing boundary for ultrasonic crack inspections – and they allow for a new way to analyse data and overcome the existing limitations in depth sizing.

## Meeting the challenge of skewed and tilted cracks

Until now, ILI technology has lacked the ability to accurately measure tilted cracks, such as hook cracks. In general, detecting these types of cracks with current technology is possible, but accurately sizing them is not. If detected and sized, they are typically undersized, which underestimates the severity of such defects. This critical factor could lead to failure.

Within the last year, NDT Global has developed solutions to 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 combines a clockwise and a counter-clockwise sensor as a pair. This allows for the recording of a third type of signal, in addition to the conventional PE and enhanced sizing information.

Figure 3 depicts the general sensor arrangement. The left-hand plot shows the situation for a pipe without any flaw. The emitted signal from the transmitting sensor (TX) is travelling in the liquid and pipe wall, reflected at the outer wall and recorded by the receiving sensor (RX). When no obstacle, such as a crack, blocks or partly blocks the signal path, the maximum reflected amplitude is recorded. A crack 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 or skew angles. Even branched cracks are accurately sized, because they also shade the signal and block the sound path.

During development of Eclipse UCx technology, systematic simulations were performed to investigate sensitivity, amplitude behaviour, and depth sizing capabilities of this arrangement for different crack types and morphologies. Figure 4 highlights some sample categories with different crack morphologies. Cross-sections and selected, simplified geometric models are shown.

The error in crack depth for conventional PE technology is low for notches that are less than 4 mm (0.16 in.) and Type A cracks with a 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 second crack component, the sizing capabilities are significantly reduced. Typically, this leads to an undersizing of flaws.

In comparison, Eclipse UCx sizing is designed to produce accurate depth values for many flaws, typically below 0.8 mm (0.0315 in.) 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 5).

Figure 6 depicts a sample unity plot for tilted flaws, sized with conventional PE technology and Eclipse UCx. The tilted flaw population generally shows a good match, but even for those flaws an enhancement, especially for the deeper flaws, is visible when applying the Eclipse UCx methodology. A significant undersizing is visible for tilted flaws based on PE technology. Based on Eclipse UCx signals, most flaws are accurately sized within a small tolerance band.

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

## Conclusion

Recent developments in ultrasonic crack detection technology and capability have been fast-paced and substantial. Along the way, gaps and limitations have been addressed and overcome with high-resolution robots, new analysis methodologies, and an inspection solution: Eclipse UCx. A combination of different data sets, characteristics, and sizing methodologies allows accurate inspection, with reduced tolerances, making sub-millimetre accuracy possible.

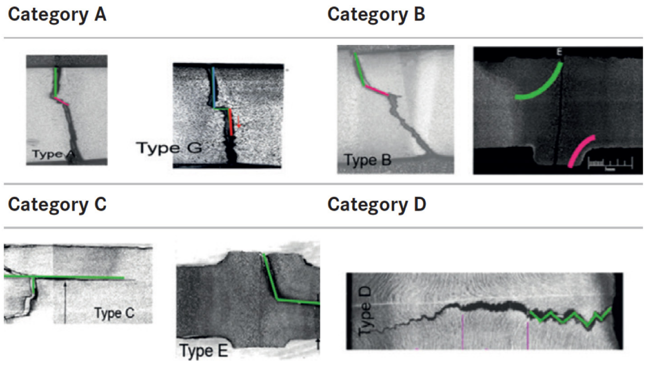


**Figure 4.** Cross-sections of real cracks and simplified geometrical representation for simulation.

**Pipe cross-section**

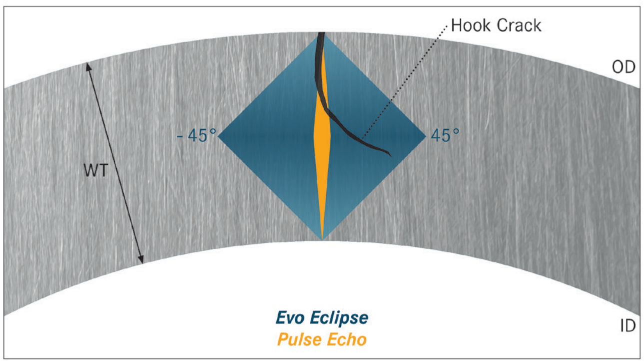


**Figure 5.** Diamond (blue) defining the working range for crack detection by Eclipse UCx and reduced area (orange) for conventional UC technology.

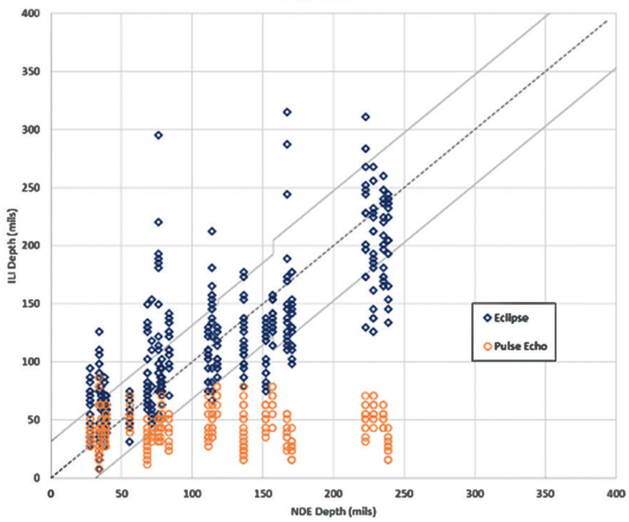


**Figure 6.** Unity plot showing tilted flaws, with results for pulse echo (orange) and Eclipse (blue) sizing methodologies.

Pipeline operators can now get a far more accurate understanding of their pipeline condition, without assuming the costs and risks of hydrostatic test inspection. In the near future, enhancements in detection and sizing capabilities will not be limited to axial cracking. The methodology will also be applied to circumferential crack inspection systems.