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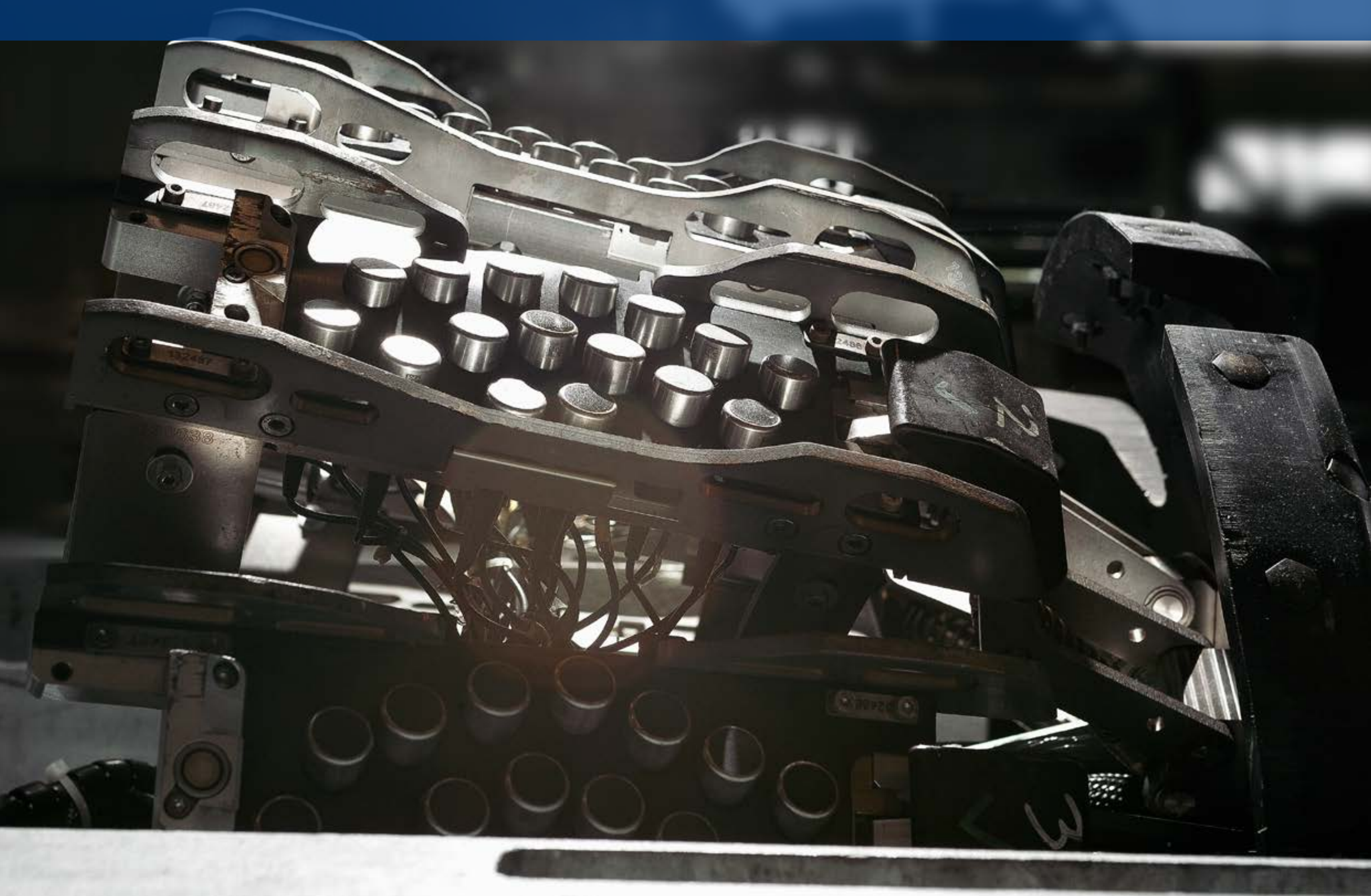
White Paper

Ultrasonic ILI Removes Crack Depth-Sizing Limits



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Introduction

The global network of high-pressure liquid and gas pipelines extends beyond three million kilometers, facilitating the transportation of substantial quantities of oil, natural gas, and related products. Steel pipelines have consistently emerged as the safest choice for this critical infrastructure. However, like any technological component, steel pipelines are subject to deterioration over time, which can lead to the emergence and propagation of flaws, ultimately risking pipeline integrity. Among these concerns, long seam features in particular are a concern. Early detection and accurate sizing reduces the pipeline risk ensuring pipeline safety.

To address these challenges, the industry has embraced Intelligent Inline Inspection (ILI) systems, which play a pivotal role in maintaining safe operations. ILI tools traverse the entire pipeline, from launcher to receiver, recording crucial data along the way. Among the various ILI technologies available, Ultrasonic Technology (UT) stands out as the most accurate and reliable. However, it had been hampered by a limitation in crack-depth sizing until recently.

This white paper delves into how the latest generation of high-resolution inspection tools has successfully overcome the crack-depth sizing constraints of previous-generation UT. It explores their enhanced capabilities for detecting, sizing, and precisely locating cracks and crack-like defects within the body and welds of transmission pipelines. Additionally, the white paper presents supporting test data to substantiate these advancements.

A Brief History of Nondestructive Testing

Nondestructive testing (NDT) has been practiced for many decades, with initial developments spurred by the technological advances that occurred during World War II and subsequent defense efforts. Its original purpose was the detection of defects. As a part of "safe life" design, it was intended that a structure should not develop macroscopic defects during its lifetime, with the detection of such defects being a cause for removal of the component from service. In response to this need, increasingly sophisticated techniques emerged from using ultrasonics, eddy currents, x-rays, dye penetrants, magnetic particles, and other forms of interrogating energy.

In the early 1970s, two events occurred that caused a major change in the NDT field. Improvements in the technology led to the ability to detect small flaws, which caused more parts to be rejected even though the probability of component failure had not changed. However, the discipline of fracture mechanics emerged, which enabled the ability to predict whether a crack of a given size will fail under a particular load when a material's fracture toughness properties are known. Other methods were developed to predict the growth rate of cracks under cyclic loading (fatigue). With the advent of these tools, it became possible to accept structures containing defects if the sizes of those defects were known. This formed the basis for the new philosophy of "damage tolerant" design. Components having known defects could continue in service as long as it is established that those defects would not grow to a critical, failure producing size.

> Advances in several areas have driven the evolution of high-resolution tools

A new challenge was thus presented to the nondestructive testing community. Detection was not enough. One needed to also obtain quantitative information about flaw size to serve as an input to fracture mechanics-based predictions of remaining life. The need for quantitative information was particularly strong in the defense and nuclear power industries and led to the emergence of quantitative nondestructive evaluation (QNDE) as a new engineering/research discipline. A number of research programs around the world were started, such as the Center for Nondestructive Evaluation at Iowa State University (emerging from major research effort at the Rockwell International Science Center), the Electric Power Research Institute in Charlotte, North Carolina, the Fraunhofer Institute for Nondestructive Testing in Saarbrucken, Germany, and the Nondestructive Testing Centre in Harwell, England.

Mainstream Technology, with Limitations

Crack inspection of pipelines using conventional ultrasonic shear wave technology has become the standard for ILI of liquid pipelines. These tools have proven very successful detection of various types of cracks or crack-like anomalies. Because most cracks or crack-like defects in pipelines are axially oriented, first-generation inspection tools were developed for axial crack inspection. In comparison to circumferential cracks, axial cracking shows a significant threat to the pipeline due to hoop stress. Cracks, crack-like anomalies, or linear anomalies can appear in the base material or in the longitudinal weld. The latter is the greatest threat because this is the weakest area in the pipeline. Axial anomalies in the long seam have different causes, such as fatigue and manufacturing anomalies.

First-Generation UT Tools

Ultrasonic tools for inline inspection first appeared in the early 1980s. The purpose of these tools was the detection and sizing of metal loss. Crack inspection tools first appeared in the mid-1990s. The major advantage of ultrasonic tools is their ability to provide quantitative measurements of the pipe wall inspected, unlike earlier-technology magnetic flux leakage (MFL) tools. Experience has also proven that ultrasonic technology provides a reliable means to detect and accurately size cracks and crack-like anomalies in pipelines.

Absolute depth sizing for crack inspections was introduced around 2013, with the limitation that features greater than 4 mm (0.16 in) could not be sized. Technology improvements, especially the introduction of high-resolution tools, have allowed new methodologies to remove this limitation and size the depth of the features for the full range.

High-resolution inspection tool – EVO 1.0 UCx

High-Resolution Tools

Advances in several areas have driven the evolution of high-resolution tools. Among these advances are sensor size and sensitivity, which enables increased density, and the ability to acquire, store, and process much greater amounts of data. The availability and quality of this data have in turn driven improvements in analysis. The result is a large increase in accuracy.

In general, the resolution of an ultrasonic ILI tool is produced by four components:

- Axial resolution is the axial distance between two consecutive measurements of the ultrasonic sensors.
- Circumferential resolution is the circumferential distance between two adjacent ultrasonic sensors. Both axial and circumferential resolution determine the scanning grid.
- Sampling frequency of analog-to-digital converter (ADC) determines the resolution of the time-of-flight measurement of ultrasonic indications as well as the maximum amplitude error of the peak amplitude measurement.
- Sampling depth of ADC determines the resolution of the amplitude measurement of ultrasonic indications. It also relates to the dynamic amplitude range that can be covered.

Previous-generation tools typically have a standard circumferential resolution of 10 mm (0.39 in). In comparison, current-generation, high-resolution tools have 5 mm (0.20 in) circumferential resolution. The resolution increase, provided by doubling the number of sensors, has two highly useful effects:

1) it reduces measurement dispersion by having more sensors scanning the same area, and

2) it increases the probability of having one sensor in the optimal position in relation to the feature.

Circumferential resolution	No. of features	Depth range
Standard	360	1 mm ... 5 mm with 1 mm steps
High resolution	2250	1 mm ... 5 mm with 1 mm steps

Loop test details from standard and high-resolution inspections

Tests have proven that the increase of circumferential resolution reduced dispersion of the measurement. Comparison between standard and high-resolution inspections was performed at NDT Global's advanced testing facility in Stutensee, Germany.During the comparison, a threshold of ±2 dB was established between the designed depth and the measured depth. Figure 1 displays the results from the standard resolution, where 0 dB on the X axis represents the amplitude expected to calculate the designed depth. Standard tools show 49% of the measurements within ±2 dB.

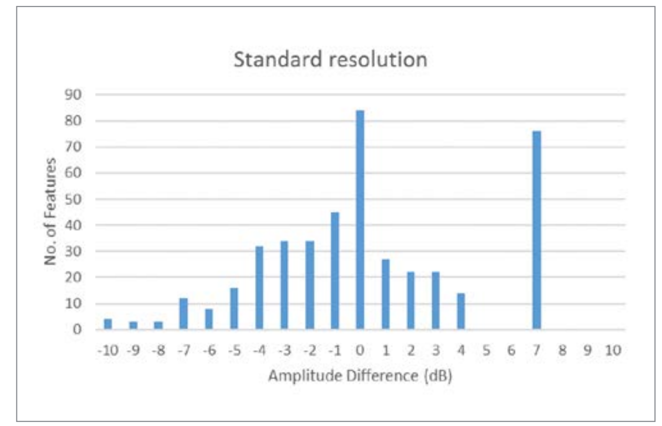

Figure 1 – Standard resolution loop test results, 49% within ±2 dB

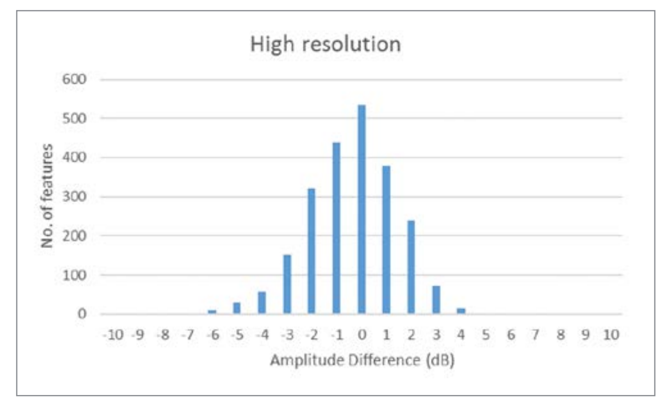

Figure 2 – High-resolution loop test results, 85% within ±2 dB

Figure 2 is the result of high-resolution loop tests. The chart shows a homogeneous bell curve where 85% of the results are within the established threshold of ±2 dB. Standard resolution required a threshold of ±6 dB to achieve 80%. This measurement dispersion or increased measurement precision translates into tighter/smaller depth tool tolerances.

Scanning Grid

Figure. 3 shows the scanning grid for the standard NDT Global crack inspection tool (Figure. 3a) and the company's scanning grid that can be achieved with high-resolution tool (Figure. 3b). Here, the scanning grid is defined by the axial resolution and the circumferential resolution. For high-resolution inspection, the ultrasonic shot density is higher by a factor of four, which increases the data volume by the same factor. The improvement of the circumferential resolution can also be recognized from the increased sensor density (Figure. 3c, 3d).

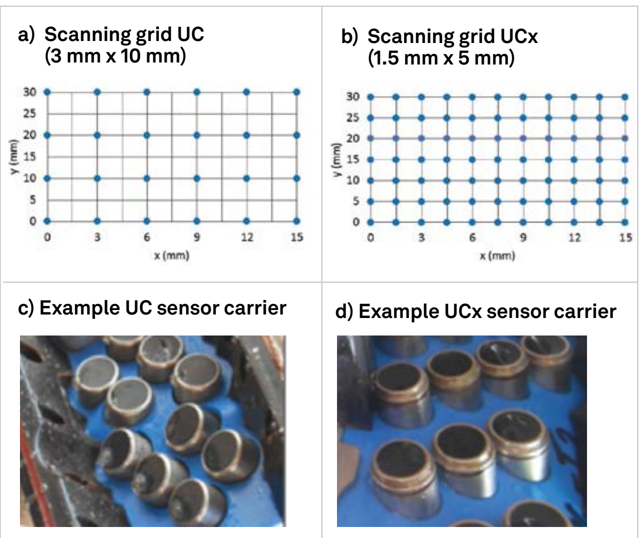

Figure 3 – Scanning grid for UC and UCx and corresponding examples of sensor carriers

New Depth-sizing Methodology

Enhanced Sizing (ES) is a new depth-sizing methodology for cracks. It is based on additional information extracted from the data recorded by the tool. There are two main benefits from ES:

1) it removes the uncertainty for features > 4 mm (0.08 in), meaning the depth sizing in absolute values is for the entire wall thickness range; and

2) for the depth range between 2 and 4 mm (0.08 in and 0.16 in), ES provides a confirmation of the pulse-echo (PE) depth. Enhanced Sizing methodology is ideal for high-resolution inspections up to a maximum wall thickness of 13.0 mm (0.51 in).

> **A new depth-sizing algorithm was developed for this methodology, which includes input from conventional pulse-echo and the ICE used for Enhanced Sizing**

Indirect Crack Echo

High-resolution is the foundation of Enhanced Sizing methodology, which removes the maximum depth-sizing capabilities of 4 mm (0.08 in) that limits conventional pulse-echo methods. This methodology also provides a depth confirmation between 2 to 4 mm (0.08 in to 0.16 in). The methodology is based on the indirect crack echo (ICE), which increases proportionally to the depth of the feature.

This echo follows a different path than the corner echo (CE) used for PE. ICE is recorded by the tool depending on the position of the sensor relative to the feature. A new depth-sizing algorithm was developed for this methodology, which includes input from conventional pulse-echo and the ICE used for Enhanced Sizing. The ICE amplitude is proportional to the depth of the crack.

The top side of Figure 4 describes the amplitude from the CE. Once it reaches a depth of 4 mm (0.16 in), the signal is saturated and it is not possible to calculate a depth beyond that point. The bottom side of Figure 4 describes the ICE amplitude: the deeper the feature, the higher the amplitude from the signal. ICE continues increasing for the full wall thickness. The sizing algorithm considers this additional information for the depth calculation. The outcome from the algorithm is the reported depth.

By exploiting the amplitude of the ICE signal, the range of crack depth sizing can be extended over the full wall thickness (WT) where the covered WT range

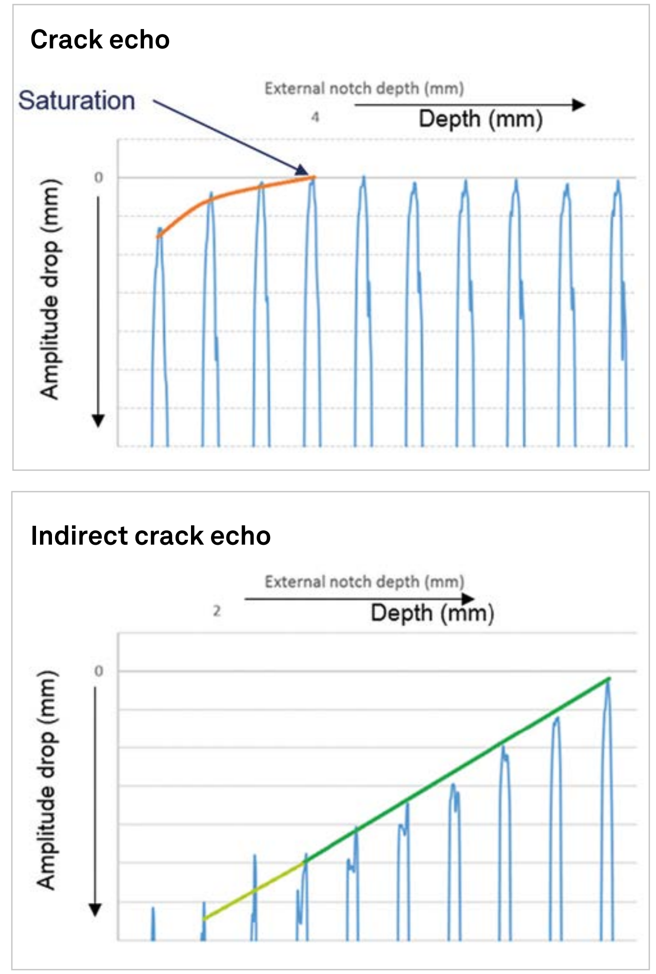

Figure 4 – CE amplitude response vs increasing feature depth (top) and ICE amplitude response vs increasing feature depth (bottom)

mainly depends on the probe diameter. This new approach was verified by modeling studies as well as comprehensive experimental work including a variety of different pipe diameters and wall thicknesses. As a result, a tolerance of ±1.2 mm (0.05 in) at a certainty of 80% was determined for features with depths ≥ 4 mm (0.08 in) (Figure. 5b). Compared to the old sizing specification (Figure. 5a), where the depth range is limited to the saturation depth of approximately 4 mm (0.08 in), the enhanced sizing approach represents a major step forward in the reliability of inline crack inspection.

Summary

The elimination of crack depth-sizing limits by ultrasonic inspection is a critically important advance in ILI inspection methodology. This technology brings a new level of accuracy to critical inspections, and should be strongly considered as a component of every pipeline integrity management program.

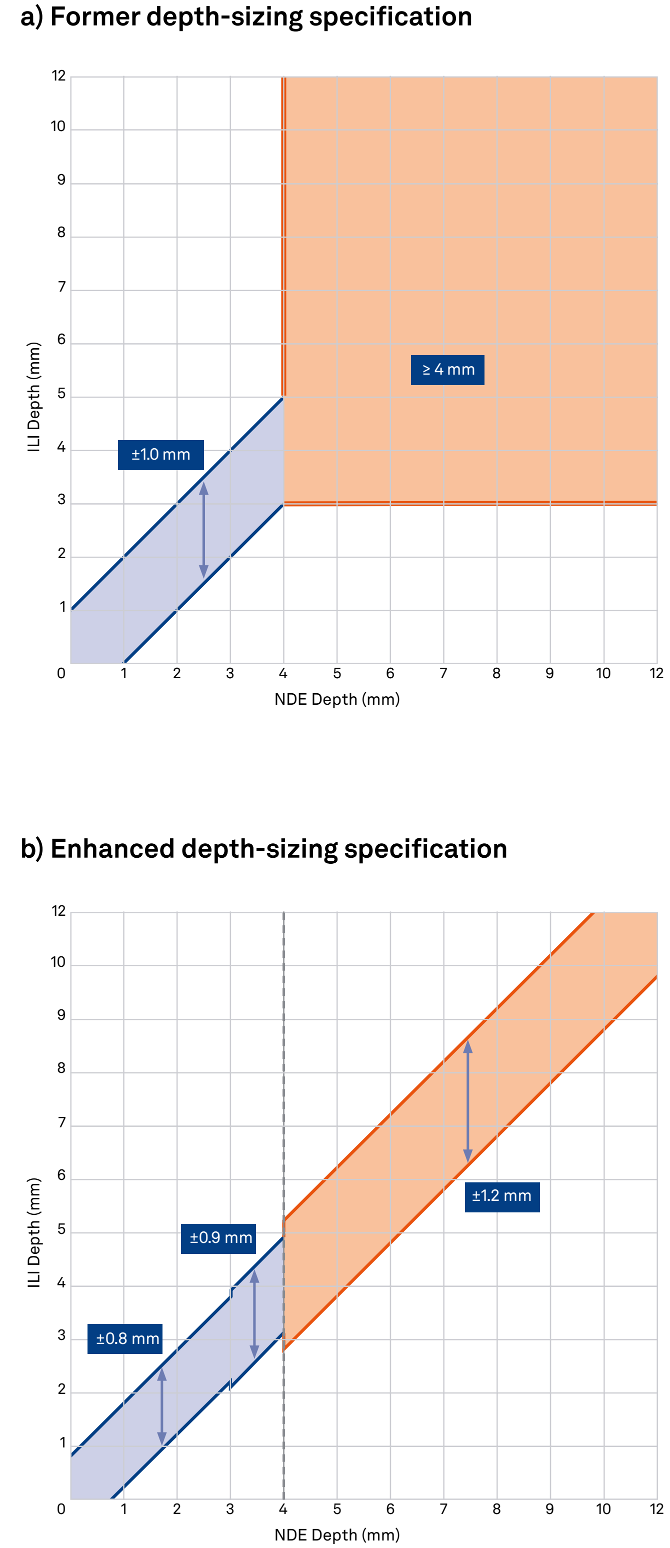

Figure 5 – Old (a) and new (b) specification range for crack-depth sizing

Axial Cracks
Circumferential Cracks
Metal Loss
Geometry Ovalities
Mapping

References

[1] National Science Foundation NDT Resource Center

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