

Portable Hand Held Crack Sizing Evolution to Phased Array

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Abstract. Stress corrosion cracking (SCC) is now recognized by pipeline operators worldwide as a significant threat to the safe and efficient operations of their systems. Onshore natural gas, oil and refined products line pipe steels have all been susceptible to this form of environmentally assisted cracking, which can develop as either near-neutral or high pH SCC. Over the years, the pipeline industry has developed several non-destructive examination (NDE) techniques to identify, document and evaluate the severity of an SCC indication, including magnetic particle inspection (MPI) and ultrasonic (UT) sizing.

While MPI can locate and assess the surface dimensions of the cracks within the SCC colony, measurements of the depth of the crack within the colony have not been as easily obtained in the field. To address the need for a field evaluation technique to quantitatively determine crack depth, researchers have been developing field based hand held ultrasonic sizing techniques to determine the actual depths of a crack. The UT-determined SCC crack depths are incorporated into engineering assessments and crack growth models (used in risk algorithms) potentially enabling operators to effectively address, manage and thus monitor this time-dependent threat. This presentation will discuss our experiences with UT crack sizing since the mid eighties, the techniques that are available in the industry, the limitations that still exist and the benefits of using UT to assess SCC crack depths.

Preliminary tests using phased arrays show promise. However, for small diameter and thin wall pipe, crack depth sizing has proven difficult when scanning from the outside surface. Under these conditions the phased array approach will provide excellent axial location and determination of the flaw ID or OD location.

Introduction

It is critical that technicians, company managers, engineering staff and the end customer understand why a specific technique is being applied and why it is superior to other options available. Eclipse Scientific Products provides all forms of NDT inspection services to numerous industries: consequently our exposure to a wide range of applications and defect styles has resulted in our ultrasonic probe selection growing to include most of the available options on the market. Both laboratory and field kits include dual element units such as the VSY™ (30-70-70), TRL™ series, FAST™, SLIC™ (various styles), creeping, and custom-made wedges with various probes adapted and optimized for the application. Conventional single element probes available in our kits include internally focused units and standard units with a wide range of frequencies and sizes to allow selection based on targeting optimized beam size, resolution and sensitivity. Phased Array (PA) equipment now follows the same template, with a wide range of wedges and probes included with each field kit. The PA flexibility for enabling a range of angles to be selected has changed some of the requirements for wedges but specially contoured wedges still need to be considered.

Crack Sizing Fundamentals

Crack sizing needs to be approached based on several categories founded on the defect location and the inspection access. Items that need to be considered when selecting the probe and approach include:

- Crack location, and other defects associated with the material or process
- Material properties, grain structure and attenuation
- Physical configurations including thickness, radius, and geometrical considerations

Following a series of logical steps to define the application will ensure appropriate selection of the tools needed. In some cases it may simply come down to the realization that ultrasonic inspection is not suitable and another NDT discipline should be selected.

For this presentation we will narrow our discussion specifically to those indications located on the same side as the access and with SCC body cracks as our discussion example. Toe cracks (cracking at the edge/toe of the weld) and SCC located within corrosion regions will need to be addressed as separate inspection approaches requiring some very specific probe and inspection configurations.

Future phased array developments will address the toe crack and in-corrosion SCC sizing requirements. The compound angle dual element Fusion Line Detection and Sizing (FLDS) probe was developed to detect both crack orientation and determine crack depth. However this requires an automated acquisition system displaying the signals in A, B and C-scan displays in order for the operator to perform post-processing and detailed sizing. In-corrosion SCC sizing requirements historically have been addressed by a lens approach but also need to have options for automation and post-processing along with the novel approaches required to couple the ultrasound to the line pipe.

Early Options For Near Side Sizing of SCC

Single element and some dual element techniques, two element dual, or tandem probe pitch catch configurations, have been applied to same side or near side crack/linear indication sizing. The use of multi-mode and diffraction options have been applied but are often based on technologies not optimized for the carbon steel pipeline application. In some cases efforts to distinguish the corner trap and the associated mode converted signal, generated from the crack tip, provide reasonable results, based on the viewing of the time-of-flight measurement values. The obvious limitations of amplitude based approaches preclude this option from being considered.

For same side sizing of SCC in pipelines we carry our own line of multi-mode probes optimized for the application. The Near Side Detection and Sizing (NSDS) probes resulted from our experience in the field. Eclipse required a design for the customers' particular requirements, specifically carbon steel line pipe ranging in wall thickness from 4mm to 25mm. The result is a line of probes designed for measuring the crack from the same side as its initiation and indifferent to wall thickness. Our goal was to eliminate as many of the variables as possible that can negatively affect the accuracy of crack sizing. Our customers needed to have very accurate results in a timely fashion to allow mitigation to take place almost immediately. This sizing approach is based upon accurately measuring the time-of-flight of the signals radiating from the crack tip. As noted by numerous authors the only real option for crack sizing is the use of some form of high accuracy time-of-flight measurement technique.

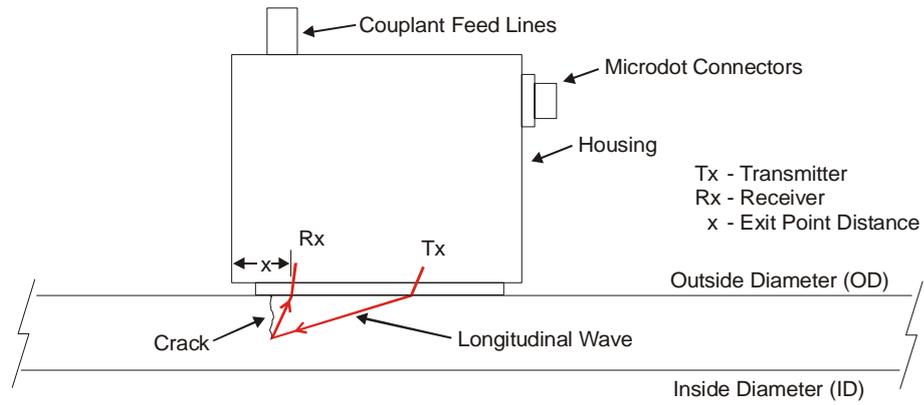


Figure 1 NSDS Probe Principles

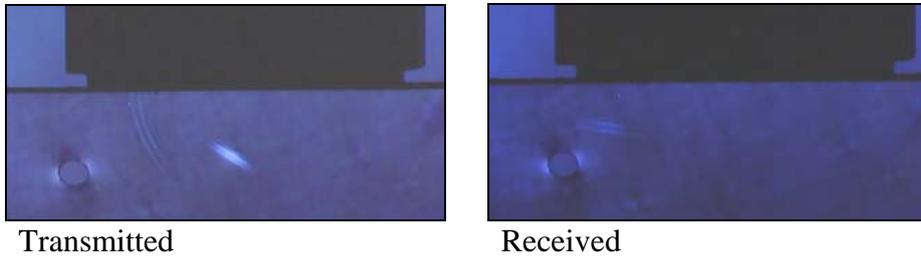


Figure 2 PhotoElastic Images of Transmitted and Received Signals (NSDS)

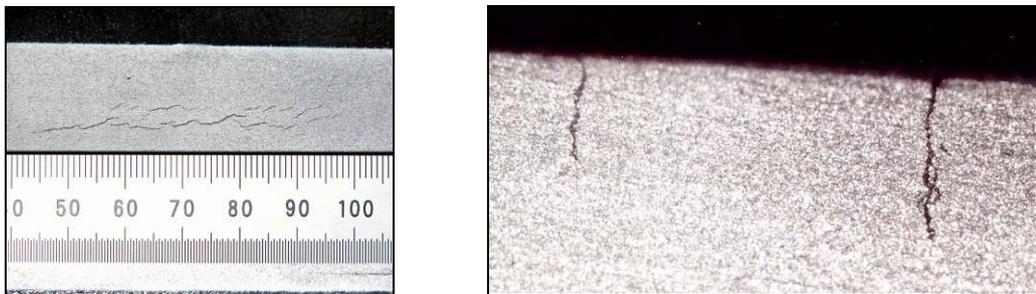


Figure 3 Typical Body SCC Example

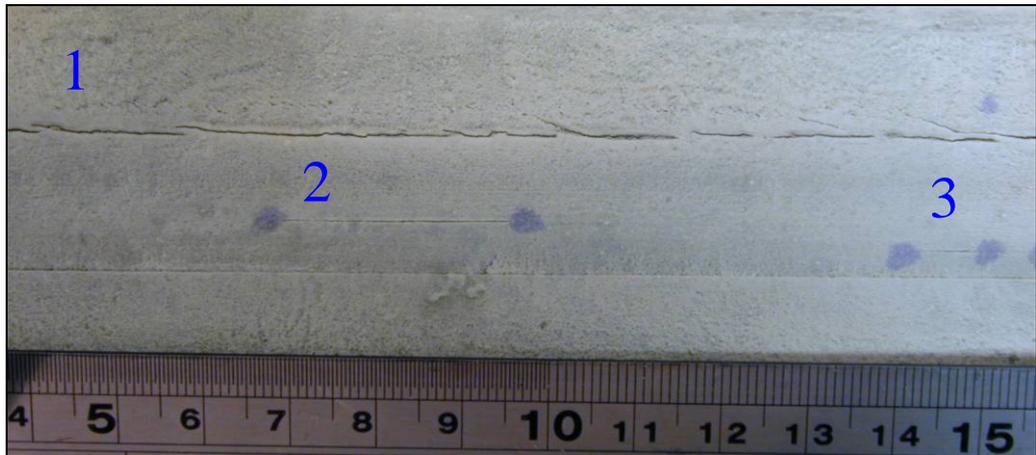


Figure 4 ERW Linear Indications 1) scarfing tool boundary 2) adjacent to weld 3) centre line

Phased Array Ultrasonic Inspection

The use of ultrasonic phased arrays and eddy current arrays for detection and sizing of SCC shows great promise and is currently being applied to field inspections for ERW and other line pipe applications. Phased Array (PA) technology is currently changing how we perform ultrasonic inspections for several industries. Now commonly found in the field, these highly portable instruments collecting full waveform and position encoded data are providing new options. This new generation of instruments is also capable of numerous display options empowering the operator to make fast, accurate decisions with saved volumetric data available for post processing. Other PA features that now add to our ultrasonic ability include varied focus ranges and beam steering enabling selection of varied angles or even a swept angle range, all these are now performed with simple user input parameters being defined.

Phased Array Background

The two principle options for the ultrasonic phased array beam patterns are linear and sectorial. More complex beam patterns can be obtained but the portable equipment is most often restricted to these two forms. The beam steering is controlled by focal laws which are parameters which control the characteristics based on element size, number and time delays between element excitation and reception.

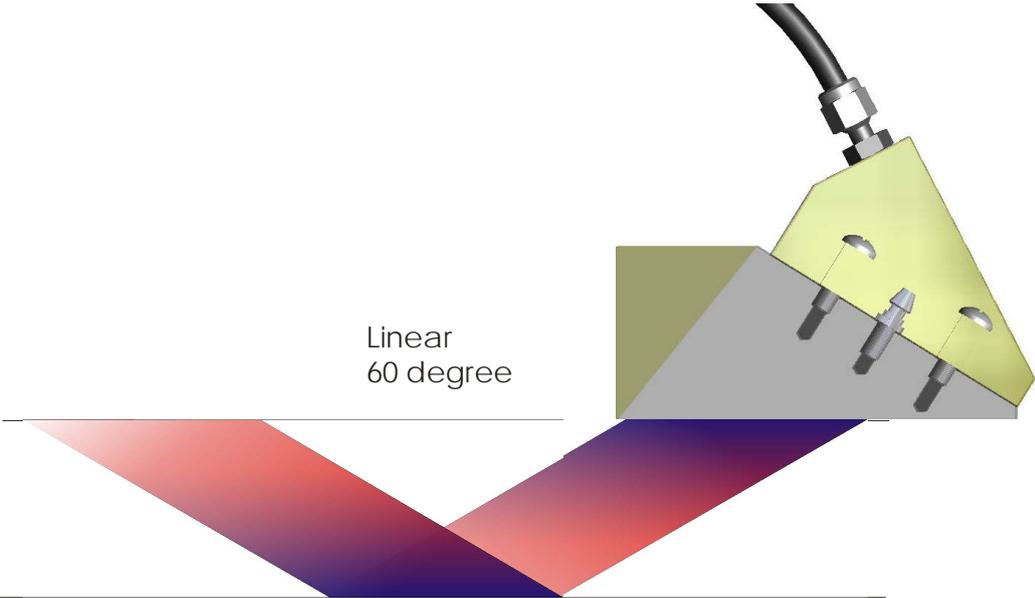


Figure 5 Linear PA Beam Pattern Example

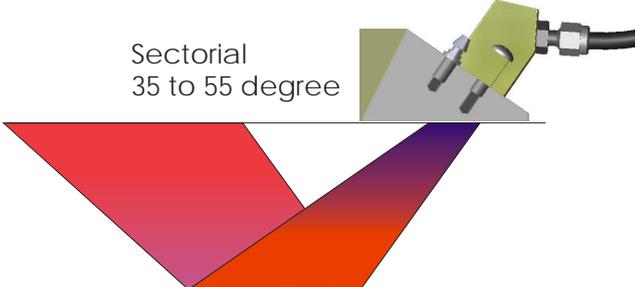


Figure 6 Sectorial PA Beam Pattern Example

Visualizing the sound and understanding the influence of the timing delay provides an understanding of how the wave is generated. The following figures show the effects of the time delay Huygens' Principle (interaction of the wave fronts).

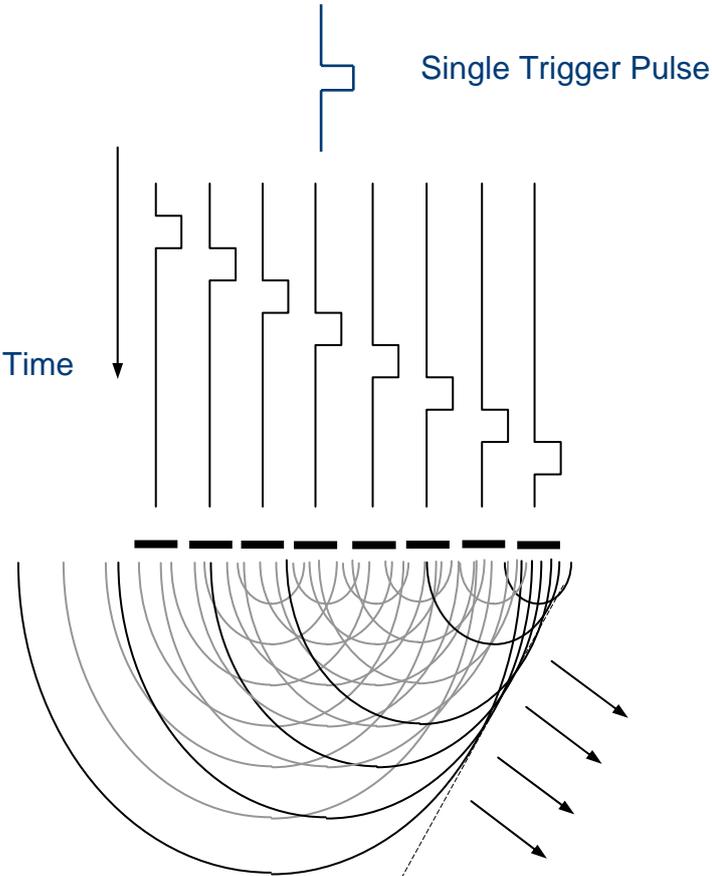


Figure 7 PA Time Delay Principles Generate/Control Beam Pattern Detail



Figure 8 PhotoElastic Image Showing Wave Front Components

Phased Array for ERW Inspection

Linear indications located at the fusion line or in the weld have been examined using phased array UT, providing a rapid method of defining location and indication extent. The use of both the sectorial technique and linear scan options provided excellent feedback for the operator.

Calibration for location and extent mapping was obtained from a sample of the pipe with introduced machined notches and side drilled holes. Shown is the calibration sample layout and the scan obtained with the single sectorial pass option.

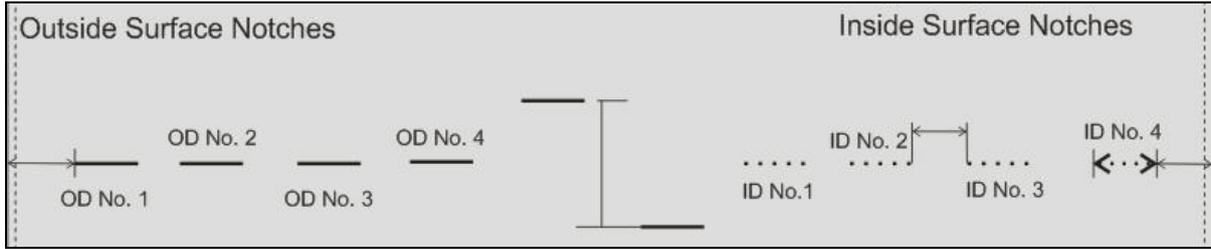


Figure 9 Typical Calibration Example for PA Application

Notch Identification	Notch Depth mm (Metric)	Notch Depth 0.00”(Imperial)
OD 1	0.5	0.020
OD 2	1	0.040
OD 3	2	0.080
OD 4	3	0.120
Outer limit A	1	0.040
Outer limit B	1	0.040
ID 1	0.5	0.020
ID 2	1	0.040
ID 3	2	0.080
ID 4	3	0.120

Table 1 Notch Depths for Typical ERW Calibration Sample

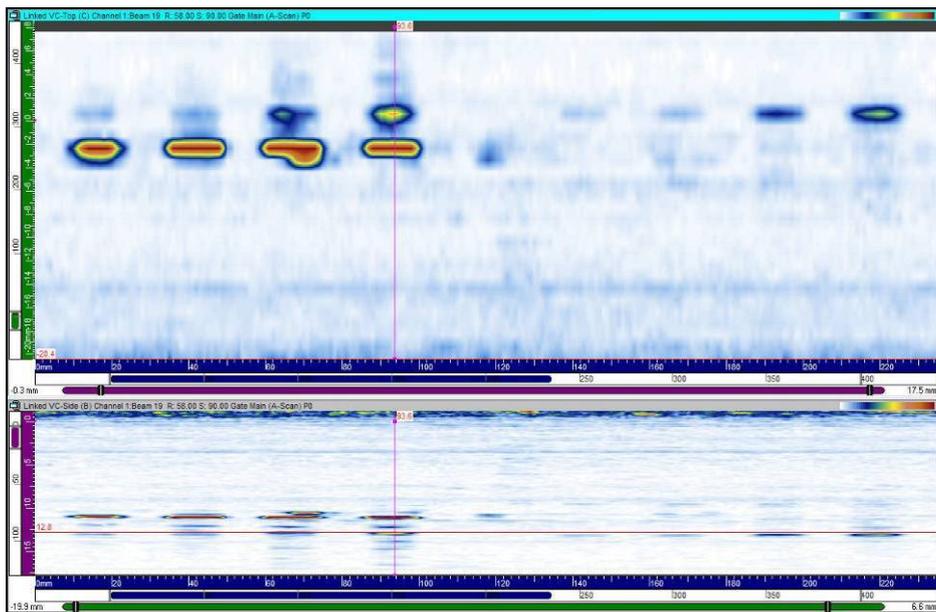


Figure 10 Outside Surface (OD) Notch Set Shown (top display is the plan view and lower is side view)

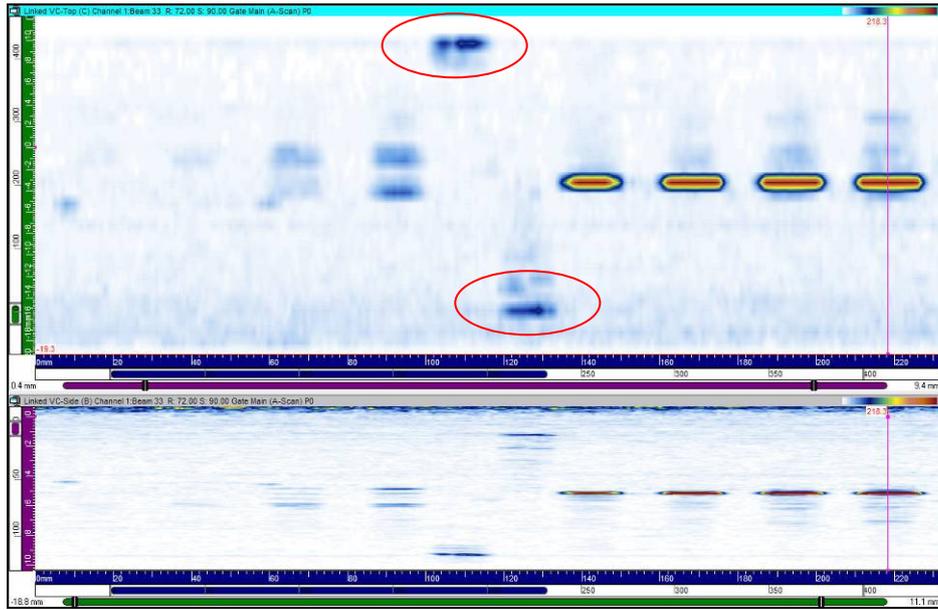


Figure 11 Inside Surface (ID) Notch Set Shown (red circles note the outer coverage notches)

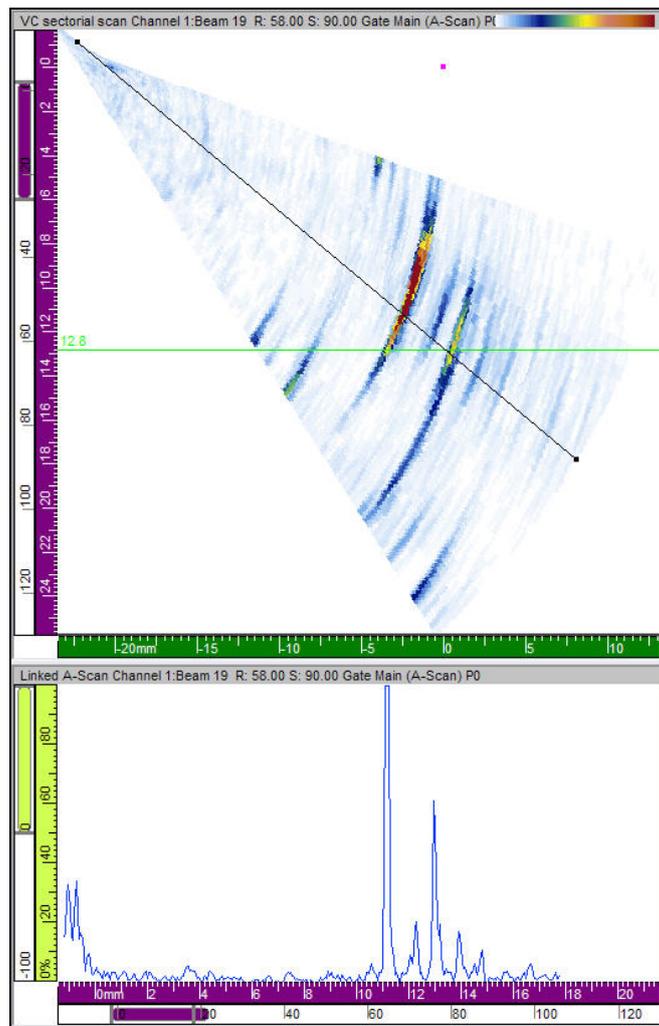


Figure 12 Example of S-scan and A-scan Displays

Phased Array SCC Sizing Solutions

The accurate sizing of the detected SCC based on a diffracted wave time-of-flight approach required trials to establish the optimum focal law configuration. It has been established that the benefits of the PA approach also include the ability to tune the array focal laws for sizing at varied depths. This potentially increases the accuracy for the defined depth range providing an additional improvement to the current practices.

Ray-trace software and an advanced focal law calculator were used to help define the initial configurations.

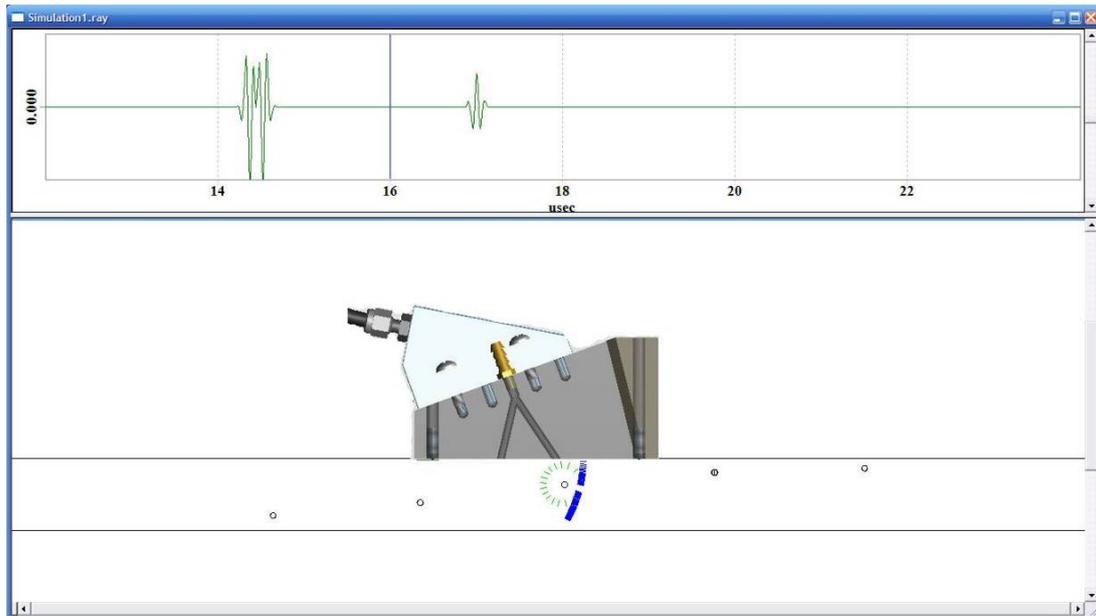


Figure 13 Ray Trace Mock-up

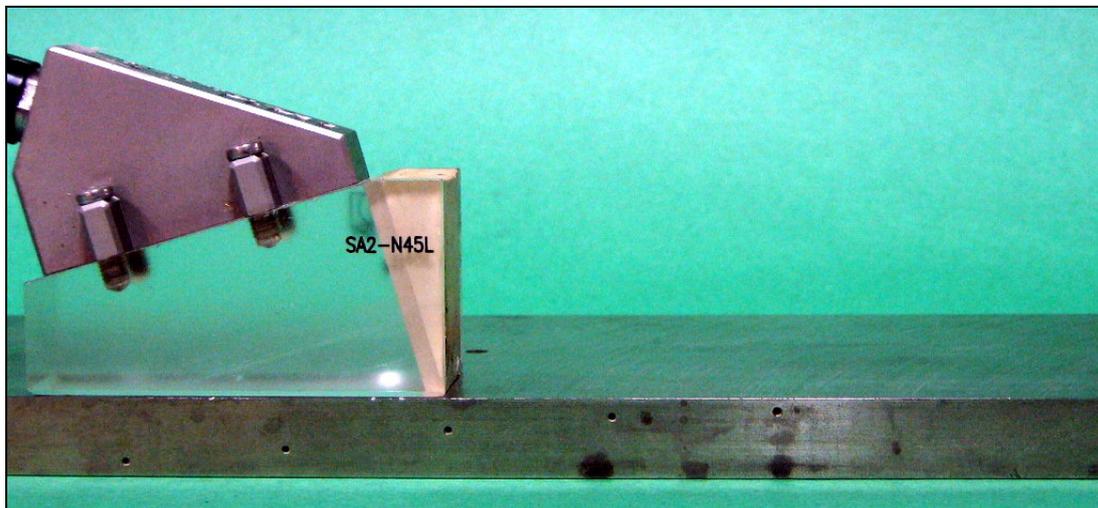


Figure 14 Side Drilled Hole (SDH) Reference Sample Used for Initial Trials

The use of the Side Drilled Holes (SDH) to provide a point source is viewed as the best option for calibrating the time-of-flight measurements. The Eclipse Thin Wall (ETW) calibration block shown also contains single and co-parallel notches to assist with other sizing approaches.

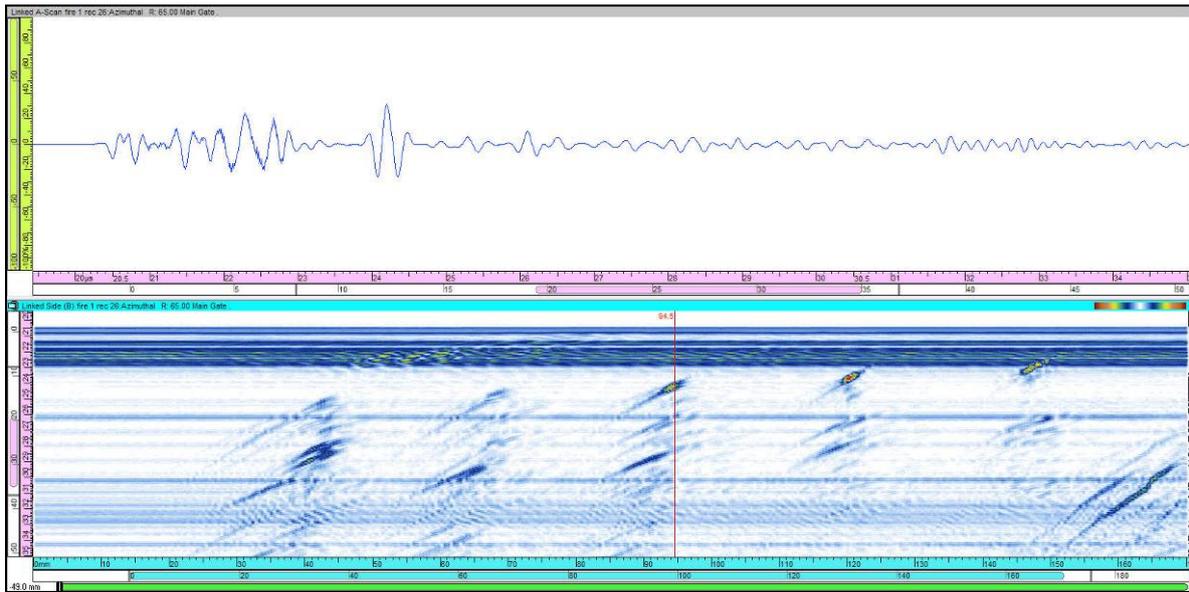


Figure 15 Transmitter and Receiver Separation Optimised for Shallow Hole Set

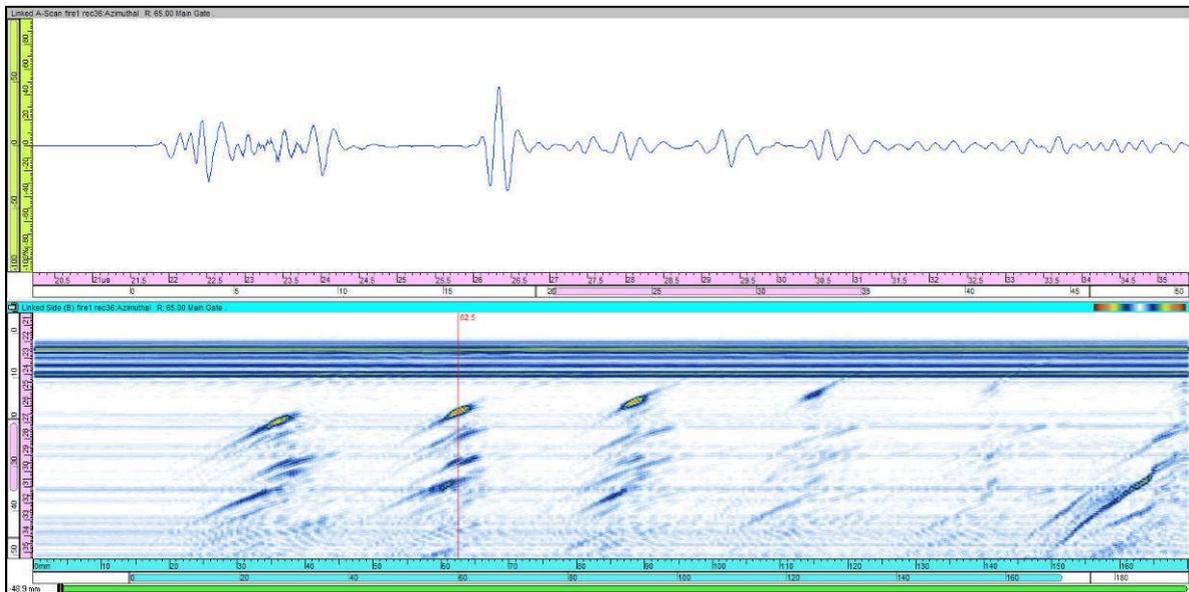


Figure 16 Transmitter and Receiver Separation Optimised for Deeper Hole Set

Initial findings have been excellent and clearly show the potential of the approach. The portability of the PA instrument, the numerous display options and the full recording of A-scan data all contribute to an effective solution. Benefits to the technician performing the inspection, and the end customer, include the potential of higher accuracy and increased confidence in calls made.

Objectives and Conclusions

At the time of writing, the objective was to finalise the format for SCC sizing by optimising the element frequency, dimensions and wedge details for the PA option. As part of on-going activities, we are developing set-up logic that permits operator input of basic parameters for focal laws and report generation.

Applying this technique to other crack sizing requirements such as mid-wall, in-clad or other applications should be considered. Toe cracks and in-corrosion applications will be our next activity and will be reported upon by the middle to end of 2006.

References

- [1] Hand Held Ultrasonic Sizing Of Stress Corrosion Cracking; Robert Ginzel (President) & James Pennie Eclipse Scientific Products Inc. and Jim Marr (Director) Marr Associates
- [2] PhotoElastic images provided by Materials Research Institute, Waterloo Ontario, Canada
- [3] PA SCC Sizing Solution scans and Focal Laws provided by Philippe Cyr of Olympus NDT.