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HAND HELD ULTRASONIC SIZING OF STRESS CORROSION CRACKING

Jim Marr, (Director)Marr Associates
Robert Ginzel (President), **James Pennie** ,Eclipse Scientific Products Inc.

ABSTRACT

Stress corrosion cracking (SCC) is now globally recognized by pipeline operators as a significant threat to the safe and efficient operation 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 low 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 a 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 indication, measurements of crack depth within the colony have not been as easily obtained under field conditions. Researchers have been developing field based hand held ultrasonic (UT) sizing techniques to determine the actual crack depths. 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, monitor and thus manage this time dependent threat. This paper will discuss our experiences since the mid 1980's with UT crack sizing, the techniques that are available in the industry, the limitations that still exist, and the benefits of using a new UT assessment transducer to assess SCC crack depths.

INTRODUCTION

Sizing cracks has been, and continues to be, a hotly debated topic within the Non Destructive Examination (NDE) industry. There are many sizing methods presently available and emerging technologies will continue to advance the accuracy and reliability of crack sizing. Limitations due to erroneous application, operator skill and experience levels, can affect the usefulness and the success rate of certain techniques presently available in the market place. It is critical that technicians, company managers, engineering staff and the end customer understand the limitations of a specific UT technique, its reliability, and the comparative options that are available, to address a potential SCC integrity threat. The primary purpose of this paper is to review existing UT techniques and introduce to the industry the NSDS probes used to size external SCC on line pipe steels.

NOMENCLATURE

Stress Corrosion Cracking (SCC) Cracking induced from the combined influence of tensile stress, susceptible steel and a corrosive environment.

Diffraction When an ultrasound wave is incident at a linear discontinuity such as a crack, diffraction takes place at its extremities (i.e. crack tip). The study of this phenomenon has led to the development and use of time of flight diffraction methods for crack sizing.

Time of Flight Diffraction (TOFD - Delta Technique) This technique uses the diffracted signals from the crack extremities as compared to conventional methods of relying on the amount of energy reflected by the extremities of the discontinuities. The transducer elements are positioned either in the same housing or separate housings but are angled towards each other.

Bimodal or Multimode Two or more modes (i.e. longitudinal and/or shear wave) transmitted into the material at the same time, each mode being used for a specific purpose.

A-Scan Data display in which the received pulse amplitude is represented as a displacement along one axis (usually the y-axis) and the travel time of the ultrasonic pulse is represented as a displacement along the other axis (usually the x-axis).

C-Scan A two dimensional graphical presentation in which the discontinuity echoes are displayed in a plan view on the test surface.

B-Scan A two dimensional graphical presentation in rectangular coordinates, in which the travel time of an ultrasonic pulse is represented as a displacement along one axis, and transducer movement is represented as a displacement along the other axis.

Dual Transducer A method of UT that uses two transducers, one transmitting and the other receiving, often referred to as *pitch and catch*.

Tandem Configuration Tandem configuration refers to a transducer setup (transmit and receive, one ahead of the other) with the elements facing the same direction.

Signal to Noise Ratio The ratio of desired sound to undesired background noise, measured in decibels (dB)

BACKGROUND EXPERIENCES

Requirements for SCC sizing have changed over the years from performing a simple visual assessment of the SCC colony to using complex phase array UT based systems. Determining crack depth to address severity of the colony was initially based on length to depth ratios. These ratios were not consistent and were highly variable between both individual colonies and the two types of SCC (i.e. low and high pH SCC). The industry required quantitative information about flaw size to serve as an input to fitness for service, fitness for purpose and/or engineering critical assessments.

The ease of measurement capability and reliability of UT results effectively enabled the engineer to determine the remaining life of a defect. These UT based measurements assisted in establishing critical crack lengths and depths to assist in determining the predicated time to failure of defects based on a quantitative, not qualitative analysis.

Concurrent to UT, several other NDE developmental technologies are becoming available, such as Eddy Current (ET) to measure crack severity. Arguably, at this point in time UT provides the most mature, robust and reliable technique to obtain crack depth measurements given the field conditions of most onshore pipelines.

CONSIDERATIONS

Items that should be considered when selecting the transducer and subsequent measurement approach include:

- Crack location and other potential defects (i.e. external corrosion) associated with the material or manufacturing process
- Material properties, grain structure and signal attenuation
- Pipe physical configurations including thickness, radius, and geometrical considerations

All technicians should be following an analytical process that addresses the proposed application and applicable UT tools. In some cases UT inspection may not be suitable and another more appropriate NDE discipline should be selected.

AVAILABLE SIZING TECHNOLOGIES

Utilizing UT techniques, crack depth is determined through the analysis of the waves reflected, transmitted or diffracted by the crack. It should be recognized that some basic UT techniques are used to qualify general defect characteristics or to convey that a defect is actually present in the material being inspected.

Until 1995, no transducers were specifically developed for the detection and sizing of OD breaking SCC. The primary categories of transducers and techniques utilized for ultrasonic crack detection and sizing techniques are briefly discussed below:

A) Conventional Ultrasonic Transducers (using the Amplitude Drop Technique)

Conventional ultrasonic transducers are commonly referred to as shear, unfocused and focused probes.

Conventional probes in conjunction with newer versions of ultrasonic instruments can be very capable of measuring some orientations of SCC or SCC like colonies, but cannot be effectively used in all circumstances. Ultimately the major problem using these traditional tools is in isolating specific cracks for sizing. This is due to the close proximity of individual cracks relative to each other within the colony.

B) Amplitude Comparison

An amplitude comparison technique is probably the oldest known UT measurement method and is applicable in certain situations. This technique usually involves the analysis of defect echo amplitudes to echo amplitudes from known reflectors from calibration blocks or reference pieces.

When the defect dimensions are less than the beam dimensions (see Figure 1), lateral probe movement from a maximum amplitude results in immediate reduction of signal amplitude. Importantly, the probe displacement is more a result of beam dimension than defect dimension. This is more pronounced as the ratio of beam width to defect width increases.

Typically the length of an SCC colony is determined by a visual technique, such as Magnetic Particle Inspection (MPI), and can be verified using a UT amplitude drop method provided that the indication is wider than beam spread. The vertical extent of the crack is not as easily obtained. When determining the vertical extent of a crack, the beam spread and amplitude of the corner reflector can significantly exaggerate the depth of the crack.

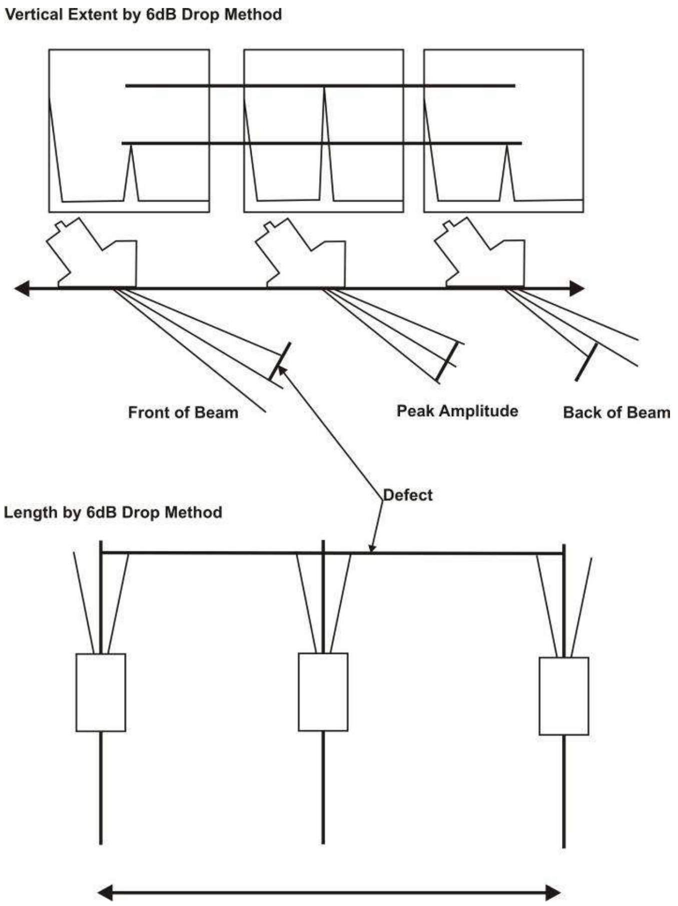

Figure 1: Amplitude Comparison -

C) Multibeam and Multimode Transducer Techniques

Usually there is a large uncertainty in crack depth measurements when utilizing the amplitude drop technique (see section A). A series of multibeam and multimode transducers were developed and have demonstrated an improved performance in the sizing of intergranular stress corrosion cracks (i.e. also known as high pH SCC) using time of flight measurements. The multibeam and multimode transducers combine the capabilities of shear and longitudinal wave transducers into a single search and sizing unit. These transducers capitalize on the multiple interactions of the transmitted shear and longitudinal waves with the crack face and its extremities.

When applied to SCC, this technique is identified as “same side sizing” of cracks. The transducer results are influenced by both wall thickness and pipe curvature. These types of transducers were generally designed and suited to the detection and sizing of ID breaking, mid-wall, or very deep cracks.

D) High Angle Dual Element Transducer Techniques

Another technique is the use of dual element transducers with a range of known configurations such as dual (side by side) and tandem (transmitting element ahead or behind receiver).

Dual element transducer configurations, those with transmitter and receiver side by side, are very common and date back to the very early ultrasonic inspection days in the 1940’s. Dual normal beam, shear and longitudinal angled beam applications are all very popular within the NDE UT industry.

Figure 2 illustrates the high angle technique that essentially produces the same wave components as the creeping wave technique (see Figure 4) and can also employ the same transducers for the same application.

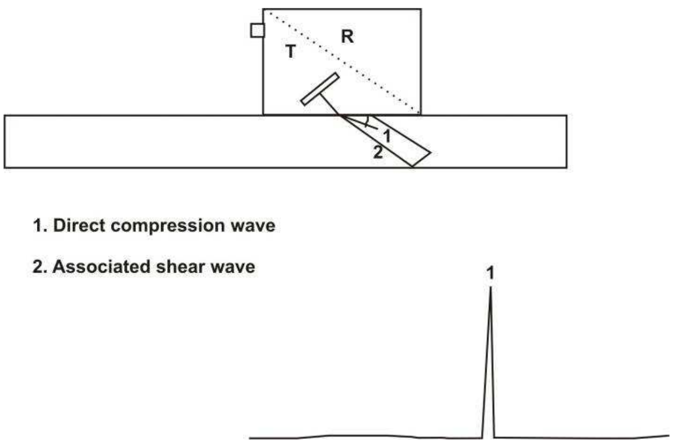

Figure 2: High Angle Longitudinal Wave Technique

Improvements in piezoelectric materials, such as the development of composite elements, have again improved signal to noise ratios and increased the effectiveness of this style of transducer. By optimizing the design, additional enhancements have been made to beam dimensions, pseudo focusing, and in some cases the ability to damp signals. The option to tighten or improve the beam dimension in combination with reduced number of signal cycles has improved the performance of this technique for certain applications.

A recent application of the dual element high angle technique was introduced to the industry as the Flaw Analysis and Sizing Transducer (FAST) technique.

The transducers used in the application of the FAST technique were initially designed to detect and provide depth approximations of a defect in stainless steel components from the inside diameter or opposite surface from which the work was being performed. The presence of the shear wave is of concern during calibration and sizing. Mode conversion of this signal may lead to misinterpretation, and false signals could potentially be recorded. Limited operator training and overall experience can be a major concern when using this technique.

E) Bi-Modal Technique

Bimodal methods typically employ the tandem configuration (one element positioned in front of the other and angled away from the other: see Figure 3). This method is normally used for sizing cracks ranging in depth from 30-70% through wall and the measurement usually originates from the ID.

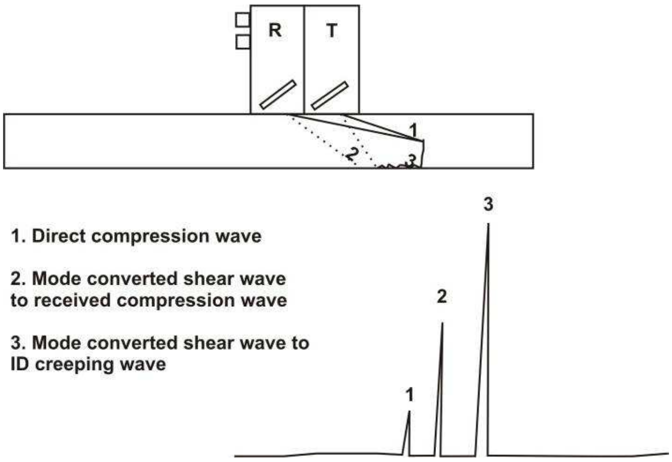

Figure 3: Bi-Modal Tandem Configuration

F) Creeping & Guided Wave Techniques

These techniques are normally used as “indicators” to detect the presence of a defect and convey a general awareness of the location of a defect to the technician (i.e. top third of material, middle or opposite wall). Dual shear and dual longitudinal transducers, including dual multimode units such as the creeping wave probes (see Figure 4), have become popular for several reasons. The popular 30-70-70 (VSY) transducer was originally intended for stainless steel applications, but while it can be applied to carbon steel with some success, it should also be classed as a preliminary detection and/or indicator approach.

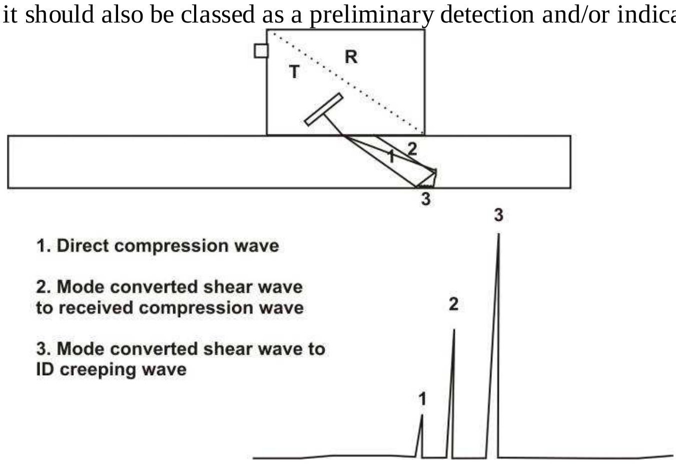

Figure 4: Typical Creeping Wave Transducer with Signal components

Crack depths can occur at all levels within the pipe material and can be at almost any orientation. They also freely pass through boundary lines, such as heat affected zones, or even turn to follow a construction or metallurgical boundary.

This technique would not be normally considered for SCC sizing based on our experiences. It has been included because it is a recognized technique and is mentioned in the literature as a crack sizing technique.

G) Diffraction Techniques

There are two known diffraction techniques used within the industry, identified as forward and back diffraction. Diffraction techniques utilize the principles of time of flight diffraction (TOFD). Both techniques are described below. Figure 5 schematically illustrates a forward diffraction technique.

G.1) Forward diffraction

TOFD is a high speed volumetric technique that can provide location and vertical extent of a defect, although traditional configurations are known to be weak at detection and sizing of near surface defects, such as SCC located on the transducer side. Various techniques can be applied to improve inspection in this specific region, including a double skip and "W" approach.

The TOFD technique continues to gain recognition and improvements will continue for both transducers and analysis techniques. This approach has several characteristics that make it very user friendly although technician experience is still a significant factor in its success.

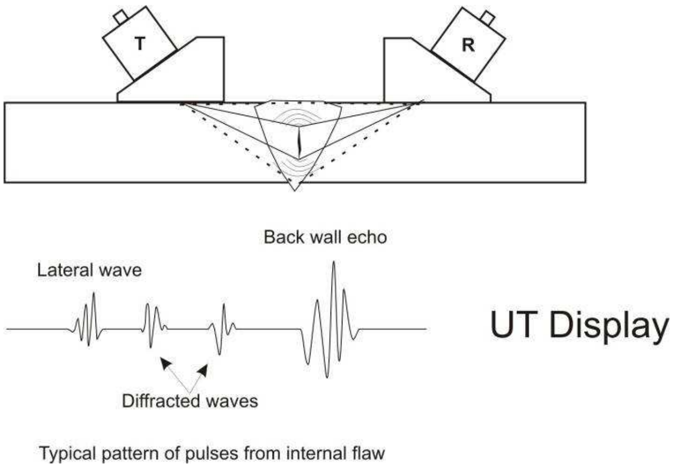

Figure 5: TOFD (Delta) Transducer Arrangement

G.2 Back Diffraction

When using this technique, the transmitter and receiver are positioned ahead or behind each other. This positioning can produce a wide range of options related to the detection and sizing of defects. These options include using similar angles for the transmitter and receiver, or varied transducer angles.

In some cases, combinations are used that include multimode options such as coexisting longitudinal and shear waves. Signals can be detected by the placement of the receiver to catch, direct or skip signals, or if seeking only one specific signal mode, by placement of the receiver directly above the defect. Actual signal characteristics would be further divided into the recognized conventional shear and longitudinal waves, with bi-modal recognized as the combination of these two wave modes.

G.3 Satellite Pulse Technique (SPT)

This method is used for sizing shallow cracks ranging from approximately 5-35% through wall. This method utilizes the arrival time of the signal from the tip of the crack to determine crack depth. To simplify this process the instrument is calibrated where each screen division corresponds to a particular flaw depth.

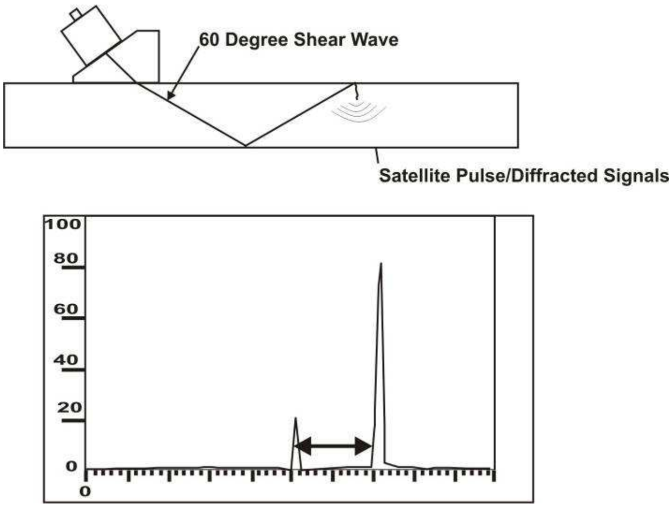

Figure 6: Illustration of Satellite Pulse Techniques SPT

The SPT technique uses back diffraction. The 60 degree shear wave is targeted at the corner trap and this causes the crack signal to oscillate. The oscillation travels down the crack and induces a diffracted signal in the test piece. This diffracted signal is received by the transducer and displayed on the instrument as arriving earlier in time than the corner trap signal. Other back diffraction techniques designed to collect the diffracted signals may use a separate receiver element to collect the diffracted signals (i.e. NSDS transducer).

FIELD EXPERIENCES AND SCC SIZING

History

Utilizing the best technology for the period, and through concurrent field and bench top testing, subsequent analysis and refinement has caused our inspection of SCC to become more reliable and consistent. Our experiences and access to sizing data, as well as pre and post mitigation of indications, has improved our confidence to a level where we are exclusively utilizing Near Side Detection and Sizing (NSDS) probes.

The NSDS probe is a transducer that has a similar design to some of the other tandem configured transducer types mentioned earlier.

Sigma and SLIC are two similar tandem configurations. The difference, based on our experience using the NSDS probe, is the signal strength and the position and angles of the transmission and receiving elements of the transducer. Most importantly, the NSDS was designed specifically for detection and sizing of both linear and SCC indications on line pipe steels (see Figures 7, 8, and 9).

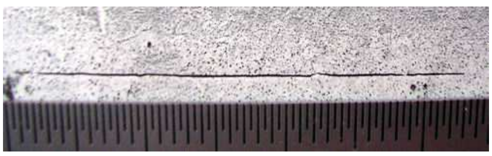

Figure 7: Linear Indication Along Electrical Resistance Weld (ERW)

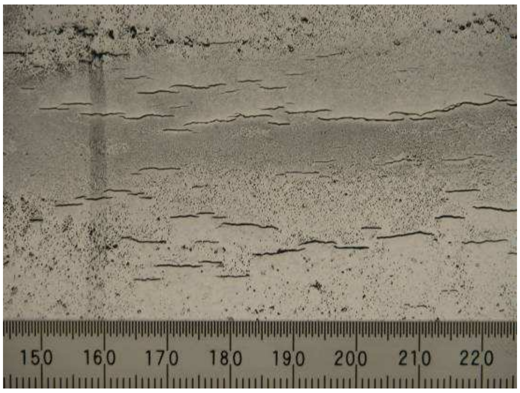

Figure 8: Typical Low pH SCC Colony

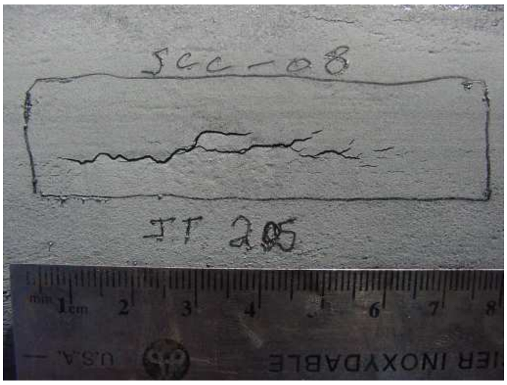

Figure 9: Typical High pH SCC Colony

NEAR SIDE DETECTION AND SIZING TRANSDUCER (NSDS)

NSDS Technology and Design

The NSDS H-series transducer design utilizes two piezoelectric elements in a tandem configuration that enables a time of flight tip diffraction measurement to be obtained from an indication. Figure 10 illustrates the path traveled by the sound beam when it is used to same side size crack-like defects. To create this beam path, the transmitting element (Tx) is positioned at the rear of the transducer and set at an angle creating a near 70^o longitudinal wave. The receiving element (Rx), located at the front of the transducer, is positioned to receive signals at shallow angles (i.e. $<15^o$). The design allows the signal to be concentrated on the tip of an SCC indication resulting in a strong, clear response.

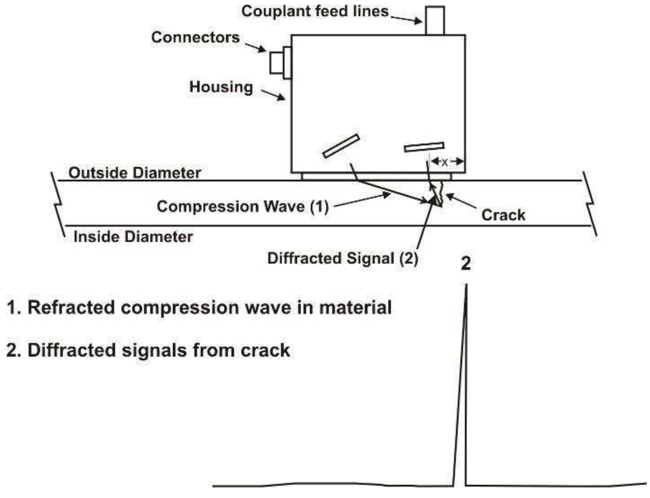

Figure 10: NSDS Transducer

As illustrated in Figure 10, the transducer must be positioned above the defect to allow recovery of the signal. The exit point of the returning signal, labeled as "x" in Figure 10, is located approximately 9mm back from the front of the transducer. The exact position of the exit point will vary depending on the defect depth being sized.

The NSDS H-series transducer is designed for same side sizing of surface breaking defects in carbon steel utilizing piezoelectric elements that provide an optimum response. Wedge design, piezoelectric element selection, and element separation are all configured to provide clean, concise signals with enhanced signal to noise ratios. The NSDS H-series transducers are capable of sizing defects as shallow as 0.5mm in material as thin as 4mm, or defects up to 15mm in depth for thicker materials. Defect sizing at even greater depths is also possible with alternative transducer designs.

The NSDS H-series transducers are designed to work with almost any UT instrument and can be used in a manual or automated inspection format. The NSDS H-series transducer is 38 by 26 by 40 mm (1.5 by 1.0 by 1.6") and includes 4-40 mounting holes located in the stainless steel housing, along with couplant lines for automated inspection formats (see Figure 11). When sizing with the NSDS transducer in a manual format an RF waveform presentation or phase specific presentation is recommended. For automated inspection formats, the collection of digitized waveform data is recommended with the option of monitoring the time of flight data and amplitude data.

Figure11: NSDS Transducer

The transducer was designed around arrival times (segregation of signals) and multiple inspection purposes (to detect and size internally generated SCC as well as other surface breaking indications). Sound waves returning from the other transducer modes arrive much further apart in time than those of the diffracted signal. This time separation can be as much as two microseconds. This allows for easy interpretation and fewer confusing signals from which to extract defect depth data.

Modified Applications of the NSDS Probe

SCC failures have been reported on pipeline diameters as low as 20 cm. It is also our experience that there are many more operators with smaller diameter lines that need to address the SCC threat. The Quest Sizing Stage (see Figure 12) was designed for accurate sizing of SCC indications on smaller diameter pipelines using the NSDS probe.

The sizing stage eliminates the need to contour the transducer, which then renders it useless for different pipe diameters. The stage approach utilizes a single transducer that can be used on all applicable pipe diameters, and only the lens contained within the stage is required to be changed.

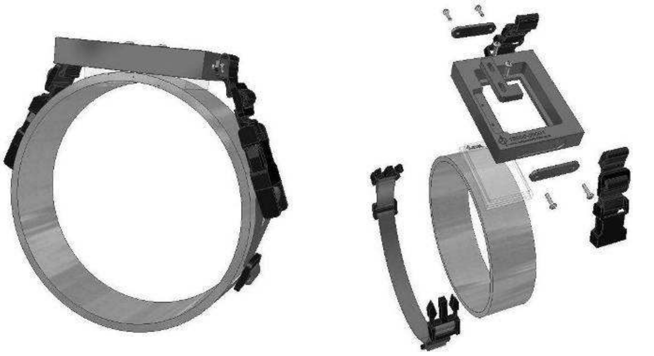

Figure 12: Quest Sizing Stage

For large diameter pipelines, the curvature becomes less necessary to achieve accurate and reliable results. Therefore a similar probe contour can be used for different diameters within a specific range. For example, probes that are not purposely contoured are successfully being used on 40 cm diameter lines and greater.

NSDS Calibration

Calibration is a critical component for most UT applications. Calibration of the NSDS probe can be performed in several ways. Based on our experiences, calibration is best performed utilizing a representative pipe material plate with side drilled holes (SDH) of varying depths.

This representative plate sample is utilized to generate a conversion chart relating signal time to corresponding depth using a B-scan. The following data (illustrated in Figure 13) was obtained from SDHs that had been introduced into a sample plate containing SCC (see Figure 14).

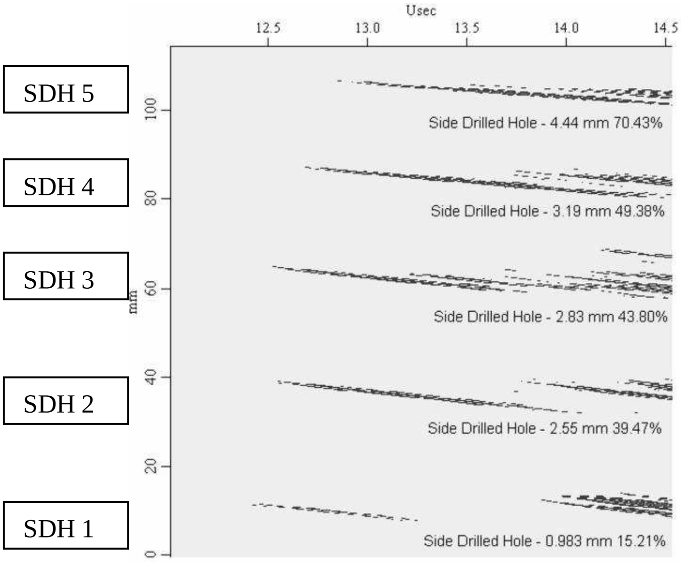

Figure 13: B-Scan of Calibration SDH

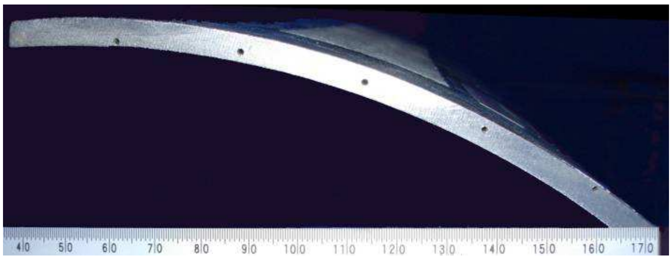

Figure 14: Calibration Sample with Side Drilled Holes

A semi-automated B-Scan of the SDHs in the plate sample was obtained using the NSDS transducer. From the B-Scan (see figure 13), time data was collected for each SDH and the data was tabulated (see Table 1) and graphed (see Figure 15) with the actual depths to generate a conversion calculation. The graph can also be used to obtain direct readings.

SDH ID	Time (μsec)	Actual Depth (mm)
1	12.590	0.983
2	12.924	2.55
3	13.076	2.83
4	13.302	3.50
5	13.798	4.55

Table 1: Data Extracted from B-Scan

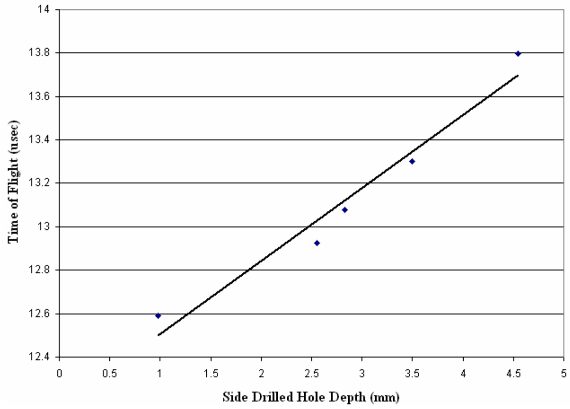

Figure 15: Time to Distance Conversion Chart

(From Table 1Data)

Interpretation Reliability (Field to Bench Top)

Over the past several years, this accurate and consistent sizing method has demonstrated excellent correlation between ultrasonic measurements and crack depths removed by buffing. In 1997 the CEPA (Canadian Energy Pipeline Association) published a Stress Corrosion Cracking Recommended Practices which includes Appendix 6 pertaining to the manual SCC sizing using this technique.

NSDS Sizing Results Compared to C-Scan Data

To address variable depths of the actual crack we have included a test result relating UT NSDS measurements to the appearance of the SCC colony. Table 2 identifies the x,y locations within the SCC colony where the NSDS C-Scan measurements were taken. The measurements taken from the C-Scan were recorded in μsec and converted to mm by calculating the material's longitudinal velocity. The NSDS measurements compare well with the opposite wall C-Scan data, with the NSDS overcalling the crack depths by 0.2mm (3.1%).

ID	Measurement Coordinate (Axial & Circumferential) Sample	C-Scan Data Time & Depth		NSDS Measurements (mm)
		μsec	mm	
A	40.8 /22.598	0.840	2.51	2.7
B	50 /22.598	0.664	1.99	2.2
C	59.77 /22.79	0.904	2.70	2.9

Table 2: NSDS Results Compared to C-Scan Data

The C-Scan (see Figure 16) data summarized in Table 2 was obtained using software and scanning the sample from the side opposite the indication in an immersion tank, with a copolymer transducer for improved resolution. Figure 16 illustrates a 1:1 comparison of the C-Scan display and the actual crack surface profile.

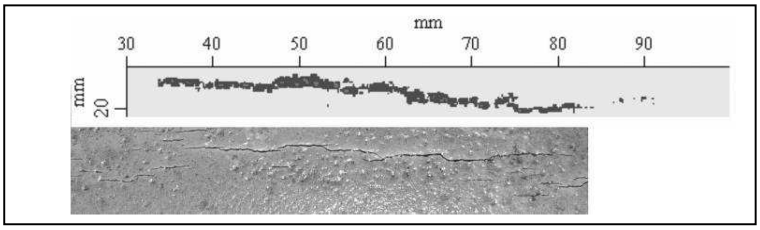

Figure 16: C-Scan of SCC indication

Future UT Developments Using NSDS Technology

Currently we are working on using the NSDS technology in combination with other instruments that will acquire and store data digitally, with the ability to view the data in multiple views (i.e. A-Scan, B-Scan, and C-Scan). Presently some instruments have limited viewing ability and others are simply too large and not suited for the field. The anticipated benefit will be that data can be reviewed and analyzed in greater detail in the field, as well as allowing a permanent record of the feature to be saved. The option of defect monitoring to establish accurate growth rates is also possible, although in most cases not realistic except in a laboratory environment.

Existing successful multiple diffraction approaches are now being applied using the new technology potential of phased arrays. Although the application to thin wall pipe line is still being researched we have looked into applying the NSDS technology to phased array. The application has had promising preliminary testing and the new probes are presently being designed to address this need. Figure 17 presents a scan that was performed using a 32 element phased array transducer and a one axis sector scan

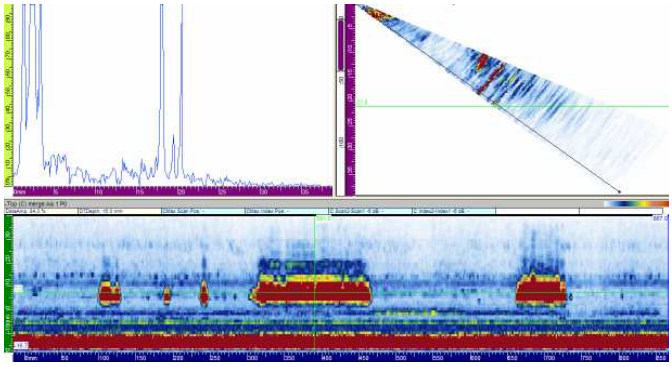

Figure 17: Phased Array Scan of 25.4cm Diameter ERW Weld with ID Linear Indications within the ERW

The phased array C-Scan indicates the presence of multiple linear indications within the seam of the ERW weld.

SUMMARY

We have been demonstrating for more than five years that the NSDS transducers can be used to accurately size SCC. The transducers can identify co-parallel cracks located within a few millimeters of one another, that are typical of an SCC colony, by using accurate time measurement techniques to produce a reliable and repeatable result. The signals obtained from the NSDS transducer are relatively strong with a good signal to noise ratio that enables operators to obtain repeatable results and report sizing measurements with a higher degree of confidence.

We are also of the opinion that while we are pleased with the results of the NSDS probes for SCC sizing, we also continue to use, as part of our investigative techniques and procedures, the more traditional UT transducers and techniques to assist in the discrimination of other defects that may also pose a threat to pipeline safety.

REFERENCES

ASNT, Handbook of Nondestructive Testing, vol. 7 second edition, American Society of Nondestructive Testing, 1989

Gruber G. J., Defect Identification and Sizing by the Ultrasonic Satellite-Pulse Technique, Journal of Nondestructive Evaluation Vol. 1, No. 4,1980

Krautkramer, J. and Krautkramer, H., Ultrasonic Testing of Materials, 4th, fully revised Edition, Springer Verlag, 1990

Ginzel R., Right Tool for The Job, Eclipse Scientific Products, Internal Paper, 2004

Ginzel E., UT2-7, MRI, 2004

http://www.NDE.net/article/az/ut_idx.htm

http:// www.NDE-ed.org/ Education Resources/ Community College / Ultrasonics / Introduction/history.htm

Silk,M.G.(1991), Flaw size distribution in pressure vessels and flaw detection probabilities in NDE, British J. of NDE,33(10), 491-494.

http://www.panametrics-ndt. Com / ndt / ndt technology / detection_sizing_tech.html

Same Side Sizing of Defects Using the Near Side Detection and Sizing (NSDS) Ultrasonic Transducers, Ginzel, R.K. & Kanters, W.A., Eclipse Scientific Products Inc., July 2002 http://www.ndt.net/article/v07n07/kanters/kanters.htm