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Special Phased Array Applications for Pipeline Girth Weld Inspections

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ABSTRACT

Ultrasonic phased arrays present major improvements over conventional multiprobe ultrasonics for inspecting pipeline girth welds, both for onshore and for offshore use. Probe pans are lighter and smaller, permitting less cutback; scans are quicker due to the smaller probe pan; phased arrays are considerably more flexible for changes in pipe dimensions or weld profiles, and for different scan patterns. More important, some of the potential advantages of phased arrays are now becoming commercially available. These include:

- Compensating for variations in seamless pipe wall thickness.
- Wedge temperature compensation.
- Improved focusing for thick and thin wall inspections.
- Premium inspections for risers, tendons and other components.
- Small diameter pipes.
- Multiple displays.
- Clad pipe.

The paper describes the latest phased array UT results for special applications.

INTRODUCTION

Pipelines are typically constructed by joining sections of pipe together, using either manual or automated welding. Since pipelines operate at a high percentage of yield strength, these welds must be constructed and inspected to a high standard. In recent years, **E**ngineering **C**ritical **A**ssessment (ECA - also called Fracture Mechanics, Fitness-For-Service or Structural Integrity) has been used to evaluate defects because ECA is considerably less conservative than traditional “workmanship” criteria. ECA is advantageous as it can reduce the reject rate significantly (1).

Compared with radiography, automated ultrasonic testing (AUT) offers the further advantage of process control, as welds can be inspected soon after completion, and feedback given rapidly to the welding crew. Overall, AUT can save construction costs by process control and the use of ECA to minimize the reject rate, often below 1% (2).

Ultrasonic phased arrays present major improvements over conventional multiprobe ultrasonics for inspecting pipeline girth welds, both for onshore and for offshore use. Probe pans are lighter and smaller, permitting less cutback; scans are quicker due to the smaller probe pan; phased arrays are considerably more flexible for changes in pipe dimensions or weld profiles, and for different scan patterns. More important, some of the potential advantages of phased arrays are now becoming commercially available. These applications include:

- Compensating for variations in seamless pipe wall thickness.
- Wedge temperature compensation.
- Premium inspections for risers, tendons and other components.
- Small diameter pipes.
- Multiple displays.
- Clad pipe.
- Portable phased arrays for tie-ins and repairs.
- Improved sizing approaches.

ULTRASONIC PHASED ARRAYS FOR PIPELINE GIRTH WELDS

Phased arrays use an array of elements, all individually wired, pulsed and time-shifted. These elements are typically pulsed in groups of ~16 elements at a time for pipeline welds. In order to make a user-friendly system, a typical set-up calculates the time-delays from operator-input, or uses a pre-defined file calculated for the inspection angle, focal distance, scan pattern etc (see Figure 1). The time delay values are back calculated using time-of-flight from the focal spot, and the scan assembled from individual "Focal Laws". Time delay circuits must be accurate to around 2 nanoseconds to provide the accuracy required. Due to the limited market, complexity, software requirements and manufacturing problems, industrial uses have been limited until the last few years (3).

From a practical viewpoint, ultrasonic phased arrays are merely a method of generating and receiving ultrasound. Consequently, many of the details of ultrasonic inspection remain unchanged; for example, if 7.5 MHz is the optimum inspection frequency with conventional ultrasonics, then phased arrays would typically use the same frequency, focal length, and incident angle.

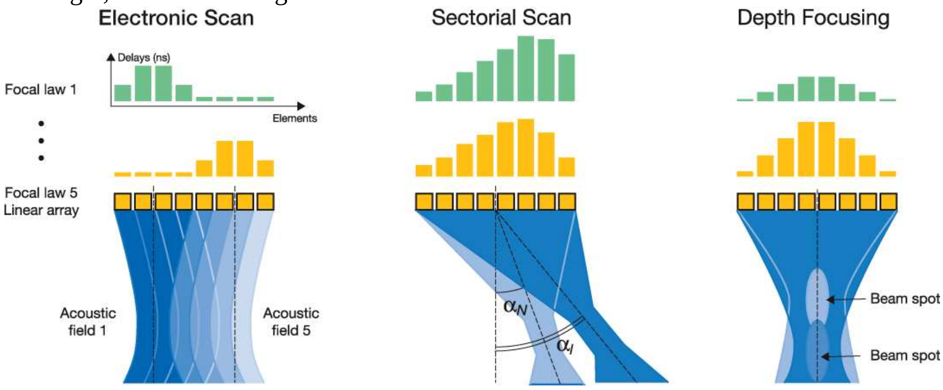

Figure 1: Schematic showing generation of linear and sectorial scans using phased arrays.

While it can be time-consuming to prepare the first set-up, the information is recorded in a file and only takes seconds to re-load. Also, modifying a prepared set-up is quick in comparison with physically adjusting conventional transducers. Using electronic pulsing and receiving provides significant opportunities for a variety of scan patterns.

Electronic Scans

Multiplexing along an array produces electronic scans (see Figure 2). Typical arrays have up to 128 elements, pulsed in groups of 8 to 16. Electronic scanning permits rapid coverage with a tight focal spot. If the array is flat and linear, then the scan pattern is a simple B-scan. If the array is curved, then the scan pattern will be curved. Linear scans are straightforward to program. For example, a phased array can be readily programmed to inspect a weld using both 45^o and 60^o shear waves, which mimic conventional manual inspections or automated raster scans.

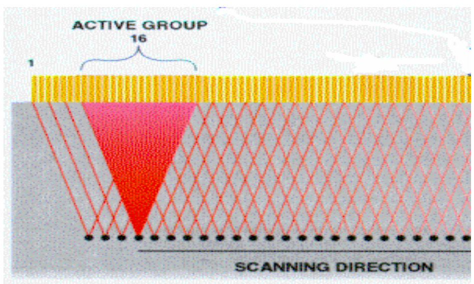

Figure 2: Schematic illustration of electronic (linear) scanning.

Sectorial (Azimuthal) Scans

Sectorial scans use a fixed set of elements, but alter the time delays to sweep the beam through a series of angles (see Figure 3). Again, this is a straightforward scan to program. Applications for sectorial scanning typically involve a stationary array, sweeping across a relatively inaccessible component like a turbine blade root (4), to map out the features (and defects). Depending primarily on the array frequency and element spacing, the sweep angles can vary from ± 20° up to ± 80°.

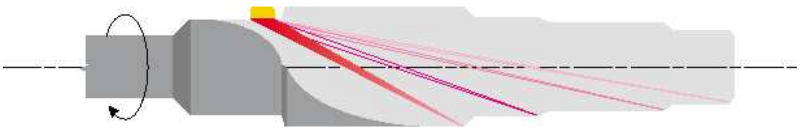

Figure 3: Schematic showing sectorial scanning used on turbine rotor.

Combined Scans

Phased arrays permit combining electronic scanning, sectorial scanning and precision focusing to give a practical combination of displays. Optimum angles can be selected for welds and other components, while electronic scanning permits fast and functional inspections. For zone discrimination scans of pipeline welds, specific angles are used for given weld geometries, as shown in Figure 4.

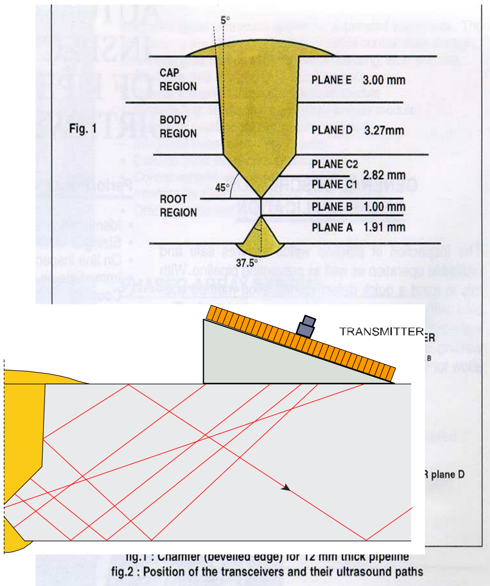

Figure 4: Schematic showing zones on a CRC-Evans weld profile, and ultrasonic beams from a phased array probe.

PIPELINE AUT INSPECTIONS

Pipeline AUT uses fully automated equipment travelling round the pipe on a welding band in a linear scan, with the array pulsing to cover all the weld zones as in Figure 4 above. Besides linear scanning, there are four specific features of pipeline AUT:

- zone discrimination,
- special calibration blocks,
- dual gate output display and
- rapid defect sizing. These features are described in detail elsewhere (1).

The special output display uses multiple strip charts, with colour-coded detection; the dual gate display shows both signal amplitude and time-in-the-gate for defect location in the weld; the calibration blocks use an angled notch or side-drilled hole to represent lack of fusion, one reflector for each zone. Rapid defect sizing is performed by counting the number of zones where above-threshold signals occur. These features are defined by ASTM E-1961-98 (5). R/D Tech has a commercial phased array system, PipeWIZARD (6), which can also meet or exceed any of the other codes - API 1104, DNV OS101, ISO 13847 (7-9).

ADVANCED INSPECTIONS

One significant feature of phased arrays is their ability to perform “specials”; some active examples are shown below.

Compensating for variations in seamless pipe wall thickness

Offshore seamless pipe has significant variations in pipe wall, up to 10-15%. For a 20 mm wall, these variations are sufficient for the zone discrimination beams to completely miss their targets. One phased array solution is to run multiple set-ups, typically the nominal, minimum and maximum walls (see Figure 5); the minimum and maximum set-ups can be performed electronically, based on a nominal calibration. The operator selects which “view” to watch based on wall thickness measurements (10).

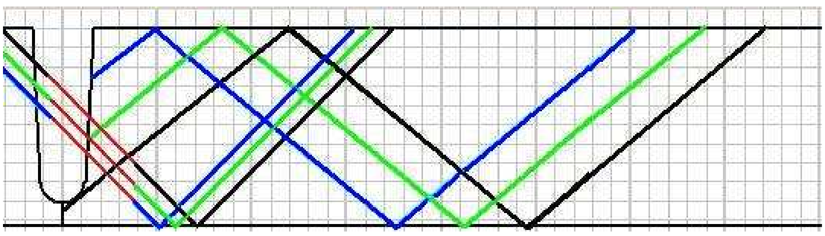

Figure 5: Ray tracing showing beams for nominal, minimum and maximum wall thicknesses, and errors.

Wedge Temperature Compensation

Phased arrays use large wedges, and there has been some concern that temperature gradients in these wedges will skew the ultrasonic beams sufficiently to cause missing targets. Preliminary modeling has shown that the effect is likely small, as shown in Figure 6.

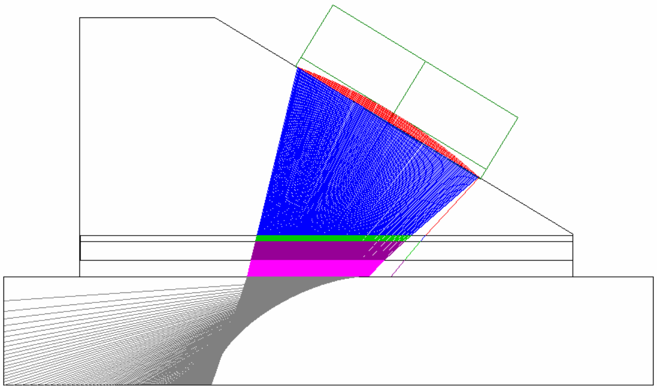

Figure 6: Imagine3D modeling of phased array and wedge on pipe, with temperature gradient in layers from base.

The modeling shows that any effects are likely to be limited to the exit point and attenuation. Currently, the standard procedure keeps the calibration block within 10 C of the pipe; however, controlling couplant (cooling) temperature is more effective (5).

Premium inspections for risers, tendons and other components

Risers and tendons are nominally built to much higher quality than standard pipelines or other welds. For example, acceptable defect sizes on 35 mm walls may be only 0.3 mm, with a sizing error of $\pm$ 0.3 mm. Phased arrays work better on such applications since they can use multiple beams at multiple angles to guarantee better coverage and defect detection.

Risers and tendons also tend to be thick-walled; thicknesses of 35-40 mm are normal, with up to 50 mm possible. This is another advantage for phased arrays, since PipeWIZARD can run an additional eight conventional transducers. This permits detailed inspections with highly focused transducers up to 50+ mm walls.

Figure 7 shows a schematic ray tracing, showing enhanced coverage of the root, cap and volumetric areas using an increased number of beams and angles. In this application, the phased array system used 84 beams (not all shown), which would have been impractical with a multiprobe system.

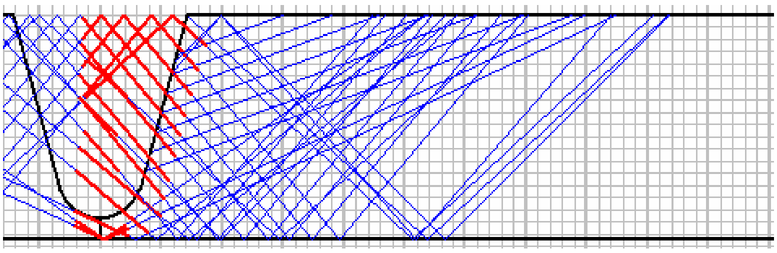

Figure 7: Ray tracing showing partial coverage of premium weld.

Small diameter pipes

Small diameter pipes are difficult to inspect well using conventional ultrasonics since there is a limit to the number of transducers that can be placed on the pipe. Phased arrays can generate an almost unlimited number of beams to provide coverage at different angles, locations and rastering. Figure 8 shows a small diameter pipe scanner which can be added to PipeWIZARD or operated independently. This scanner requires four rings to cover diameters from 60 mm to 400 mm.

Figure 8: Small diameter scanner.

Multiple Displays

With the customizing capabilities of phased arrays, suitable software and displays are available, including multiple views. Figure 9 shows an example of a user-friendly display, showing defect locations on the weld and position/length around the circumference.

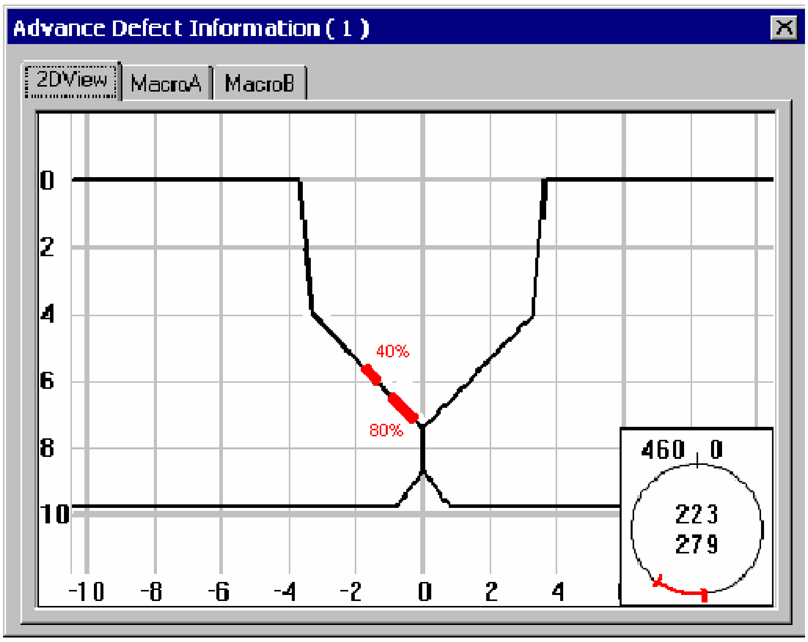

Figure 9: Software display showing defect location, length and position.

Figure 10 shows a scan with an additional B-scan image; in this instance, it clarifies what looks like two defects as the same defect seen from both sides.

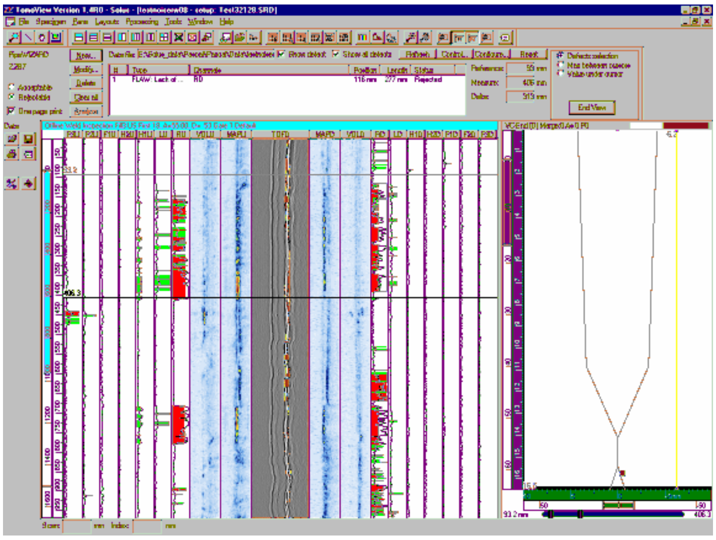

Figure 10: Standard ASTM strip chart display with additional B-scan for interpretation.

Clad pipe

Clad pipe is becoming more common for corrosion resistance. Normally cladding is austenitic stainless steel or nickel alloy-based. Both materials can be very difficult for conventional shear wave ultrasonics; large austenitic grains skew and attenuate shear wave beams. Longitudinal waves (L-waves) are significantly less affected, so standard practice in the nuclear industry (which uses a lot of austenitic piping) is to perform L-wave inspections. L-waves can be easily generated by phased arrays and PipeWIZARD, but the standard zone discrimination approach (5) will not work since it is not practical to bounce beams off the inside of the clad pipe. Developments are on-going in this area. Figure 11 shows an L-wave scan of a pipe, showing notch and notch tip using an S-scan.

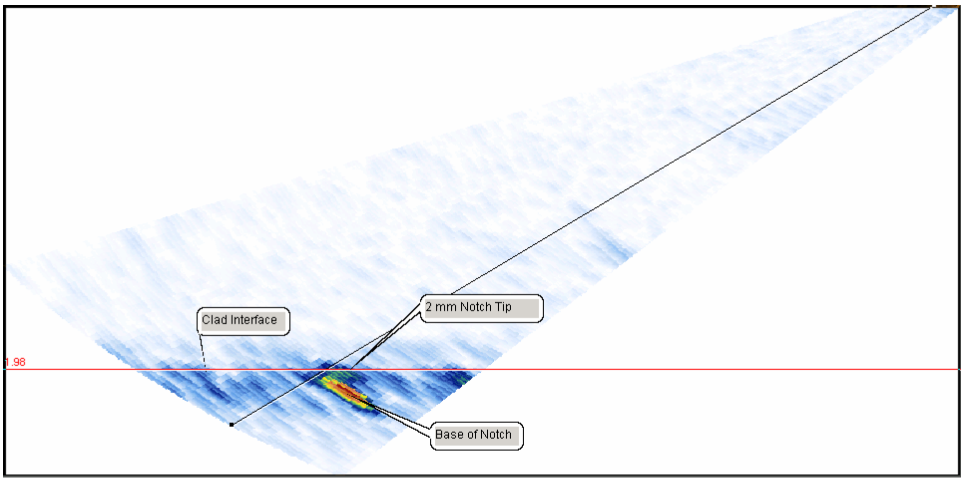

Figure 11: Clad plate inspection clockwise using S-scan, showing notch base, notch tip and clad interface.

Portable phased arrays for tie-ins and repairs

While large AUT phased array systems can be used for both tie-ins and repairs, economics and practical considerations favour smaller, portable systems. An encoded array, calibration block and appropriate set-up can perform a rapid linear scan; C-scan and B-scan displays are generated in real-time. The OmniScan system (11) in Figure 12 can perform both electronic and S-scans; the resultant scan patterns are closer to ASME-type raster scans than to ASTM E-1961 zone discrimination, but are suitable and acceptable for tie-ins and repairs.

Figure 12: Portable phased array instrument for tie-ins and repairs, performing a linear scan on a weld.

Improved Defect Sizing

Defect sizing is a contentious issue with pipelines, with some companies claiming they can size to $\pm$ 0.3 mm accuracy. Unfortunately, early round robin trials showed sizing in the range of 1.5-2 mm, though more recent trials have shown sizing to $\pm$ 0.6 mm or better (12). Part of this is improved focusing using phased arrays, part due to more extensive use of TOFD to eliminate large errors. Multiple techniques certainly help, though there are physical limitations that must be overcome.

Diffraction techniques offer better sizing accuracies than amplitude-based techniques. New techniques like back diffraction offer advantages, though they are slow. Figure 13 shows the back diffraction concept (13).

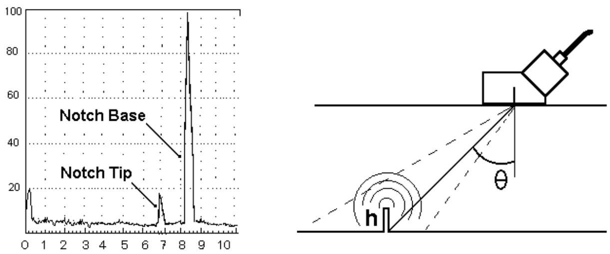

Figure 13: Back diffraction – left, A-scan presentation, right ultrasonic set-up.

Back diffraction works better with phased arrays as only electronic scanning is required, and the coupling remains constant during the scan.

CONCLUSIONS

1. Ultrasonic phased arrays offer considerable technical advantages over conventional multiprobe AUT systems, or radiography.
2. Using phased array AUT, operators can simply load a file to provide rapid scanning.
3. For pipelines, phased arrays offer some specific applications that are difficult or impossible for multiprobe systems to match:
   a. Compensating for variations in seamless pipe wall thickness.
   b. Premium inspections for risers, tendons and other components.

c. Small diameter pipes.
d. Clad and austenitic pipe.
e. Portable phased arrays for tie-ins and repairs.
f. Multiple displays.
g. Improved sizing.

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