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Phased Arrays for Pipeline Girth Weld Inspections

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Abstract

Ultrasonic phased arrays offer significant advantages over radiography for pipeline weld inspections: they have higher detection rates for critical planar defects (i.e. cracks and lack of fusion), better defined interpretation, vertical sizing capability for Engineering Critical Assessment, no safety hazards, no licensing issues, no chemical wastes, and no requirement to evacuate the area. Phased arrays also offer major advantages over multiprobe systems and manual ultrasonics.

Initially, this paper describes the standard zone discrimination inspection of pipeline welds. Then the Olympus NDT PipeWIZARD phased array system for large pipelines is described, plus some of its advantages. As phased arrays are very good for special applications, this paper will briefly show some of the key applications, like seamless piping, cladding, premium inspections and improved focusing. In addition, the paper will present a portable phased array system –suitable for repairs, tie-ins and difficult to access areas.

1. 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 to a high standard. The advent of higher strength steels, high demand for pipelines, greater environmental concerns, thinner pipe walls and improved technology have all lead to more demanding inspection requirements.

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, and provide better structural integrity.

Radiography has been used to inspect pipeline welds for decades, but this has severe limitations, particularly for ECA assessments. As a result, radiography for pipelines is being steadily replaced by ultrasonics worldwide. Specifically, radiography cannot measure defect depths for ECA; radiography is typically slower than ultrasonics, and operator-subjective. Detection is usually inferior to conventional automated ultrasonics as well. Ultrasonics offers the further advantage of process control, as welds can be inspected soon after completion, and feedback given rapidly to the welding crew. Overall, ultrasonics can save construction costs by process control and the use of ECA to minimize the reject rate, often below 1%. In addition, radiography is slower, more subjective, and presents radiation and licensing issues.

This paper describes phased array developments in automated ultrasonic testing (AUT) inspection of pipelines. Phased arrays offer all the advantages of AUT over radiography, plus several more:

- Smaller and lighter probe pans;
- Faster inspections;
- Significant flexibility in pipe diameters, wall thicknesses and weld bevel geometries;
- Rapid set-ups,
- Improved sizing and imaging,
- plus "specials" as described below.

2. Ultrasonic Phased Arrays

Ultrasonic phased arrays are well described in other publications(1), so only a quick mention of their capabilities will be given here. Briefly, an ultrasonic phased array consists of an array of individual elements, with firing and receiving under computer control. This permits sweeping, steering, scanning and focusing of the beam, as illustrated in Figure 1.

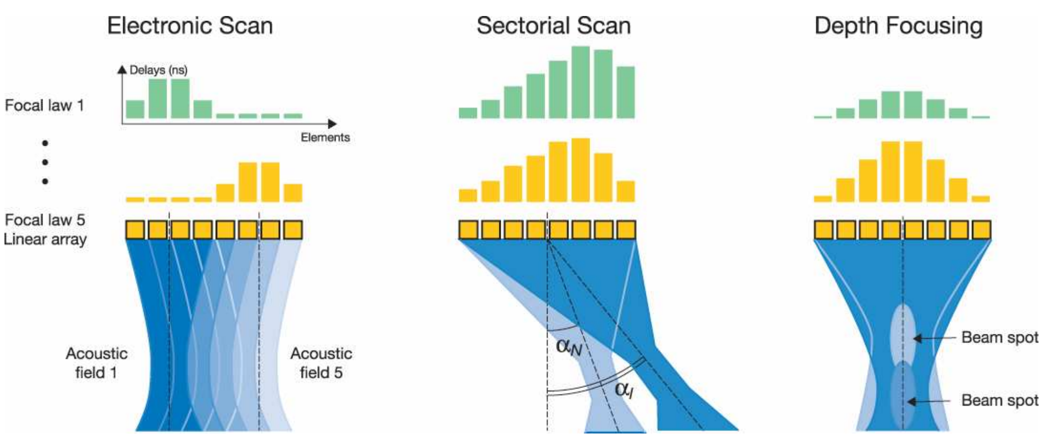

Figure 1: Schematic showing generation of electronic, sectorial and Dynamic Depth Focusing scans using phased arrays.

2.1 E- (Electronic) Scans

Multiplexing along an array produces E-scans (see Figure 2). Typical arrays have up to 128 elements, pulsed in groups of 8 to 16. E-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. E-scans are straightforward to program. For example, a phased array can be readily programmed to inspect a weld using 45^{o} and 60^{o} shear waves, which emulate conventional manual inspections.

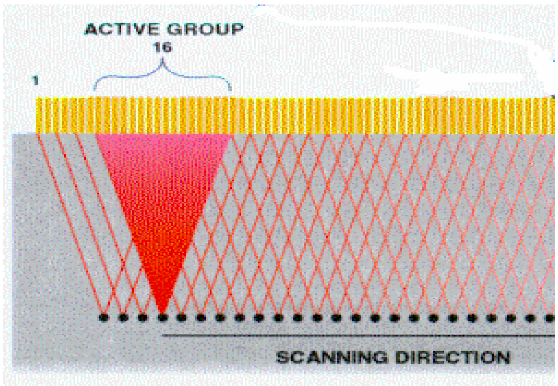

Figure 2: Schematic illustration of electronic scanning.

2.2 S- (Sectorial) Scans

S-scans use the same 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(2), to map out the features (and defects). Depending primarily on the array frequency and element spacing, the sweep angles can vary from $\pm$ 20^{o} up to $\pm$ 80^{o}.

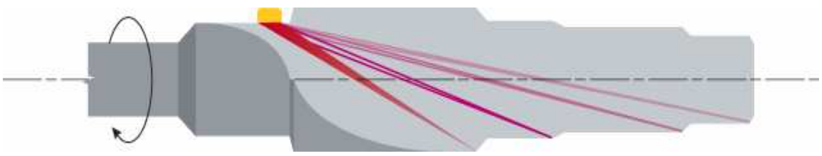

Figure 3: Schematic showing sectorial scanning used on turbine rotor.

Combining E-scanning, S-scanning and precision focusing leads to tailored inspections with custom displays. Optimum angles can be selected for welds and other components, while scanning permits fast and functional inspections.

2.3 Linear scanning of welds

Linear scanning of welds (using a one-axis type scan while the array electronically scans along the other axis) speeds up inspections enormously. Raster scanning (as shown in Figure 4a) is slow due to null zones and other limitations, while linear scanning (Figure 4b) has no mechanical dead zones.

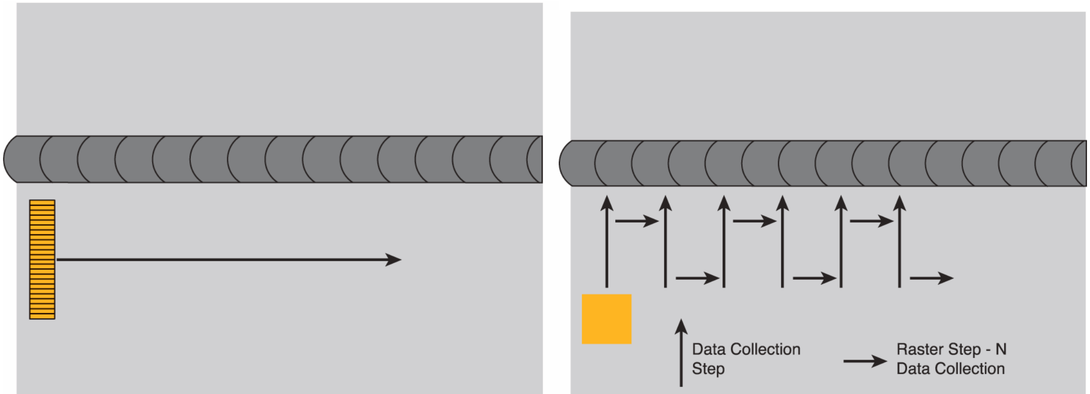

Figure 4a (left). Conventional raster scanning; Figure 4b (right). Linear scanning.

2.4 Typical Applications

Realistically, there is no "typical application" for PAs. Ultrasonic phased arrays are being installed in a wide variety of industries, where the technology has inherent advantages. These industries include: aerospace, nuclear power, steel mills, pipe mills, petrochemical plants, pipeline construction, plus a selection of special applications. All these applications take advantage of one or more of the dominant features of PAs:

- **Speed**: scanning with phased arrays is an order of magnitude faster than single transducer conventional mechanical systems, with better coverage;
- **Flexibility**: set-ups can be changed in a few minutes, and typically a lot more component dimensional flexibility is available;
- **Inspection angles**: a wide variety of inspection angles can be used, depending on the requirements and the array;
- **Small footprint**: small matrix arrays can give infinitely more flexibility for inspecting restricted areas than conventional transducers.

3. Conventional Pipeline AUT

Current pipeline AUT inspections use a number of special developments that have been tried and tested over a couple of decades(3-7). Besides the multi-transducer, linear scanning approach, the key developments of the current approach are:

- zone discrimination,
- special calibration blocks,
- dual gate output display and
- rapid defect sizing.

Pipeline AUT is well defined by codes. The original NOVA/TCPL AUT specifications were published in a more generalized form as ASTM E-1961-98(8). This code is very specific on zone discrimination, displays and calibration. For example, FBH diameter and angles are defined with manufacturing tolerances, along with calibration and threshold amplitudes. In 1999, the American Petroleum Institute published the 19th Edition of API 1104(9), which includes the optional use of ultrasonics with client approval of procedure, and the optional use of ECA. In contrast to ASTM E-1961, API 1104 is a very flexible code. One likely approach to future specifications for AUT of girth welds is a combination of the rigorous ASTM E-1961 and flexible API 1104 codes. DNV has an offshore zone discrimination code, OS F101[10].

4. "PipeWIZARD" Pipeline Ultrasonic Phased Array System

A typical phased array system for pipeline girth weld inspections consists of two linear arrays, probe pan and motor, umbilical cable, welding band, junction box, plus the motor driver, instrumentation, computer, keyboard and mouse inside the truck or cabinet. The instrumentation and probe pan are shown in Figure 5 below.


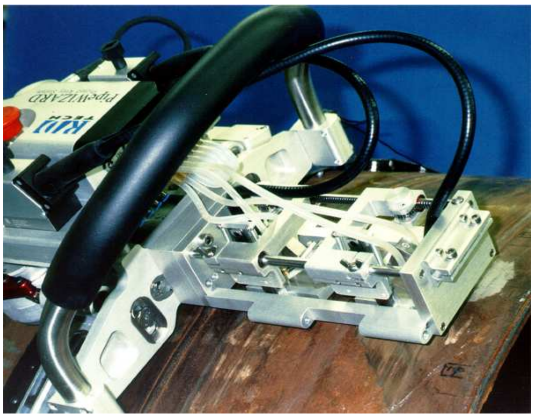

Figure 5: Right, Photo of PipeWIZARD; Left, instrumentation; right, probe pan.

Two 60-element, 7.5 MHz arrays are used, one on either side of the weld. These arrays can perform all required pulse-echo and tandem inspections (and more), plus TOFD if required. If needed, separate TOFD probes or transverse probes can be installed in extra modules. The phased array probe pan is much reduced in size and weight from a multiprobe pan. The motor and carriage are standard commercial products, as is the welding band. The umbilical is a reinforced cable about 50 mm in diameter containing 128 miniature ultrasonic coaxial cables, power cable, encoder cable and water line for coupling. The instrumentation is a standard 32/128 FOCUS phased array unit, with eight spare cables. The computer is a late-model industrial PC running a customized version of TomoView specifically for girth weld inspections.

As required, scanning speed is 100 mm/sec, which inspects a 36" (914 mm) pipeline weld in less than one minute, with real time data display, storage and analysis.

5. Phased Arrays vs. Conventional AUT

Early laboratory trials comparing multiprobe AUT and phased arrays showed little practical inspection differences between the two techniques when both used the same zone discrimination set-up[11]. A field comparison was performed on 202 welds on the Maritimes & Northeastern Pipeline in New Brunswick, Canada, in July 1999 using both conventional and phased array systems[12]. Again, the results showed very little differences between the two approaches; the phased array system recorded a couple more defects, but these were just under the recording threshold for the conventional systems. Overall, the phased array system had equal or slightly better sensitivity, particularly for size estimates, and detected all the same defects. However, the phased array system had far fewer moving parts, and was much faster for switching configurations as expected.

6. Special Applications using Phased Arrays

Besides reproducing conventional AUT inspections, phased arrays can perform a number of extra inspections that can/will improve the overall inspection process. The features used depend on the application, and the number is increasing steadily with time. The following examples describe some "specials" currently available, or in preparation.

6.1 Increased number of zones

Multiprobe AUT is physically limited in the number of inspection zones by the number of probes that can fit inside the probe pan. This is typically twenty-four probes, or perhaps ten zones (typically some zones use tandem probes, or TOFD). Phased arrays are not limited in this fashion; in fact, up to 128 beams can be generated or received using two 60-element arrays with little penalty in terms of inspection speed. Besides strip charts, B-scans, C-scans and D-scans can all be displayed.

6.2 Automated set-ups

Phased arrays are inherently complex due to their great flexibility, so set-ups can be difficult and time consuming. As there are a number of different weld profiles from different manufacturers, plus an almost infinite number of wall thickness and pipe diameter combinations, an automated set-up procedure has been developed. Figure 6 below shows an automated set-up for a CRC-Evans weld profile with a conventional number of zones.

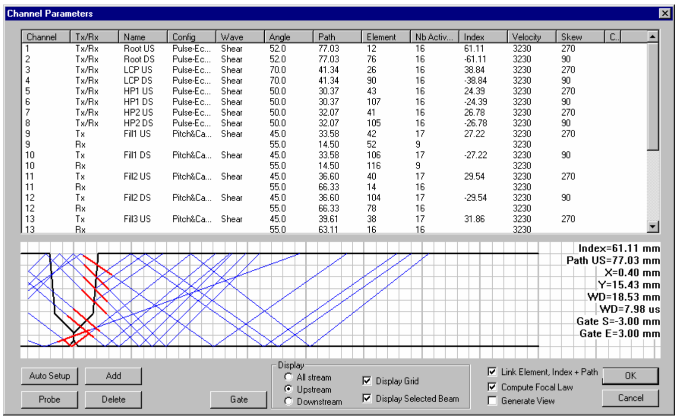

Figure 6: Automated set-up with gates for CRC-Evans weld profile.

To set-up the scan, the operator selects a suitable weld profile from file, then modifies it with the appropriate physical parameters: wall thickness, fill depth and angle, hot pass depth and angle, etc. Then the computer automatically determines the Focal Laws for this particular inspection, and displays them on-screen. The operator can select/deselect beams, shift beam start points, change focal distance etc. as required. Normally, the fine-adjustments would come after calibration to optimize the inspection.

7. Advanced Phased Array Techniques, or "Specials"

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

7.1 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 for nominal, minimum and maximum wall thicknesses (see Figure 7); 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(13).

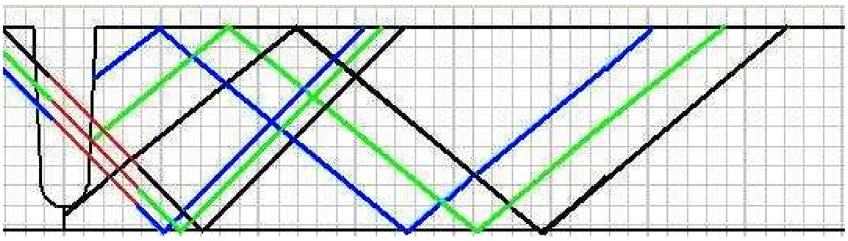

Figure 7: Ray tracing showing beams for nominal, minimum and maximum wall thicknesses, and errors.

7.2 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 ± 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 8 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.

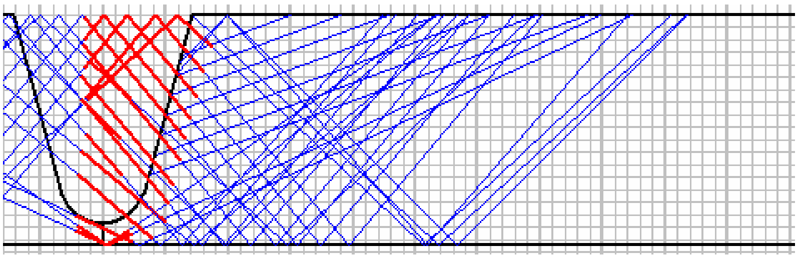

Figure 8: Ray tracing showing partial coverage of premium weld.

7.3 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 9 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 9: Small diameter scanner.

7.4 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 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 10 shows an L-wave scan of a pipe, showing notch and notch tip using an S-scan.

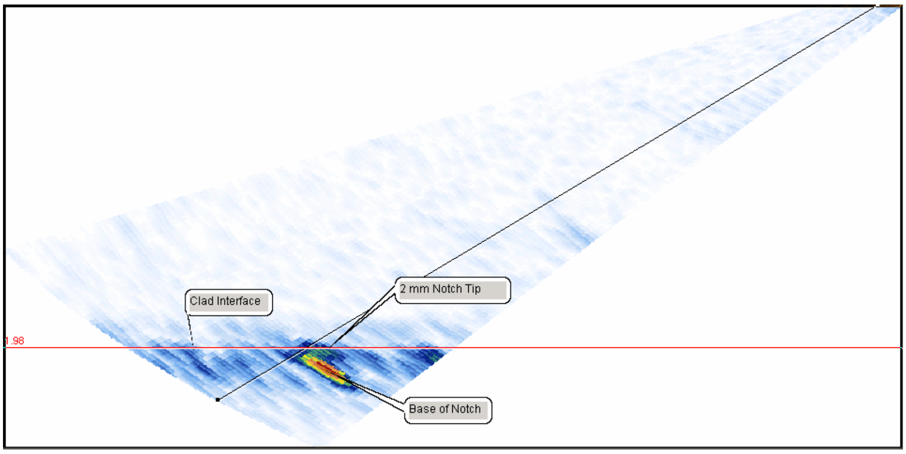

Figure 10: Clad plate inspection clockwise using S-scan, showing notch base, notch tip and clad interface.

7.5 Improved Focusing

Depending on wall thickness, it is possible to get significantly improved focusing by using curved linear arrays, or by using a curved matrix array for very thick walls. Tests on calibration blocks comparing unfocused and curved arrays show that the curved (focused) arrays can size to much tighter tolerances. Figure 11 shows notch measurements for the curved array (left) and flat array (right). The 2 mm notch is measured at 3.1 mm with focusing, but over 6 mm without focusing(14).

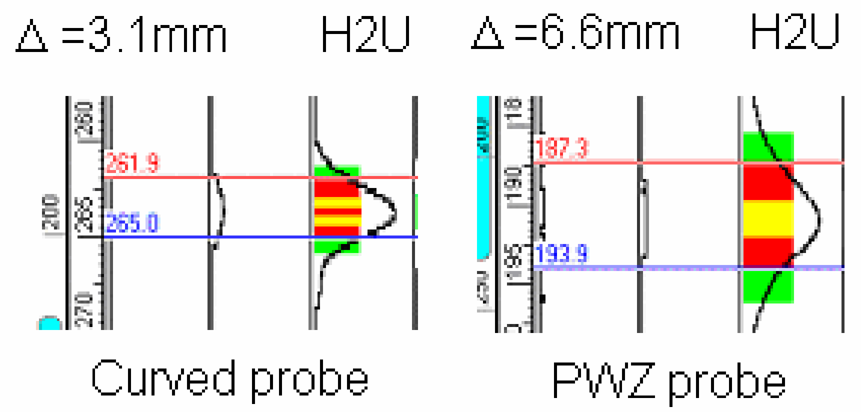

Figure 11: Left, notch width using focused array; right, notch width using flat array.

7.6 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. The OmniScan system(15) in Figure 10 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.

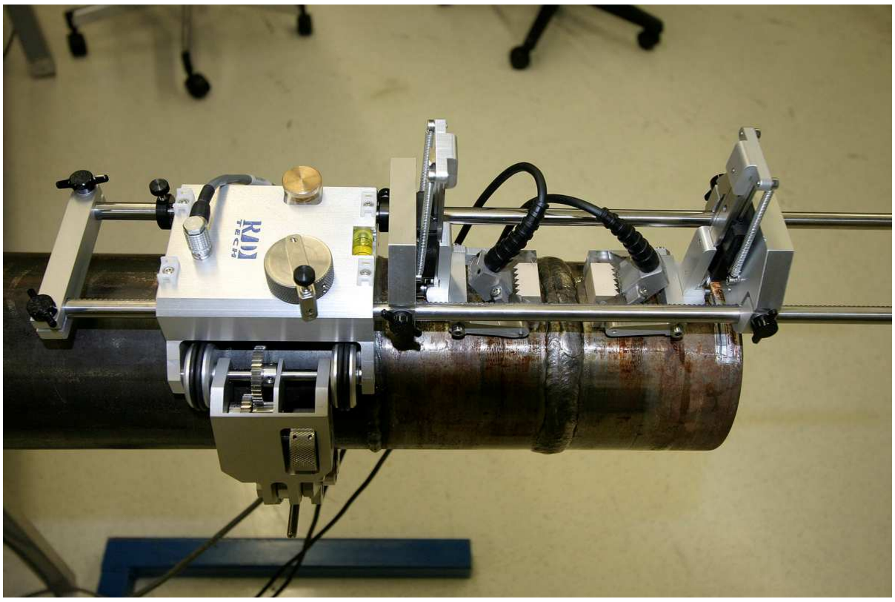

Figure 10: Portable phased array instrument for tie-ins and repairs, performing a linear scan on a weld.

8. Conclusions

Ultrasonic phased arrays for pipeline girth weld inspections have several advantages over conventional AUT.

1. Probe pans are smaller and lighter, making handling easier.
2. Phased array inspections are typically several seconds faster than conventional AUT due to the smaller probe pan.
3. Phased arrays can scan from 50 mm to 1.5 m pipes using the same equipment and arrays; typically only the welding band and wedges need changing.
4. Loading the appropriate set-up file, or automatically creating a set-up file, can inspect any weld profile and pipe parameters.
5. Improved imaging and increased number of zones can produce better detection with no extra inspection time.
6. AUT using phased arrays is potentially applicable to a wide range of "special" applications, including seamless pipe, cladding, risers, thick-section welds, manual welds, repairs, and tie-ins.

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