Application of Phased Array Ultrasonic Testing (PAUT) on single V-butt weld integrity determination

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Abstract

Phased Array Ultrasonic Testing (PAUT) utilizes arrays of piezoelectric elements that are embedded in an epoxy base. The benefit of having such kind of array is that beam forming such as steering and focusing the beam front possible. This enables scanning patterns such as linear scan, sectorial scan and depth focusing scan to be performed. Ultrasonic phased array systems can potentially be employed in almost any test where conventional ultrasonic flaw detectors have traditionally been used. Weld inspection and crack detection are the most important applications, and these tests are done across a wide range of industries including aerospace, power generation, petrochemical, metal billet and tubular goods suppliers, pipeline construction and maintenance, structural metals, and general manufacturing. Phased arrays can also be effectively used to profile remaining wall thickness in corrosion survey applications. The benefits of PAUT are simplifying inspection of components of complex geometry, inspection of components with limited access, testing of welds with multiple angles from a single probe and increasing the probability of detection while improving signal-to-noise ratio. This paper compares the result of inspection on several specimens using PAUT as to digital radiography. The specimens are welded plates with single V-butt weld made of carbon steel. Digital radiography is done using blue imaging plate with x-ray source. PAUT is done using Olympus MX2 with 5MHz probe consisting of 64 elements. The location, size and length of defect is compared.

Keyword : phased array ultrasonic testing

Introduction

Ultrasonic test instruments have been used in industrial applications for more than sixty years. Since the 1940s, the laws of physics that govern the propagation of high frequency sound waves through solid materials have been used to detect hidden cracks, voids, porosity, and other internal discontinuities in metals, composites, plastics, and ceramics, as well as to measure thickness and analyze material properties.

Sound waves are simply organized mechanical vibrations traveling through a medium. These waves will travel through a given medium at a specific speed or velocity, in a predictable direction, and when they encounter a boundary with a different medium they will be reflected or transmitted according to simple rules.

Essentially, a phased array probe is a long conventional probe cut into many small elements, which are individually excited. It is like having many small conventional ultrasonic probes integrated inside a single probe and can be individually excited.

Figure 1 : Array of piezo elements in phased array ultrasonic probe

Phased Array probes are based on composite technology. The signal to noise ratio obtained from composite is typically 10 to 30dB greater compared with piezoceramic probes. A metallic layer is deposited on the surface of the piezocomposite. This metallic layer conforms to the element pattern and provides electrical contacts for each element.

Figure 2 : Phased Array probe

Beam forming

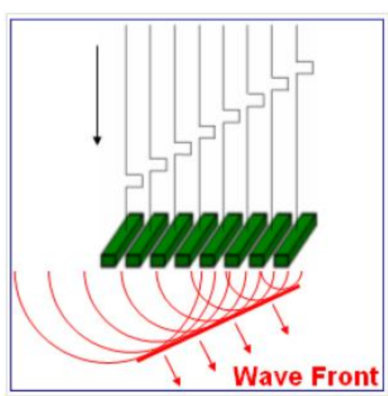

Figure 3 : Time delay in element trigger

Ultrasonic phased arrays consist of a series of individual elements, each with its own connector, time delay circuit, and A/D converter. Elements are acoustically insulated from each other. Elements are pulsed in groups with precalculated time delays for each element (i.e., "phasing").

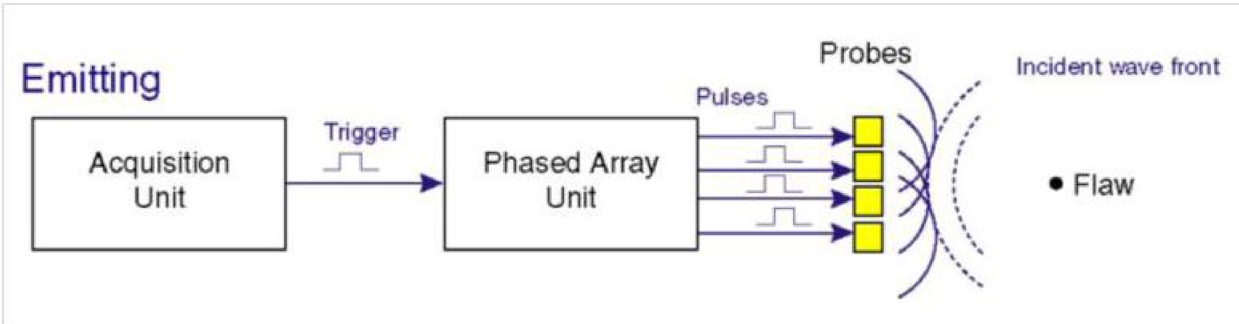

Figure 4 : Phased Array Transmitter components

Appropriate delays introduced electronically during emission to generate a specific beam. Beam forming requires precise pulsing and time delays. Acoustic beam is generated by Huyghens principle. Receiving is the opposite of pulsing. Appropriate delays are introduced electronically during reception. Only signals satisfying the delay law shall be in phase and generate a significant signal after summation.

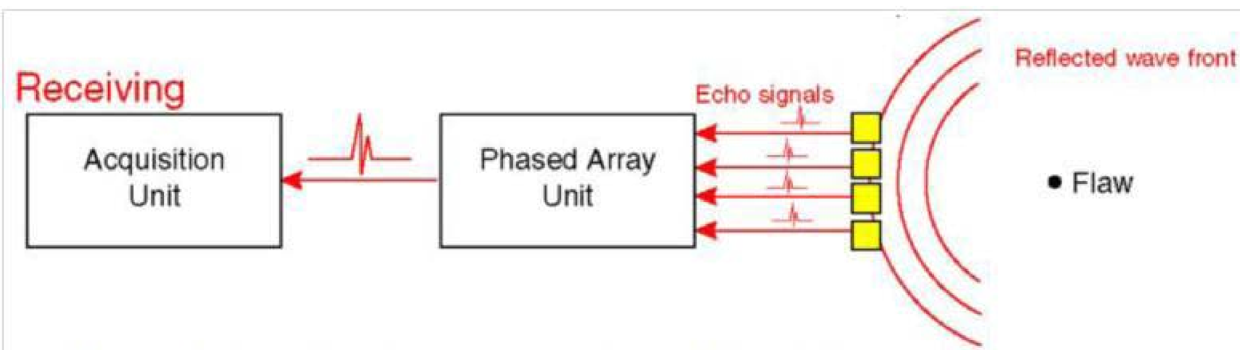

Figure 5 : Phased Array Receiver components

Beam Steering

It provides the capability to modify the refracted angle of the beam generated by the array probe. It also allows for multiple angle inspections, using a single probe. The focal laws is symmetrical in nature. The angle of steering is limited to the nature of probe construction.

Beam Forming

When no time delay is applied between each element (elements in the array are yellow and the delay applied to each element is in green), a PAUT probe becomes like a conventional UT probe.

Beam Steering + Focusing

By combining both steering and focusing focal laws (delay applied to each element is in green), the focal point can be angled. Using a single group of elements, on the same probe, different beam configurations can be performed

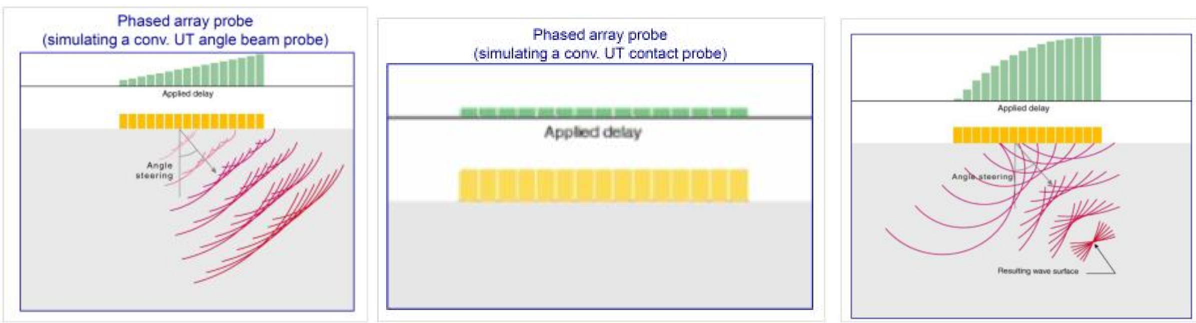

Figure 6 : Beam Steering (left), Beam Forming (centre) and Beam Steering plus Focusing (right)

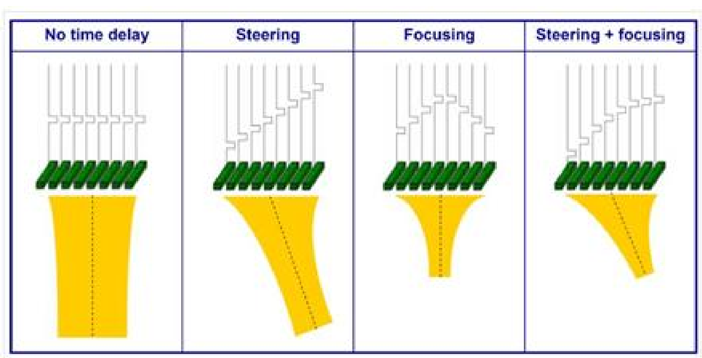

Figure 7 : Comparison of various type of beam shaping

Linear Electronic Scan

The movement of the acoustic beam is along the axis of the array, without any mechanical movement. The beam movement is performed by time multiplexing of the active elements. Arrays are multiplexed using the same focal law.

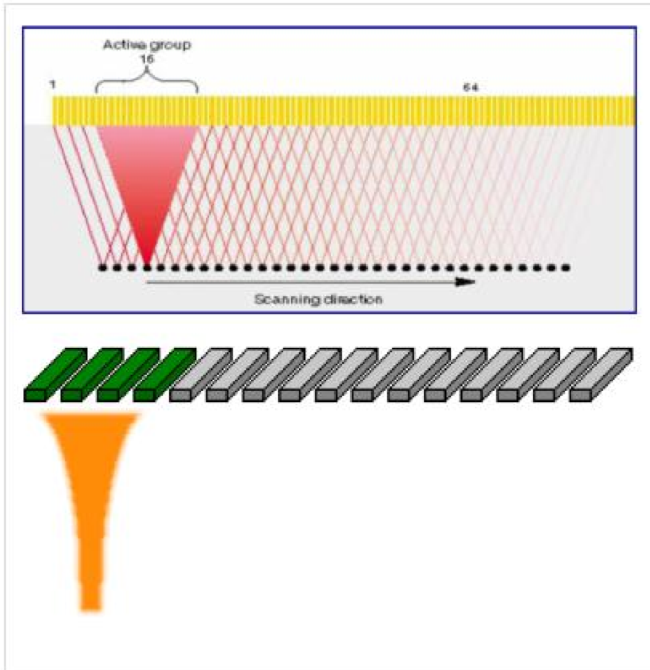

Figure 8 : Linear Electronic scan

Sectorial Scan

The ability to scan a complete sector of volume without any probe movement. Useful for inspection of complex geometries, or geometries with space restrictions. Combines the advantages of a wide beam and/or multiple focused probes in a single phased array probe.

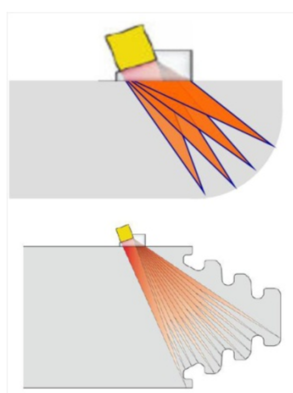

Figure 9 : Sectorial Scan

Depth Focusing Scan

Instead of requiring one focal law for each depth position, the DDF (dynamic depth focusing) algorithm allows the use of a single pulsed focal law by dynamically changing the focusing depth at reception of the signal. DDF is an excellent way of inspecting thick components with a single pulse.

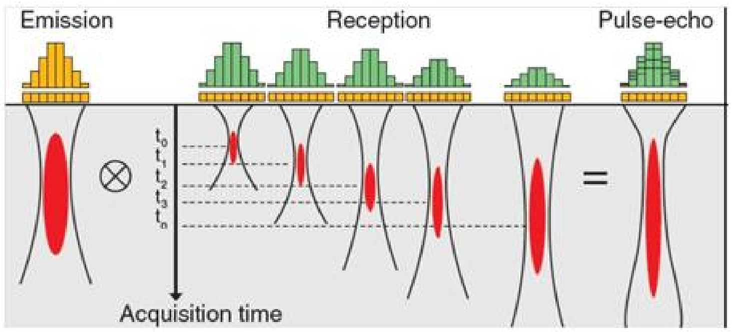

Figure 10 : Depth Focusing Scan

Methodology

Inspection of two welded plates with ID number 1155 and 14820 was done using Phased Array Ultrasonic Testing System Omniscan MX2 with 5L64-A12 probe attached to SA12-N55S wedge.. The equipment was calibrated on a V1 block. The couplant used was glycerin. An encoder was attached to the probe to track the distance of probe travel. Data was recorded in A-scan, C-Scan and S-scan presentation. The result of inspection was then analysed and all discontinuities were measured and reported.

Figure 10 : PAUT on welded plate specimen

Phased Array Inspection result

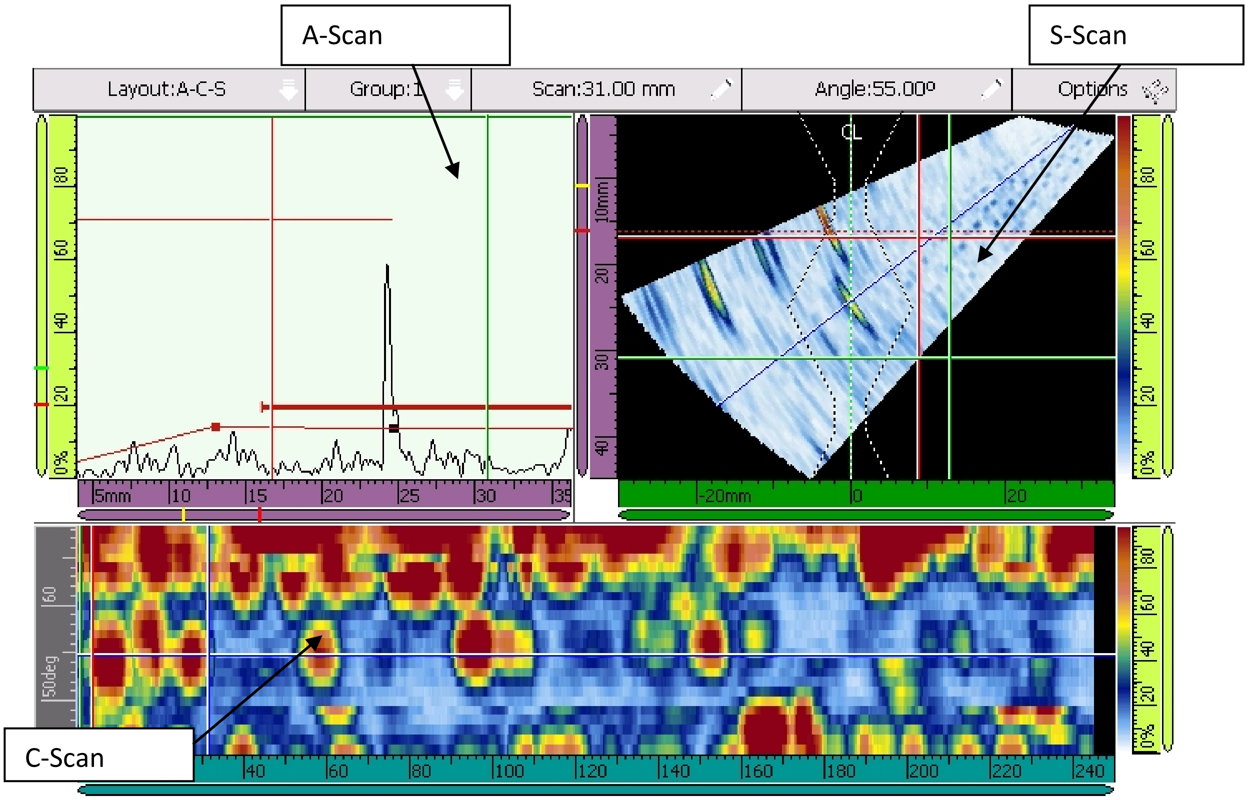

Figure 11 : Display of PAUT result

The result of PAUT was analysed and discontinuities were identified. The location and length of defect were measured as in Table 6.

Table 6 : Data Evaluation using PAUT

WELDED PLATE ID	TYPES OF DISCONTINUITIES	LOCATION FROM '0' (mm)	LENGTH OF DEFECT (mm)
PLATE 1155	1. Porosity 2. Excessive Penetration	1. 92.5 2. 168	1. 18.5 2. 19.0
PLATE 14820	1. Crack 2. Porosity	1. 3.5 2. 136	1. 28.5 2. 25.0

Next the plates were radiographed using Digital Radiography System Durr NDT. The images were analysed and evaluated. The discontinuities found were analysed and compared to PAUT result.

Figure 12 : Digital radiography image of Welded Plate 1155

Figure 13 : Digital radiography image of Welded Plate14820

Table 2 : Discontinuities obtained by DIR

WELDING PLATE	TYPES OF DISCONTINUITIES	LOCATION FROM '0' (mm)	LENGTH OF DEFECT (mm)
PLATE 1155	1. Porosity 2. Excessive Penetration	1. 95.5 2. 187	1. 3.24 2. 17.8
PLATE 14820	1. Crack 2. Porosity	1. 19.9 2. 150	1. 25.7 2. 21.6

Conclusion

Comparing the result from PAUT and digital radiography, it was found that the same discontinuities were detected for both methods. However, the length of the discontinuities measured by using PAUT is partially longer than measured by using digital radiography. This is expected because edges of discontinuities are much more difficult to determine due to sensitivity and noise issues for digital radiography. Further work needs to be done with more specimens and statistical analysis to improve reliability of results.

Reference

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