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Welding Control using Ultrasonic Multi-elements Method

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Abstract

Ultrasonic Multi-elements is a safe and non-destructive inspection method. It is intensively used in industrial applications to search for hidden indications such as cracks, voids, porosity and other internal discontinuities in different materials. Such method is accompanied with an easy-to-use operating system. Indeed, when a sound wave strikes an object, it bounces back, or echoes. By measuring these echo waves, it is possible to determine the remoteness, the size, the shape and the consistency of any object. The ultrasonic multi-elements method is based on the use of transducer decomposed into individual elements that can be controlled independently. Thus, compared to the single-element technology, the phased array transducer allows a faster object scanning, an electronic focusing of the beam and a deflection for transmitting a beam in a plurality of incidence angle. In this task, the ultrasonic phased arrays are used to control the welding quality. This method has proven to be very appropriate technique for weld inspections. It can be applied to almost any weld profile and predicted defects. Besides showing the normal advantages of phased arrays for welds (high speed, reduced costs, full data storage and increased productivity).

1. Introduction

Non-destructive testing has become an indispensable tool in industry. These techniques permit to detect the heterogeneities and anomalies of apparatus or objects, without altering their operation or future use. Non-destructive testing includes several techniques, such as infrared thermography [1, 2] and Foucault currents.

This task deals with the use of the ultrasonic phased array technique, which is increasingly used in industry to control weld. The implementation of this control is both simpler and complex [3]. This technique is applied to monitor a V-type weld to assess the potential of this technology in terms of reducing control times, improving quality of results and facilitating interpretation. The current study aims to highlight the detection of weld defects [4, 5].

This paper is organized as follows. Section 2 presents a generality on the phased array. Section 3 describes the experimental framework. Then, section 4 combines the results and interpretations. Finally, section 5 is dedicated to conclusions.

2. Materials and methods

During recent decades, commercial ultrasonic instruments relied entirely on single element transducer using a piezoelectric crystal to generate and receive sound waves [6]. Dual element transducers that had separate transmitting and receiving crystals, and pitch-and-catch or through transmission systems that used a pair of single element transducer in tandem. These approaches are still used by the majority of current commercial ultrasonic instruments designed for industrial flaw detection and thickness gaging [7]; however, instruments using phased arrays are steadily becoming more important in the ultrasonic non-destructive testing (NDT) field [8].

The principle of constructive and destructive interaction of waves was demonstrated by Thomas Young in 1802 in a notable experiment utilizing two point sources of light to create interference patterns. Waves that combine in phase reinforce each other, while waves that combine out-of-phase cancel each other [9]. In the 1960s, researchers began developing ultrasonic phased array systems that utilized multiple point-source transducers that were pulsed so as to direct sound beams by means of these controlled interference patterns. In the early 1970s, commercial phased array systems for medical diagnostic use, first appeared using steered beams to create cross-sectional images of the human body (see Figure 1).

Figure 1: Phased arrays used for medical diagnoses

Initially, the use of ultrasonic phased array systems was largely confined to medical field, aided by the fact that the predictable composition and structure of the human body makes instrument design and image interpretation relatively straightforward [7]. Industrial applications, on the other hand, represents a much greater challenge because of the widely varying acoustic properties of metals, composites, ceramics, plastics, and fiberglass, as well as the enormous variety of thicknesses and geometries encountered across the scope of industrial testing [10]. The first industrial phased array systems, introduced in the 1980s, were extremely large, and required data transfer to a computer in order to do the processing and image presentation [11, 12]. These systems were most typically used for in-service power generation inspections. In large part, this technology was pushed heavily in the nuclear market, where critical assessment greatly allows the use of cutting edge technology for improving probability of detection. Other early applications involved large forged shafts and low-pressure turbine components [6].

3. Materials

3.1. *Phased Array Ultrasonic Flaw Detector*

Phased Array is an organized assembly of a large quantity of identical elements [13]. The simplest form of non-destructive testing ultrasound array is a series of single-element probe arranged to increase coverage or inspection speed. In medical and underwater sonar fields, recent years have seen the rise of array ultrasonic materials use [14, 15], both of which require highly sensitive and linear transduction systems. In this work, the Olympus Omniscan SX-PA Ultrasonic Flaw Detector described in [16] is used.

Figure 2: Omni Scan SX

This device allows both exciting phased array transducer elements with an adequate delay and receiving signals before converting them into different representations (A-Scan, B-Scan, C-scan, S-scan...). It is noted that the basic ultrasonic wave data representation is the A-scan view which shows the amplitude of the echo and the transit time on a single grid whose vertical axis represents the amplitude and the horizontal axis represents the time. Transit time, in turn, is usually correlated to reflector depth or distance, based on the sound velocity of the test material and the following simple relationship: Distance = Velocity * Time. The B-scan presentation is a profile view of the test specimen. In the B-scan, the time-of-flight (travel time) of the sound energy is displayed along the vertical axis and the linear position of the transducer is displayed along the horizontal axis. The C-scan is another possibility of presentation. This is a two-dimensional data presentation displayed as plan view of the part to be inspected. The planar images is generated on the flat parts by collecting the data of the locations on the x and y axes. The most common format for medical sonograms as well as for industrial phased array images is S-scan representation. It is also called sectorial scan image which represents a two-dimensional cross-sectional view derived from a series of A-scans that have been plotted with respect to time delay and refracted angle. The horizontal axis corresponds to test piece width, and the vertical axis to depth. The sound beam sweeps through a series of angles to generate an approximately cone-shaped cross-sectional image. It should be noted that in this example, by sweeping the beam, the phased array probe is able to map all three holes from a single transducer position [16].

3.2. Phased Array transducer

Ultrasonic transducers convert electrical energy into high frequency sound energy and vice versa. The transducer sends out inaudible, high frequency sound waves into the materials, and then, sensing the reflected echoes from it, similar to sonar used by boats and submarines. There are several types of phased array transducers, the most common are shown below [17]:

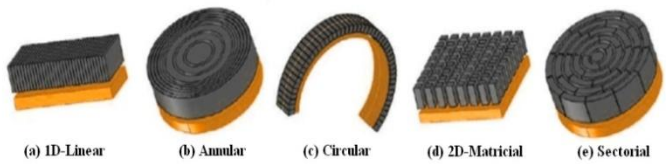

Figure 3: Different types of phased array transducers

a. Linear (figure 3 (a), as a whole, the elements are aligned according to axis. These transducers do not allow carrying out checks in the azimuthal plane of the transducer.
b. Annular (figure 3(b)), the elements are concentric rings. These transducers allow focusing the beam on different depths along an axis. The surface of the rings is in most cases constant, which implies a different width for each ring.
c. Circular (figure 3(c)), the elements are placed on a crown. These transducers are typically used for control of tube (by inside or outside).
d. Matricial, the elements are placed in two dimensions, for example in the form of checkerboard (Figure 9 (d)) or sectored rings (Figure 3(e)). These transducers allow perform the controls in 3D.

In this task, a phased array transducer composed of SA11-N55S wedge and 5L32-A11 probe is used. These array probes have a frequency of 5 MHz and have 32 elements.

Figure 4: Phased array transducer

3.3. The piece

The piece was welded in the Technological Platform of Mechanical and Materials Engineering laboratory (PFT-2M) of the applied sciences national school of Oujda. It is a solder containing two faces named OV and VO. It is a soft steel piece with 12 mm thickness. The welds natures are V-type.

Figure 5: The piece used in this work

4. Results and Discussions

The images bellow show the OV part scanning for different angle values. In the A-scan representation figure.6 to the right, the initial pulse generated by the transducer is represented by the signal on the left, which is near distance zero. As the transducer is scanned along the surface of the piece, other signals are likely to appear at different distances on the image. When the transducer is at 27 mm position, higher amplitude appears which shows the presence of the welding defect. In fact, the higher amplitude can be explained by the presence of the discontinuities in test piece surface.

Note that the red bar is a gate that allows selecting a part of the acoustic wave train for analysis. Here we cut off on the echo amplitude.

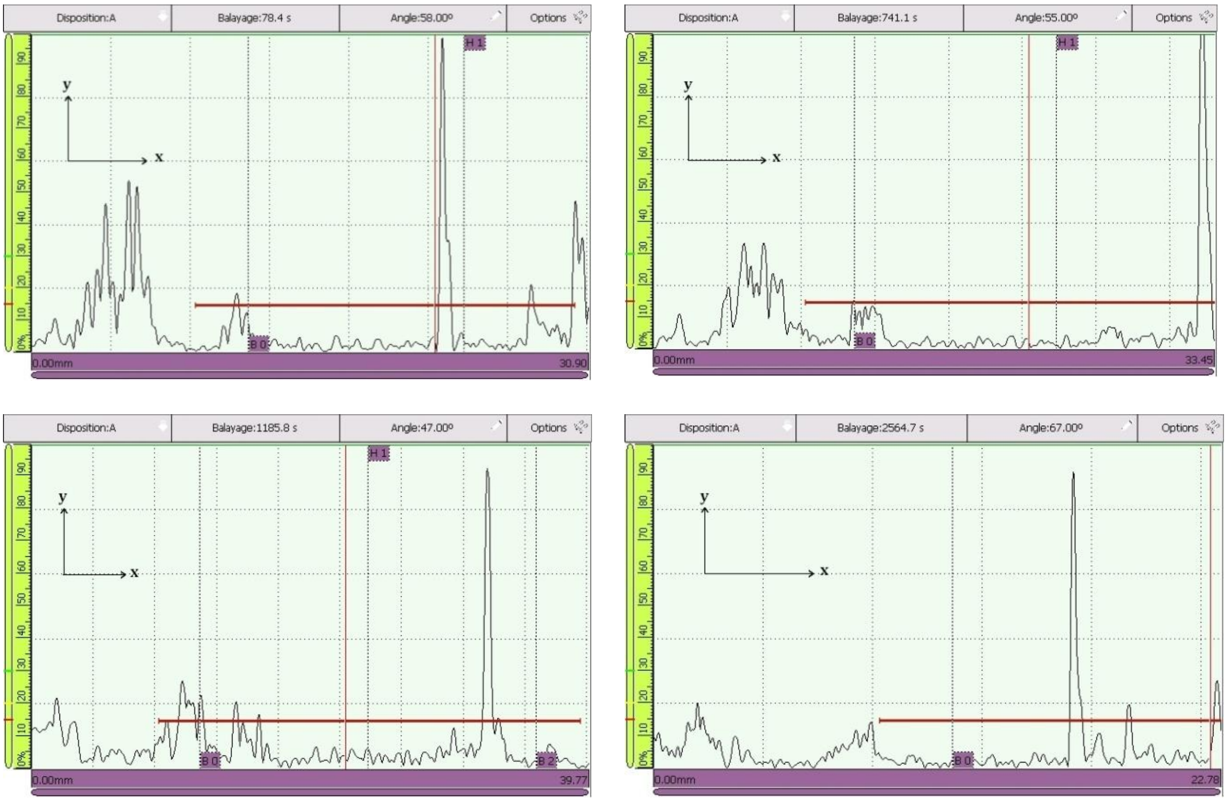

Figure 6: Cartography A-scan of weld OV Part

Figure.7 shows the S-scan representation of OV part scanning for different angle values. The horizontal scale under the S-scan images indicates the position of the reflector with respect to the rising edge of the probe, while the vertical color bar on the right side of the image is linked to the signal amplitude. The cross section represents the actual depth of the reflectors in the weld as well as the actual position relative to the front of the probe.

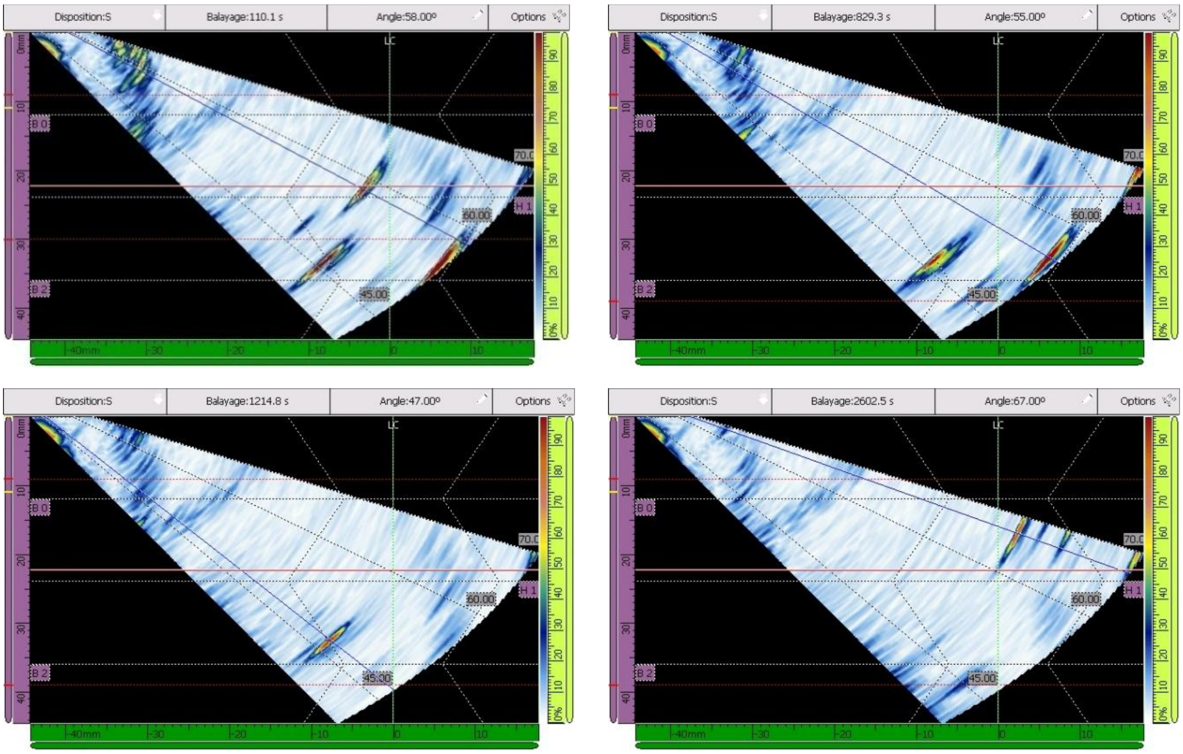

Figure 7: Cartography S-scan of weld OV Part

The images bellow show the VO part scanning for different angle values. Figure.8 shows the A-scan representation while figure.9 shows the S-scan one.

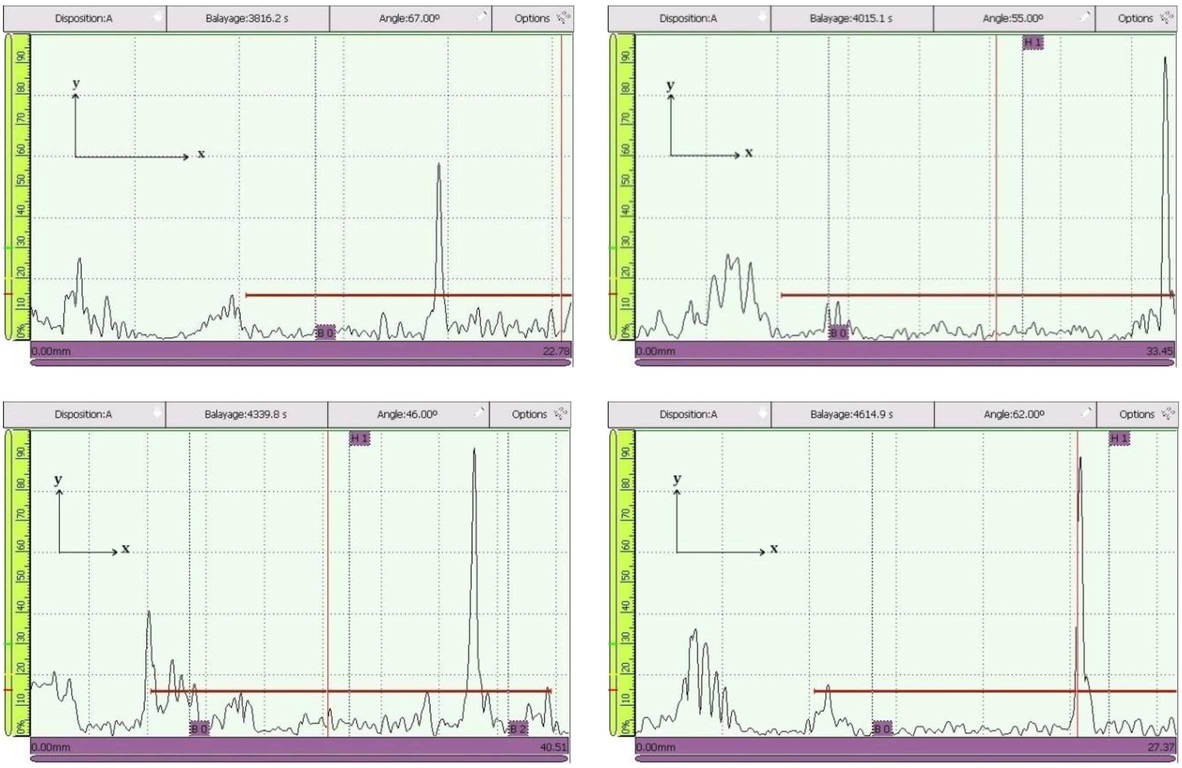

Figure 8: Cartography A-scan of weld VO Part

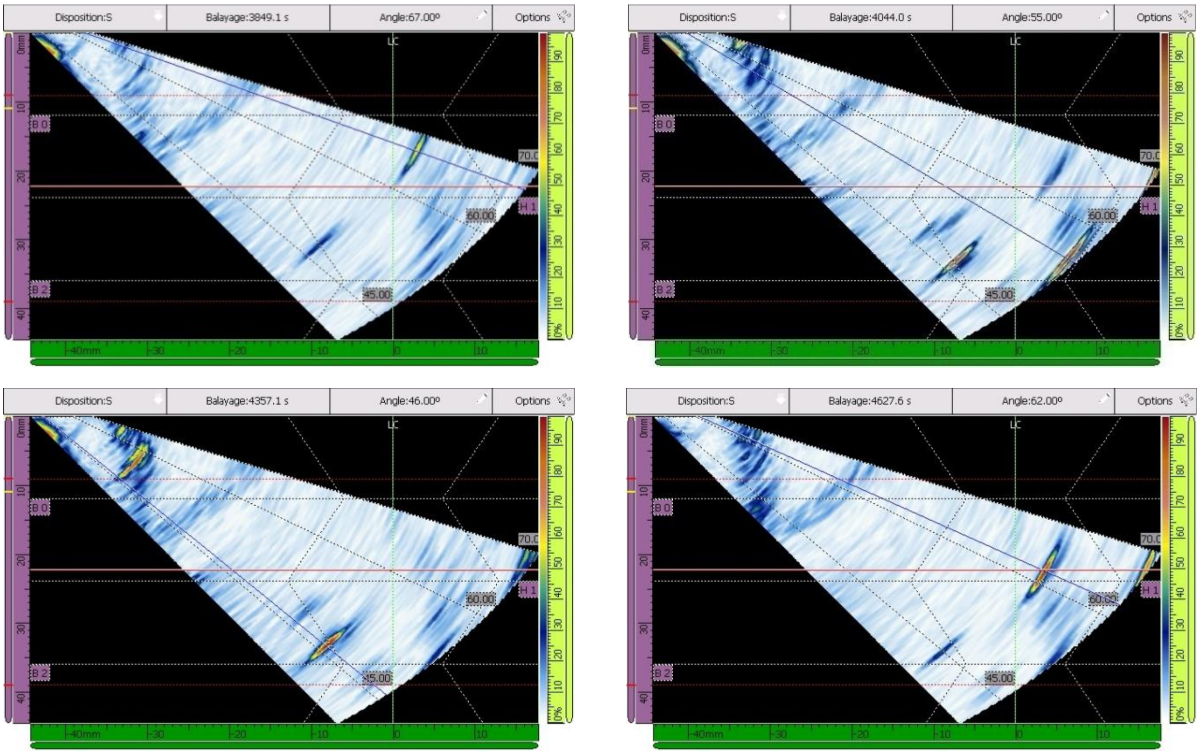

Figure 9: Cartography S-scan of weld VO Part

The result of the angular sweep shown above was performed with an aperture of 16 elements centered on the probe 32 elements. The pitch of each probe is 0.6 mm. This sweep was performed in real time so as to directly visualize the section below the probe which is moved on the inspected part. According to the section shape, the actual reflector depths in the material are represented. Thus, actual position of the defects with respect to the probe front is amounted. The horizontal scale presented in figure 6 and figure 8 indicate the depth or distance to the reflector represented by a peak given in the A-Scan, which has the vertical scale indicating the relative echo amplitude. The horizontal scale located under the linear scan image indicates the position of the reflector relative to the rising edge of the probe, while the color gamut of the right side of the screen is related to the amplitude of the signal. The blue line shows the angular component of the S-scan that is represented by the A-scan. Whereas, the horizontal red dotted lines mark the beginning and the end of the data gate used for measurement, and the vertical green line marks the position on the image that corresponds to the front of the wedge.

Conclusions

The aim of this task was to control the weld by using the ultrasonic technique which is a safe and non-destructive inspection method. In the current study an angular scanning of both welds faces has been carried out. The results are given in two different representations A-scan and S-scan. From the results obtained and shown in the above images of both weld faces, we succeeded to detect inspected piece defects. The nature of these defects can be an air bubble and or a lack of penetration. Through further analysis, the depth, size, and shape of the structure producing the reflection can be determined. The technique of control by ultrasound phased array, has allowed to examine the weld and to detect defects. It is concluded that this technique is very effective and easily implemented. Hence, it can be a reference technique for weld diagnosis.

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