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ULTRASONIC PHASED ARRAY FOR DEFECT CHARACTERIZATION

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ABSTRACT

Conventional ultrasonic transducers have limitations with respect to sensitivity and reliability. Also, for a complete imaging of the defects, scans at different orientations are required which is time consuming. The ultrasonic phased array systems with their beam steering capability, variable depth focusing, and real time B-scan imaging capability without mechanical scanning overcomes the traditional limitations of detection and sizing of unfavorably oriented defects even under restricted geometric conditions. This paper describes the initial experiments carried out on standard calibration blocks to demonstrate the accuracy of the phased array with respect to sensitivity and resolution. The efficiency and reliability of using a phased array to provide qualitative as well as quantitative assessment of defects is demonstrated by imaging the crack profile in a fatigue-loaded specimen.

Keywords: Phased Array, Crack characterization, beam steering, depth focusing

1. INTRODUCTION:

Conventional transducers are commonly used for inspection of plates, tubes and pipelines. The limitations of using such traditional transducers in defect characterization are well known. With the recent advent of ultrasonic Phased Arrays, it is of value and relevance to assess their performance for defect characterization on such specimens. The Phased Array concept is based on the use of transducers made up of individual elements that can each be independently driven. These probes are connected to specially adapted drive units enabling independent, simultaneous emission and reception along each channel. These units are also able to effect, during both emission and reception, different electronic time delays for each channel. For some applications implementing electronic scanning, all the elements of the probe are not used simultaneously. In this case, the drive unit uses dynamic multiplexing to distribute the active elements among the elements of the transducer. Electronic scanning consists of moving a beam in space by activating different active apertures selectively where each aperture is made up of several elements of a phased array probe. It allows a mechanical scanning axis to be replaced electronically. Electronic focusing is based on the use of electronic delays applied during emission and reception along each of the channels of the probe. These delays have an effect similar to that of a focusing lens and enable focusing to different depths. The use of several single-element probes with different focal distances can be replaced by a single phased array system using electronic focusing. Electronic deflection uses delay laws for electronic steering. They are calculated to give the emitted beam an angle of incidence, which can be varied simply by modifying the delay law. Electronic deflection enables only one probe to be used for inspections traditionally requiring several probes working at different angles. In addition, it allows the beam to be deflected without using a wedge, allowing parts to be inspected from very small spaces. Electronic beam steering and focusing are shown in Figure 2(a) and (b) respectively. Electronic scanning, focusing and deflection can be combined to resolve complex geometry inspections.

2. EXPERIMENTAL SETUP

The main components of a Phased Array system are presented in Figure 1(a) and the experimental setup of Phased Array system with calibration block is presented in Figure 1(b) below.

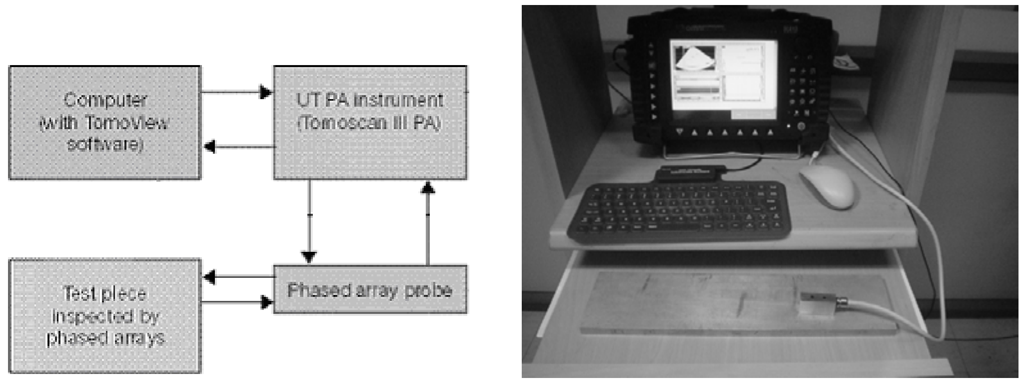


Figure 1. (a) Basic components of a phased Array array system **(b)** Experimental setup of Phased Omniscan MX with a 5 MHz probe

3. EXPERIMENTS:

The experimental setup used in this study consists of the R/D Tech Omniscan MX ultrasonic Phased Array system with linear phased array transducers. The data presented in this paper were acquired using 5MHz, 64 elements (46 mm x 15 mm area) probe. This paper discusses the test results obtained for vertical cracks in a 13 mm-thick Aluminium standard calibration blocks shown in Figure 3(a) imaged by sector scan technique and also detection and imaging of cracks in a fatigue-cracked specimen using phased array transducers. All the inspections for the defects in standard calibration blocks used a sectorial scan with an angular range from 20° to 70°, with an angle step of 0.2 degree. The angular range was arrived at after some trial experiments to completely accommodate the defect image within the sector. In order to prove the superiority of the Phased Array technique over traditional ultrasonic testing, defect imaging

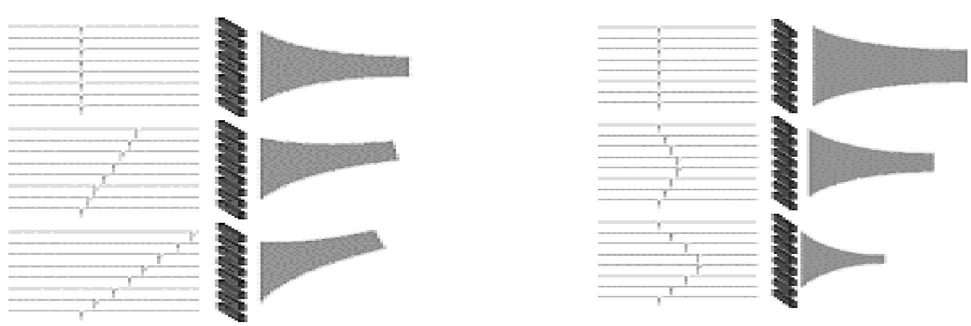


Figure 2(a): Beam steering in Phased Array **(b):** Beam focusing in Phased Array was done by traditional ultrasonic TOFD technique and a comparison between the two was made with respect to four vertical defects. A 5 MHz. frequency probe mounted on a 60° L wedge was used in the TOFD data collection. Data was acquired by moving the probes over the defect and defect free region and processed by TOFD imaging software.

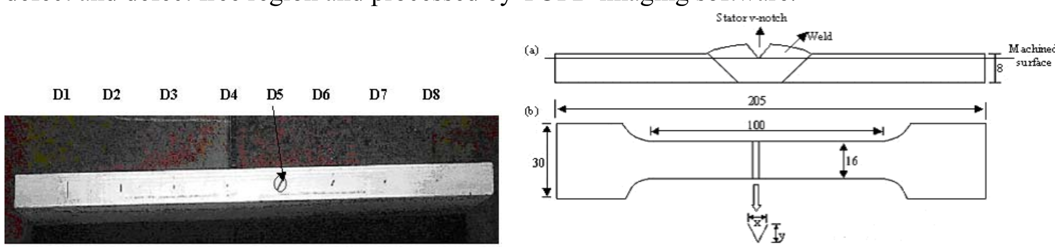


Figure 3(a): 13 mm-thick Aluminium sample with simulated defects

(b): Sketch of (a) side and (b) top view of with fatigue sample

A maraging steel weld sample with realistic fatigue cracks in the weld region shown in Figure 3(b) was prepared in the following way. A through-width V-notch was made to initiate the crack. The dimensions of the specimen and the crack initiating V-notches are provided in Figure 3(b). The sample was fatigued in a standard servo hydraulic testing machine. The crack initiation was monitored using the acoustic emission technique. Once the crack initiated, the crack length was controlled by controlling the load and number of cycles in the experiments. The sample was then ground to remove the crack initiator V-notch. This resulted in a surface-breaking realistic crack inside the material. The details of the V-notch dimensions and fatigue parameters are shown in Table 3.

5. DISCUSSIONS

5.1 Sector Scan

A sector scan is a plot between the scan length given along x axis and the thickness of the block given along the y-axis. The probe is moved along the scan axis till an undistorted image of the defect is obtained in the sector scan. By placing the cursor on the center of the defect, the corresponding ordinate gives us the position of the crack from the scan surface. The angles subtended by the defect tips with respect to the vertical can be read directly by placing the cursors on the extremities of the defect image.

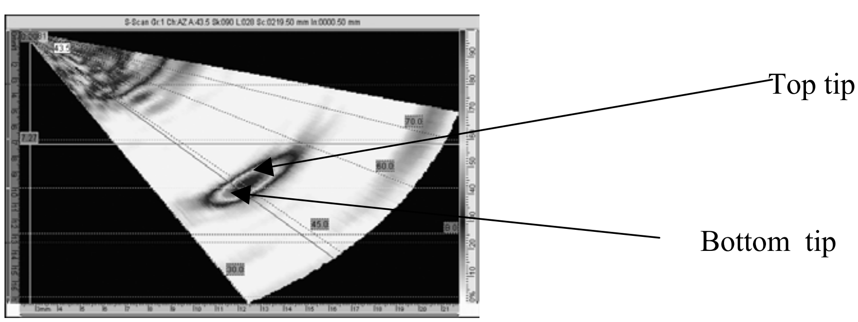


Figure 4 : Sector scan showing the image of a defect

5.2 Estimation of the length of the crack

The beam path within the specimen having a vertical crack is shown in Figure 5 below. Using the sector scan, it is possible to determine the angles subtended by the crack tips with the vertical. The angle subtended by the crack can be used to determine its length by using the formula given below.

$$GC = 2T[\tan\theta_1 - \tan\theta_2]$$

where GC is the length of the defect and T is the thickness of the specimen

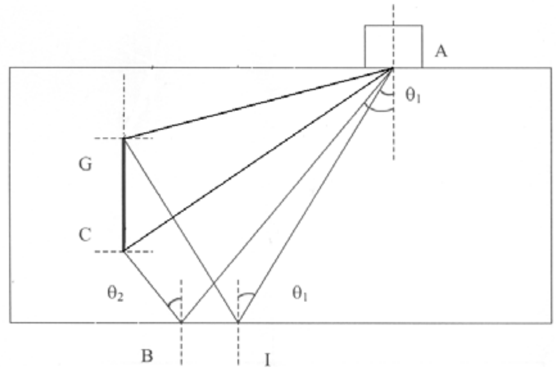


Figure 5 : Beam path inside the specimen

5.3. Crack detection and sizing by phased array technique on 13 mm-thick Aluminium calibration sample

Experiments were carried out with 13 mm thick Aluminium calibration sample with simulated defects , all of 0.5 mm width created using EDM [Figure 3(a)]. Experimental results for vertical EDM notches in the Aluminium sample using traditional ultrasonic TOFD B-scan imaging and sector scan using phased array are shown in Figure 6. It is very difficult to locate the crack tip echo directly from the traditional TOFD B-Scan image for the 6.5 mm vertical slot because the tip-diffracted echoes are superimposed with the lateral wave and back wall signals. The actual sizes of the defects and the angles subtended by the crack tips with the vertical as obtained from the sector scan of the defect are given in Table1 and the sizes of the defects obtained using TOFD technique and Phased Array and their respective percentage errors are given in Table 2.

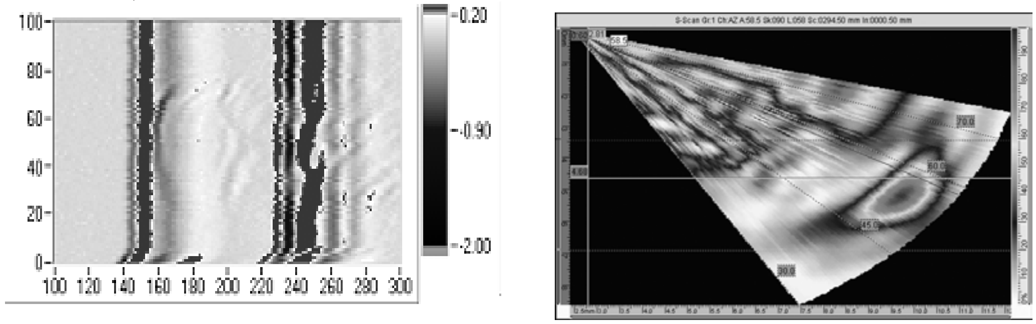
Table 1. The details of EDM notches, size and angles with respect to vertical

Defect Number	Type	Actual Length (mm)	θ_1	θ_2
D1	Vertical Slot	6.50	48.2	41
D2	Vertical Slot	3.25	45.4	41.6
D3	Vertical Slot	1.625	44.6	42.7
D4	Vertical Slot	0.8125	44.4	43.5

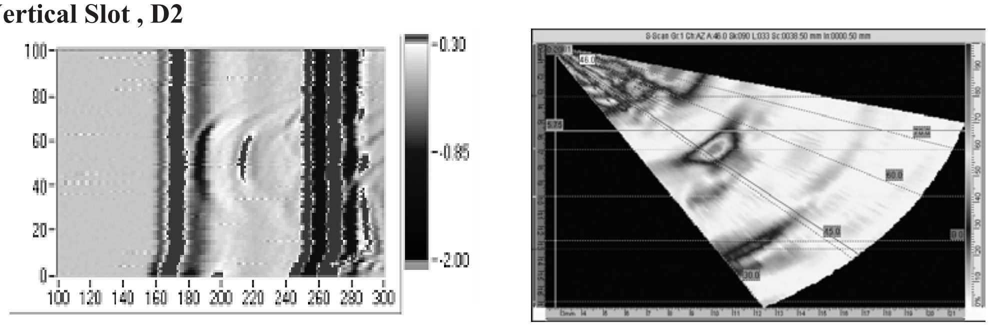
Table 2. Comparison between conventional TOFD and Phased Array

Defect Number	Actual Length (mm)	Defect Size estimated Using Conventional TOFD (mm)	Defect Size estimated Using Phased Array (mm)	% age Error using TOFD (Actual-TOFD) *100/(Actual)	% age Error using PA (Actual-PA) *100/(Actual)
D1	6.50	5.60	6.477	+13.8	+0.353
D2	3.25	2.90	3.28	+10.76	-0.92
D3	1.625	1.7	1.64	-4.6	+1.37
D4	0.8125	0.87	0.788	-7.076	+3.01

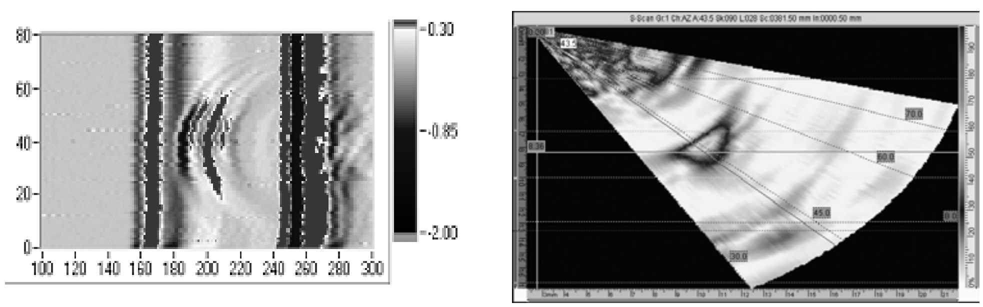
Vertical Slot , D1



Vertical Slot , D2



Vertical Slot , D3



Vertical Slot , D4

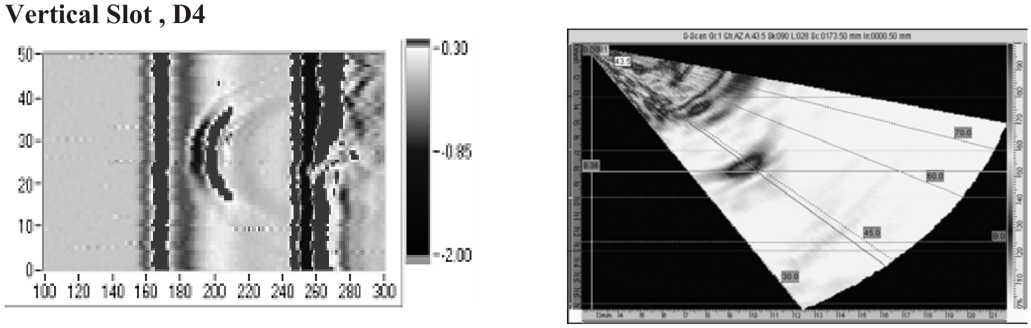


Figure 6: Comparison of the defect images obtained from conventional TOFD technique and Phased array

5.4 Inspection of thin sections (< 10 mm)

Inspection of thin sections are quite difficult as the number of mode converted signals reaching the receiver-transducer increases with decreasing thickness of the specimen. Moreover, in the case of surface breaking cracks the defect echo tends to merge with the frontwall and the backwall echo. The problem of inspection of thin sections can be tackled by using higher frequency (>=5 MHz) transducers, which increases the resolution of the B-scan image. This may be acceptable since the accompanying higher attenuation is less of a problem in thin samples. Using the phased array, it is possible to increase the angular resolution and vary the gain dynamically to clearly separate the defect echo from the backwall.

5.5 Crack detection and sizing by phased array technique on a 8 mm thick fatigue-cracked specimen

Experiments were carried out using 5 MHz frequency, 64 elements linear phased array probe. The testing used a sectorial scan with an angular range from -10° to 45°, with an angle step of 0.1 degree. The details of measured crack depth using phased array are shown in Table 2.

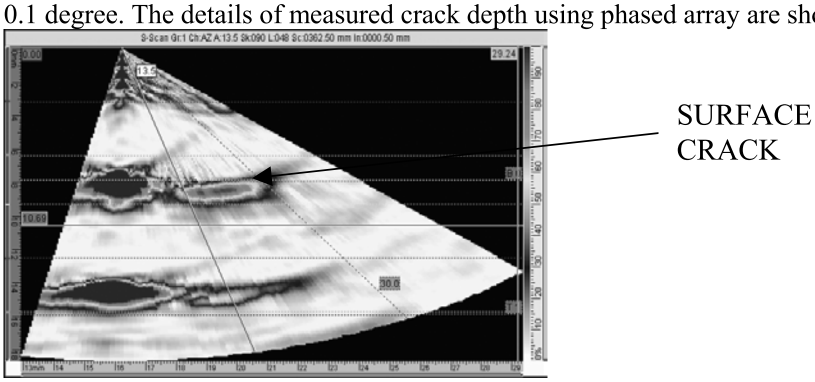


Figure 12: Sector scan of a dog bone fatigue cracked specimen showing presence of a surface breaking crack

Table 5. Fatigue testing details

Specimen thickness before (after) machining	V-notch dimensions X & Y	Maximum Fatigue load ((R?)loading ratio 0.2)	Number of cycles x10^3	Crack depth	θ_1	θ_2	Estimated crack size Using Phased array
8.58(7.2) mm	1.5 mm width 1.5 mm depth	4.0 tons	600	about 50% of the thickness	15.6	28.4	4.18 mm

6. CONCLUSIONS

The electronic scanning and beam steering capability of the phased array technique has been demonstrated for use in the imaging of defects in a standard calibration block as well as a fatigue-cracked specimen. Its superiority over the traditional ultrasonic testing with respect to imaging and sizing has also been experimentally shown. Initially experiments carried out on standard calibration blocks showed the efficacy of the phased array technique with respect to imaging of cracks and their improved quantification. The accuracy of the phased array technique was implemented on fatigue-cracked specimens, and this method was found to be effective for real cracks in an actual component.

7. REFERENCES

1. Introduction to Phased Array Ultrasonic Technology Applications, First Edition, R/D Tech Guideline, R/D Tech Inc.
2. J Poguet, J Marguet, F Pichonnat - IMASONIC S.A. / A Garcia, J Vasquez - TECNATOM,"Phased Array technology: Concepts, probes and applications ", 8th European Congress on Non Destructive Testing, June 2002, Barcelona, Spain
3. J.P. Charlesworth and J.A.G. Temple, "Engineering Applications of Ultrasonic Time of Flight Diffraction", Second Edition, Research studies press Ltd, England.
4. Baskaran, G, Balasubramaniam, K and Lakshmana Rao, C, "Ultrasonic TOFD flaw sizing and imaging in thin plates using Embedded Signal Identification Technique (ESIT)", Insight - Non-Destructive Testing and Condition Monitoring (The Journal of The British Institute of Non-Destructive Testing), Vol 46, No9, September 2004.