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ELIMINATION OF FAILURES OF NARROW GROOVE WELD JOINTS, THOROUGH PHASE ARRAY INVESTIGATION

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Abstract

Machine down time as well as repair and maintenance of structural components are costly and difficult to manage due to size, weight, and expertise to repair at site. Considering fabricated structures being back bone of any machinery, this work deals with analysis and action to eliminate critical failure of specific joint which are narrow grove joints, by detecting potential defects using Phase Array Ultrasonic testing methodology. The circular joint discussed in this article was welded with semiautomatic setup and has probability of weld defects, because of narrow and shallow joint design. Design change for ease of manufacturability was also not feasible due to excessive cost of die change and machining process involved. Even if design changes could be done, it was not feasible to check joint using conventional non-destructive inspection methods due to thickness limitation of parent materials constituting the joint. In absence of proper inspection methodology, defects were not arrested inside circular weld joint of boom foot boss and resulting in premature failures of boom at field. Through this investigation technique of Phase array, failures were eliminated and enhanced the overall structure of life.

Keyworks
Fabricated structure; boom; boom foot boss; weld defect; phase array ultrasonic testing.

1. Introduction

Fabricated boom has multiple butt joints, fillet joints and circular weld joints. Welded boom foot boss section of boom is having circular butt weld joint (Yener 2005). All critical welded joints were subjected to conventional ultrasonic testing (Arsić et al. 2021). But due to joint form and inaccessibility of conventional ultrasonic testing circular butt joint of boom (Yener 2005)foot boss had never been subjected to ultrasonic testing. To resolve critical and pre-mature welding failure of boom foot boss circular welding various process improvements were done but were not able to eliminate the failure. Stated boom foot boss weld joint was quite susceptible to welding defect due to very narrow groove joint design and, were not able to detect weld defect with conventional ultrasonic testing machine. Design of joint configuration change had some limitations so, failed to change narrow groove joint to better joint configuration. Magnetic particle testing was assessed (Vetterlein and Georgi 2006), but due to limitation of depth of assessment of magnetic partial testing, it was not successful. Magnetic particle testing has limitation of depth or thickness of 6 to 7 mm, and we need to assess weld joint of 8 mm depth and 9 to 10 mm including depth of penetration. Above issues created need for some advanced and innovative technology for weld joint inspection, to identify defects and so repair weld defect could be done.

D. J. Huggett & M. W. Dewan et al. (2017) while comparing the NDE technique of digital X-ray radiography with Phase array ultrasonic testing (PAUT), found that a calibrated PAUT system is able to discover defects less than 0.2 mm where X-ray radiography could not. Incomplete penetration (IP), wormhole (WH), surface cavity (SC), and internal void (IV) defects are analysed. Furthermore, an online PAUT system for FSW has been developed and successfully evaluated.

Li, Zhou et al. (2019) in their work established a full-coverage inspection solution using multi-array transducers. The whole inspection area was divided and the wedge parameters in each subarea are iteratively designed. Based on the finite element method (FEM), a response simulation model of the ultrasonic array was established to testify the feasibility and validity of the inspection scheme of butt welds for complex surface parts using ultrasonic phased array.

Geonwoo, Kimab Mu-Kyung et al. (2020) in their work developed a phased array ultrasonic system for detecting rail cracks (PAUSR), which consists of two phased array (PA) ultrasonic transducers, a water tank, a display monitor, a battery, a commercial sixty-four channel PA board, and its control software. To accomplish this, the acoustic fields and crack detection images of newly developed PA ultrasonic transducers were simulated and analysed by the CIVA (CIVA 2016, NDE CIVA, USA) software. The major design factors for the PAUSR are the capability of evaluating crack size (over 2 mm), generating proper acoustic fields in the rail and easy and safe handling for operators.

1.1 Details of excavator boom

Basic details of excavator boom are specified in Figure 1. This boom is made of combination of various cut plate sections and had 3 major minting section called boom foot boss, center hub and end bracket. Boom for boss and center hub were made of combination of forged section at both ends and tube at middle portion, which were combine using welding at circular weld joints between forged end sections with middle tube.

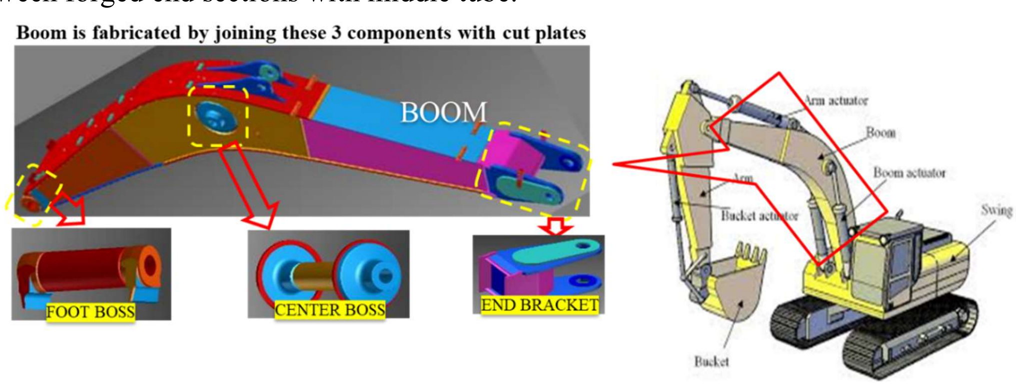


Figure 1: Details of excavator boom

1.2 Problem description

Joint Configuration: Boom foot boss is sub assemble of cylindrical hollow tube at center and machine forging sections at both ends . These 3 parts , 2 forgings and 1 tube were joined together using a welded circular butt joint as specified in Figure 2.

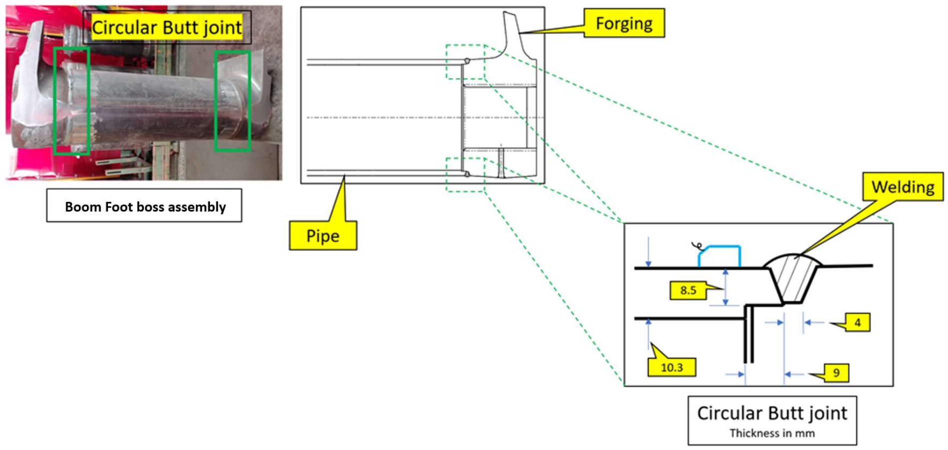


Figure 2. Boom foot boss joint configuration

1.3 Failure details

Circular butt welded joints were reported with visble cracks on the surface , as specified in Figure 3. Fauilres were reported at average hours within 2000 hours of machine operation at site . This failure hous was considered to be very pre-mature considering average operation of of machine upto 10000 hours. This failure of weld joints results in immediate breakdown of exacavtaor for customer and needs to either reapir locally of replace the boom structure. Both this actions were considered to be very costly and time consuming for both manufactururs and customers.

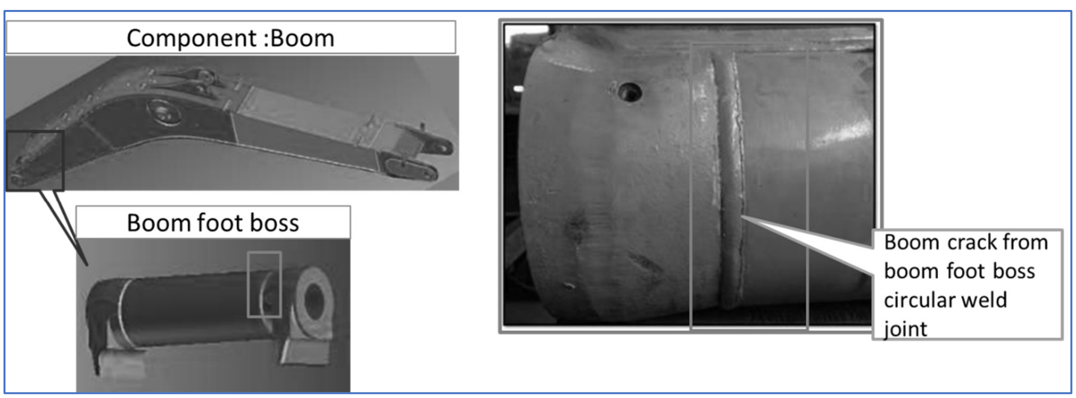


Figure 3: Failure detail- crack in boom foot boss circular joint

1.4 Root Cause Analysis: Failed part received at manufacturing plant for failure analysis

Once failure part was received from field, quality team had initiated failure cause analysis. Metallurgical and mechanical tests for the failed components were found to be accepted. The defect details of failure analysis observation are stated below in Figure 4 a. and 4 b. As per macro sample examination lack of fusion was observed at the root of the section towards joining end of central tub of boom foot boss. The fracture surface depicted that the crack initiated from the lack of fusion zone at root of weld section and propagated towards the surface of weld joint. No fusion found in root run welding: length- 50mm height- 5mm. as specified in Figure 4 b.

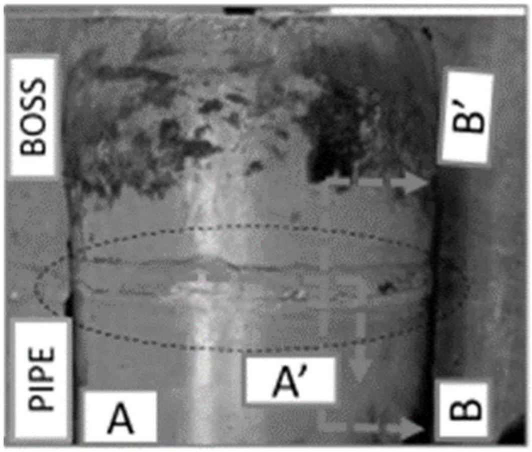


Figure 4 a.: details of circular weld joint crack

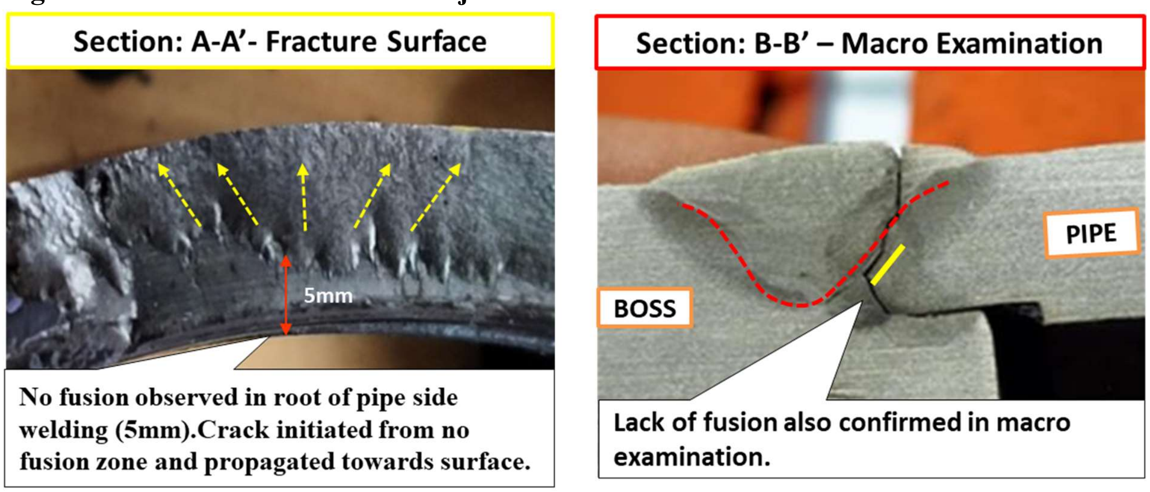


Figure 4 b.: details of circular weld joint crack, defect location at root of weld section

1.5 Fishbone analysis for cause of lack of fusion

As a standard practice and tool for root cause analysis Fish bone or Ishikawa (Liliana 2016) has be deployed to identify the actual cause of failure and specified in Figure 5. In this work gap of nondestructive testing (NDT) has been taken for improvement.

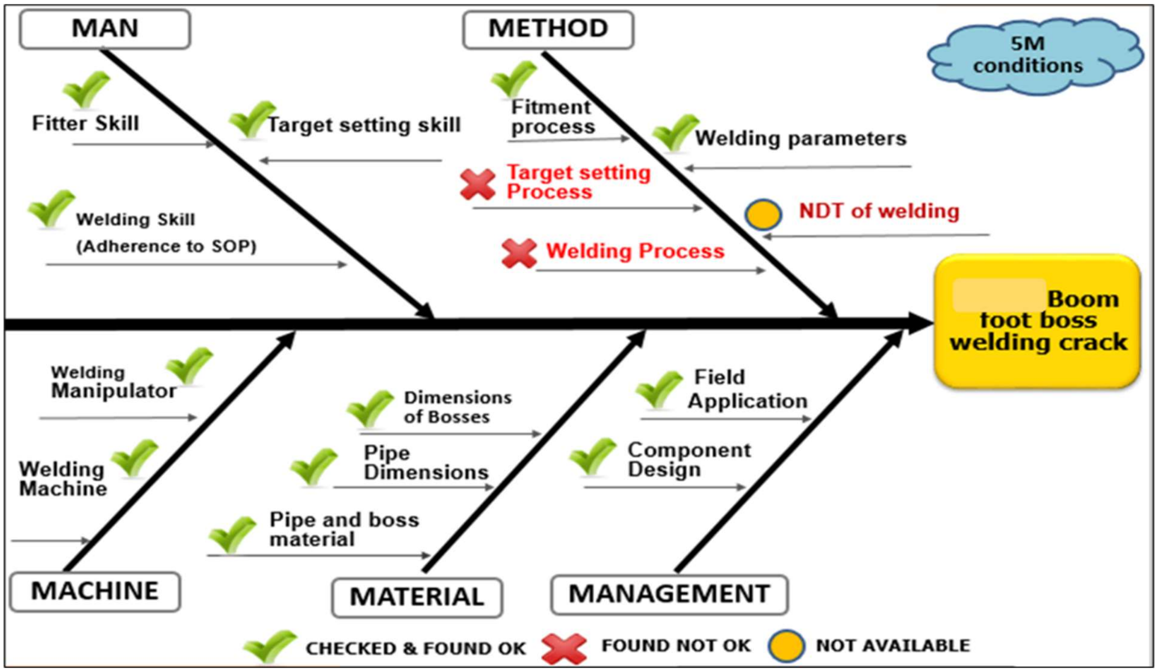


Figure 5: Fish bone or Ishikawa for lack of fusion

2. Methods

2.1 Understanding of Phase array ultrasonic testing (PAUT)

The term "phased" refers to "delay applied": the sequential firing of elements and the term array refers to multiple crystals/elements in the PAUT Probe (Quantification 2009).

The basic principle behind Phased array ultrasonic testing is Acoustic impedance Mismatch (Mulaveesala 2021). The distinct feature that makes PAUT stand out from conventional ultrasonic testing is PAUT's ability of beam formations and data presentation. The conventional ultrasonic probe commonly consists of a single piezoelectric material which acts as both transmitter of ultrasound and receiver of ultrasound (Tabatabaeipour et al. 2016) or probe with two piezoelectric materials one for transmitting the ultrasound and one for receiving the ultrasound. The Phased array ultrasonic probes consist of multiple piezoelectric materials that could be pulsed /fired individually. These multiple piezoelectric elements are arranged in patterns within a housing called as arrays. The PAUT probes typically have anywhere between 16 to 256 elements. Linear array Probe with eight elements, as specified in Figure 6 (Rhim, Shin, and Lee 2008) and (Sudhir, n.d.). If all the elements are pulsed/fired together simultaneously, the resulting wavefront is because of the interference of various spherical waves from each element. This wavefront is like the ultrasonic beam produced by a zero degrees normal probe with the same probe dimensions as this multiple-element array.

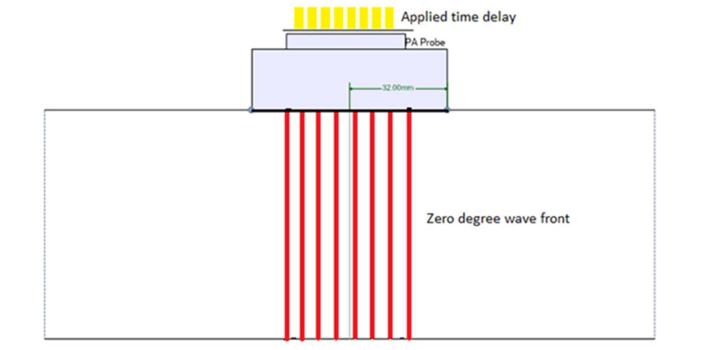


Figure 6: Linear array Probe with eight elements

For the wavefront to be steered at a particular angle, there should be a constant delay in pulsing between each successive element in the probe. This wavefront generated as specified in Figure 7, due to this delay in pulsing is like ultrasonic beam produced by a conventional ultrasonic angled probe(Sudhir, n.d.).

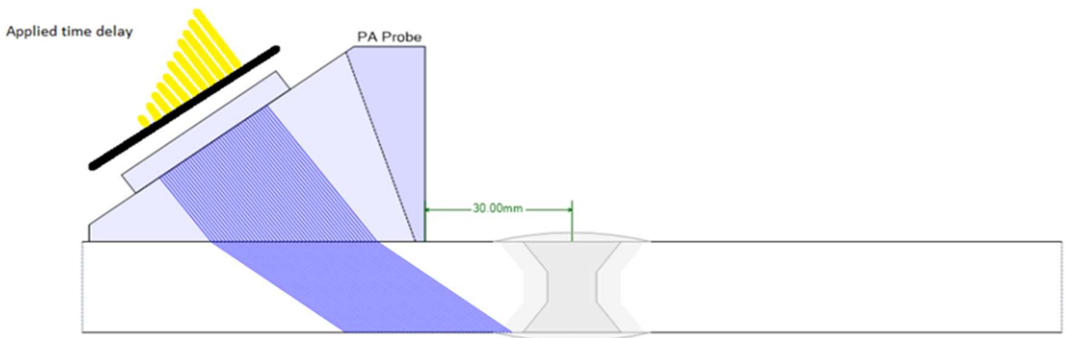


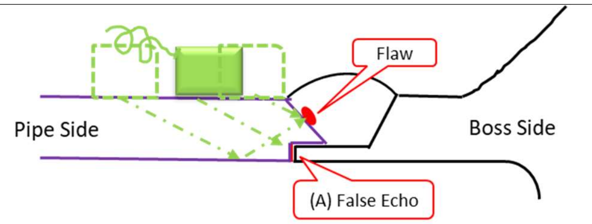
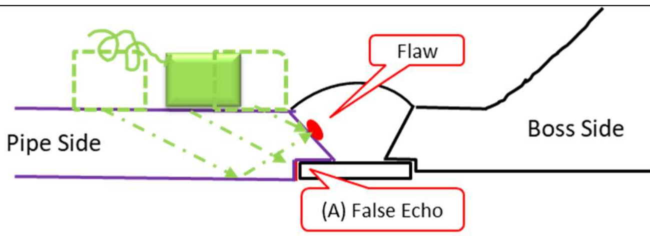
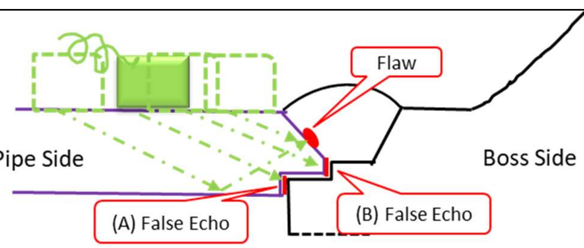
Figure 7: Wave front

Phased array systems can sweep a sound beam through a range of refracted angles (Sectorial scanning) or along a linear path (Linear scanning), or dynamically focus on different depths. Due to this feature of using a range of beam angles in PAUT, the probability of detection of discontinuities was better when compared to conventional ultrasonic testing. For 100% weld volume coverage, raster scan required when using conventional ultrasonic testing. Phased array provides adequate coverage with one or more lines scans (depends on the thickness of material) (Sudhir, n.d.).

2.2 Identification of challenges in present conventional ultrasonic testing

Before stating to explore application of phase array ultrasonic testing, it was important to understand the limitation faced with scanning using the conventional ultrasonic testing. The identified practical limitations or constraints of conventional ultrasonic testing is specified in Table 1. This stated a limitation that assessment would be subjected on inspector's discretion

Table 1: understanding of practical constraints

Sl. No.	**Boss and pipe weld joint Detail**	**Description**
Case 1		• False indication at position A. • UT can be done considering this false indication and verifying flaw echo at half and full skip. • Assessment is subjected on inspector's discretion
Case 2		• False indication at position A. • UT can be done considering this false indication and verifying flaw echo at half and full skip. Assessment is subjected on inspector's discretion
Case 3		• False indication at position A and B. • Distinction between false indication and flaw echo is difficult. • Assessment is subjected on inspector's discretion

On analysis of practical situation, a fact surfaced that due to joint configuration and thickness limitation for Case 1 & Case 2 as stated above Table 1, it was difficult for inspector to judge the defect location and he needs to be more judgemental on theoretical basis. This may result in missing defects. In case of Case 3, as specified in Table 1, it was completely not feasible for him to isolate defect and give judgement.

2.3 Selection of suitable configuration of machine

Suitable machines and probe combinations were selected and specified in Figure 8. Omniscan SX, Olympus Make (Lamarre 2017) phase array ultrasonic testing machine was selected with probe specification of SL16-A10 suited with 12 steps/mm of encoder.

Figure 8: details of Phase array ultrasonic testing machine and probe specification

2.4 Machine set-up

Details of setup and sequence specified in Figure 9 & Figure 10. The machine setup in instrument wizard has two steps. First step is to define part and weld, as specified in Figure 9 Second stage is setup in instrument wizard for starting the process of scan as specified in Figure 10.

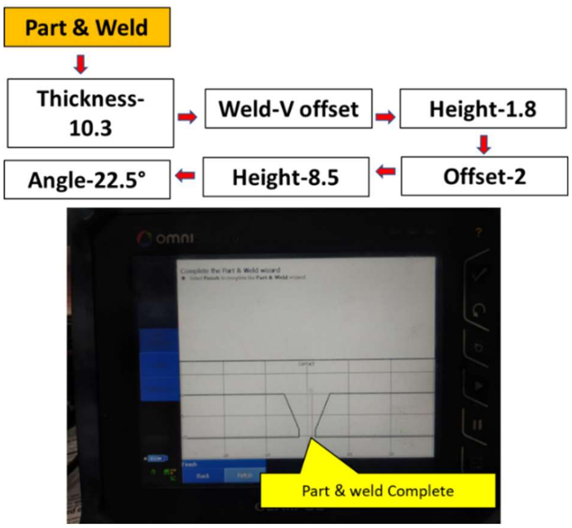


Figure 9: Defining part and weld in instrument wizard

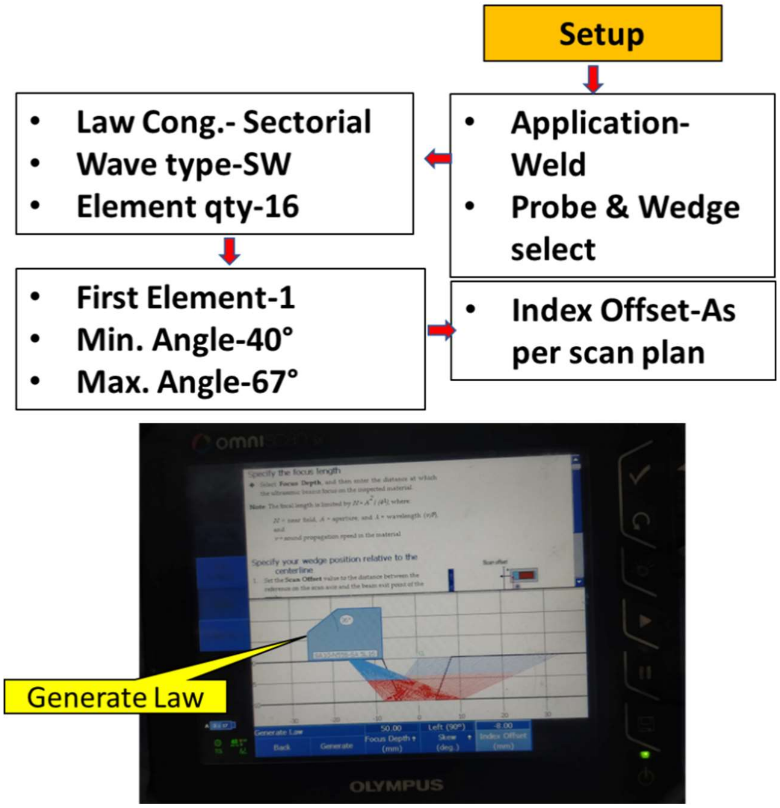


Figure 10: Setup in instrument wizard

2.5 Preparation of Demo test pieces and calibration

For ease of understanding of location and nature of defects dummy calibration block were prepared, which was replica of actual job and joint configuration. It helped inspector for easy isolation of multiple defects and actual positioning, details as specified in Figure 11.

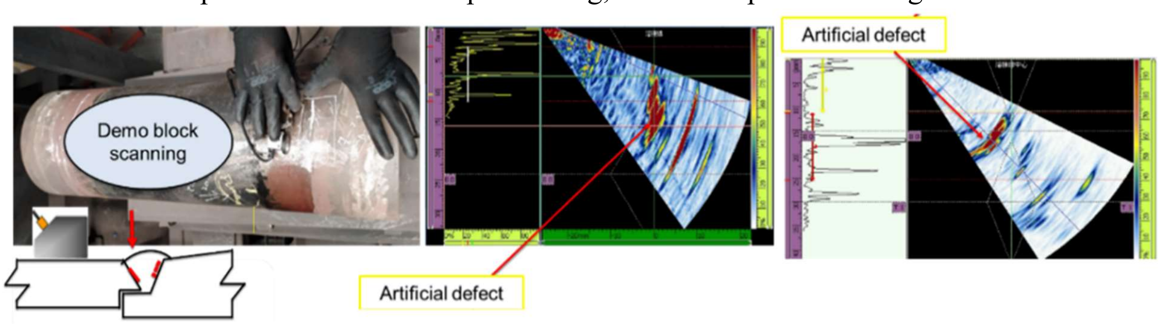


Figure 11: Details of dummy calibration block

2.6 Standardization of calibration methodology:

This is important so the error free judgement could be made, and exact location, size and depth of defect can be identified. Calibration methodology is complex, and sequence of operation as specified in Figure 12, consisting of three steps viz. Step A called as velocity calibration, Step B called as wedge delay calibration & Step C called as sensitivity calibration. In Step A of velocity calibration, sound speed calibration was performed using the Radius part of the STB-A1 test piece (Yamada, Yano, and Udagawa 2004). 100 unit was selected as the reflection echo from R100 in “Radius 1”, similarly 200 for R100's repetitive reflection echo in radius 2. Setting of the radius 1 and radius 2 was done. Angle axis was selected for sound velocity calibration in “Angular axis.” The speed of sound calibrated on the selected angle axis will be applied to the other angle axis. 250 was selected for “Measuring range” of 0 to 250 to sufficiently cover the reflected echo from the 200 mm path. Scanning of the probe back and forth was done to fix it at the peak position so that the reflected echo of R100 captures the peak. In Step B of wedge delay calibration, wedge delay calibration was performed using the Radius part of the STB-A1 specimen (Yamada, Yano, and Udagawa 2004). Selected the radius with “Echo Type” with 100 as the reflection echo from R100 in “Radius A”. Entered 1 for "Tolerance". Numeric value set by radius A ± 1 position (In this case, 99mm and 101mm positions). Entered the range of the angle axis to be calibrated in “Angle end position.” Entered 75 this time. R100 reflected echo gate A was adjusted to the “Start position” and “Width” so that the (red gate) is enclosed. 80.0% gain was set " that appears when pressed and hold the gain shortcut and set the peak echo in Gate A to 80%. “Next” was the Gate A setting for radius A. The probe was scanned back and forth so that the reflected echo of R100 captures the peak, and the depth information at the peak position was recorded for each angular component. The probe was scanned back and forth so that the reflected echo of R100 captures the peak, and the depth information at the peak position is recorded for each angular component. In case the echo exceeds 100% or falls below the gate A threshold, depth information could not be recorded correctly. In that case, adjusted the “gain” each time. After recording peak echoes for all angle components, press Calibrate” to calibrate depth in formation.

To check whether the calibration has been performed correctly, the probe was scanned back and forth again to confirm that the depth information captured by all angle components is within the pre-set tolerance.

If the wedge delay has been calibrated correctly, approval for finishing the wedge delay calibration is given. In Step C, sensitivity calibration was performed using φ1.5mm SDH of STB-A1 specimen (Yamada, Yano, and Udagawa 2004), “measurement range” was adjusted so that a φ1.5 mm SDH echo can be confirmed at 40 ° and 70 ° when scanning back and forth and Reference Amplitude” is set at 80% with a tolerance of +/-5% amplitude. range of the angle axis to be calibrated in “Angle end position is selected as 75, Gate A (red gate) surrounds the reflection echo of Φ1.5mm SDH adjusted “Start Position” and “Width” with 10 threshold. The probe was scanned back and forth so that the reflected echo of Φ1.5mm SDH captures the peak at all angles, and the peak echo height information was recorded at each angle component. The peak echo of all angle components was kept within 20% to 80%. Adjust “Gain”. When all the peaks do not fit within 20% to 80% with “Gain” adjustment `` Correction gain ‘’ was used. With all the peaks within 20% to 80%, correction gain setting was done. To check whether the calibration has been performed correctly, the probe was scanned back and forth again to confirm that the peak echoes captured by all angle components were within the preset tolerance.

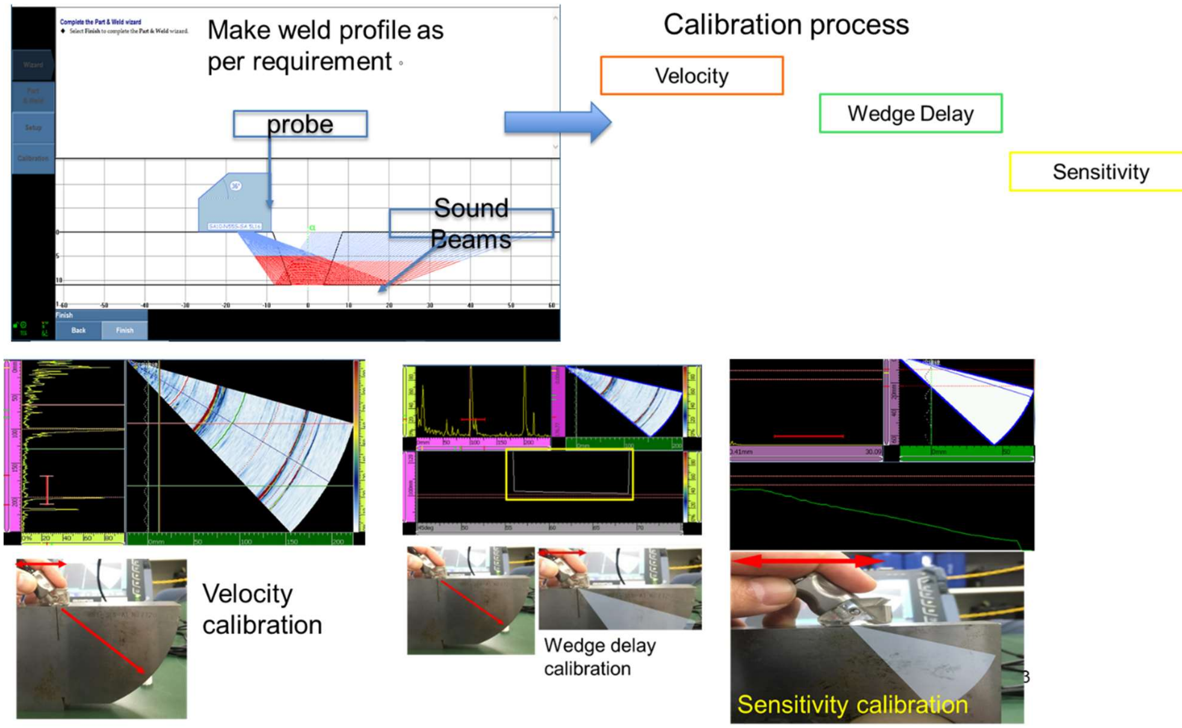


Figure 12: Details of calibration

2.7 Evaluation of Defect

Evaluation of defect was performed in a sequence of steps as stated in Figure 13, it consists of C -S-S-C scan procedures.

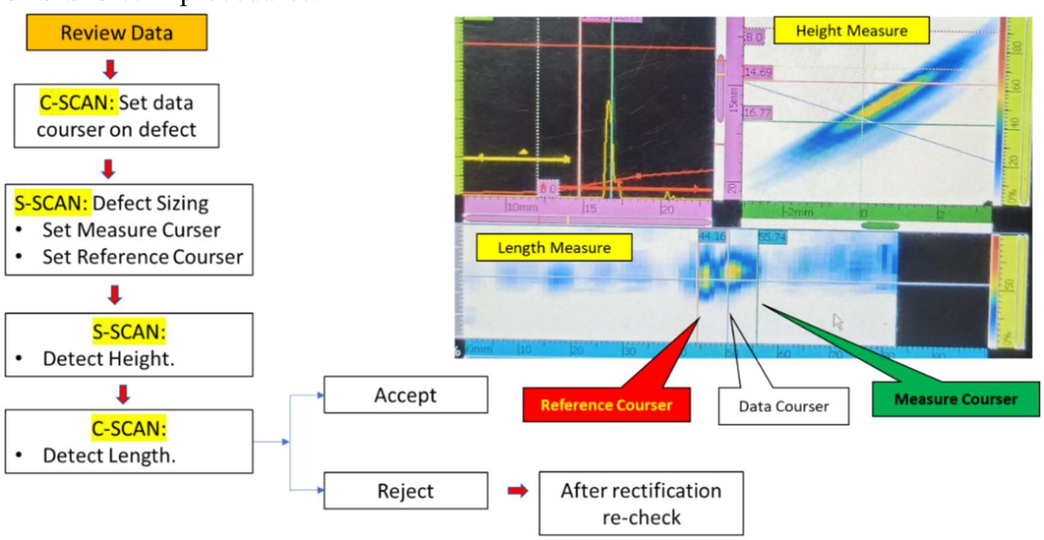


Figure 13: Details of scanning steps for defect identification

2.8 Flow Chart of Accept & Reject

Defect acceptance/rejection steps was performed as per steps detailed in Figure 14.

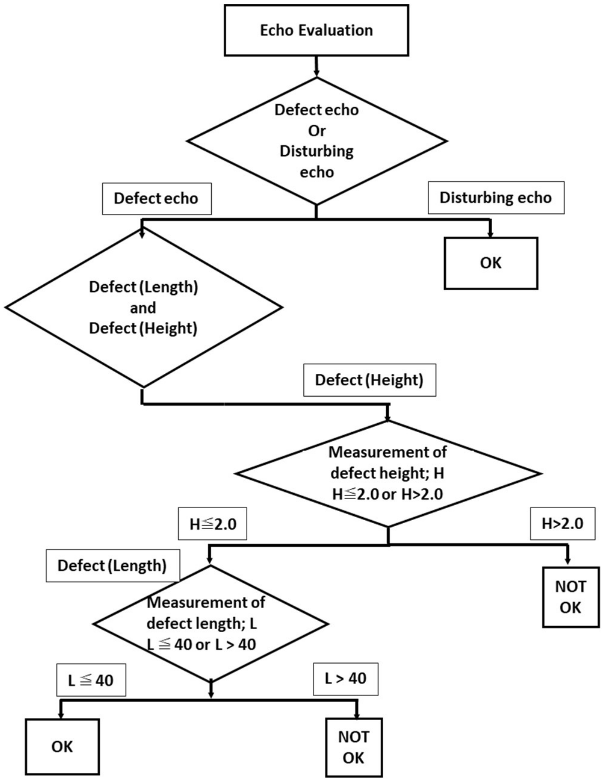


Figure 14- Defect acceptance, rejection flow chart

3. Results

Phase array ultrasonic testing was implemented for excavator boom foot boss weld joint test with 100 % coverage of joints. After implementation of phase array, inspectors were able to identify the defects in critical weld joint which they were not able to check earlier through conventional ultrasonic testing and able to arrest average 15 % of defect jobs being send to customer.

Once able to identify defects, defects were repaired, and rechecking was performed for defective joint. This improvement had resulted complete elimination of defects and failures of stated circular boom foot joint and hence eliminated customer's machine downtime. Defect maps observed using phase array ultrasonic testing are shown in Figure 15 & Figure 16 for lack of fusion and porosity defect respectively, within the weld joints.

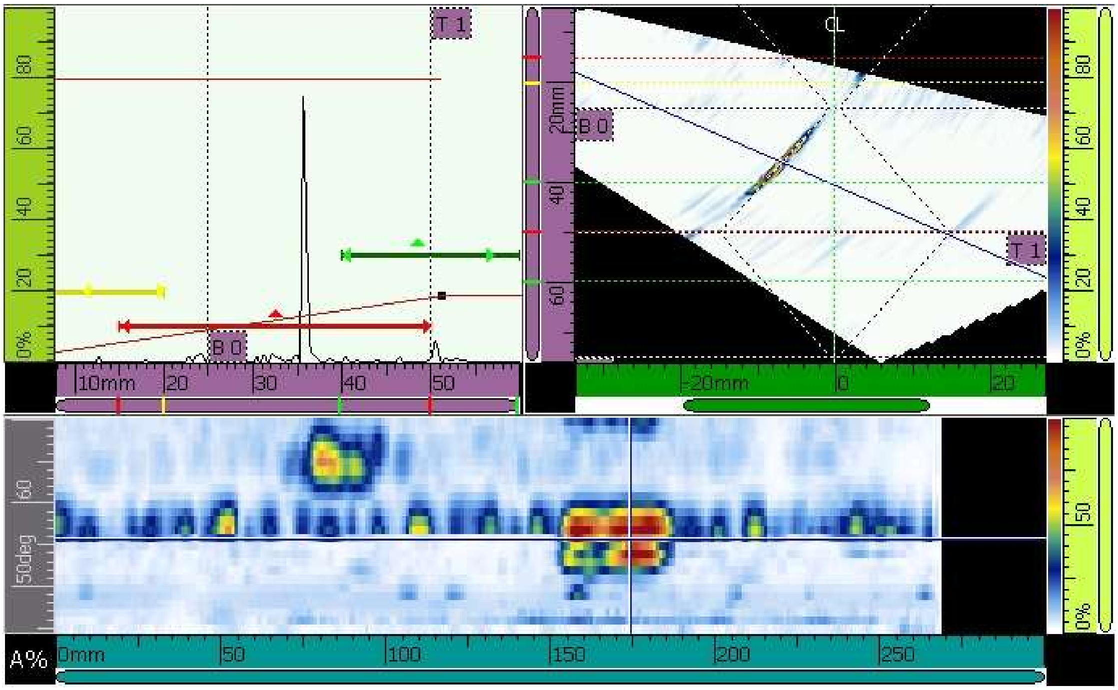


Figure 15: Defect map for lack of fusion observed with weld joint

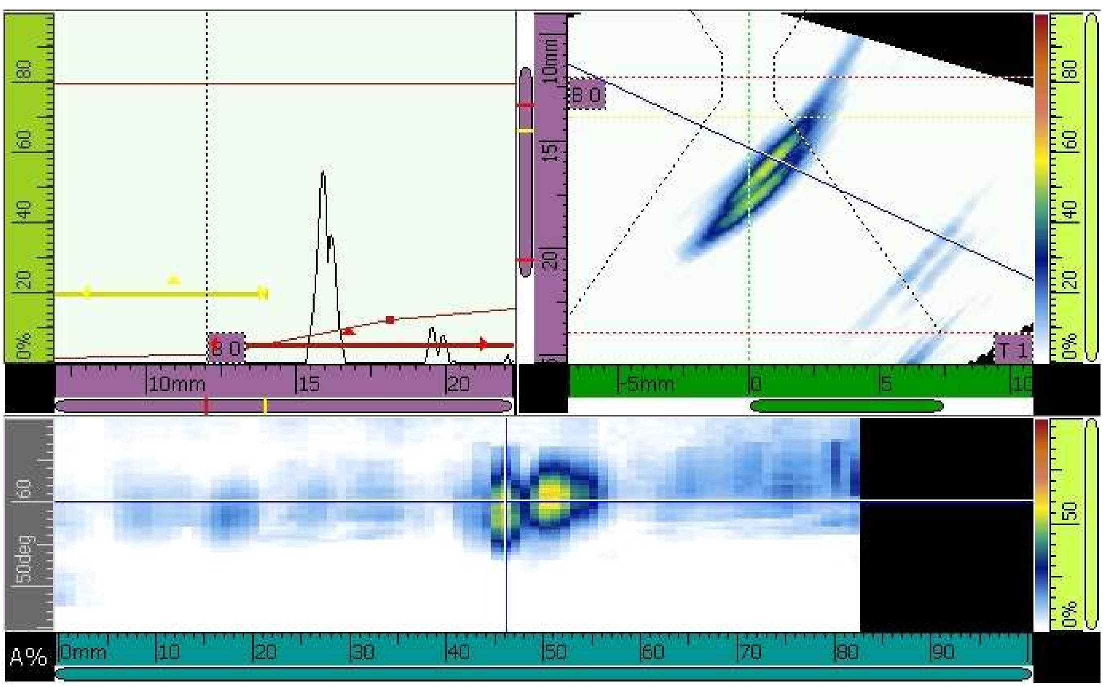


Figure 16: Defect map for lack of fusion observed with weld joint

4. Conclusion

Implementation of phase array ultrasonic testing for assessment of joints which were not suitable with conventional ultrasonic testing machine was found to be useful in detecting the

defects which were missed in conventional ultrasonic testing machine. Phase array was also suitable in case of failure of implementation of magnetic particle testing.
Thickness and narrow joint configuration were not found to have any limitation in phase array examination. The user was able to arrest 100 % defects in critical joint by using phase array ultrasonic testing and hence resulted in zero failures in field and reduction in down time of machineries for customer. On an average 15 % jobs were arrested from being send to customer with defect, because the user was able to identify the defects and conduct necessary rectification.

Declaration of interest statement

The authors report there are no competing interests to declare

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