



CALIBRATION OF PHASED ARRAY ULTRASONIC TESTING (PAUT) USING MASTER CASTING REFERENCE BLOCK

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ABSTRACT :

This study involves the preparation and utilization of a master casting reference block with multiple flat-bottom holes (FBH) at different depths for the calibration of Phased Array Ultrasonic Testing (PAUT) equipment. The block was designed to simulate different defect depths in a uniform medium, enabling proper sensitivity adjustment and accuracy verification of the PAUT system.

KEYWORDS : Phased Array Ultrasonic Testing (PAUT), Spheroidal Graphite Iron (SGI), Casting defects, Non-Destructive Testing (NDT), Defect characterization.

INTRODUCTION

Phased Array Ultrasonic Testing (PAUT) is an advanced non-destructive testing (NDT) technique widely used for the detection and sizing of internal flaws in metallic and non-metallic materials. Unlike conventional ultrasonic testing, PAUT utilizes multiple elements within a probe to generate and steer ultrasonic beams electronically, enabling better coverage, higher accuracy, and faster inspection. For any ultrasonic inspection, calibration plays a critical role

in ensuring accuracy, repeatability, and reliability of results. A reference standard or master calibration block is generally used to set sensitivity levels, verify depth accuracy, and establish linearity of the system. The calibration block is usually manufactured from material similar to the test component, with artificial reflectors such as flat-bottom holes (FBH), side-drilled holes (SDH), or notches at predefined depths. In the present work, a master casting calibration block was fabricated with four flat-bottom holes at depths of 11 mm, 25 mm, 40 mm, and 55 mm. This configuration simulates artificial reflectors at different depths, enabling proper calibration of PAUT equipment across a wide thickness range. By using this master block, the accuracy of time-of-flight, sensitivity adjustment, and flaw detection capability of the PAUT system can be established before actual component inspection.

1. Challenges in Conventional Ultrasonic Testing

- High acoustic attenuation due to graphite nodules
- Scattering of ultrasonic waves leading to poor signal-to-noise ratio.
- Limited coverage and angle dependence in single-probe UT.
- Difficulty in detecting small defects in complex casting geometries.

2. Phased Array Ultrasonic Testing (PAUT) Principles

- **Multiple Elements:** A PAUT probe consists of several small piezoelectric elements that can be fired individually or in groups.
- **Beam Steering:** The ultrasonic beam can be electronically steered at different angles without physically moving the probe.
- **Dynamic Focusing:** Provides improved sensitivity at different depths.
- **Sectorial Scanning (S-Scan):** Generates a 2D image of defects within the casting

3. Application of PAUT in Casting Inspection

- **Defect Detection:** Porosity, shrinkage cavities, hot tears, and inclusions can be detected with higher accuracy.
- **Defect Sizing & Imaging:** PAUT enables accurate sizing through C-scan and S-scan imaging.
- **Coverage:** Larger inspection area in shorter time compared to conventional UT.
- **Case Study (Example):** PAUT detected shrinkage defects of size 2–4 mm at depths up to 40 mm, which conventional UT failed to identify reliably.

Comparison of PAUT vs Conventional UT

Probe Type

- **Conventional UT:** Uses a single piezoelectric element probe. The probe has to be mechanically moved and angled to cover different regions. The inspection depends entirely on the skill of the operator to find the correct angle and location.
- **PAUT:** Consists of multiple (typically 16–128) small piezoelectric elements within a single probe. These can be pulsed individually or in groups, allowing electronic beam steering and focusing. Hence, one PAUT probe can replace multiple conventional probes.

Coverage

- **Conventional UT:** Coverage is limited because the probe can send waves only in a fixed angle at one time. To cover multiple angles or large volumes, the probe must be repositioned several times, which is time-consuming.
- **PAUT:** Provides wide coverage using sectorial scanning (S-scan). The beam can sweep through a range of angles electronically without moving the probe. This reduces inspection time and ensures complete volumetric coverage.

Defect Sizing Accuracy

- **Conventional UT:** Can detect defects but has limited capability to size them accurately. The sizing is mainly based on signal amplitude and is affected by operator interpretation. Accuracy is typically poor (variation of ± 2 – 3 mm).
- **PAUT:** Offers dynamic focusing and multiple scan modes (B-scan, C-scan, S-scan), which allow accurate measurement of defect size, orientation, and depth. Accuracy can be within ± 0.5 mm for most applications.

Imaging Capability

- **Conventional UT:** Provides only A-scan (1D) display. This is a simple amplitude vs. time signal, which requires expert interpretation and gives no visual image of the defect.
- **PAUT:** Provides multiple imaging modes:
- **A-scan:** Basic signal display.
- **B-scan:** Cross-sectional view along a line.
- **C-scan:** Plan view mapping defects in 2D.
- **S-scan:** Sectorial view showing defects at different angles.

These imaging modes make defect detection, sizing, and reporting much easier and less operator-dependent.

Operator Dependency

- **Conventional UT:** Highly dependent on the operator's skill, experience, and interpretation. Small mistakes in probe angle, coupling, or interpretation can lead to missed defects.
- **PAUT:** Semi-automated, with beam steering and real-time imaging, which reduces dependency on operator skill. Automated scan plans can be designed and repeated consistently.

Time Efficiency

- **Conventional UT:** Moderate efficiency. Since multiple probe positions and angles are required, inspection is slower, especially for large castings with complex geometry.
- **PAUT:** Much faster. With electronic scanning, multiple angles are inspected in a single pass. Larger volume can be covered in less time, reducing inspection cycle time in foundries or production environments.

Equipment Used

Phased Array UT (PAUT)

Instrument: Sonatest VEO3

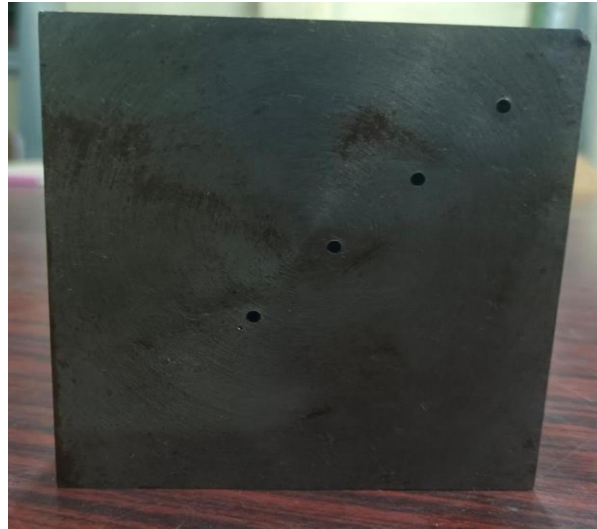
Probe: 5L64 (5 MHz, 64-element linear array) Wedge: 0° and 45° refracted longitudinal

Experimental Setup

Material of Block : Steel Casting Block Size : Square plate (as shown)

Calibration Holes :

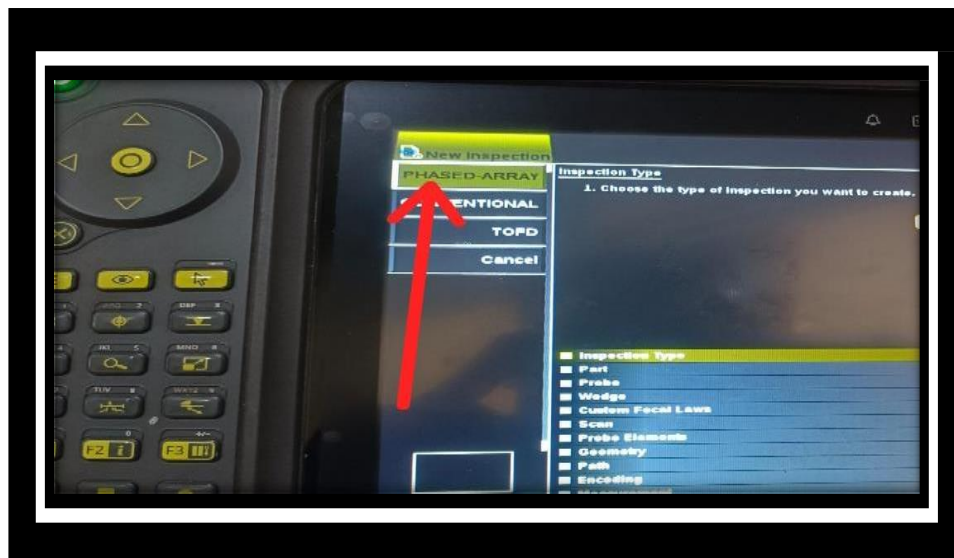
- Hole 1 – 11 mm depth
- Hole 2 – 25 mm depth
- Hole 3 – 40 mm depth
- Hole 4 – 55 mm depth

**Testing Procedure**

PAUT:

NEW INSPECTION

- Choose the type of inspection you want to create (ex. PHASED ARRAY)

**PART**

- Choose the kind of part being inspected. (ex. plate)
- Choose the weld geometry being inspected.
- The chosen material will be used to determine the velocity used while inspecting (ex. Iron)

PROBE

- Load a predefined probe configuration from the probe database or define your own probe.

WEDGE

- Load a predefined wedge configuration from the wedge database or define your own wedge.

CUSTOM FOCAL LAW

- Define where source of focal laws comes from.
- If an external source (other than sonatest) is chosen, please select file containing the focal laws, otherwise you can't pass the step.

**SCAN**

- Choose the type of scan (ex. sectorial PE)

PROBE ELEMENTS

- Set the first active elements of the probe
- Set the last active elements of the probe

GEOMETRY

- Place your probe.

PATH

- Choose where to start sampling A-scans
- Choose the scan path length
- Define the scan resolution
- Define the scan angles
- Choose the focalisation type
- Define the focal distance

ENCODING

- Choose the type of encoder to use, if any. (ex. Time based)

MEASUREMENT

Select your 6 preferred measurements for the top measurement bar.



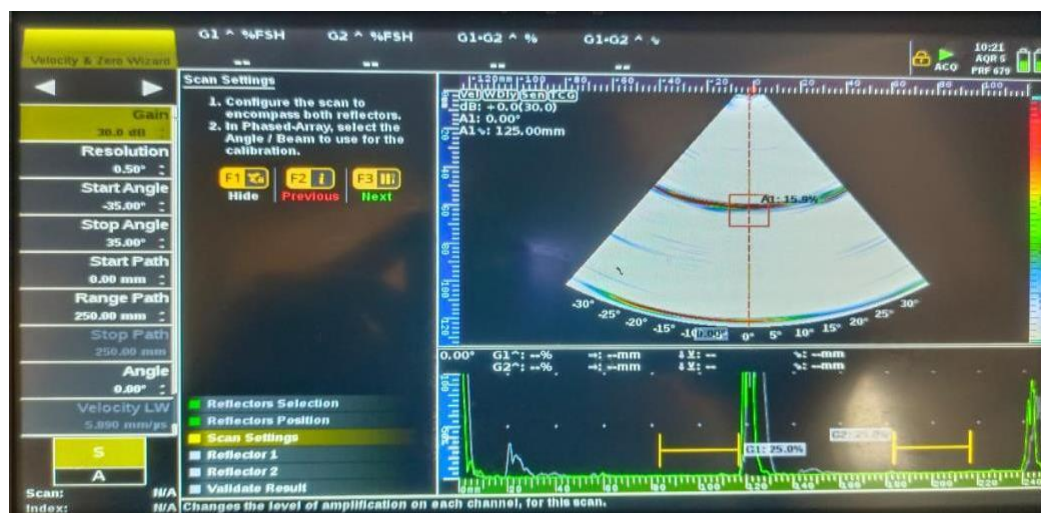
CALIBRATE

VELOCITY & ZERO WIZARD REFLECTORS SELECTION

- Select which kind of reflectors will be used to calibrate the velocity and zero (delay). choose either radius, SDH (side-drilled holes) or backwall reflectors. the focalisation method will be modified will be for the duration of the calibration to constand path for radius reflector and constant depth for the others.
- For Curved PA Configuration, only radius supported.

REFLECTORS POSITION

- Enter the position of the two reflectors used for calibration. For the radius calibration, enter the two radius, for side drilled holes, enter the depth of each hole, for backwall reflectors, enter the two thickness.



REFLECTOR 1

- Position the gate over the first reflector
- Adjust the gain to obtain a peak of 80% FSH for the first reflector.
- Move the probe to create an envelope in the A-scan.
- Press F3 to capture the peak envelope position.

WEDGE DELAY WIZARD

- Select the reflector type

SCAN SETTING

- Enter the scan setting to use for this calibration. Note that you could calibrate the sectorial scan on a large angle range and later decide to reduce this range and still have a valid calibration.



BOX POSITION

- Position of the box cursor so that it encompasses the reflector correctly.

REFERENCE AND TOLERANCE

- Enter the reference and tolerance path or depth.

CALIBRATION

- Move the probe back and forth to create the envelope.
- Press "apply" to compare and set the calibration.
- Verify your calibration by moving the probe back and forth again. The red line should be inside the tolerance.
- Press accept to compare the wizard.



SENSITIVITY/ACG WIZARD SCAN SETTING

- Enter the scan setting to use for this calibration. Note that you could calibrate the sectorial scan on a large angle range and later decide to reduce this range and still have a valid calibration.

BOX POSITION

- Position of the box cursor so that it encompasses the reflector correctly.

REFERENCE AND TOLERANCE

- Enter the reference amplitude and tolerance % for this calibration.

TCG/DAC/DGS WIZARD

- The TCG/DAC/DGS Wizard item guides the user in a step by step fashion to calibrate the TCG, DAC OR DCG Curves.

TCG (Time corrected gain)

- The DCG Wizard equalized the amplitude level of a given reflector size at different sound path by adjusting the gain. the unit increases or reduces the gain progressively to correct the attenuation in the material and the effect of focusing.

DAC (Distance amplitude correcting)

- The DAC Wizard creates a DAC Curve representing the signal amplitude change of a given size reflector at different sound path. The DAC curve is plotted on the A-scan without changing the gain. These curves work like deflection gates, set at different screen height to compensate for the attenuation in the material and the effect of focusing.

DGS (Distance gain sizing)

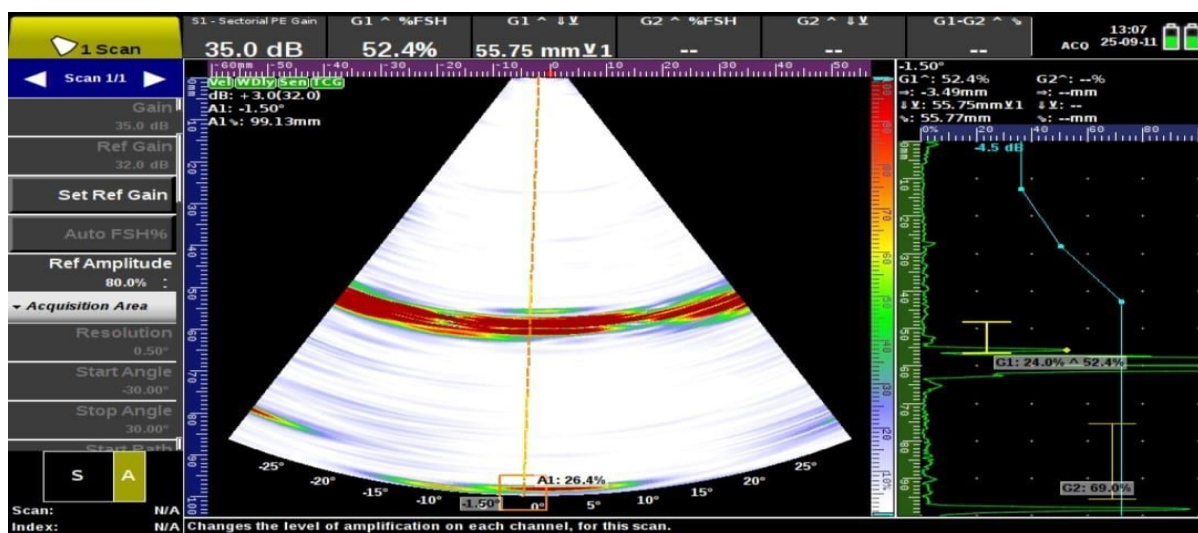
- The DGS Wizard created an attenuation curve to size disk shaped reflectors. The attenuation curve takes into account the probe and reflector characteristics. These curves work like detection gates, set at different screen height to compensate for the attenuation in the material.

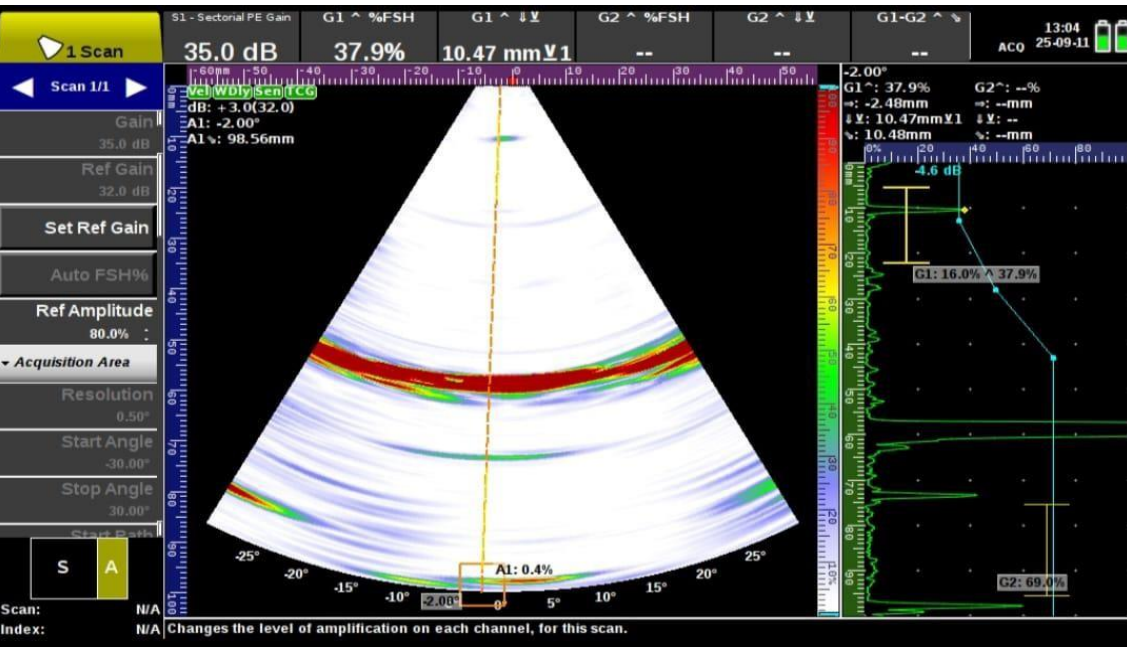
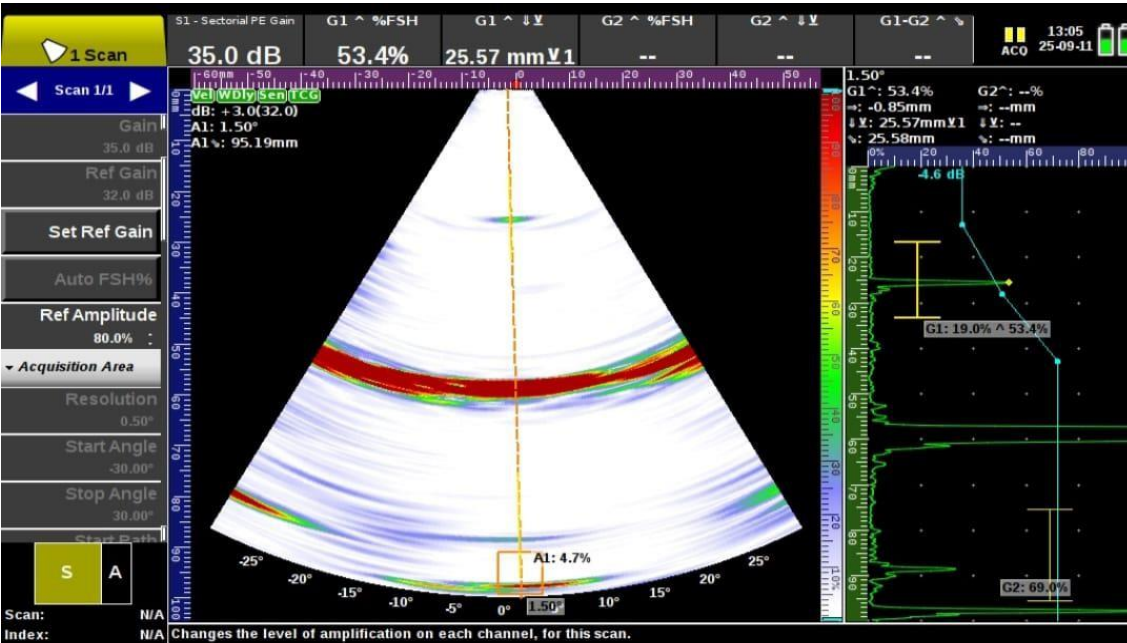
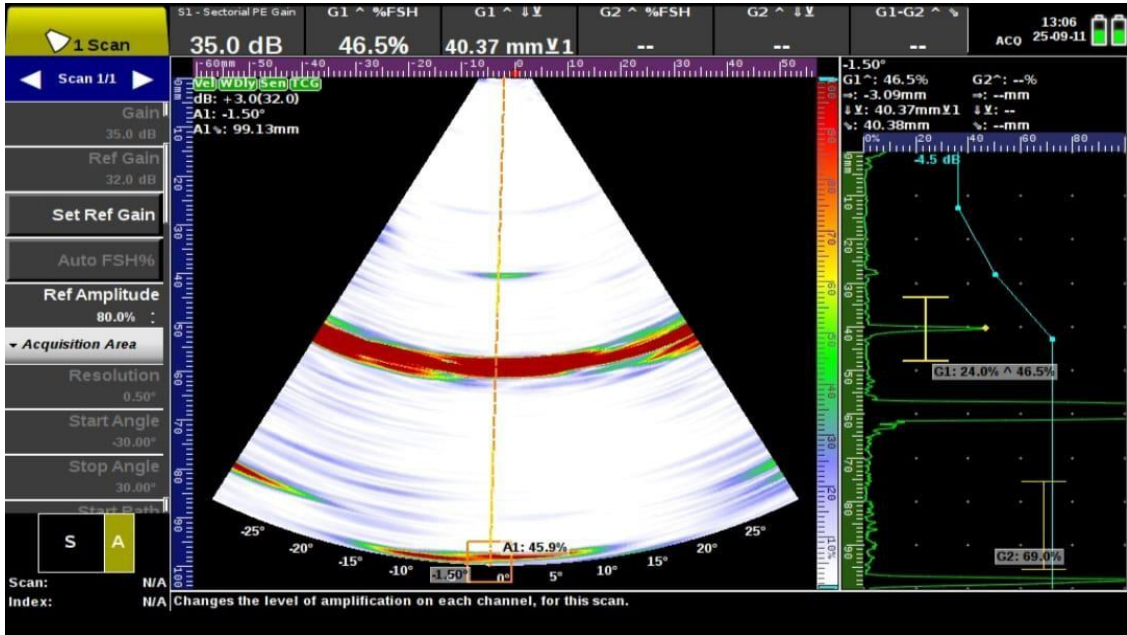
Observations

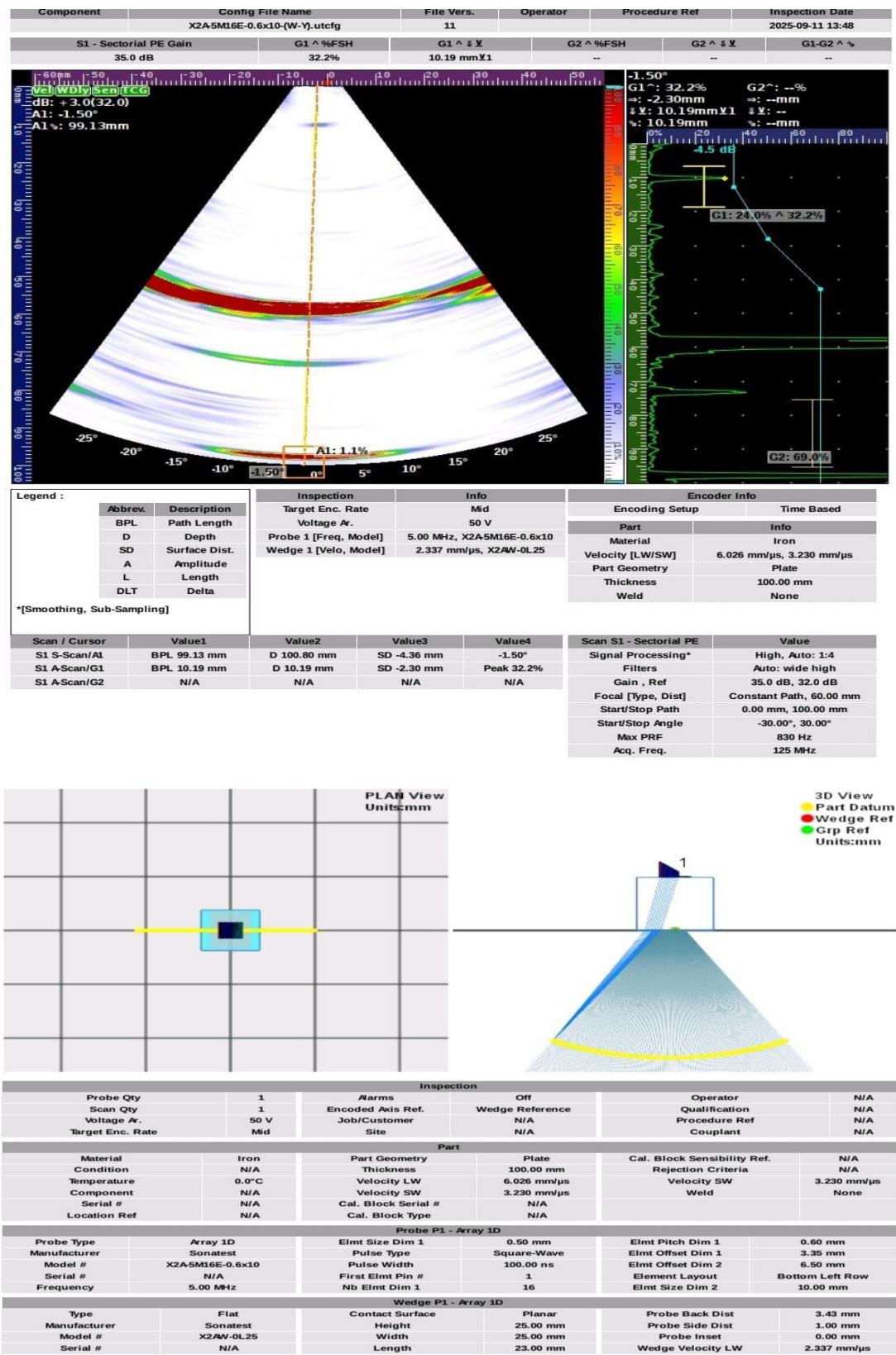
- All four holes produced clear and distinct echo signals.
- Signal amplitude decreased gradually with increasing depth, as expected.
- The equipment sensitivity was set such that even the 55 mm depth hole was clearly detectable.

Results and Discussion

Calibration verified across full depth range (11 mm to 55 mm). Equipment linearity and sensitivity confirmed. Reference block effective for repeatable calibration before inspection.







Scan S1 - Sectorial PE							
Type	Sectorial PE	Max PRF	830 Hz	Last Elmt RX		10	
Gain , Ref	35.0 dB, 32.0 dB	Signal Rectification	Full	Beam Qty.		121	
Resolution	0.50°	Filters	Auto: wide high	Samples Qty.		1040	
Start Angle	-30.00°	Sub-Sampling	Auto: 1:4	Path Res.		10.4 spl/mm	
Stop Angle	30.00°	Rejection	Disabled	Acq. Freq.		125 MHz	
Start Path	0.00 mm	Smoothing	High	Velocity Cal Status		Accepted	
Range Path	100.00 mm	Contouring	No	Wedge Delay Cal Status		Accepted	
Stop Path	100.00 mm	Probe TX/RX	P1 - Array 1D	Sensitivity Cal Status		Accepted	
Zero	1.05 µs	Probe RX	P1 - Array 1D	Amp Tolerance		7.50%	
Wave Mode	LW 6.026 mm/µs	First Elmt TX	1	TCG Cal Status		Accepted	
Travel Mode	Half Path	Last Elmt TX	10	Amp Tolerance		10.0%	
Focal Mode	Constant Path	Active Aperture	10				
Focal Dist	60.00 mm	First Elmt RX	1				
Geometry							
W1 Index Off.		0.00 mm		W1 Rotation			90.0°
W1 Scan Off.		0.00 mm					
S1 S-Scan	BPL	Depth	SD	Angle	Beam	Peak	Delta
Angular 1 (A1)	99.13 mm	100.80 mm	-4.36 mm	-1.50°	58	1.1%	---
S1 A-Scan	BPL	Depth	SD	Amplitude	Ref Ampl	Ref dB	
Gate 1 (G1)	---	---	---	24.0%	---	---	
Gate 1 (Peak)	10.19 mm	10.19 mm	-2.30 mm	32.2%	28.5%	-10.9 dB	
Gate 2 (G2)	---	---	---	69.0%	---	---	
Gate 2 (Peak)	N/A	N/A	N/A	N/A	N/A	N/A	
Delta (G1-G2)	---	---	---	-45.0 %	---	---	
Delta (G1^G2^)	N/A	N/A	N/A	N/A	N/A	N/A	

Conclusion

The master casting calibration block prepared with four different depth holes has proven effective for PAUT calibration. The setup ensured accurate depth detection, sensitivity adjustment, and linearity verification of the ultrasonic system. This block can be used as a standard reference for periodic calibration, ensuring reliable flaw detection in industrial applications.

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