

CIVA CALIBRATION FOR LINEAR SCANNING PHASED ARRAY ULTRASONIC TESTING

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ABSTRACT

CIVA is a popular ultrasonic simulation tool, used across many industries to improve various aspects of transducer design, defect diagnosis and inspection planning. When planning a weld inspection, linear scanning phased arrays are fundamental in providing ultrasonic coverage across Time of Flight Diffraction (TOFD) back-wall and near-surface dead zones. Prior to generating ultrasound scans experimentally, a Time Corrected Gain (TCG) calibration has to be performed - in order that any detected defects can be characterized, sized and sentenced according to the associated standards. The calibration process ensures that identical defects at varying depths will produce the same amplitude response. CIVA simulations, however, will produce differing amplitude responses for identical reflectors at varying depths. Furthermore, CIVA currently does not have the ability to perform such a calibration and response amplitudes obtained from the simulation suite, cannot be readily compared with experimental data. This paper presents a methodology for performing a TCG calibration on a CIVA simulation using a custom processing script in MATLAB. The results will show equal response amplitudes from multiple identical shaped reflectors at varying depths. This work will allow linear scanning phased array CIVA simulations to be calibrated properly and to be compared with experimental work for validation.

Keywords: Time Corrected Gain, CIVA, Linear Scanning Phased Array, Ultrasound

1. INTRODUCTION

Phased array ultrasonic testing is a widely used NDT inspection method due to its ability to provide real-time imaging, inspect complex geometries using beam steering, and acquire large coverage areas from a single probe. To aid in the deployment of phased array ultrasound, modelling applications such as CIVA are providing a platform to design more sophisticated inspection plans through coverage mapping and assessment of probability of detection. In addition, CIVA can

also be used to evaluate how defects can be characterized and sized. Simulating inspection processes and validating them through experimental comparison, will reduce time and costs involved in manufacturing test samples and inspection operator workload.

When modelling a phased array inspection setup, the limitations in pulsing capabilities of certain Phased Array Controllers (PAC) have to be considered. Not all PACs have enough individual pulser channels to accommodate all elements of a probe aperture to steer/focus an ultrasonic beam simultaneously. Instead, a number of sequential elements can be grouped to create a sub-aperture, or Virtual Probe Aperture (VPA). Various VPAs can then be generated by stepping the initial VPA along the full probe aperture. Combining the A-scan responses from each VPA will allow other scan images, such as a B-scan, C-scan and/or S-scan, to be generated.

To effectively deploy this technique for a linear or sectorial scan, a calibration methodology known as Time Corrected Gain (TCG) calibration has to be applied. The process aims to achieve equal response amplitudes from defects/reflectors of equal area at varying depths. [1] This is achieved by applying an appropriate magnitude of gain to each active virtual aperture to bring the response amplitude to 80% Screen Height (SH).

CIVA has the ability to perform calibration processes on a variety of inspection setups including Distance Amplitude Correction (DAC) calibrations for single/dual element ultrasound. However, CIVA currently lacks a built-in capability to perform a TCG calibration for phased array inspections. This paper presents an alternative method to generating a TCG calibrated CIVA simulation through MATLAB. It will be demonstrated through the simulation of a carbon-steel block with multiple close proximity Side-Drilled Holes (SDHs) at varying depths. This approach can act as a method to further validate CIVA for modelling phased array inspection scenarios.

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2. MATERIALS AND METHODS

2.1 CIVA Simulation Setup

FIGURE 1 illustrates a 60 mm thick carbon steel block being investigated with 3mm SDHs at depths of 2.5, 10, 22.5 and 42.5 mm from the top surface. The longitudinal and transverse wave velocities used for steel are 5900 ms^{-1} and 3240 ms^{-1} :

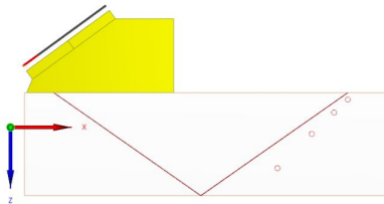


FIGURE 1: CARBON STEEL TEST BLOCK SIMULATION WITH 3MM SIDE-DRILLED HOLES AT SPECIFIED DEPTHS

The selected probe is an OLYMPUS 60-element 5 MHz PipeWIZARD Probe (5L60-PWZ1) mounted on a 55° refraction angle PipeWIZARD wedge (SPWZ1-N55S-IHC-RevC).

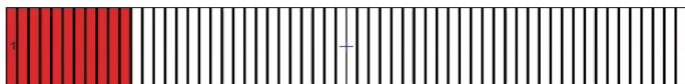


FIGURE 2: 5 MHz PIPEWIZARD PROBE WITH VPA 1 HIGHLIGHTED IN RED

The VPA pulsing setup used is illustrated in FIGURE 2, where the 60-element probe firing the first 11-element virtual aperture. This VPA is then stepped sequentially across the full array aperture, where the first VPA (shown in red) fires elements 1-11, the second VPA fires elements 2-12, the third VPA fires 3-13, etc. – resulting in a total of 50 VPAs. When scanning, each VPA will undergo a generation and reception phase prior to the next VPA being made active. Once the final VPA has been completed, the process will repeat back to VPA 1.

2.2 CIVA TCG Calibration Replication Scans

EXTENDE, developers and distributors of CIVA, advise determining the CIVA reference Amplitude that generates an 80% amplitude response from a Side-Drilled Hole (SDH) at the specific depth of the largest amplitude response [2]. From the simulation, the response with the highest CIVA reference amplitude is set to 100% screen height. However, this process will calibrate the entire simulated image relative to the calibration amplitude from that calibration SDH on that particular VPA. As a result, this calibrated image would not be appropriate for comparison with experimental data as the calibration methodology used within the experimental setup would employ a TCG calibration. Furthermore, in scenarios where multiple defects appear at the same scan step and on different VPAs, calibrating both VPAs using the same amplitude would be inappropriate. This could cause improper response amplitudes that could lead to incorrect defect sizing.

Therefore, to replicate the experimental calibration process, Figure 3 shows the probe setup, as described in Section 2.1, on a calibration block. The block has the same material properties as the sample block and four SDHs at vary depths in a block. Four independent simulations are run, isolating one SDH for each simulation. Within each simulation, the probe is moved across the SDH to acquire a response for each VPA. From this, the CIVA reference amplitudes that produce an 80% screen height response amplitude for each virtual aperture across each SDH can be determined.

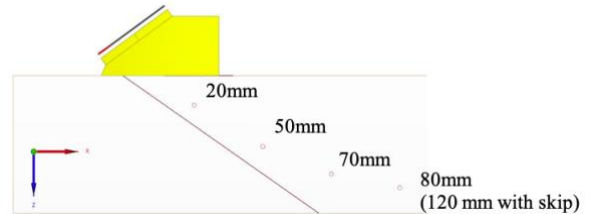


FIGURE 3: CALIBRATION BLOCK SIMULATION SETUP WITH 3MM SIDE-DRILLED HOLES AT SPECIFIED DEPTHS

Figure 3 illustrates 4 SDHs at depths of 20, 50, 70mm and 80 mm from the top surface of a known calibration block of 100 mm thickness. Instead of generating a TCG amplitude for 80 mm depth, this SDH can replicate an SDH at 120 mm deep by using a back-wall skip. The CIVA reference amplitude values for depths between the simulated SDHs in Figure 3 are determined through interpolation. This replicates the process used in an experimental calibration setup of acquiring the gain values relative to each time step within a signal to set the response amplitude to 80% SH. To effectively apply these CIVA reference amplitudes to a simulated scan, the A-scan files for each VPA within the scan have to be extracted into text files containing the SH percentage values and calibration reference amplitudes at each time step. Both the A-scans of all VPAs of a scan and the interpolated calibration CIVA reference amplitudes can be imported into MATLAB.

2.3 MATLAB TCG Implementation

Each time step within each A-scan can be converted to a depth within the structure. The time step on one VPA will represent a different depth to another VPA at the same time step; due to differences in sound path length within the wedge. Determining the depths for each time step on each VPA, the CIVA reference amplitude of the scan data can be calibrated relative to the interpolated reference amplitude at the calculated depth for that VPA. From this calibrated data, a sector-scan representation can be generated by plotting the amplitude response against its cross-sectional position for each position along the scan length. In circumstances where the scanning direction moves VPAs to positions already inspected by other VPAs, a single image illustrating the entire cross-section of the structure can be generated.

3. RESULTS AND DISCUSSION

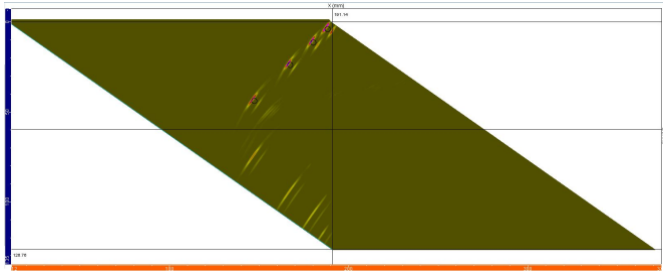


FIGURE 4: RAW CIVA SIMULATION DATA OF CARBON STEEL TEST SAMPLE, SCHEMATIC SHOWN IN FIGURE 1

FIGURE 4 illustrates the CIVA simulation sector scan of the setup shown in FIGURE 1. Response indications from the four SDHs above the back-wall line illustrate the signals received from direct interactions; while the signals after the back-wall line illustrate the amplitudes received after a back-wall reflection (or skip) has occurred. TABLE 1 presents the maximum percentage amplitudes at SDH from the simulation illustrated in FIGURE 4:

TABLE 1: MAXIMUM AMPLITUDE RESPONSES OF CARBON STEEL TEST SAMPLE CIVA SIMULATION

SDH Depth (mm)	2.5	10	22.5	42.5
% Amplitude (Direct)	98%	100%	96%	55%
% Amplitude (Backwall Skip)	12%	16%	19%	26%

As mentioned in Section 2.2, CIVA simulations operate by setting the highest amplitude response to 100%. If the EXTENDE calibration approach was to be implemented to adjust the maximum response amplitude to 80%, it would incorrectly adjust the amplitudes for the other SDHs. This is due to the differing magnitudes of the associated CIVA reference amplitudes given to each response for each SDH.

By comparison, the TCG calibration process implemented within MATLAB produces the results shown within FIGURE 5:

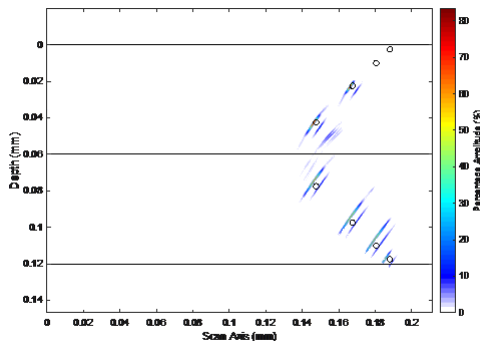


FIGURE 5: TCG CALIBRATED CIVA SIMULATION DATA OF CARBON STEEL TEST SAMPLE, SCHEMATIC SHOWN IN FIGURE 1

To aid in the visualization of the backwall reflected response signals, FIGURE 5 illustrates each of the relative SDH backwall reflection locations. TABLE 2 presents the maximum percentage

amplitudes at each SDH from the simulation illustrated in FIGURE 4:

TABLE 1: TCG CALIBRATED SDH MAXIMUM AMPLITUDE RESPONSES OF CARBON STEEL TEST SAMPLE

SDH Depth (mm)	2.5	10	22.5	42.5
% Amplitude (Direct)	0%	0%	83%	80%
% Amplitude (Backwall Skip)	58%	66%	66%	68%

The system has not yet been designed to calibrate responses shallower than the depth of the first calibration hole. Therefore, the two holes positioned at 2.5 mm and 10 mm deep show no amplitude response due to the first calibration SDH depth to be 20 mm. Although 80% SH amplitude was not reached, these magnitudes show potential that the calibration process is making an attempt to normalise the data with a number of factors potentially interfering with the calibration. Possible factors include, the position of certain SDHs masking other SDHs; and/or the calibration magnitudes may require further investigation when dealing with skipped signals rather than direct.

4. CONCLUSION

Overall, the implementation of a TCG calibration has shown some success as the percentage amplitude response of each reflector from the CIVA simulated data was calibrated relative to an appropriate reference amplitude. Although not all reflectors were fully adjusted to provide the desired 80% calibrated amplitude response, experimental calibration setup includes a measurement tolerance as the percentage amplitude will never be adjusted to set the gain for each SDH on each VPA to exactly 80% SH. Potential factors causing inconsistent amplitude responses have been mentioned and will be investigated. Further development of this simulation calibration approach and comparison with experimental data for validation, greater confidence can be taken in performing phased array ultrasonic simulation. In doing so, it could provide a platform to reduce costs and time spent relating to test sample production, inspections and improve defect diagnosis and characterization.

ACKNOWLEDGEMENTS

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