Comparative study of advanced image reconstruction algorithms for complex arbitrary components

Sumana Sumana 1, C.harles N. MacLeod 1, Simon Parke 2, David Lines 1, Jon Bates 2

1 a) Centre for Ultrasonic Engineering (CUE) b) Centre for Ultrasonic Engineering (CUE), Department of Electronic and Electrical Engineering; University of Strathclyde, Glasgow, Scotland, United Kingdom 2 Peak NDT Ltd., Derby, United Kingdom

Abstract: Accurate ultrasonic imaging and inspection of specimens with non-planar complex surfaces are often challenging from both transducer coupling and imaging perspectives. Several inspection strategies have been developed to inspect such complex interfaced components such as flat arrays with flexible wedges or water-filled chambers with a flexible membrane. In these methods, firstly surface profiles are estimated and then Fermat’s principle or other algorithms are applied to calculate delay laws. The main drawback of these methods is the longer computation time and therefore real time inspection is limited, also a coupling problem due to the complex geometries. Alternative approaches have been developed to compute the ultrasonic beam paths such as the Fast-Marching Method (FMM), Dijkstra’s algorithms, numerical analysis, bisection and root-finding algorithms for the inspection of complex surface components. These algorithms can be applied in two and three-dimensional domains resulting in high computation time. This work presents an experimental comparison of an iterative beamforming method for arbitrary shaped surface profile imaging against both Full Matrix Capture-Total Focusing Method (FMC-TFM) and CIVA simulation on an aluminium calibration block with Side drilled holes (SDHs) at various depths in the range of 15-80 mm. The performance of the iterative beamforming method is evaluated in terms of sensitivity, Signal to Noise Ratio (SNR) and Array Performance Indicators (API). The method provides a 2 dB improved SNR when compared to FMC-TFM.

Keywords: API, CIVA, SNR, FMC-TFM, beamforming method, arbitrary surfaces, bisection method
Comparative Study of Advanced Image Reconstruction Algorithms for Complex Arbitrary Components

Sumana S\textsuperscript{1,2,*}, Charles N. MacLeod\textsuperscript{1}, Simon Parke\textsuperscript{2}, David Lines\textsuperscript{1} and Jon Bates\textsuperscript{2}

\textsuperscript{1} Centre for Ultrasound Engineering, University of Strathclyde, Scotland, UK
\textsuperscript{2} PEAK NDT Limited, Derby, UK

* Contact author: sumana@peakndt.com/sumana.sumana@strath.ac.uk
➢ Introduction to challenges of arbitrary surface components inspection

➢ Ray tracing method (Conventional beam forming method)

➢ Materials and methods

➢ Comparative study from CIVA Simulation, FMC-TFM and Beam forming method

➢ Summary
Introduction

➢ Imaging of complex arbitrary surface components - Challenges for inspection
   ▪ Surface geometry
   ▪ Signal interferences
   ▪ Signal shadowing
   ▪ Resolution limitations

➢ Solutions
   ▪ Flat arrays with flexible wedges or water filled chambers with flexible membrane
   ▪ Flexible arrays
     ▪ Fermat’s principles
       • Longer computation time and real time inspection is limited
       • Coupling problem

➢ Recently, Fast-Marching method, Dijkstra’s algorithms, numerical analysis, Ray tracing algorithms were utilized for inspection of complex surface components.
   • Casula O., Toullelan G., Roy O., and Dumas P. "Ultrasonic nondestructive testing of complex components with flexible phased-array transducers". 10th European Conference on Non-Destructive Testing, pp. 7-11. 2010
Bisection method and Newton-based and Bairstow methods

- Bisection method is used for root finding method
  \[ z = \frac{x + y}{2} \] also known as Interval halving method

- Newton-based and Bairstow method is used for ray-tracing of ultrasonic beam in two dimensional domain in LabVIEW platform

Time of flight calculations:

\[ I_{1}^{x} = S^{x} + [S^{y} - f(I_{1}^{x})].\tan(\theta_{1}) \]

Similarly, for the target point,

\[ T^{x} = I_{i-1}^{x} + [f_{i-1}(I_{i-1}^{x}) - T^{y}].\tan(\theta_{i}) \]
Materials and methods

Details
• Transducer : Linear array
• Frequency  : 5 MHz
• Pitch : 0.7 mm
• Instrument : MicroPulse 6 (256/256 Phased array ultrasonic testing equipment) *Manufactured by PEAK NDT ltd.*

• Inspection done using beam forming method developed in LabVIEW software platform

Sketch of Aluminum block having 3 mm SDHs
Sensitivity, SNR and API Comparison

Sensitivity on arbitrary surface

- CIVA and beam forming method showed similar Sensitivity
- FMC-TFM showed 2.5 dB lower compared to beam forming method
Sensitivity comparison on planar surface

- With same gain, equivalent sensitivity can be obtained from planar surface inspection

CIVA simulation

FMC-TFM

Beam forming method
**Array Performance indicator (API) and SNR**

- API values from the beamforming method are equal to FMC-TFM with a small rise from CIVA simulation for both planar and arbitrary surface inspections.

- SNR – 2 dB lower FMC-TFM than CIVA and beam forming method.

\[
API = \frac{A_{-6\,\text{dB}}}{\lambda^2}
\]

Where, A-6 dB is the area below 6 dB mark from the indication 
\( \lambda \) is the wavelength, so \( \lambda^2 \) is the normalization factor.

\[
SNR = 20 \cdot \log \frac{I_{\text{Defect}}}{I_{\text{Noise}}}
\]
**Summary**

**Array Performance indicator (API) and SNR**

- Experimental implementation of an iterative beam forming algorithm for solving the ray tracing problem for arbitrary complex layered structures is presented here.
- The beam formed method is compared with FMC-TFM, CIVA simulation and defect quantification accuracy is discussed in terms of sensitivity, API and SNR.
- Experimentally, beam forming method showed comparable API values and improvement in SNR for near depth defects on both planar as well as arbitrarily shaped interfaces.
- Improved sensitivity (2.5 dB) and SNR (2 dB) obtained for beam forming method and CIVA simulation as compared to FMC-TFM.
- Future work includes to create 3-dimensional images using a beam formed method using LabVIEW platform.
Thank you...

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sumana@peakndt.com