ARRAY BASED DEFECT DETECTION AND 2D RECONSTRUCTION: A SELF CONTAINED, NON-ITERATIVE TECHNIQUE

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ABSTRACT

Amongst a number of NDE methods Ultrasonics has been a tool of choice to inspect, since the likely defects and important material properties are most easily, and inexpensively, uncovered in ultrasonic NDE. Due to physical constraints of accessing the other side of the structure and the immeasurability of transmitted signal (like cardiovascular imaging), ultrasonic reflection technique has great importance in NDE and medical. In present work, ultrasonic reflection methodology has been devised for reconstruction of centered as well as offset defects with equal efficiency. It involves defect characterization by analyzing the reflected signal data collected using phased array ultrasound instrument in pulse echo mode. Approximate location of the underlying defect was estimated by performing a linear scan across the accessible periphery of the specimen. Accordingly sectorial scan data collected at various positions of the probe along the boundary of the specimen was assimilated into a single database. This was succeeded by an extensive error analysis of the data which aimed at filtering out the various noise components. The filtered output was acted upon by the MATLAB code to reconstruct the defect. From the point of view of computation time and quality of reconstructed image, the algorithm has reconstructed defects with reasonable accuracy. The samples included various defect geometries; circular, elliptical, rectangular, to name a few. Various material combinations of samples and their respective defect inserts were tested, like, aluminium-steel, perspex-air, steel-epoxy, etc. Results have shown that algorithm is capable of characterizing multiple defects with a little lesser accuracy depending on defect dimensions. Comparisons with actual defect geometries have been presented.

Keywords: Ultrasonics, Phased Array, Pulse Echo, Reconstruction, Defects.

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INTRODUCTION

In ultrasonic technique (UT), sensitivity largely depends on the energy of the ultrasonic waves reflected from flaws [1]. Transmission mode is, therefore, not possible sometimes because of physical constraints like where it is impossible to access other side (like in a boiler) and also due to immeasurability of the transmitted signal (like in case of cardiovascular imaging, the transmitted signal is almost immeasurable because of large impedance discontinuities at tissue-bone and air-tissue interfaces and other attenuation losses).

Hence, pulse-echo mode has been considered for the reconstruction of defects in an isotropic material. In conventional ultrasonic pulse echo testing, the transducer introduces a beam of ultrasonic waves into a component. Suffering reflections at different interfaces, the waves returning back to the transducer are analyzed, revealing the presence of any embedded defects. To carry out a complete inspection of an item, such as a crack, it thus becomes necessary to introduce beams at a number of orientations.

Phased array technique typically incorporates a multi-element (usually 16, 32, 64 or 128) array transducer that generates a sweeping beam that can examine a component, from various angles [2]. The individual transducer elements are pulsed in groups with programmed time delays, creating interacting beam components that add and cancel in predictable ways; termed as phasing. The operator can sweep the beam through...
a selected volume of the test piece by varying the sequence in which the elements are pulsed, corresponding to potential flaw locations.

THEORY

The reflection and refraction behavior of the wave front at an interface plays an important role in ultrasonic investigations [3]. Specifically, this is the effect that is used to determine the presence of a flaw or other anomaly. At a boundary between two different media only a portion of incident wave is reflected. The remainder penetrates into the underlying medium (wave refraction).

The relative amplitudes of reflected waves depend upon the mismatch in specific acoustic impedances at an interface, the angle of incidence, the distance of an interface from the pulse source, and the attenuation along the wave path. The specific acoustic impedance 'z' of a medium can be expressed as product of density $\rho$ of the medium and the ultrasonic wave velocity 'v' in that medium.

Apparently greater the difference in impedances at the interface, the greater will be the amount of energy reflected; conversely, where impedances are similar, most will be transmitted.

Under normal circumstances, the waves collected back by the transducer are essentially the reflections directly from the back wall or a series of reflections from the boundary of the specimen. But in case of presence of any abnormalities in the sample, the amplitudes of the back wall reflections received would, suddenly, start showing a decreasing trend. This behavior can be accounted for by the partial blockage of the ray path by the defect itself. The points where the intensity (The intensity being discussed here is due to the reflections encountered after twice the time taken for the rays to hit the back wall), becomes half the maximum intensity received demarcate the region of uncertainty where the defect would be lying. These points correspond to 6dB intensity decrease.

METHODOLOGY: 2D PHASE MEASUREMENT

First of all, linear scan is performed traversing the entire (accessible) boundary of the specimen or the structural member to be examined. The purpose of performing the linear scan is to discover 6dB points in order to identify the region of uncertainty. In cases where the defect size is very small, the uncertainty region can be defined by the 3dB points. Thereafter, from different positions of probe along the periphery of the specimen, sectorial scans are performed such that the entire region of uncertainty is swept through. The different data sets collected are converted to compatible formats and are accumulated, along with the respective probe coordinates, into a single database. Now, this database is fed into our MATLAB code.

Algorithm: The data obtained consists of the required signal (fetal signal) along with an error component. This error signal further comprises of a maternal component, i.e., constant instrumental error, along with various noise elements. Now, this maternal component can be separately measured prior to the experiment and thus, can be taken care of. As far as other disturbances are concerned, a simple projective noise removal technique can filter these out. Hence, a raw fetal signal is extracted in the pure form from the aforesaid database.

Using this raw A-Scan data, for every probe coordinates, the different parameters, i.e., half depth and the angle (between ray path and probe surface), as shown in Figure 2, corresponding to the maximum amplitude, are extracted into a separate array. If for a particular probe position, several angles correspond to the same maximum amplitude, then their mean value is assigned to the angle parameter and the half depth corresponding to this angle is assigned to the half depth parameter.

For every probe location, using the corresponding parameters (stored in the array), a line representing the tangent to the defect geometry is drawn. Once all the lines have been drawn, the additional lines lying outside the region restricted by the 6dB (or 3dB, howsoever the case may be) benchmarks are trimmed off. The region enveloped by these lines represents the defect.

For instance, if $(x_0, y_0)$ represent the position coordinates of leftmost end of the probe, and ‘d’ and ‘$\theta$’ be the half depth and angle parameters respectively for this probe location, then the extremities of the line segment drawn tangential to the defect periphery would be given as,

$$
\begin{align*}
x_1 &= x_p + \frac{d}{2} \cos \theta - \frac{1}{2} (\sin \theta)^2, \\
y_1 &= y_p + \frac{d}{2} \sin \theta - \frac{1}{2} (\sin \theta \cos \theta), \\
x_2 &= x_p + \frac{d}{2} \cos \theta + \frac{1}{2} (\sin \theta)^2, \\
y_2 &= y_p + \frac{d}{2} \sin \theta + \frac{1}{2} (\sin \theta \cos \theta).
\end{align*}
$$

where ‘l’ is length of the active probe aperture. Also, ‘d’ can be conveniently found out using time of flight data, i.e., $d = c \times t$, where ‘c’ is wave velocity in the medium.

![Fig. 2](image-url)
RESULTS

Figures 3.1 to 3.6 show the photographs of the actual specimen and the respective reconstructed images. By measuring the dimensions and positions of the defects in the reconstructed images and comparing them with the actual specimens, the percentage linear errors have been calculated and shown in Table 1.

When the defect was symmetrically placed in the specimen, the data was not collected from all the four sides of specimen. For example, the readings were taken from a single side in case of square and from two adjacent sides in cases of ellipse and rectangle. And then, these readings were extrapolated to the other sides to form a complete picture of the defect. Also, in cases where the impedance mismatch (between the sample material and the insert) was high, the image reconstructions were more accurate.

Fig. 3.1: Left: Reconstruction, Right: Aluminum specimen (48.9×48.9) with M.S. square insert (20×20).

Fig. 3.2: Left: Reconstruction, Right: Perspex specimen (50×50) with rectangular cavity (20×20).

Fig. 3.3: Left: Reconstruction, Right: M.S. specimen (50.1×50.1) with epoxy circular insert (Ø19.4).
Fig. 3.4: Left: Reconstruction, Right: Araldite (LY556) specimen (99.0×99.0) with elliptical insert.

Fig. 3.5: Left: Reconstruction, Right: M.S. specimen (81.3×66.6) with linear oblique crack (20mm).

Fig. 3.6: Left: Reconstruction, Right: Perspex specimen (80.2×80.2) with 3 holes (Ø7.1, Ø5.2 & Ø1.6).

Furthermore, the reconstructed images often contained some stray line segments, scattered outside the region of uncertainty, owing to several minute defects embedded in the samples under scrutiny. But they were ultimately taken care of by 6dB (or 3dB) benchmarks, already set.

The active aperture length was, by and large, 4.8 mm (16 elements). The smallest defect which could be distinctively detected by the above technique was found out to be around 1.6 mm. Also it is in fair agreement with expected value i.e. 1.4 mm.
Table 1: Percentage error in reconstruction of different defects.

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Defect Shape</th>
<th>Defect Type</th>
<th>% Linear Error</th>
</tr>
</thead>
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<tr>
<td>3.1</td>
<td>Square</td>
<td>Centered</td>
<td>&lt;0.50</td>
</tr>
<tr>
<td>3.2</td>
<td>Rectangle</td>
<td>Centered</td>
<td>0.50-1.00</td>
</tr>
<tr>
<td>3.3</td>
<td>Circle</td>
<td>Offset</td>
<td>1.00-1.50</td>
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<tr>
<td>3.4</td>
<td>Ellipse</td>
<td>Centered</td>
<td>0.80-1.30</td>
</tr>
<tr>
<td>3.5</td>
<td>Crack</td>
<td>Linear, Oblique</td>
<td>0.50-1.00</td>
</tr>
<tr>
<td>3.6</td>
<td>Circular hole</td>
<td>Multiple, Offset</td>
<td>4.00-4.50</td>
</tr>
</tbody>
</table>

CONCLUSION

Instead of following the conventional tomographic approach, the reconstruction procedure described above exploits the geometry of the defects present directly. The algorithm does not involve any time consuming iterative steps in order to satisfy some convergence criteria. Also, when the defect boundaries are not curvilinear or the impedance mismatch between a specimen and its insert is significant, the technique offers quite reliable reconstructions.

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REFERENCES