SCANNING TOMOGRAPHIC ACOUSTIC MICROSCOPY WITH MULTIPLE TRANSDUCERS AND FREQUENCIES

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To cite this version:


HAL Id: jpa-00230695
https://hal.archives-ouvertes.fr/jpa-00230695

Submitted on 1 Jan 1990

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Abstract - The scanning tomographic acoustic microscope (STAM) is an instrument that utilizes the principles of diffraction tomography and acoustical holography to produce unambiguous subsurface images of structurally complex objects.

One of the several techniques to obtain projection data is to rotate the transducer and another, to rotate the specimen. In either case a small unknown movement out of register will cause phase errors which can severely degrade the tomograms. A third technique uses a multiplicity of fixed transducers and frequencies. Our simulation studies show that this technique is capable of producing the best images because it is entirely free of either transducer or specimen movement.

1 - INTRODUCTION
Acoustic microscopy is used in non-destructive evaluation to obtain images of the detailed structure of small optically opaque objects. The scanning tomographic acoustic microscope (STAM) is an instrument that utilizes the principles of diffraction tomography and acoustical holography to enhance the capability of such microscopy. A modified scanning laser acoustic microscope (SLAM) is employed for data acquisition in STAM. Digital processing of the data using back-and-forth propagation completes the image reconstruction /1,2/. This approach to acoustic microscopy is advantageous over conventional approaches, especially for viewing complex objects where the structure of interest lies in well-defined planes.

We have designed and built a quadrature detector for SLAM to obtain both amplitude and phase information of the received wave-field. We reconstruct tomograms by computationally back propagating the received wave-field and forward propagating the source wave-field to the plane of interest. Our experimental results show conclusively that we can obtain high-quality high-resolution subsurface images with STAM that are not obtainable with SLAM /3/.

We have developed several different techniques to obtain projection data. One of these techniques uses specimen rotation and another, transducer rotation /4/. We systematically rotate either the specimen or the transducer and obtain a number of projections in sequence. In either case a small unknown movement out of register will cause phase errors which can severely degrade the tomograms. Good tomograms are possible only if there is no phase error due to movement between projections. A third technique for obtaining projection data uses a multiplicity of fixed transducers and frequencies. This technique combines the effect of the two rotation schemes and employs the same reconstruction algorithm with very little modification. Our simulation studies show that this technique is capable of producing the best images because it is entirely free of either transducer or specimen movement.

2 - SCHEMES FOR DATA ACQUISITION
We need data from several projections to obtain tomograms. These data can be gathered by changing the angular direction of the insonifying waves with respect to the specimen. Two different kinds of rotation schemes have been proposed to accomplish this /4/. Both schemes are prone to introducing phase errors in the acquired data. In this paper, we propose a third scheme which requires no rotation or movement of any element in the system and hence eliminates the possibility of introducing phase error due to mechanical motion in the data.
Fig. 1 illustrates the data acquisition schemes. In schemes that involve rotation, we systematically rotate either the transducer or the specimen and thus obtain a number of projections in sequence. In the transducer rotation scheme, shown in Fig. 1(a), the transducer is rotated about the y-axis which points into the page from the center of the bottom surface of the specimen. In the specimen rotation scheme, shown in Fig. 1(b), the specimen is rotated about the z-axis. In both these cases, the distance between the transducer and the specimen must be kept constant or at least be known to avoid phase errors. A third scheme, shown in Fig. 1(c) with three transducers, uses a multiplicity of fixed transducers. Since there are no movements during data collection in this scheme, we can avoid the phase errors introduced by moving either the transducer or the specimen. We can also use several different frequencies with each transducer to increase the totality of the collected data.

3 - COMPUTER SIMULATIONS
We used computer simulations to investigate the phase-error problem and to compare the fixed transducer scheme with the transducer rotation scheme. The simulations use a two-dimensional object of 128 pixels length. (There is no variation in the y-direction). The object is assumed to be attenuation free except for two thin layers, separated by ten wavelengths. The data is collected at a plane eight wavelengths above the second layer. The layers were assumed to contain binary attenuation patterns with regions of greatest transparency being one hundred percent transparent and others fifty percent transparent to the acoustic waves. Fig. 2 shows the transmission pattern of the two layers.

We simulated nine projections generated by assuming that the incident angle of the ultrasonic plane wave inside the specimen was increased in uniform angular increments from $-40^\circ$ to $+40^\circ$. The projection data were processed using an algorithm for tomographic reconstruction based on back-and-forth propagation /2/. Fig. 3 shows the reconstructed transmission functions for the two layers when there was no error in the assumed position of the transducer for the different projections. Fig. 4 shows the transmission functions when the assumed positions of the transducer was in random error for each projection by up to $\pm 1^\circ$ in angle and up to $\pm \frac{\lambda}{2}$ in distance. We see the degradation in the transmission functions by comparing these to those of Fig. 3.
Fig. 2 - Transmission patterns of the two layers used in the simulation.

Fig. 3 - Simulated reconstructions of the transmission patterns of the two layers, assuming transducer rotation and no positioning error.

Fig. 4 - Simulated reconstructions of the transmission patterns of the two layers, assuming transducer rotation and positioning errors, in both angle and distance.

Fig. 5 - Simulated reconstructions of the transmission patterns of the two layers, assuming three fixed transducers employing the three frequencies of frequency set 1.
To simulate the fixed transducer scheme, we assumed three transducers at $-40^\circ$, $0^\circ$ and $+40^\circ$ respectively. In order to better compare the results from this approach to the previous results which used nine projections, we simulated the employment of three different frequencies for each transducer.

Fig. 5 shows the results when the insonifying wavelengths were 1.6, 1.8 and 2 pixels (which we will call frequency set 1) and Fig. 6 shows the results when the insonifying wavelengths were 1.2, 1.6 and 2 pixels (frequency set 2). These reconstructions are superior to those of Fig. 4 and approach those of Fig. 3.

Simulation results using a three-dimensional object are presented elsewhere /5/.

In order to compare these results quantitatively, we computed the mean-square errors for these results. These are shown in the following table. It can be clearly seen that the mean-square error is very high when there is error in the position of the transducer. In the case of a fixed transducer, the mean-square error is comparable to the case for which there is no position error. Also, mean-square error decreases as the frequency range increases.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Layer 1</th>
<th>Layer 2</th>
</tr>
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<tbody>
<tr>
<td>transducer rotation</td>
<td>0.00152611877905</td>
<td>0.00222758874649</td>
</tr>
<tr>
<td>(no error)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>transducer rotation</td>
<td>0.12255811318819</td>
<td>0.36407787053182</td>
</tr>
<tr>
<td>(random error)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fixed transducer</td>
<td>0.00205241128073</td>
<td>0.00248882970101</td>
</tr>
<tr>
<td>(frequency set 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fixed transducer</td>
<td>0.00182966990906</td>
<td>0.00233763525664</td>
</tr>
<tr>
<td>(frequency set 2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 - CONCLUSIONS

We have described three different schemes of data acquisition for STAM. We have shown by computer simulations that the rotation schemes are prone to introducing phase errors that cause substantial degradation to the reconstructed image. We have also shown that the scheme which uses a multiplicity of fixed transducers, with several different frequencies, eliminates this type of error and produces good images. Also, by increasing the frequency range we are able to reduce the error in the image.

5 - ACKNOWLEDGEMENT

We would like to acknowledge the support of the Committee on Research, Academic Senate, University of California, Santa Barbara in carrying out this work.

REFERENCES