

ABSOLUTE MAGNITUDE OF FRONT SURFACE REFLECTIONS IN ULTRASONIC
MEASUREMENTS

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INTRODUCTION

It has been shown in other papers in this volume (1,2) that the application of deconvolution, diffraction, and attenuation corrections to received ultrasonic signals is sufficient to extract the absolute value of the flaw scattering amplitude from the signal. This capability provides a new opportunity to obtain additional flaw characterization information from the ultrasonic signal. More specifically, it is postulated upon reasonable grounds that the absolute magnitude of the front surface ultrasonic echo from a flaw can be related to both the flaw dimensions and its acoustic impedance. Assuming that the size can be obtained by other means, the front surface echo can then be utilized to help identify the flaw. The purpose of this paper is thus twofold: 1) to utilize the diffraction and attenuation corrections developed by Thompson and Gray (3) to obtain absolute values of flaw impulse responses, and 2) to investigate the feasibility of using absolute values of front surface echoes to determine a flaw's identity.

The work reported in this paper is a continuation of the work reported in a companion paper in this volume using the same transducers and samples (1). In that paper, scattering results were given for three different transducers and three different sample configurations (three different flaws in different host materials) from which absolute values of flaw scattering amplitudes were extracted using deconvolution, diffraction, and attenuation corrections. Emphasis in this paper is placed upon extraction of the impulse responses in the time domain and the absolute magnitude of the front surface echoes.

EXPERIMENTAL RESULTS

In Fig. 1 are shown the as-received ultrasonic time-domain signals for three different transducers and samples obtained with an immersion technique. The top row gives the responses of the three transducers for backscattering from a 114 micron spherical tin-lead inclusion in Lucite, the second row gives the same information for the same three transducers for backscattering from a 200 x 400 micron oblate spheroidal void in titanium (propagation direction parallel to the 200 micron semi-axis), and the third row provides the same information for the same three transducers in backscatter from a 140 micron spherical void in glass. Similarly, the columns show the responses for a given transducer to three different flaws in different host media. All ordinates in this figure are in volts and are relative while the abscisses are given in microseconds. Transducer identification numbers are given across the top row.

The data shown in Fig. 1 were Fourier transformed, deconvolved, and corrected for diffraction and attenuation effects. Results of these steps are given in Fig. 4 in the companion paper (1) in which absolute values of the scattering cross sections were obtained for all nine cases and compared with theoretical predictions. For reasons of brevity, these results are not reproduced here.

In Fig. 2 are shown the flaw impulse responses obtained by transforming the corrected scattering amplitude given in Fig. 4 of the companion paper back to the time domain. The legends and format of this figure are the same as those of Fig. 1 of this paper. However, there are two significant differences. Because the results in this figure are transforms of absolute scattering amplitudes, the impulse responses are also given in absolute units (cm/sec) instead of relative values in Fig. 1. Secondly, a column of theoretical impulse responses is given with which the experimental functions can be compared. These have been obtained by transforming the theoretical scattering amplitudes of Fig. 4 (dotted lines) given in the companion paper. It will be seen that the agreement between measured and calculated impulse responses is reasonably good even though there is "ringing" on the results due to the transformation of band limited data.

INTERPRETATION AND DISCUSSION OF RESULTS

Although the authors are unaware of a rigorous derivation which relates the magnitude of the front surface echo of the impulse response function to properties of the scattering flaw, it can be argued plausibly (4,5), that R , the strength of the front surface echo, is given by

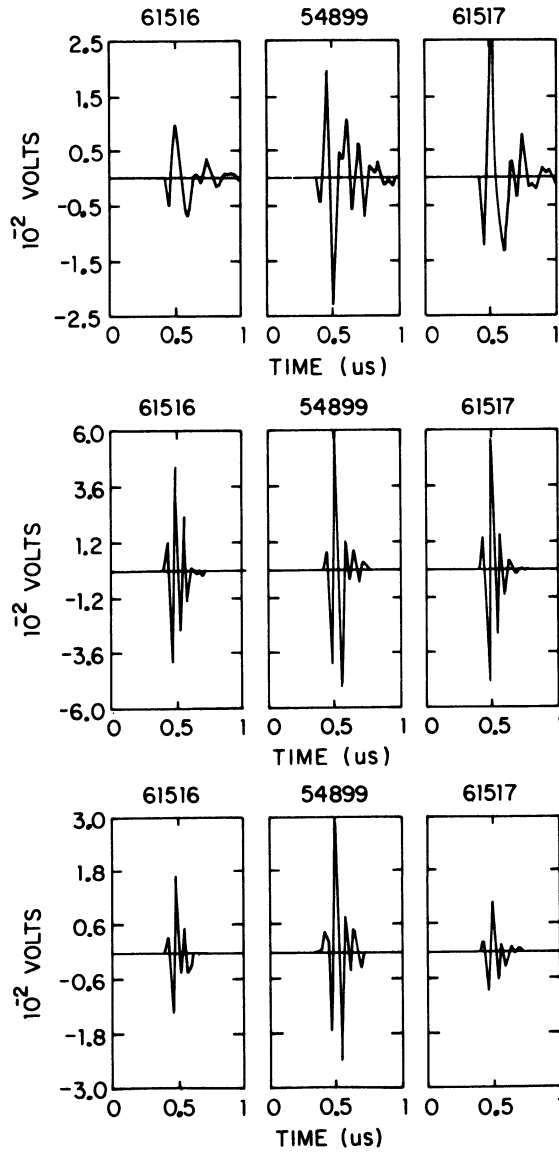


Fig. 1. Backscattered signals from three samples and three transducers with attenuation and diffraction corrections.

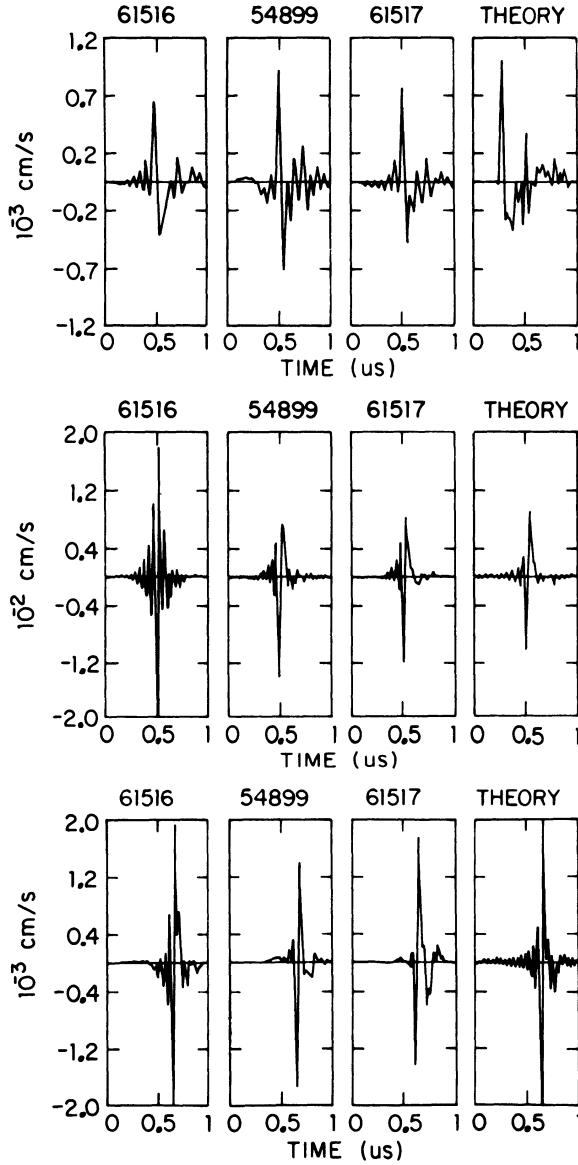


Fig. 2. Backscattered signals from three samples and three transducers.

$$R = 1/2 \frac{z_1 - z_o}{z_1 + z_o} \frac{a_1 a_2 a_3}{r^2} \delta\left(t + \frac{2r}{c}\right) \quad (1)$$

in which z_1 is the acoustic impedance of the flaw, z_o is the acoustic impedance of the host, c is the acoustic velocity in the host, a_1 , a_2 and a_3 are the semiaxes of the flaw taken to be ellipsoidal in shape, t is the time, and r is the normal distance from the center of the ellipsoid to the impinging wave front when the wave front is first tangent to the flaw. These definitions may be made clearer by reference to Fig. 3. It is evident from this equation that if the magnitude of the front surface echo R can be obtained from the impulse response and if the size factors can be obtained by other means, then an estimate of the acoustic impedances can be made.

The bandlimited nature of the data must be taken into account in evaluating the strength of the front surface echo. Bandlimiting causes the δ function characteristic of the front surface response to appear as a function of the form $\sin(x)/x$. Taking this into account, the desired strength of the δ function response can be obtained from a measure of the area under the maximum lobe of the front surface echo. The two are related by a constant. Although this is a straightforward step, care needs to be exercised to sort out any contribution to "ringing" that is associated only with the transformation and not with the scattering phenomena.

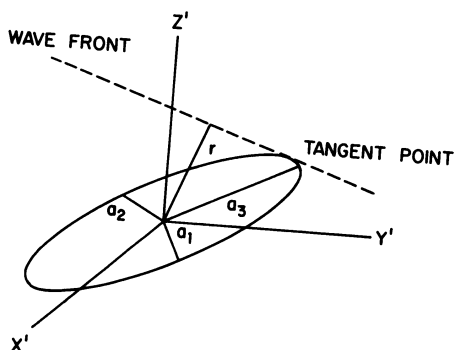


Fig. 3. A diagram showing front surface reflection parameters.

Numerical results obtained for the strength of the front surface echo and for the measured acoustic impedances are given in Table I for the set of three different transducers and flaws. Information in the first column summarizes the scattering flaws and the second column provides the transducer identification number. Calculated and measured values of the strength of the front surface echo are given in columns three and four. The measured values are obtained from the experimental data shown in Fig. 2 whereas the calculated values are obtained from the theoretical responses given in that figure. Columns five and six give the known values of the acoustic impedance of the scattering flaw and the experimentally determined values. As is evident, the latter values were obtained by substituting the measured values of the front surface responses, the known flaw sizes, and the known acoustic impedance z_0 of the host sample materials into Eqn. (1) and then computing z_1 , the acoustic impedance of the flaw. A positive sign in column four shows that $z_1 > z_0$ whereas a negative sign shows the opposite condition.

TABLE I.

Flaw	Transducer	Calculated Front- Surface Echo (cm)	Measured Front- Surface Echo (cm)	Calculated Acoustic Impedance z_1 (gr/cm ² μsec)	Measured Acoustic Impedance z_1 (gr/cm ² μsec)
114 micron lead-tin sphere in Lucite	#61516 #54899 #61517	4.09x10 ⁻³ 4.09 4.09	3.73x10 ⁻³ 4.71 4.27	2.56 2.56 2.56	1.53 3.36 2.23
200x400 micron spheroidal void in Titanium	#61516 #54899 #61517	-4.27x10 ⁻² -4.27 -4.27	-5.60x10 ⁻² -4.60 -3.92	0 0 0	-0.40 -0.12 0.52
140 micron spheroidal void in glass	#61516 #54899 #61517	-5.75x10 ⁻³ -5.75 -5.75	-6.36x10 ⁻³ -6.36 -5.15	0 0 0	0.07 0.07 0.23

DISCUSSION

Several conclusions may be drawn from this work. First, the work shows that absolute values of flaw impulse response functions can be obtained with reasonable ease after the original data are treated in the frequency domain to produce absolute flaw scattering amplitudes utilizing the convenient analytic forms for diffraction and attenuation corrections developed by Thompson and Gray. Secondly, the strengths of the front surface echoes can be extracted from the impulse response; if additional flaw sizing information is available, values of the acoustic impedance of the scattering flaw can then be obtained from Eqn. (1). This feature may prove to be of value in providing flaw identification information. Fertig and Richardson (6) have discussed this feature in some detail in relation to his more general "unified" algorithm. It would appear that the current results utilizing diffraction and attenuation corrections in the frequency domain to produce absolute values of impulse response functions may simplify their approach considerably.

The extent to which this signal processing technique will be of value in flaw identification and characterization will depend primarily upon both the accuracy that can be obtained in the estimation of values of the acoustic impedance and the application intended. The accuracy of flaw sizing techniques available must be incorporated into this assessment. Examination of the results given in column six of Table I shows that results for the acoustic impedance obtained by averaging over three transducers differ from the calculated values by approximately 12 percent whereas the results for any single transducer may differ from the calculated value by a considerably greater amount. It is believed that this difference is primarily traceable to the deconvolution process used in the companion paper (1) for these transducers which yielded an imperfect "normalization". Improvement of the deconvolution step would thus be expected to reduce the variability in these results. On the other hand, the resolution obtained in this work may be sufficient for some applications in which the expected flaws show a spread in properties. Acoustic impedance values may range from 0 for voids to as much as 5-6 gr/cm²usec for some metallic inclusions. If the expected flaws are separated in acoustic impedance values by a factor of 2, then current resolution would be sufficient to separate them. Ahlberg et al. (7) used a probabilistic format for flaw identification with an a priori listing of possible flaws. This approach improves the resolution. No attempt has as yet been made to assess the current results in a probabilistic format.

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REFERENCES

1. S. J. Wormley and D. O. Thompson, "Comparison of scattering amplitude from various transducers using diffraction and attenuation corrections", this volume.
2. R. B. Thompson and T. A. Gray, "Application of diffraction corrections to the absolute measurement of scattering amplitudes", *ibid.*
3. T. A. Gray and R. B. Thompson, "Review of Progress in Quantitative NDE, edited by D. O. Thompson and D. E. Chimenti, 2A, 89 (Plenum Press, New York, 1982).
4. J. H. Rose, private communication.
5. E. M. Kennaugh and D. L. Moffatt, Proceedings of the IEEE, 53, 893 (1965).
6. K. W. Fertig and J. M. Richardson, Proceedings of the DARPA/AFML Review of Progress in Quantitative NDE, AFWAL-TR-80-4078, p. 528.
7. L. A. Ahlberg, R. K. Elsley, L. J. Graham, and J. M. Richardson, Proceedings of the DARPA/AFML Review of Progress in Quantitative NDE, AFWAL-TR-80-4078, p. 656.

DISCUSSION

- R. K. Elsley (Rockwell International Science Center): When you deconvolved and corrected and plotted the frequency spectrum, I notice that for the lead-tin inclusion, two of the spectral curves now fell very nicely on top of one another. The third one was a much as almost a factor of 2 higher. Do you have any explanation for that?
- D. O. Thompson (Ames Laboratory): No, I don't. It seems that there are some systematics in these transducer variations that we're not controlling. There is an interesting observation that Sam and I have made. In ordering this set of transducers, we ordered seven, as a matched set. They were delivered in pairs. What we found was that taken two at a time, the two that came in on a given order, matched up reasonably well but they did not match with the pair that came in the next week or the following week. There are some processing variables that seem to be evident about which we have no knowledge.

G. J. Gruber (Southwest Research Institute): What was the nominal frequency of these transducers?

D. O. Thompson: These are nominal 15 Megahertz quarter-inch diameter plane wave.

G. J. Gruber: Where was the actual center frequency?

D. O. Thompson: Nominally, they varied from about 10 to 12 megahertz.