BLUR REDUCTION IN ULTRASONIC IMAGES USING

PSEUDO THREE-DIMENSIONAL WIENER FILTERING

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INTRODUCTION

The ability to quantitatively image material anomalies with ultrasonic methods is severely restricted by the axial and lateral resolution of the interrogating transducer. Axial resolution is controlled by the pulse duration of the transducer with shorter pulse durations yielding better axial resolution. Lateral resolution is controlled by the width of the interrogating beam with narrower beams providing better lateral resolution.

Significant improvements in depth resolution have been achieved by collecting information from narrow software gates applied directly to the rf A-scans [1,2]. Further improvements have been obtained by using a one-dimensional Wiener filter to axially deconvolve the rf A-scans and then using the narrow software gates to collect information from the deconvolved A-scans [3,4]. Another study has shown that improvements in the lateral resolution of C-scan images can be achieved by using a two-dimensional Wiener filter to deconvolve the lateral point-spread function (psf) from the image [5]. That study has also shown that a Gaussian-shaped computer-simulated psf can be used in place of the actual psf to perform the Wiener deconvolution so long as the transducer’s psf is symmetric.

This paper describes a method for improving both the depth resolution and the lateral resolution in C-scan images by serially combining the one-dimensional axial Wiener deconvolution, software gating and two-dimensional lateral Wiener deconvolution techniques. The method consists of first digitizing and storing rf A-scans. The rf A-scans are then axially deconvolved using a one-dimensional Wiener filter. Next, software gates are applied to the Wiener deconvolved A-scans to generate C-scan images at desired locations. Finally, the two-dimensional Wiener filtering technique is applied to the C-scan images to improve the lateral resolution.

WIENER DECONVOLUTION

One-dimensional axial Wiener deconvolutions were used to remove the "signature" of the ultrasonic transducer from the rf A-scans. The deconvolutions effectively reduce the pulse length of the transducer,
thereby improving the depth resolution. The axial Wiener deconvolution technique has been explained in previous publications and will not be discussed further here [3, 6].

Two-dimensional Wiener deconvolutions were used to remove the lateral psf from C-scan images. As in the one-dimensional case, the measured image feature, $f(x,y)$ is assumed to be a convolution of the system response, $h(x,y)$, and the "true" image feature, $s(x,y)$ [7]. Thus,

$$f(x,y) = h(x,y) * s(x,y)$$  \hspace{2cm} (1)

The system response, $h(x,y)$, for an ultrasonic transducer can be obtained from a C-scan image of a "small" spherical reflector. The Wiener deconvolution is most easily implemented in the Fourier domain using the relation

$$S(u,v) = \left[ \frac{H^*(u,v)}{[H(u,v)]^2 + K} \right] F(u,v)$$  \hspace{2cm} (2)

where $H^*(u,v)$ is the complex conjugate of $H(u,v)$ and "K" is a constant which is an estimate of the noise-to-signal ratio of the image. The constant also provides stability to the filter when $H(u,v)$ is small. Transformation of $S(u,v)$ back to the spatial domain yields an estimate of the "true" image feature.

**SAMPLE**

The sample used in this study is a 32-ply thick, quasi-isotropic graphic/epoxy composite. The separation between ply interfaces in this sample is approximately 0.14 mm. Prior to ultrasonic inspection, the sample had been intentionally damaged by a 5.4 joule impact from a 12.7 mm diameter stainless steel ball on a pendulum impacter.

**DATA COLLECTION**

A computer controlled ultrasonic immersion scanning system was used to collect 256 point, 8-bit rf A-scans at each of 40,000 discrete points in a 20.3 mm by 20.3 mm square area surrounding the impact damage site. The spatial separation between data collection points was 0.10 mm in both planar directions. All 40,000 A-scan lines were stored in the computer memory for later processing. The rf A-scans were stored as 200 individual B-scan data files with 200 rf A-scans per B-scan file. Each individual A-scan within a B-scan file represented one step in the "X" direction, while each B-scan file represented one discrete step in the "Y" direction. A 3.5 MHz center frequency, 12.7 mm diameter, 50.8 mm focal length transducer was used for all data collection. Excitation for the transducer was a broadband spike pulse. A reference waveform (rf echo from the front surface of a flat plate) was collected and stored for the axial deconvolutions. The psf for the lateral Wiener deconvolutions was approximated by a computer-simulated Gaussian-shaped pressure profile.

**AXIAL WIENER DECONVOLUTION**

All 40,000 of the rf A-scans were axially deconvolved using a one-dimensional Wiener filter. These deconvolved A-scans were then stored as 200 separate B-scan files with 200 individual A-scans in each of the
files. The improvement in depth resolution which results from deconvolution can be seen in Fig. 1. Figure 1a shows the rf B-scan image across a delaminated region of the sample. The entry surface echo appears as a broad dark region across the B-scan about one-third of the way down from the top. Delaminations appear as lighter regions due to a phase reversal of the echoes from the delaminated regions. The B-scan image generated from axially deconvolved A-scans across the same region of the sample is shown in Fig. 1b. The improvement in depth resolution is clearly evident from the narrowing of the black entry surface echo and the light delamination echoes. Such improvements in depth resolution are in agreement with results published by other investigators [8,9].

**C-SCAN IMAGE GENERATION**

C-scan images were generated by applying narrow software gates to the rf A-scans and to the Wiener deconvolved A-scans. The gates were located to interrogate the second and third ply interfaces below the entry surface. Since the round-trip distance between adjacent interfaces in the sample was approximately 0.28 mm and the wavelength of the 3.5 MHz interrogating beam was 0.86 mm, the gates were separated by about one-third of a wavelength. Figure 2 shows an rf A-scan and a deconvolved A-scan with four narrow gates on each. The minimum value in each gate was used to generate C-scan images because the phase reversal at a ply delamination results in a negative spike in echoes from each damage site.

C-scan images generated from the rf A-scans and from the Wiener deconvolved A-scans are shown in Fig. 3. Figures 3a and 3b are images of the second and third ply interfaces generated by software gating the rf A-scans. Figures 3c and 3d are images of the second and third ply interfaces generated by software gating the axially Wiener-deconvolved A-scans. Note that the C-scan images generated from the axially Wiener-deconvolved A-scans have better lateral resolution than the C-scan images generated directly from the rf A-scans.

![Fig. 1. B-scan images of impact damage site in graphite/epoxy composite: (a) from rf A-scans; (b) from axially Wiener-deconvolved A-scans.](image-url)
Fig. 2. A-scans showing four gates for C-scan image generation: (a) rf A-scan and (b) axially Wiener-deconvolved A-scan.

Fig. 3. C-scan images of impact damage at interfaces between: (a) second and third plies (from rf A-scans); (b) third and fourth plies (from rf A-scans); (c) second and third plies (from axially Wiener-deconvolved A-scans) and (d) third and fourth plies (from axially Wiener-deconvolved A-scans).
TWO-DIMENSIONAL LATERAL WIENER DECONVOLUTION

The psf used for two-dimensional lateral Wiener deconvolutions of the C-scan images was derived by fitting a two-dimensional Gaussian function to an experimentally determined psf [5].

The results of deconvolving the two-dimensional psf's from the C-scan images of Fig. 3 are shown in Fig. 4. Figures 4a and 4b result from two-dimensional Wiener deconvolutions of the C-scan images generated from the rf A-scans (Figs. 3a and 3b respectively). Figures 4c and 4d result from two-dimensional Wiener deconvolutions of the C-scan images generated from the axially Wiener-deconvolved A-scans (Figs. 3c and 3d respectively). It is evident from these images that the two-dimensional Wiener deconvolution operation improves the resolution of C-scan image features. It is also evident that the resolution in the two-dimensional Wiener-deconvolved C-scan images generated from one-dimensional axially Wiener-deconvolved A-scans is better than the resolution in the two-dimensional Wiener-deconvolved C-scan images which were generated directly from the rf A-scans.

During the course of this investigation, it was found that the psf required for deconvolving the C-scan images generated from axially deconvolved A-scans was narrower than that required for two-dimensional Wiener deconvolutions of the C-scan images generated from the rf A-scans. In fact, the variance of the Gaussian psf used for Wiener deconvolutions of the C-scan images in Figs. 3a and 3b (yielding the images in Figs. 4a and 4b) was 20 pixels, whereas the variance used for Wiener deconvolutions of the C-scan images in Figs. 3c and 3d (yielding the images in Figs. 4c and 4d) was 8 pixels. The reason for this difference in psf sizes is still under investigation.

Fig. 4. Two-dimensional Wiener filtering of C-scan images in:
(a) Fig. 3a; (b) Fig. 3b; (c) Fig. 3c and (d) Fig. 3d.
CONCLUSIONS

B-scan images generated from axially Wiener-deconvolved A-scans have been shown to have better depth resolution than B-scan images generated directly from rf A-scans. This improvement in depth resolution is due to the decrease in pulse length which results from the Wiener deconvolution process. Also, the C-scan images which have been generated by gating the axially Wiener-deconvolved A-scans exhibit better lateral resolution than do the C-scan images which have been generated by gating the rf A-scans. The reasons for this improvement in lateral resolution is still under investigation.

The use of two-dimensional lateral Wiener deconvolution significantly improves the resolution in C-scan images. This improvement in lateral resolution is primarily due to the partial removal of the point-spread function of the ultrasonic transducer from the C-scan images. The greatest improvement in lateral resolution has been achieved by applying two-dimensional lateral Wiener deconvolution techniques to C-scan images which have been generated from axially Wiener-deconvolved A-scans. The lateral resolution in those images is significantly better than that achieved by two-dimensional lateral Wiener deconvolution of C-scan images generated by gating rf A-scans.

Finally, the diameter of the psf used for two-dimensional lateral Wiener deconvolutions of C-scan images generated from one-dimensional axially Wiener-deconvolved A-scans is smaller than is the psf used for two-dimensional lateral Wiener deconvolutions of C-scan images generated directly from rf A-scans. The reasons for this difference in psf diameters is still under investigation.

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REFERENCES


