

COMPUTER AIDED INTERPRETATION OF  
NDE SIGNALS

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ABSTRACT

In order to improve NDE reliability, it is important to recover as much as possible of the useful information in NDE waveforms. An on-line minicomputer is ideally suited to both the collection of data and the performance of sophisticated signal processing tasks. Using a variety of signal processing techniques, including windowing, self-normalization (of transducer properties and far-field diffraction effects), transformations (Fourier magnitude and phase transforms, autocorrelations, cepstra), feature extraction and pattern recognition, it has been possible to obtain information about very small defects, strength of adhesive bonds and acoustic emissions which are not available by conventional means. Examples of these various capabilities are given.

In the past, the ultrasonic signals from non-destructive testing apparatus have been processed in only one simple way: the waveforms are rectified and converted into a "video" signal and displayed on an oscilloscope. A peak in this video signal is taken to be an indication of a defect at the location corresponding to the arrival time of the signal, and the amplitude of the peak is taken as a measure of the defect's size.

This method ignores a great deal of the information present in the ultrasonic signals: no use is made of variations in the frequency content of the signals, phase relationships between parts of the signal are ignored, and long duration signals, such as an echo train from a layered structure, are not treated as one signal.

In order to use more of the information present, first, ultrasonic RF waveforms have to be captured; second, preprocessing operations which enhance the usable information have to be performed, and third, features of the signals which best predict defect type and size have to be determined.

Figure 1 shows a laboratory minicomputer-based signal processing facility. The entire RF waveform is recorded digitally, and the computer performs a wide variety of signal processing operations using Rockwell's interpretive signal processor language.

Figures 2 and 3 show how the properties of the particular ultrasonic transducer and associated electronics used can be removed from the signal in order to allow direct comparisons between experiments, standards and theoretical predictions. In particular, Fig. 3 shows that some signals contain the information needed to "self-normalize" themselves.

Figure 4 shows that the use of a simple gate to pick out a part of a signal can be improved upon by using instead a window of carefully selected shape.

Figure 5 shows that the size of defects no larger than one wavelength of sound can be accu-

rately determined by looking at appropriate properties of the signals.

Figure 6 shows the results of automatic pattern recognition experiments in which the computer learned what features of acoustic emission signals are indicative of what is going on within a part.

Finally, Fig. 7 lists the areas in which the computer system has made contributions to non-destructive evaluation research.

By using more of the information present in ultrasonic signals, it is now possible to answer questions about defects that it was not possible to answer before.

Acknowledgement

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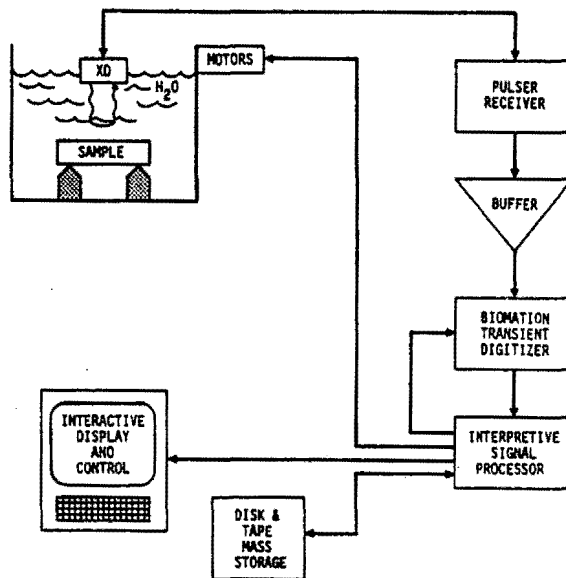


Figure 1. Laboratory minicomputer-based signal processing facility.

WHEN MAKING BROADBAND SPECTRAL MEASUREMENTS, THERE ARE 2 DISTINCT FREQUENCY-DEPENDENT EFFECTS ASSOCIATED WITH THE TRANSDUCER.

1. RESONANT ELECTROMECHANICAL RESPONSE OF TRANSDUCER AND PULSER: NOT MUCH ENERGY AT VERY LOW OR HIGH FREQUENCIES.
2. DIFFRACTION DUE TO FINITE SIZE OF TRANSDUCER: LOW FREQUENCIES ARE IN FAR FIELD, HIGH FREQUENCIES ARE IN NEAR FIELD.

USING A REFERENCE WAVEFORM (e.g. FROM A REFERENCE BLOCK OR BACK SURFACE), ONE CAN NORMALIZE OUT THE TRANSDUCER RESPONSE AND THE FAR FIELD DIFFRACTION.

THE RAW (UNNORMALIZED) SPECTRUM IS THEREBY CONVERTED TO A NORMALIZED SPECTRUM WITH FLAT FREQUENCY RESPONSE WHEREVER SUFFICIENT SOUND ENERGY IS PRESENT.

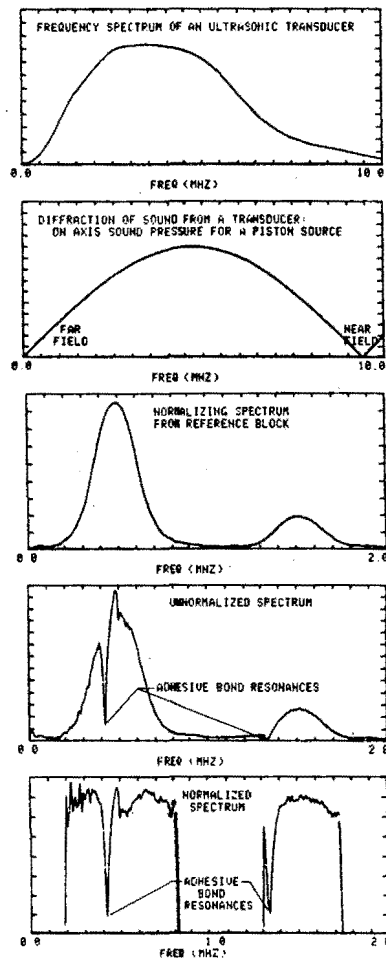


Figure 2. Removing transducer effects I.

IN SOME CASES EACH ULTRASONIC WAVEFORM CAN NORMALIZE (i. e. CORRECT) ITSELF.

THIS REMOVES NOT ONLY TRANSDUCER AND PULSER PROPERTIES AT THAT MOMENT, BUT ALSO TEST PART IRREGULARITIES SUCH AS WARPAGE OR MISALIGNMENT AT THAT POSITION ON THE PART.

- IN PULSE-ECHO TESTING OF ADHESIVELY BONDED ALUMINUM STRUCTURES, THE FRONT SURFACE ECHO IS USED TO NORMALIZE (CORRECT) THE ENTIRE WAVEFORM.
- RAW (UNCORRECTED) FREQUENCY SPECTRA ARE VERY DIFFERENT FOR DIFFERENT TRANSDUCERS.

AFTER SELF-NORMALIZATION, SPECTRA ARE IDENTICAL FROM 1 TO 18 MHZ.

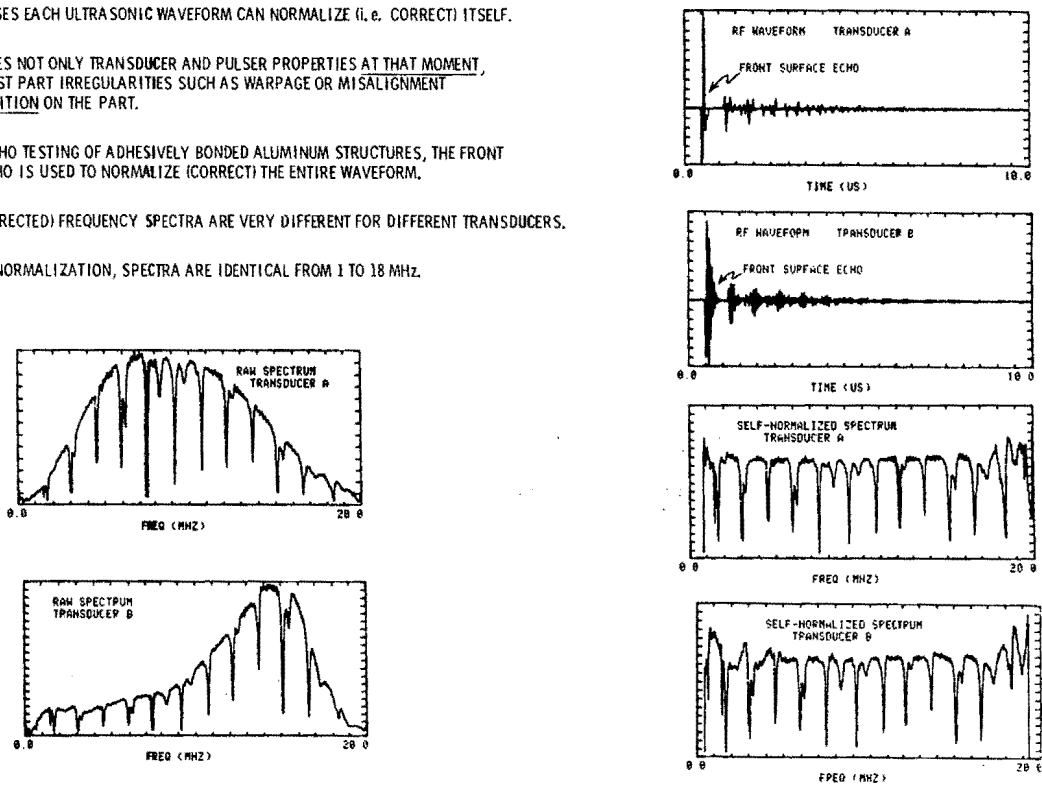
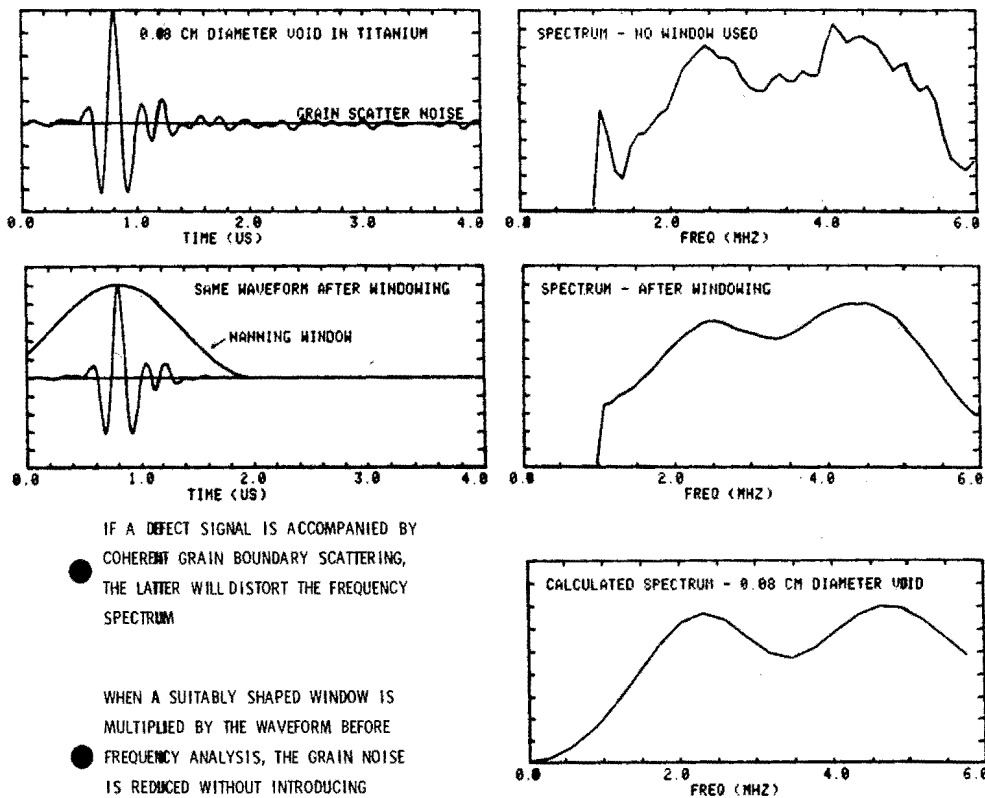


Figure 3. Removing transducer effects II. Self-normalization.



● IF A DEFECT SIGNAL IS ACCOMPANIED BY COHERENT GRAIN BOUNDARY SCATTERING, THE LATTER WILL DISTORT THE FREQUENCY SPECTRUM

● WHEN A SUITABLY SHAPED WINDOW IS MULTIPLIED BY THE WAVEFORM BEFORE FREQUENCY ANALYSIS, THE GRAIN NOISE IS REDUCED WITHOUT INTRODUCING RINGING INTO THE SPECTRUM

Figure 4. Windowing to recover defects from grain noise.

- SEVERAL TECHNIQUES HAVE BEEN DEVELOPED FOR ESTIMATING THE SIZE OF SMALL DEFECTS

FOR VOID DEFECTS WHICH ARE ROUGHLY SPHERICAL, CHANGING SIZE MERELY STRETCHES FREQUENCY SCALE. THUS ANY FEATURE OF FREQUENCY SPECTRUM, SUCH AS PEAK POSITION, GIVES AN ESTIMATE OF DIAMETER

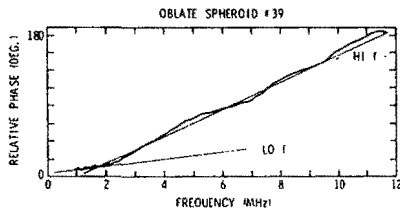
- MORE GENERALLY, SLOPE OF PHASE PART OF FREQUENCY SPECTRUM TELLS ABOUT SIZE AS FOLLOWS

SLOPE OF PHASE GIVES ARRIVAL TIME OF PULSE

AT HIGH FREQUENCY, SLOPE GIVES ARRIVAL TIME FROM FRONT OF DEFECT

AT LOW FREQUENCIES, SLOPE GIVES ARRIVAL TIME FROM CENTER OF DEFECT

THE DIFFERENCE GIVES A MATERIAL INDEPENDENT MEASURE OF SIZE FOR INCLUSIONS



$$HI f \frac{d\phi}{df} = \frac{3.4 \text{ rad}}{11.5 \text{ MHz}} \quad \tau_{HI} = \frac{1}{2\pi} \frac{d\phi}{df} = .0246 \mu\text{sec}$$

$$LO f \frac{d\phi}{df} = \frac{1 \text{ rad}}{2 \text{ MHz}} \quad \tau_{LO} = .0066 \mu\text{sec}$$

$$\tau_{HI} - \tau_{LO} = .018 \mu\text{sec} \quad R = \text{vdt} = .0114 \text{ cm}$$

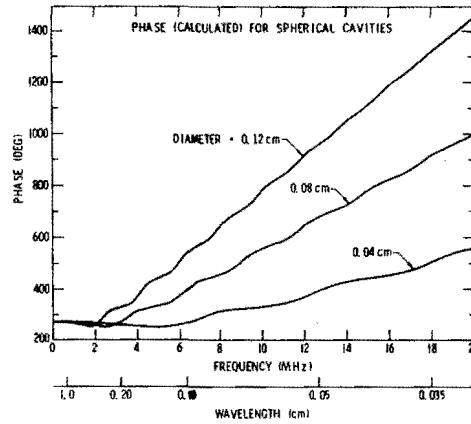
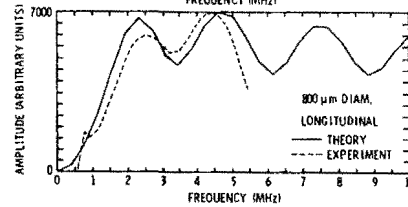
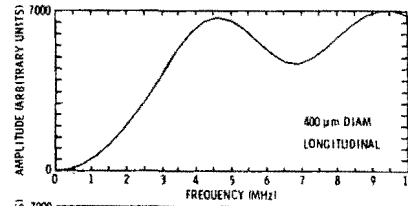


Figure 5. Size of small defects.

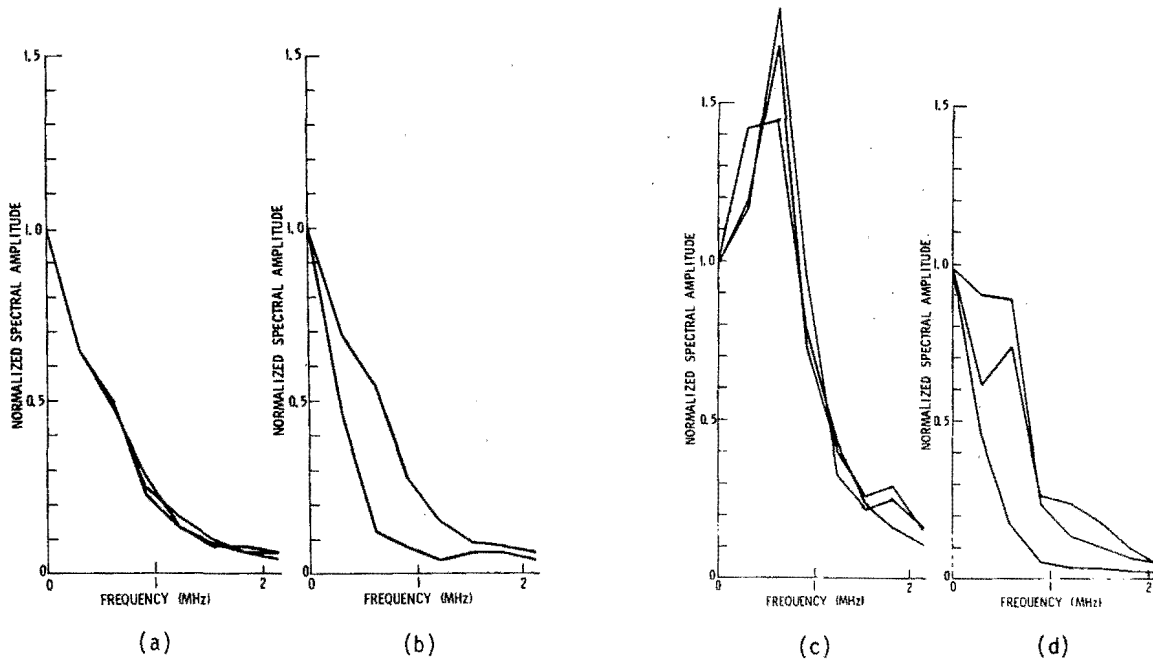
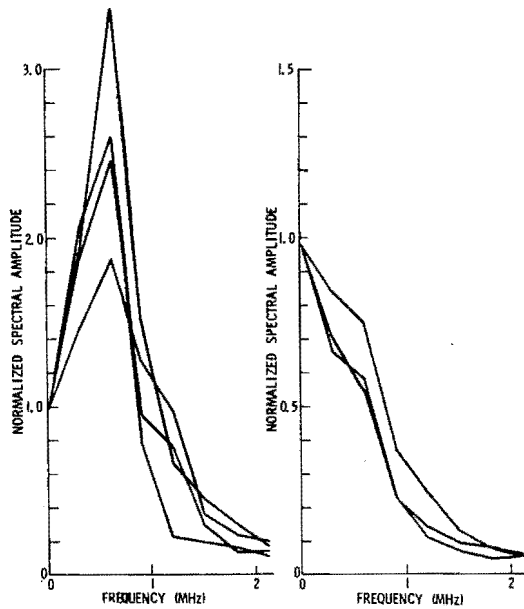


Figure 6. Results of automatic pattern recognition experiments.



(e) (f)  
Figure 6. (Continued)

THE MINICOMPUTER SIGNAL PROCESSING SYSTEM HAS BEEN APPLIED IN THE FOLLOWING AREAS:

- ANALYZE BROADBAND DATA FROM SMALL VOIDS AND INCLUSIONS IN TITANIUM
- CALCULATE THEORETICAL SOLUTIONS FOR SCATTERING FROM SMALL DEFECTS
- ESTIMATE SIZE AND IMPEDANCE OF SMALL SCATTERERS
- ANALYZE BROADBAND DATA FROM ADHESIVELY BONDED ALUMINUM PARTS
- CALCULATE THEORETICAL PULSE ECHO DATA FOR ADHESIVELY BONDED PARTS
- DETERMINE STRENGTH RELATED FEATURES OF ADHESIVE BOND SIGNALS
- COLLECT AMPLITUDE-TIME DATA FOR EVERY ACOUSTIC EMISSION IN A TEST
- COLLECT WAVEFORMS AND SPECTRA FOR MOST ACOUSTIC EMISSIONS IN A TEST
- AUTOMATICALLY IDENTIFY VARIOUS TYPES OF ACOUSTIC EMISSION SPECTRA
- MEASURE VELOCITY, THICKNESS AND ATTENUATION OF COMPOSITES
- ANALYZE CLEAN SURFACES BY ELLIPSOMETRY, SURFACE POTENTIAL DIFFERENCE AND PHOTOELECTRON EMISSION
- MEASURE BONDING OF VERY INHOMOGENEOUS SPACE SHUTTLE INSULATION TILES
- DISPLAY CHLADNI FIGURES OF HONEYCOMB SANDWICH PANELS
- SIGNAL AVERAGE NON-CONTACT ELECTROMAGNETIC TRANSDUCER WAVEFORMS

Figure 7. Applications