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NONDESTRUCTIVE EVALUATION BY ACOUSTO-ULTRASONICS

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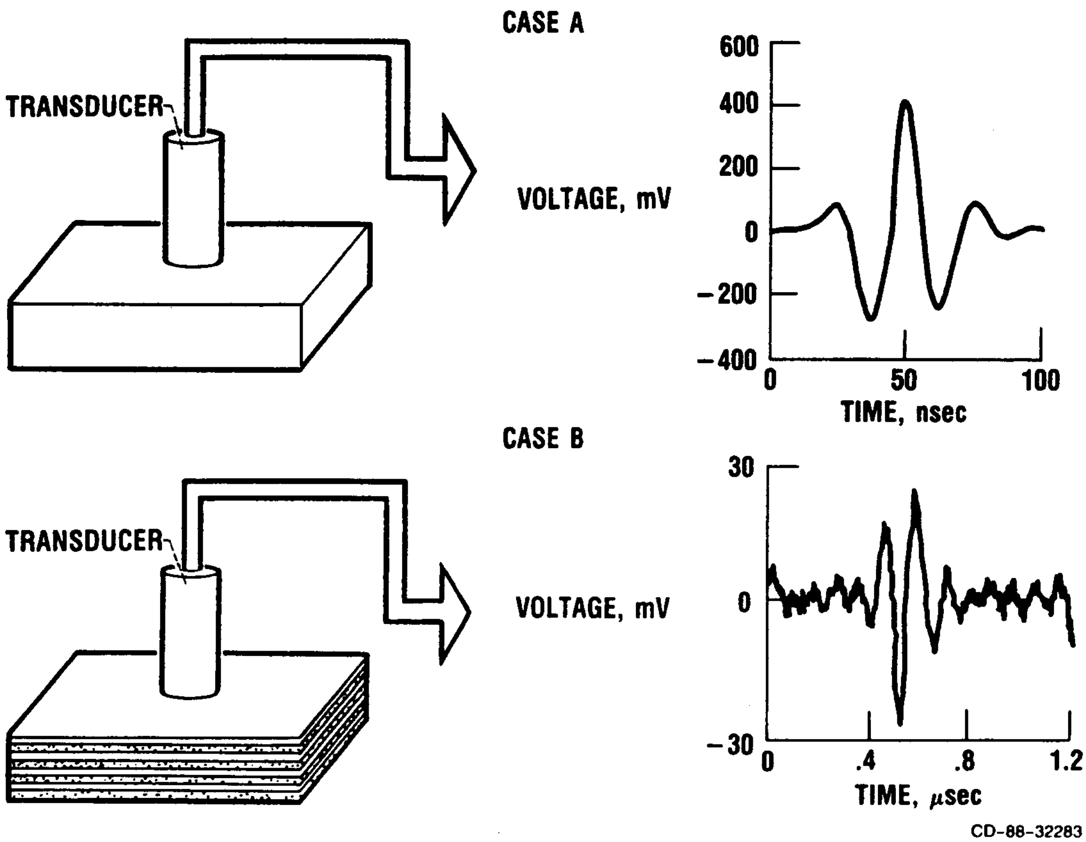
ABSTRACT

Acousto-ultrasonics is an ultrasonic technique that was originally devised to cope with the particular problems associated with nondestructive evaluation (NDE) of fiber/polymer composite structures. The fiber/polymer composites are more attenuating to ultrasound than any other material presently of interest. This limits the applicability of high-frequency ultrasonics. A common use of ultrasound is the imaging of flaws internal to a structure by scattering from the interface with the flaw. However, structural features of composites can scatter ultrasound internally, thus obscuring such flaws.

A somewhat unique need relative to composites is to be able to nondestructively measure the strength of laminar boundries in order to assess the integrity of a structure. Acousto-ultrasonics has exhibited the ability to use the internal scattering to provide information for determining the strength of laminar boundries. Analysis of acousto-ultrasonic signals by the wave ray paths that compose it leads to waveform partitioning that enhances the sensitivity to mechanical strength parameters.

PROBLEM: ULTRASONIC CHARACTERIZATION OF COMPOSITES

It is difficult to analyze ultrasonic signals recovered from composites by conventional methods. This is demonstrated below for "pulse-echo" ultrasonics (Hull et al., 1985). Case A shows an echo recovered from a metal specimen as used for precise velocity and attenuation determination. Case B is an echo from a laminated composite where considerable internal scattering has introduced ambiguity into the signal. These "noisy" signals can be difficult to interpret, necessitating a different approach. An approach referred to as acousto-ultrasonics is described next.

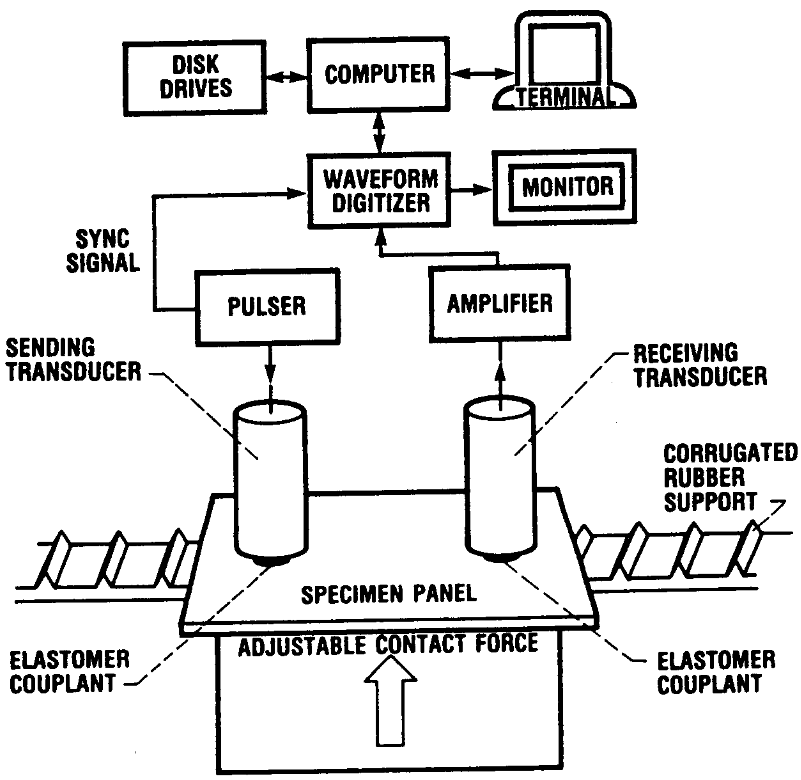


THE ACOUSTO-ULTRASONIC TECHNIQUE

Acousto-ultrasonics (A-U) employs two transducers:

(1) A sender injects ultrasonic energy into the specimen.
(2) A receiver detects the energy after interacting with the specimen.

Rather than avoiding the multiple reflections in a composite, A-U uses them to sense mechanical strength. A-U imitates the stress waves of acoustic emission with ultrasonics in place of mechanical stress. This is totally nondestructive (Vary and Bowles, 1979; Vary, 1979, 1982, 1987).



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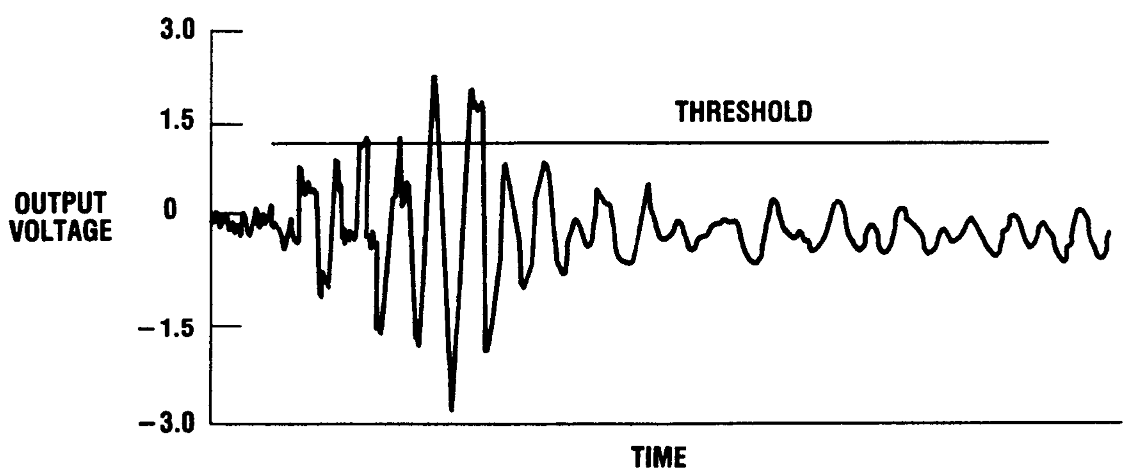
THE STRESS WAVE FACTOR

Acousto-ultrasonic signal strength is calculated as the stress wave factor (SWF). Two common measures of SWF are energy and ringdown count. Energy is measured by

$$SWF = \int_{t_1}^{t_2} V^2 \, dt$$

where V is receiver output voltage. Ringdown count measured by the number of voltage peaks above threshold is illustrated below.



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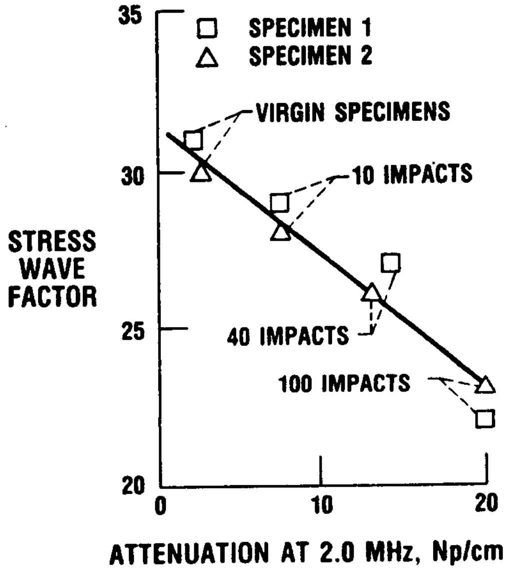
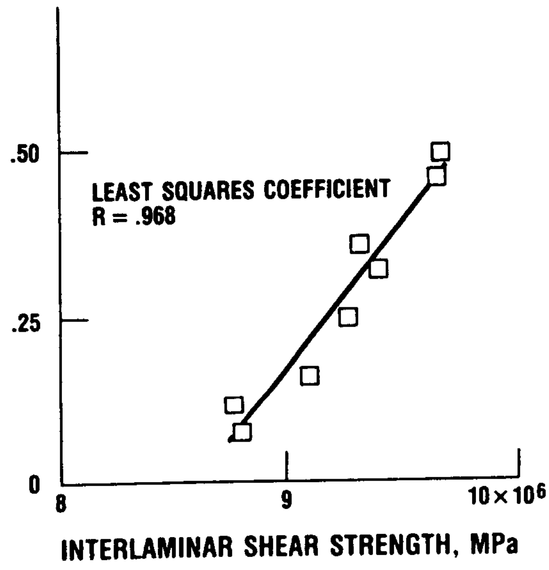
EARLY RESULTS WITH THE STRESS WAVE FACTOR AND GRAPHITE/POLYMER COMPOSITES

Acousto-ultrasonic and ultrasonic attenuation measurements were made on graphite fiber/polymer matrix panels at various stages of impact damage. The SWF and ultrasonic attenuation were calculated for each stage and compared with the number of impacts (Williams and Lampert, 1980), as shown in the figure on the left side.

Acousto-ultrasonic measurements were made on bend specimens prior to destructive testing. The SWF was compared to the interlaminar shear strength (ISS) as calculated from the bend test results (Kautz, 1986). These are shown in the figure on the right side.





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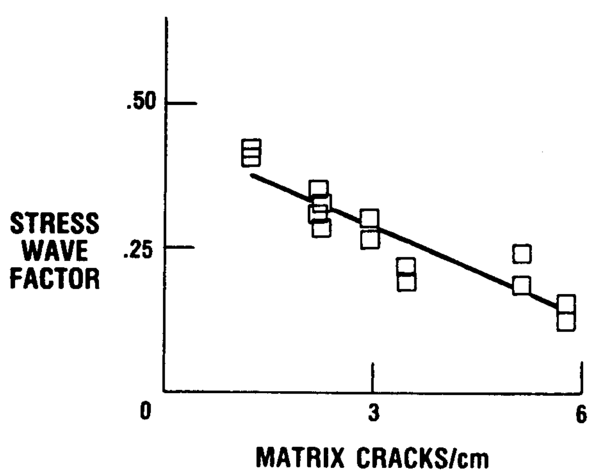
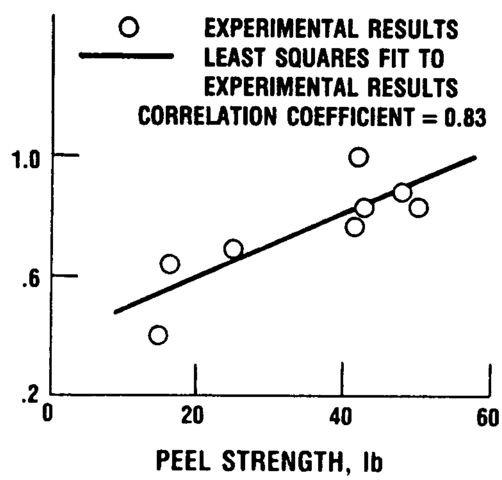
MORE RECENT RESULTS WITH SWF

Graphite fiber/polymer matrix specimens were put under tensile stress to produce a range of matrix crack densities through the central lamina. The SWF was measured after each tensile experiment and was compared with the crack density (Hemann et al., 1987), as shown in the figure on the left.

Acousto-ultrasonic measurements were done on specimens with vulcanized steel-rubber bonds. The SWF was compared with the strength coefficient from subsequent peel tests (Reis and Kautz, 1986), as shown in the figure on the right.





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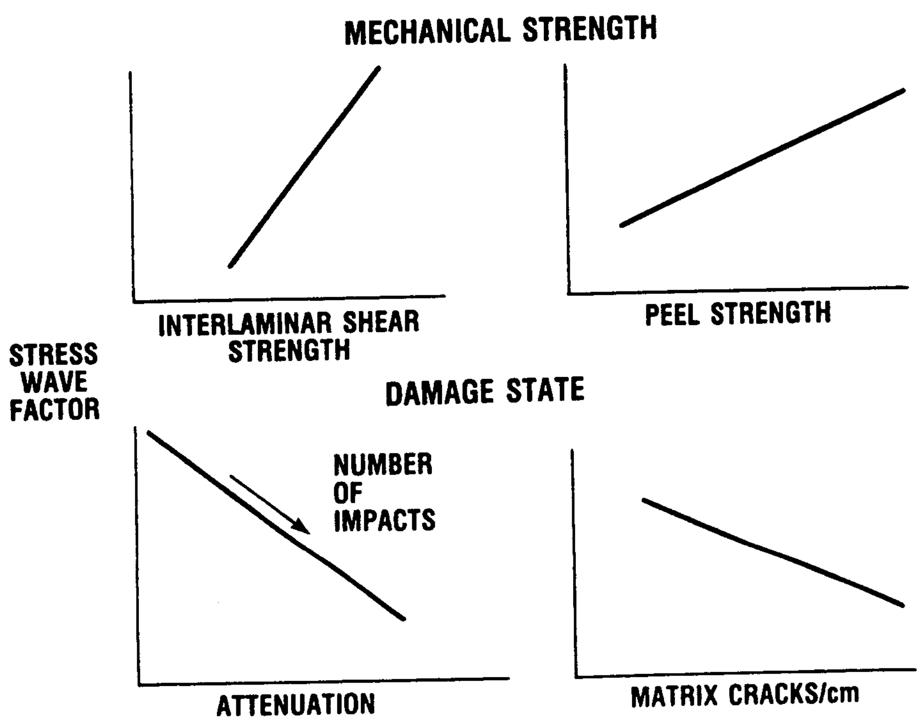
GENERAL CONCLUSIONS FOR SWF

When SWF was compared to a bond strength, such as interlaminar shear or against peel, the SWF was found to increase with the strength. When SWF was compared to a damage state, such as number of impacts or matrix cracks per centimeter, the SWF was found to decrease with increasing damage. In all these cases the SWF was larger for specimens with greater mechanical strength.



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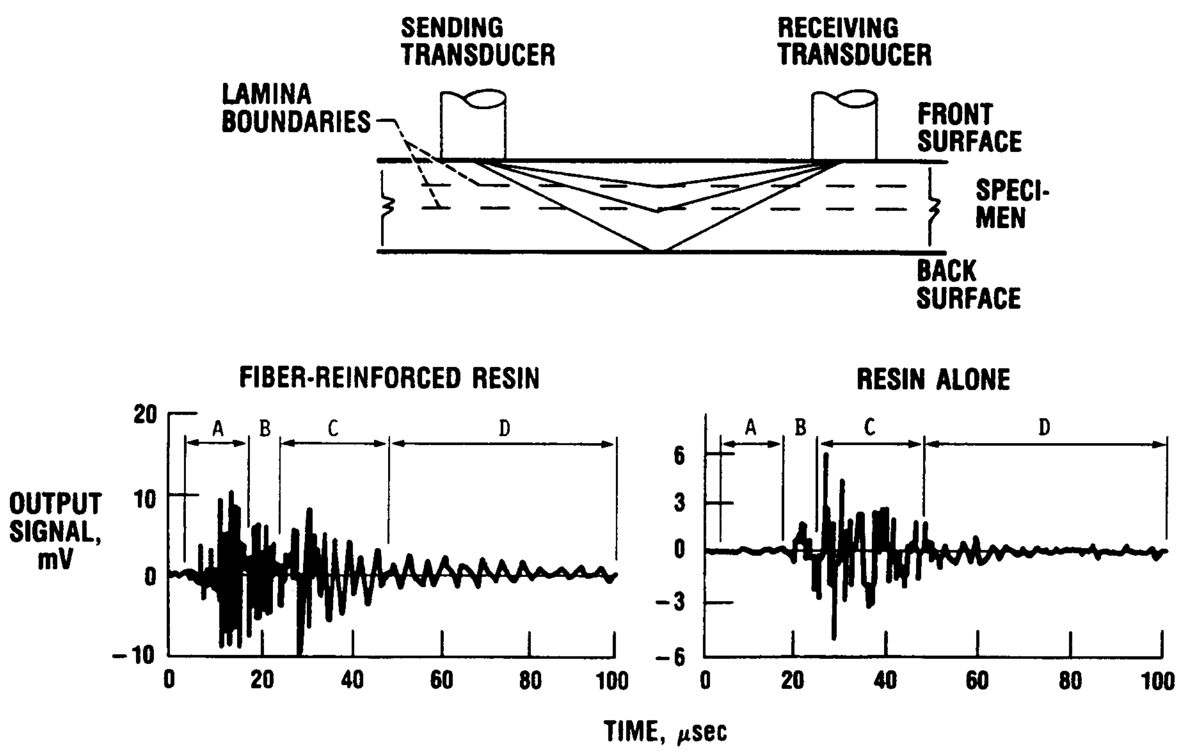
ANALYSIS OF PROPAGATION PATHS

The acousto-ultrasonic signal that arrives at the receiving transducer is the superposition of pulses that have traveled different paths and arrive there over a range of time (Kautz, 1986). This is illustrated below.

Signal propagation paths can be traced experimentally by comparing a fiber-reinforced resin specimen with a resin alone specimen (Kautz, 1987). Parts A of the time records shown below reveal a strong fiber path signal in the composite but nothing in the resin alone specimen. Parts B still show a strong fiber path signal. But in this time region the resin alone shows that signals are just beginning to arrive at the receiver. Parts C are dominated by resin path signal arrivals. Parts D are still dominated by resin path signal components. However, we see that they are enhanced in the composite by the presence of the fibers.



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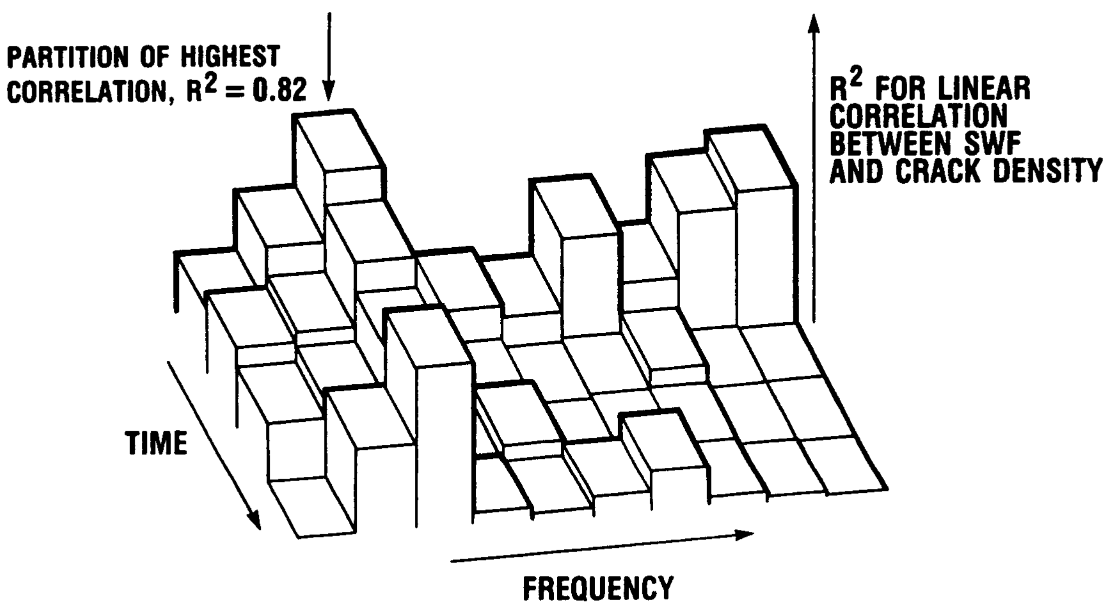
ACOUSTO-ULTRASONIC WAVEFORM PARTITIONING

Propagation path analysis can be used to enhance the sensitivity of SWF to mechanical properties. This is done by calculating SWF for partitions of the acousto-ultrasonic signal (Kautz, 1986). Correlation coefficients are shown for a 10 × 4 matrix of partition SWF values versus crack density for graphite/polymer specimens. The partitions that extend the highest are portions of the time-frequency field of the acousto-ultrasonic signal that are most sensitive to the crack density.



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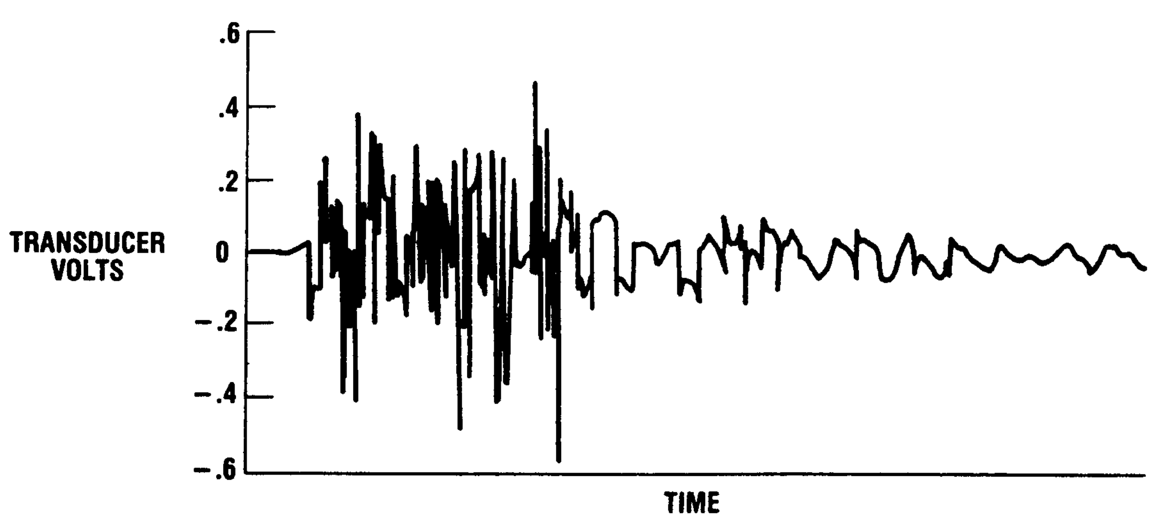
LASER ACOUSTO-ULTRASONICS

Laser in and laser out acousto-ultrasonics will improve reproducibilty by eliminating piezoelectric transducer coupling. Input and output position will be more precisely defined while at the same time permitting better automation for scanning large panels or other hardware.

Shown below is a laser acousto-ultrasonic signal induced in a fiber/polymer composite as detected with a piezoelectric transducer. The laser-induced signal exhibits similar fiber-matrix distribution of ray paths to the one obtained with a transducer-induced signal.

The laser pulse used to produce this signal was 4 nsec in duration. The pulse should have a frequency spectrum envelope that is about 250 MHz. However the frequency spectrum of the induced ultrasonic signal is typical of that produced by a 1-MHz or a 2.25-MHz broadband transducer. This makes it quite appropriate for acousto-ultrasonics.



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FURTHER APPLICATION OF ACOUSTO-ULTRASONICS

Acousto-ultrasonics has shown itself to be sensitive to the strength of structures at boundaries between both similar and dissimilar materials. For this reason it is actively being explored as a means of assessing the fiber-to-matrix bonding in ceramic composites. Similar studies are being conducted to compare SWF to strength parameters in metal matrix composites as well.

In order to understand and interpret acousto-ultrasonics in ceramic matrix and metal matrix composites it is necessary to identify the propagation paths that constitute the signals that are observed.

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