LASER-BASED ULTRASONICS ON GR/EPOXY COMPOSITE: INTERFEROMETRIC DETECTION

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INTRODUCTION

The use of non-contact ultrasonic techniques for the inspection of wings, tail sections and fuselages of aircraft in the field environment is an attractive alternative to current contact or squirter approaches. This paper reports on the use of laser generation and detection of ultrasound for flaw detection in Gr/Epoxy composite panels. Laser-based ultrasonics is a well documented technique which has been demonstrated by many researchers [1-8] and is being applied in several industrial areas [9-11].

In a previous paper [12], we carried out a laser-in/laser-out systems analysis which estimated the principal losses based on generation with a Q-switched Nd:YAG laser and detection with an actively stabilized spherical Fabry-Perot interferometer. In this paper we demonstrate the feasibility of this analysis with the successful acquisition of a transmission C-scan on a 150 ply Gr/Epoxy panel containing a simulated (1 cm × 1 cm) delamination. We describe the interferometer and its performance and discuss the critical issues for a practical eventually field usable concept of source-detector integration.

INTERFEROMETER DESIGN CONSIDERATIONS

The optical detector must meet the following requirements:

(1) insensitivity to environmental (depot) disturbances;
(2) insensitivity to surface roughness and curvature; and
(3) sensitivity for flaw detection without laser surface damage.

A key feature is the insensitivity to environmental changes in path length caused by dust particles, air flow/turbulence, part-to-interferometer distance and mechanical vibrations. These requirements are met by the spherical Fabry-Perot etalon and the optical heterodyne two-wave interferometer (Mach-Zehnder). They are are not met by other types of interferometers, including the Michelson Interferometer.

Another key feature is the requirement for a large "etendue" for the interferometer. It must be sensitive to waves from off-axis angles, insensitive to the nature of the wave front (i.e. non-planar waves), and insensitive to surface roughness. The spherical Fabry-Perot etalon has a large collection efficiency; i.e., "etendue"; it shows an important advantage over the Mach-Zehnder.

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Figure 1 shows a schematic diagram of our Rockwell interferometric detector patterned after that described by Monchalin [10]. Key components are the probe laser, the Fabry-Perot etalon and its feedback circuit, the calibration circuit and the signal processing circuit. Our Fabry-Perot etalon is an optical resonator with spherical mirrors whose spacing is 500 mm and whose reflectivity $R = 0.90$. Figure 2 shows the etalon feedback loop whose purpose is to compensate for long term drift in mirror spacing and probe laser frequency instability. As shown in Figure 2 a portion of the probe laser beam is tapped with a beam splitter BS1 and sent into the etalon by a polarized beam splitter PBS_2 as a vertically (V) polarized beam. The primary signal is horizontally polarized (H). The optical feedback signal is diverted by another polarized beam splitter PB_1, into a detector D_2. The corresponding voltage signal is sent into a compensation circuit (bandwidth 2 kHz) and into the controller (Burleigh RC-45) which provides control signals to PZT elements. These adjust the mirror spacing to maintain resonance as the frequency of the laser beam fluctuates. Our probe laser is an argon-ion laser adjusted for single frequency, single line operation at a wavelength of 514.5 nm. The beam power used in the experiments ranged from 400 mw to 1 W.

We have analyzed the sensitivity of SPF etalon detection and calculated the detected ultrasonic displacement as a function of probe laser power for a specular surface and an isotropically scattering diffuse surface with 100% reflectance [13]. The graph of Figure 3 shows the resultant curves and also identifies the thermal noise and shot noise-limited regimes. Also shown is the limit of piezoelectric detection. The calculations are shown for a bandwidth of 1 MHz. The approximate operating range for our interferometer is shown in the figure and as indicated is located in the shot noise-limited regime.

RESULTS

The interferometer was used to detect out-of-plane surface displacements caused by through transmitted longitudinal wave pulses generated by a Q-switched Nd:YAG laser. The sample was 150 ply fully cured Gr/Epoxy with the Gr fibers oriented in parallel. The generating beam had an energy of 343 mj, a pulse duration of 10 nsec and a spot size of about 3 mm. The interferometric detection system's probe laser had a power of 400 mw and a 2 mm spot size.

Figure 4 shows the received signal as a function of time and displays the first through transmission pulse and subsequent multiple path echoes. The signal-to-noise ratio for the first pulse is greater than 40 dB after traversing a path length of 15 mm of uniaxially laid up Gr/Epoxy. On the generation side, a 125 μm thick high temperature Kapton film was used as a constraint. The generating beam was kept well below the ablation limit so that no visible alteration in either the film or the Gr/Epoxy underneath could be observed after many days of continuous operation. On the detection side, a 2 mil thick aluminum mylar film was used to enhance the reflectivity. Figure 5 shows a comparison between the signals obtained in the region with and without a flaw. The signal is seen to be strongly attenuated over the flaw which was a delamination simulated by a 250 μm thick teflon film 10 × 10 mm in size. Figure 6 shows a line scan across the flaw which was 5 mm below the surface on the generation side of the sample. The flaw is indicated by a steep drop in signal amplitude over a distance of about 10 mm. Figure 7 shows a two-dimensional transmission C-scan over the same flaw with a pixel size of 2 mm. The total scan area was 20 mm × 20 mm. The grey scale image shown here indicates the presence of the flaw in the low amplitude (black) region whose square appearance and size is in good agreement with the geometry of the teflon film. The slight drop in amplitude in the lower half of the image is a result of weakening in the battery power supply for the diode detector which was discovered after the run.

In a previous paper [13], we presented the angular reflectance for a white painted Gr/Epoxy aircraft component and showed that in addition to a specular component, the reflectivity also had a strong diffuse component. Since a painted

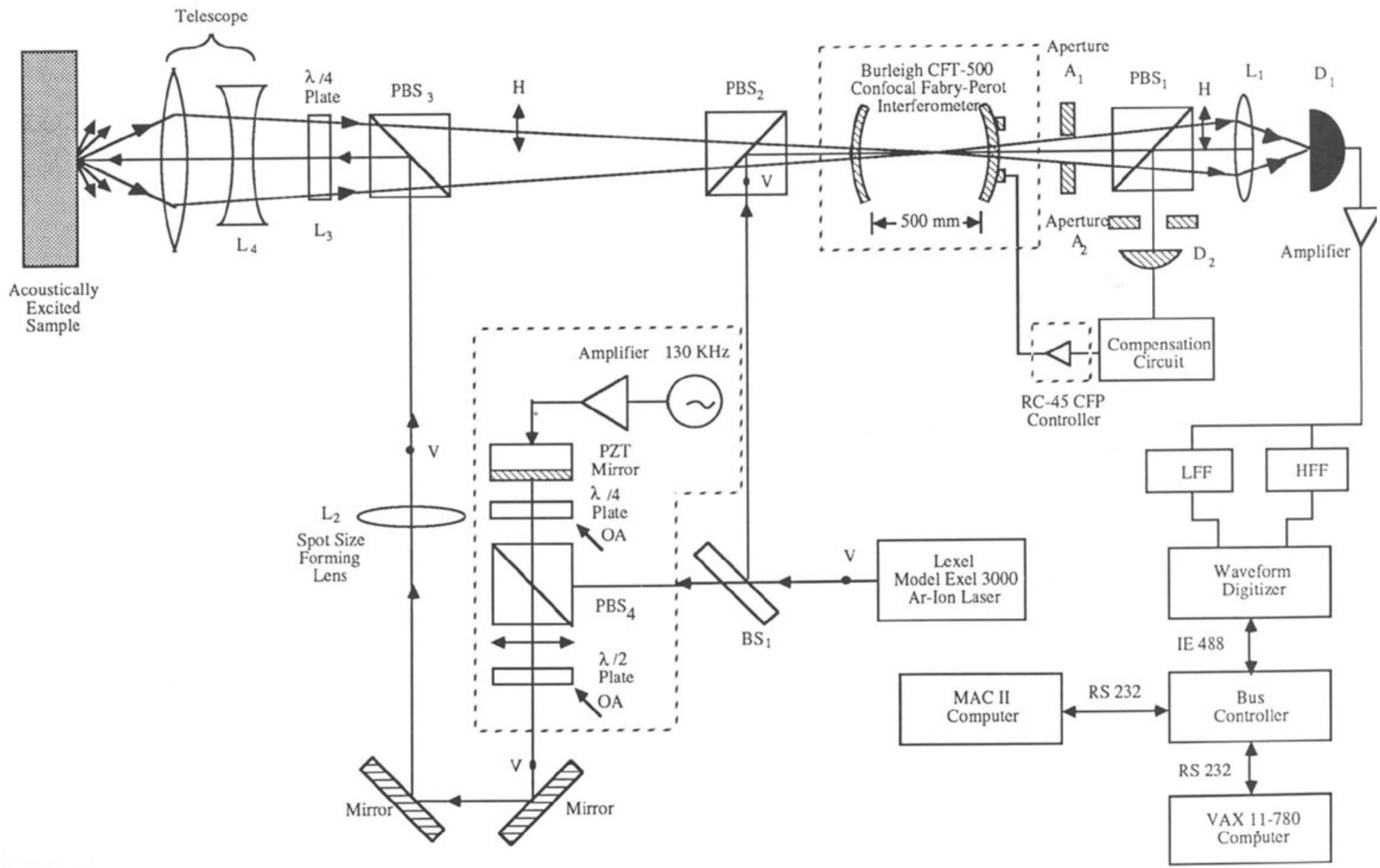

Figure 1 Schematic of the Rockwell interferometer detector.

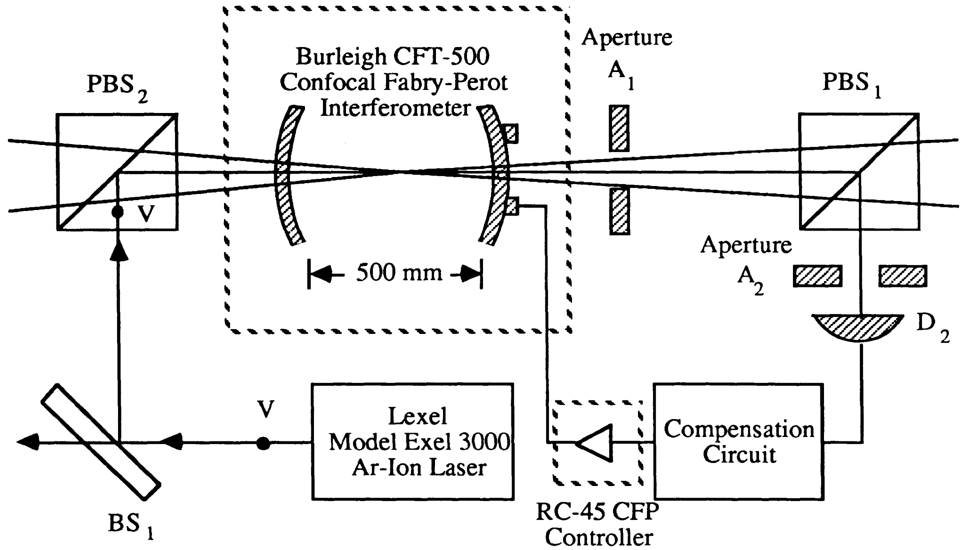

Figure 2 Etalon feedback loop.

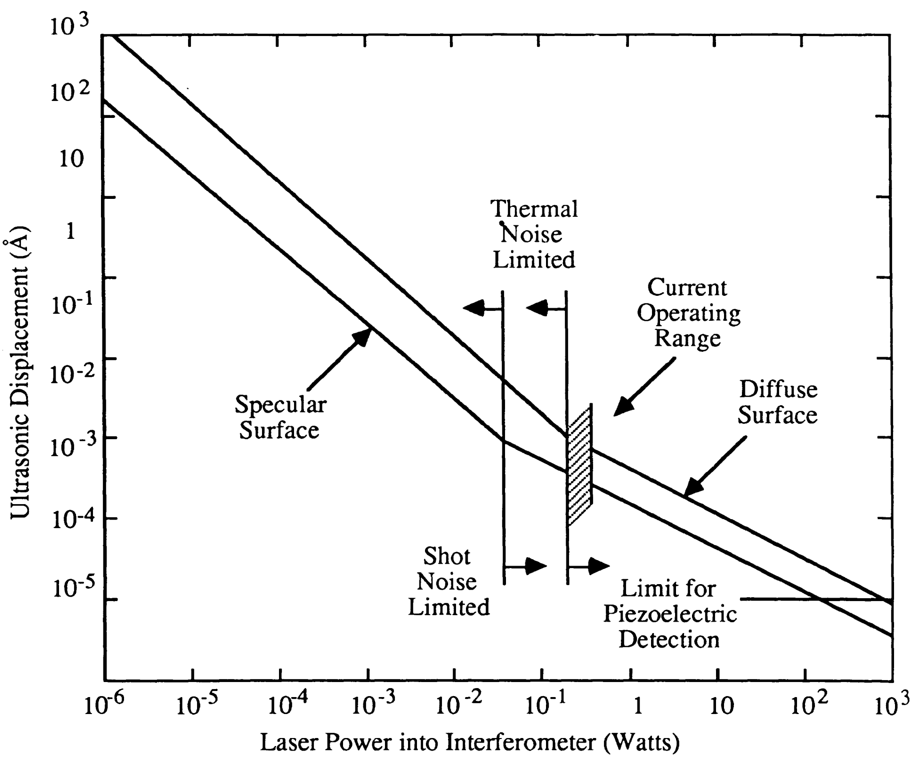

Figure 3 Sensitivity to SPF etalon detection.

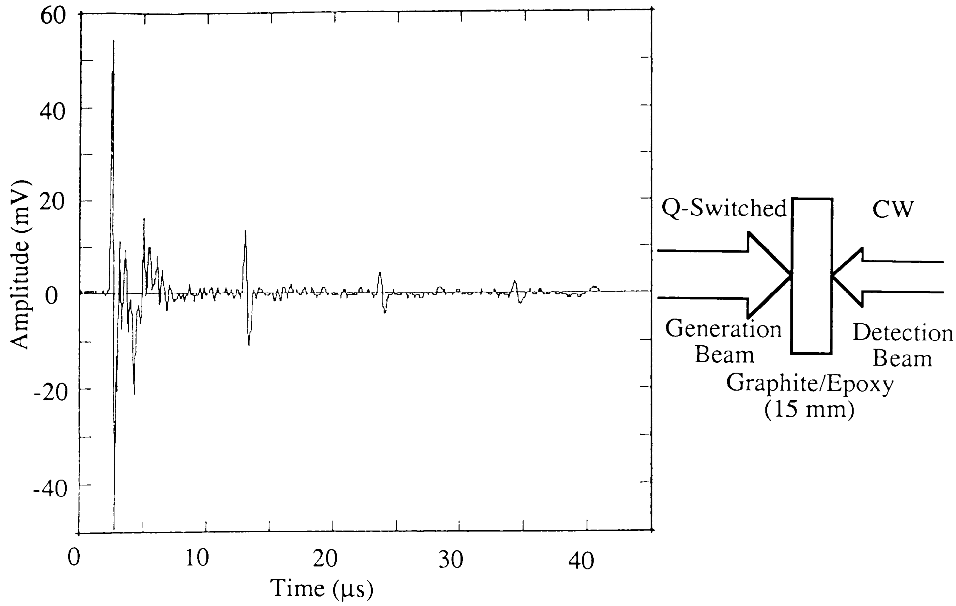

Figure 4 Received signal as a function of time.

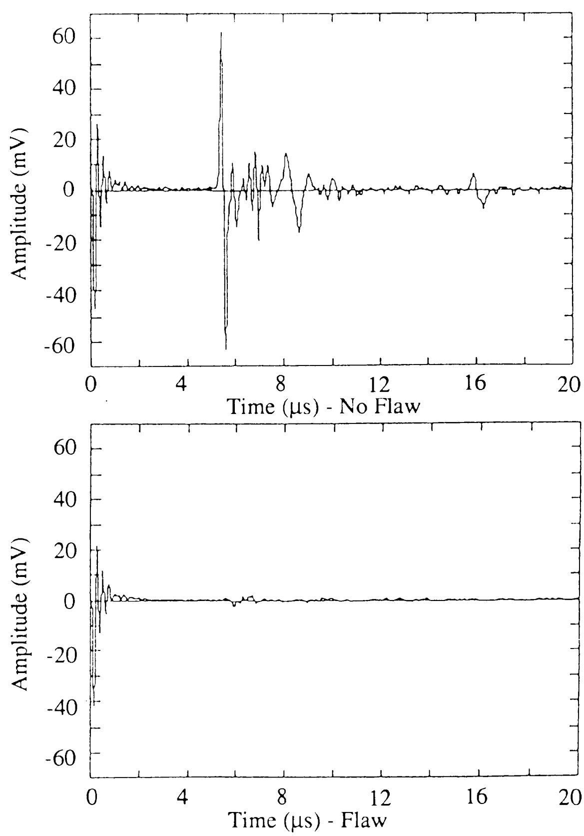

Figure 5 Comparison between signals in the region with and without a flaw.

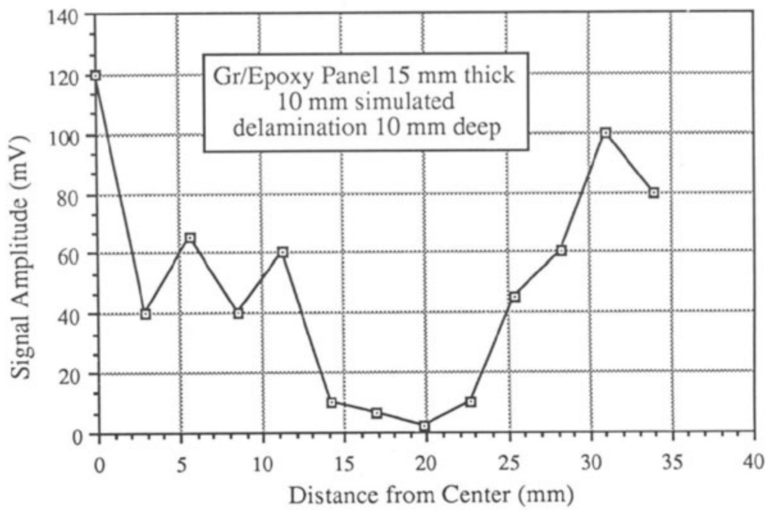

Figure 6 Laser-in/laser-out: line scan over flaw.

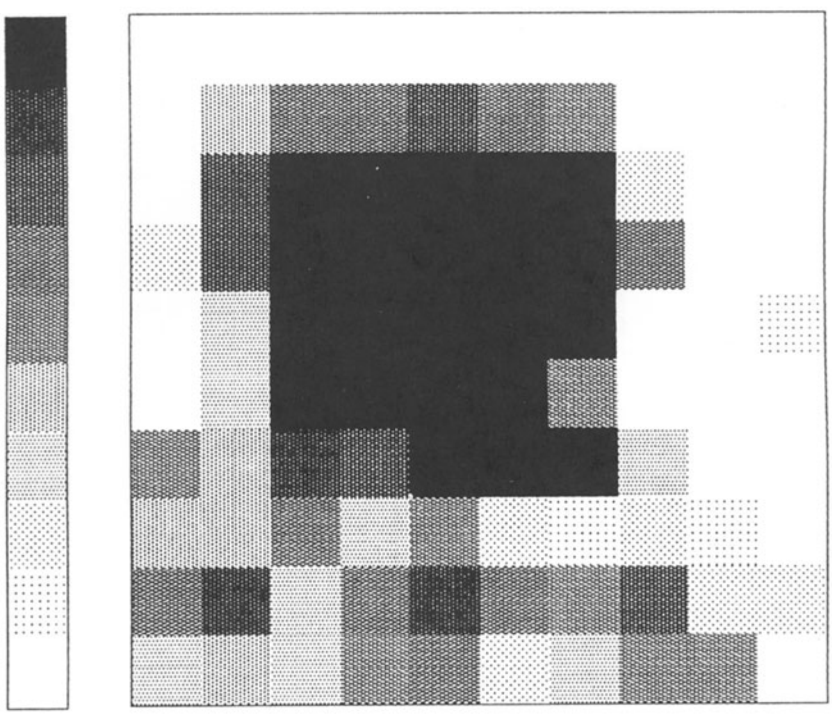

Figure 7 Two-dimensional C-scan.

sample containing a flaw was not available, we prepared a sample of Gr/Epoxy with an unpainted but polished surface, simulating the aerodynamically smooth painted surface. Figure 8 shows a through-transmission signal for a 150 ply Gr/Epoxy sample with the interferometric detection on the bare diffuse surface; i.e., with no peel-ply attached. Considering the low reflection coefficient of the black surface, the signal shown in Figure 8 has an amplitude still useful for NDE.

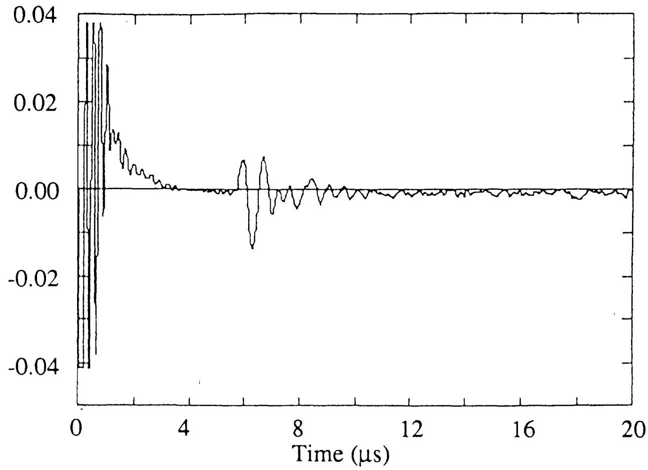

Figure 8 Signal from diffuse reflection.

CONCLUSIONS

We have demonstrated the feasibility of a laser based transmission C-scan of a simulated (10 mm × 10 mm) delamination in Gr/Epoxy. The laser generated, laser detected signal has a signal-to-noise ratio S/N = 40 dB through 15 mm Gr/Epoxy. The detector used is a Fabry-Perot etalon with a PZT feedback loop to correct for frequency fluctuations of the 400 mw argon-ion probe laser. The detector has a measured noise figure of 5-10 dB and is operating in the shot-noise limited regime.

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