Laser-based NDE using Gas-coupled Laser Acoustic Detection

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Abstract: An optical beam-deflection technique has been applied to the ultrasonic inspection of materials. The technique is similar to air-coupled detection, except the airborne wave is detected through beam deflection instead of with an electro-acoustic transducer. It is a non-contact, laser-based, detection technique that does not depend on reflection of the detection laser beam from the surface. It is thus independent of the surface optical properties of the material under test. Applications of gas-coupled laser acoustic detection (GCLAD) with laser ultrasound generation will be illustrated with (1) waveforms showing numerous, well-resolved echoes, (2) surface acoustic waves, and (3) C-scans showing sub-surface defects.

An optical probe beam passing through a gas is deflected when it passes through a region of transversely-varying density and corresponding gradients in the index of refraction. We report successful observations of beam deflection through airborne ultrasound radiated from solid materials. Gas-coupled laser acoustic detection (GCLAD) has been used to detect acoustic waves in materials and image subsurface flaws. With pulsed-laser generation of ultrasound, the technique has possible application in remote sensing and nondestructive evaluation.

The apparatus used for observation of solid-borne ultrasound is shown schematically in Fig. 1. A 532 nm cw probe beam is directed parallel to the surface of a sample. Ultrasound can be generated in the sample by a pulsed laser (as shown) or by contact transducers. Upon reaching the lower surface of the sample, the ultrasonic pulse causes surface motion and associated radiation of an acoustic wave into the surrounding air. The density variations in the airborne wave modulate the index of refraction of the air transverse to the beam propagation and cause a beam deflection. The beam deflection is measured by a position-sensitive photodetector remote (typically one meter) from the sample.

GCLAD provides an alternative detection technique for laser-based ultrasonic inspection of materials. (1,2) Unlike interferometric techniques, the optical beam is not reflected or scattered from the surface of the sample. Hence the technique is not sensitive to the surface optical properties of the material under investigation. It is similar to detection with air-coupled transducers, (3,4) but has greater sensitivity and does not have the bandwidth limitations of air-coupled transducers. Figure 2 shows ultrasonic waveforms generated and detected using the apparatus of Fig. 1. The waveforms were thermoelastically generated by pulsed laser in a 3.0 mm-thick graphite/PEEK pultruded rod, a 2.9 mm thick graphite/PEEK composite panel, and a 8.9 mm thick graphite/epoxy panel. The distance $x$ from the sample to the probe beam was about 4 mm. The first detected pulse occurs at a time equal to the sum of the propagation time in the sample and the propagation time in the air. The detected waveforms were digitally averaged over 6 shots.

This technology has also been applied towards the detection of surface acoustic waves. (5) For this application, the generating laser pulse is incident on the detection side of the sample. Thus the surface-acoustic wave travels approximately 1 cm before detection. Figure 2 shows laser-generated surface acoustic waves in two metal plates averaged over 16 shots.

**FIGURE 1:** Experimental arrangement for observation of laser-generated ultrasonic waveforms with GCLAD. Ultrasonic waveforms, upon transmission through the material, radiate an airborne wave, which modulates the index of refraction transverse to the probe beam and causes beam deflection.
FIGURE 2: Left: Laser generated/GCLAD detected ultrasonic waveforms in various polymer/graphite composites. The ordinates are the voltages at the photodetector outputs in arbitrary units, with arbitrary vertical offsets. Right: Laser-generated/GCLAD detected surface acoustic waves are displayed. The upper plot shows a Rayleigh wave from a 76 mm thick aluminum plate. The lower plot shows a Lamb wave in a 0.1 mm thick stainless steel plate.

FIGURE 3: A 50×50 mm² C-scan of a 16 layer, AS-4/epoxy panel with subsurface impact damage (left) and a tow-placed, 8-layer, AS-4/PEKK composite panel with intentional flaws (right). Each pixel represents 1×1 mm² of the sample area. In addition to showing the impact damage, the image also shows variations in the ultrasound energy resulting from the lay-up of the graphite fibers.

The imaging capability of GCLAD has been demonstrated with a through-transmission C-scanning configuration in which the sample in Fig. 1 is translated under computer control in a plane perpendicular to the generation beam. (6) Figure 3 shows a 50×50 mm² C-scan of an AS-4/epoxy panel which was previously subjected to impact testing, and a tow-placed AS-4/PEKK composite panel with intentional flaws introduced during the fabrication. Darker pixels represent poor acoustic energy transmission, indicative of subsurface damage or poorly-consolidated regions within the composite panels.

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