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APPLICATIONS OF LASER-ULTRASONIC TECHNIQUES

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ABSTRACT

Laser-ultrasonics uses lasers to generate and detect ultrasonic waves. It is a non-contact technique used to measure materials thickness, detect flaws and materials characterization. The basic components of a laser-ultrasonic system are a generation laser, a detection laser and a detector. Standard ultrasonic techniques have the disadvantage of requiring direct contact between the measuring device and the sample. If testing is performed manually, a coupling agent is usually applied between sample and measuring head. For automatic testing a water-jet is used to couple sample and transducer, or the sample is placed into a bath of water. On hot samples (e.g. glowing steel), or other devices where contact measurement is prohibited by the test specifications, laser ultrasound permits testing of the device. Another advantage of laser ultrasound is the enhanced resolution.

KEYWORDS: Laser Ultrasound, Bulk Waves, Acoustics Waves, Imaging.

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Laser ultrasonic measurement systems are particularly attractive to nondestructive structural and materials characterization of solids because:

1. They are noncontact, leading to increased speed of inspection.

2. They can be nondestructive if the optical power is kept sufficiently small.

3. They can be used for *in situ* measurements in an industrial setting.

4. They are couplant independent (unlike contact acoustic microscopy techniques), providing absolute measurements of ultrasonic wave displacements.

5. They have a very small footprint and can be operated on curved complex surfaces.

6. They are broadband systems providing information from the kHz to the GHz range, enabling the probing of macrostructures to very thin films.

LASER GENERATION OF ULTRASOUND

Laser generation of ultrasound was first demonstrated by White (1963). Since then, lasers have been used to generate ultrasound in solids, liquids, and gases for a number of applications. A comprehensive review of laser generation of ultrasound is given in Hutchins (1988), and Scruby and Drain (1990). Here we will restrict attention to the generation of ultrasound in solids using pulsed lasers.

Generation Mechanisms

The dominant mechanisms involved in laser generation of ultrasound in a solid are easy to outline. A pulsed laser beam impinges on a material and is partially absorbed by it. The optical power that is absorbed by the material is converted to heat, leading to rapid localized temperature increase. This results in rapid thermal expansion of a local region, which leads to generation of ultrasound into the medium. If the optical power is kept sufficiently low enough that the material does not melt and ablate.

Ultrasonic waves are generated on the surface of a sample by exposing a small spot to a short and focused laser pulse. Depending on the power density, ultrasonic waves are generated by ablation or by thermo elastic expansion. The type of wave generation influences the propagation direction and energy of the ultrasonic waves. Note that the material itself is the emitter of ultrasonic waves. Thus the propagation direction is independent from the incidence angle of the exciting laser beam. Consequently, also at sample areas which are difficult to access and therefore illuminated under shallow incident angles, the ultrasonic waves are emitted in the same way as under perpendicular incidence. (Figure 1)

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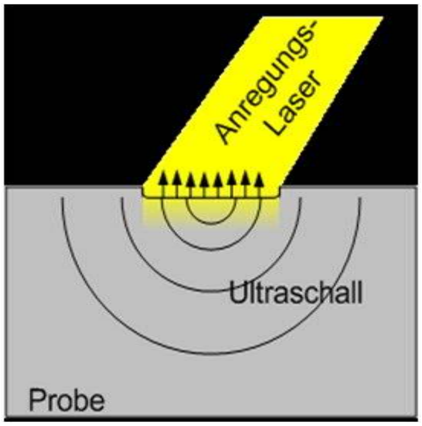

Figures 1: Production of Ultrasound waves

Detection of the ultrasonic waves is performed by illuminating a point on the sample with a cw laser. The ultrasonic waves lead to small displacements in the order of 10 nm and surface speeds of several meter/second. These displacements lead to a Doppler shift (i.e. change of the wave length) which can be demodulated, for example, by a Fabry-Pérot interferometer. Alternatively the surface displacements can, for example, be measured with a photorefractive crystal interferometer. In both interferometric techniques the resulting laser light is detected with a high frequency photodiode. (Figure 2)

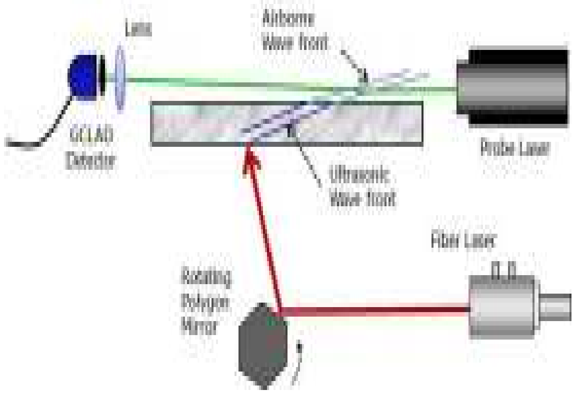

Figure2. A typical setup used for sensing generating and detecting ultrasound in materials. Changes in the wave front as it passes through the material indicate material defects. The deflection shown is greatly exaggerated. Here a GCLAD system is used for detection, but a scanning laser interferomteric system may also be used.

APPLICATIONS

Laser ultrasonics has found wide ranging applications both in industry and academic research. Here we will consider some illustrative applications of laser ultrasonics in nondestructive flaw identification, materials characterization, and process monitoring.

Laser ultrasonic techniques have been used for nondestructive flaw detection in metallic and composite structures. Here we describe a few representative example applications in flaw imaging using bulk waves, surface acoustic waves, and Lamb waves.

Thermoelastic generation of bulk waves in the epicentral direction is generally weak in materials for which the optical penetration depth and thermal diffusion effects are small. Laser ultrasonic techniques using bulk waves have been used primarily for imaging of defects in composite structures (where the penetration depth is large), or on structures that are coated with a sacrificial film that enhances epicentral generation. (Figure 3)

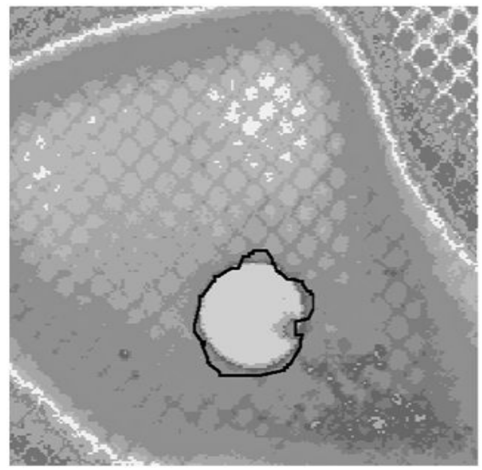

Figure 3: Superposed image of the tomographic image (solid line) and a conventional ultrasonic C-scan image.

Lockheed Martin has recently installed a large-scale laser ultrasonic facility for inspecting polymer-matrix composite structures in aircraft such as the joint strike figher (Yawn et al., 1999). In this system, a pulsed CO_2-laser was used to thermoleastically generate bulk waves into the composite part. Acoaxial long-pulse Nd:YAG detection laser demodulated by a confocal FP was used to monitor the back reflections of the bulk waves. The system has been demonstrated on prototype F-22 inlet ducts. Yawn et al. (1999) estimate that the inspection time using the non-contact laser system is about 70 minutes as opposed to about 24 hours for a conventional ultrasonic squirter system. Choquet et al. (2001) have demonstrated that laser ultrasonics can be used to detect hidden corrosion in painted metallic aircraft lap-joint structures. They use spectral analysis to assess the residual thickness of the metal layer, and state that their technique can identify a 1% loss in thickness due to corrosion.

CONCLUSION

In this chapter, various laser ultrasonic techniques and their applications are outlined. The material discussed here represents only a small cross section of the topic.

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