1.10.14. ULTRASONIC ENERGY PROPAGATION IMAGING OF COMPOSITE STRUCTURES

Chen Ciang CHIA, Jung-Ryul Lee
[1]DEPT. OF AEROSPACE ENG., CHONBUK NATIONAL UNIVERSITY, Jeonju, Chonbuk Korea

Ultrasonic wavefield and wave propagation imaging capability is important for advanced non-destructive evaluation and integrated health monitoring of engineering structures because an image can reveal not only the existence of an anomaly, but also the location and severity of multiple anomalies. Laser ultrasonic wavefield and wave propagation imaging methods deserves extra attention as it offers many advantages, including: (i) fast non-contact ultrasonic generation at low pulse energy; (ii) remote sensing equipment for use in hostile environments, including the inspection of targets under elevated temperature or containing hazardous materials; (iii) high spatial resolution; and (iv) the ability to inspect targets with complex surface geometries due to the allowable incidence angle of ±70°. To harness these advantages, we propose a system for ultrasonic energy propagation imaging (UEPI) with frequency selectivity. The system was built based on a 100 Hz Q-switched laser, laser mirror scanner and wavelet transform technology. Complete system description, including the hardware composition and result processing algorithm will be given in full paper. The system generates Ultrasonic Energy Propagation Movie (UEPM) visible as an ultrasonic energy field emerging from the sensing location. Damages or anomalies could be quantitatively evaluated from area with exclusive high ultrasonic energy concentration or abrupt energy field gradient change in UEPM or snapshots.

To illustrate experimentally the concept and frequency selectivity of the UEPI, an intact 600 mm×600 mm×5 mm carbon fiber reinforced plastics (CFRP) plate with stacking sequence $[45/90/-45/0_2/-45/0/90/0/45/0/45/90/-45]_s$ was scanned, as shown in fig. 1a. Sample scalogram with a 200 kHz line and corresponding UEPM snapshots at 28 μs and 128 μs were given in figs. 1b to d, respectively. Two ultrasonic energy fields correspond to the S_0 and A_0 modes were observed in fig. 1c. When the result was re-process at 100 kHz, only A_0 mode was observes, as shown in figs. 1e to g. Higher energy distribution at upper right and lower left quadrants is due to the fiber orientation of CFRP plate.

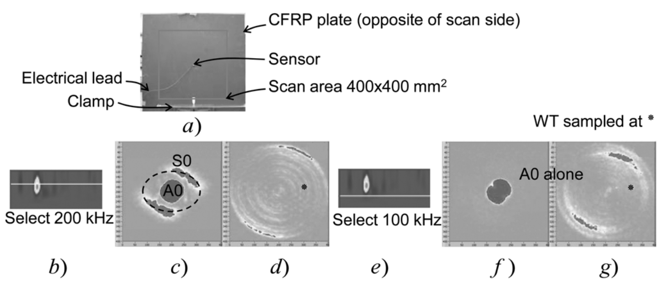
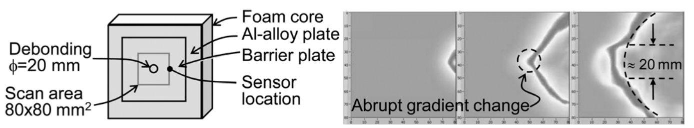


Fig. 1. CFRP plate inspection:
(a) Experimental conditions; (b) Sample scalogram with a 200 kHz line and corresponding UEPM snapshots at (c) 28 μs and (d) 128 μs; (e) Sample scalogram with a 100 kHz line and corresponding UEPM snapshots at (f) 28 μs and (g) 128 μs

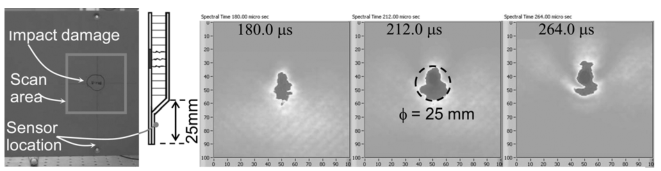
To demonstrate the system functionality for defect evaluation, a sandwich structure comprised of a pair of 0.5 mm Al-alloy plates, a foam core, and a 0.5 mm Al-alloy secondary protection plate epoxy-bonded to the first Al-alloy plate, was inspected. At the center of the specimen, the first Al-alloy plate and the secondary protection plate were not bonded for a circular area with a diameter of 20 mm to simulate a frequent manufacturing defect, as schematized in fig. 2a. The UEPM snapshots at 7.04 μs, 12.08 μs and 18.72 μs are shown in figs. 2b to d, respectively. A single arc-shaped ultrasonic energy field emerging from the sensor location is shown in fig. 2b, but the gradient in the energy field changed abruptly in fig. 2c. The length between the two points where the gradient changed abruptly suggests that the size of the defect was about 20 mm, as indicated in fig. 2d.

The UEPI is capable of inspecting complex structures. To demonstrate this, a radome made of quartz/epoxy plates and honeycomb core (Hexcel, cell size = 9.5 mm) rectangular in shape (1445mm×245mm×9mm) with all edges closed was inspected. It has an impact damage with diameter ϕ = 25 mm at the center, as shown in fig. 3a. The UEPM snapshots at 180 μs, 212 μs and 264 μs are shown in figs. 3b to d, respectively. Exclusive high ultrasonic energy concentration at damage location could be seen. The area with high energy growth to the maximum size at 212 μs, indicating the impact damage of diameter ϕ = 25 mm. This clearly demonstrates the effectiveness of location and size evaluation of damage using UEPM.



(a) (b) (c) (d)

Fig. 2. Bonding flaw inspection:
(a) Experimental conditions; (b) Snapshots of normalized UEPM at 7.04 μs; (c) 12.08 μs; (d) 18.72 μs



(a) (b) (c) (d)

Fig. 3. Radome panel inspection. (a) Illustration of specimen. Snapshots from UEPM generated at 10.0 kHz. High ultrasonic energy concentration at damage location could be seen in (b) to (d)

In conclusion, an ultrasound optical imaging system capable of rapidly scanning a target with a speed of 100 Hz, selectively visualizing energy propagation of ultrasound with a specific frequency, and quantitatively evaluating defects was developed. The ultrasonic frequency selection option was useful for the isolation of ultrasonic modes of interest in generating UEPMs. Damages or anomalies in the scanned structure, such as defect size and location, could be quantitatively evaluated using UEPM. The system is useful for nondestructive quality evaluation and structural health monitoring in the field.