Identification of impact damages in composites by nonlinear guided wave modulation technique

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Abstract

Considering the second harmonics could provide information sensitive for structural health condition, this paper investigates an experimental scheme for measuring the micro-damages caused by low-velocity impacts in carbon/epoxy composites. The present results show a monotonic increase of acoustic nonlinearity with respect to the increase of impact energy. This relevance between the acoustic nonlinear parameters and impact energy indicates that the use of nonlinear ultrasonic guided wave can be a sensitive means for the low-velocity impact damages in composites.

Keywords: Composites; Impact damages; Nonlinearity; Guided waves

1 Introduction

The use of ultrasonic guided waves offers a convenient method of material characterization. However, earlier studies mainly focus on using linear feature of ultrasonic guided waves for gross defects detection. The use of nonlinear ultrasonic wave has been proposed as one of the most promising methods for evaluating material micro-structural changes in early stage [1-6]. Earlier investigations show that acoustic nonlinear response can be the much higher sensitive indicator for micro-damages in composites than linear ones. Considering that second harmonics could provide information sensitive for structural health condition, this paper investigates an experimental scheme for detecting the low-velocity impact damages in aircraft composites using second harmonic generation of guided waves. The phase matched guided wave mode is selected to measure the cumulative second harmonics. The guided wave mode excitation and checking approaches are discussed in this paper. The proposed approach is used to evaluate the low-velocity impact damages. The correlation is presented between the acoustic nonlinear parameter and impact energy.

2 Nonlinear guided wave in composites

Phase matching guided wave modes are selected for efficient data acquisition of second harmonics, for the reason that the cumulative effect of the second harmonic amplitude enables us to measure the nonlinear effect with sufficient signal-to-noise ratio. The resonant double frequency guided wave mode
whose phase velocity matches that primary wave mode is of great concern for the reason that these phase matching modes can remain in the field after guided wave propagation some distance, while all others can decay due to material attenuation and destructive interference with each other, and thus the phase matched double frequency guided wave mode component with accumulative effect will dominate the second harmonics field. The cumulative effect of second harmonics requires that the primary mode and the generated second harmonic mode possess identical phase and group velocities.

Figure 1: Phase velocity (a) and group velocity (b) dispersion curves for guided waves in carbon/epoxy laminates, the propagation direction of the waves is along the fiber direction.

3 Experiments

The specimens investigated in this study are unidirectional carbon fiber reinforced polymer (CFRP) laminates with stacking sequences. The tested laminates are made of 6 plies with 1.0 mm thickness. The dimensions of these specimens are 200 mm×200 mm. Impact energy of 5 J and 15 J were calculated according to the equations of gravitational potential energy. A high power termination is connected to the actuator to generate a high-power narrow band signal with a central frequency of 2.5 MHz. The central frequency of incident transducer is 2.25 MHz while the receiver is 5 MHz to obtain primarily the double frequency second harmonic wave. The data obtained receiver is processed into frequency domain with fast Fourier transformation (FFT).

4 Results and discussion

In this study, the phase matching S1 mode at frequency of 2.5 MHz is chosen to excited and measure the cumulative second harmonic wave. Figure 2 shows the frequency spectrogram for specimens with different impact energy. The variation of fundamental wave amplitudes in the specimens under different damage state is negligible. However, it is clearly shown that the second harmonic amplitude increase with the impact energy in the composite structure. The nonlinearity increase significantly as the change of impact energy in the composite specimen. Consequently, these results indicate that the low-velocity
impact induced micro-damage in composites can be detected by nonlinear guided wave. Thus it can be concluded that the used of nonlinear guided wave is a promising potential method for the diagnostics and prediction of micro-damages in composite structure.

![Figure 2: Frequency spectrogram of different impact energy.](image)

**Conclusion**

In this work, second harmonic generation of ultrasonic guided waves propagation is investigated to detect low-velocity impact micro-damages in aircraft carbon fiber reinforce polymer composite laminates. Experimental results show the linear increase of value of the relative nonlinear parameter with propagation distance, verifying the cumulative second harmonic generation. The proposed procedure is applied for the detection of low-velocity impact induced micro-damages in specimens. This work shows the potential application of measured nonlinear parameter as an alternative indicator for early detection of impact damage in composite materials.

**References**


