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Damage detection of CFRP using fiber Bragg gratings

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In maintenance of composite structures, a structural health monitoring method called active sensing diagnostics has recently been paid much attention. An active sensing system contains actuators and sensors so it generates plate waves in the structure and monitors the response. The integrity of structures can be monitored from the response to plate waves because damage in structures affects the propagation properties of plate waves. In previous studies on active sensing diagnostics, piezoelectric (PZT) devices were used as sensor [1, 2]. There is a great advantage in practical application if fiber Bragg gratings (FBG) can be used as sensor in active sensing. This is because a FBG is lightweight, small size and immune to electromagnetic interference, moreover, can be multiplexed [3].

When broadband light is launched into a FBG, only a narrow band of light centered at a wavelength called the Bragg wavelength is reflected. The Bragg wavelength varies with the strain to which the FBG is subjected. Consider light reflected from the FBG is transmitted through an optical filter whose transmissivity changes with wavelength. The Bragg wavelength can be converted to the intensity of light transmitted through the optical filter. Light intensity can be measured with a photodetector at high speed. It has been reported that FBG sensors can detect plate waves generated with PZT pulsers by using FBG as optical filter in the system described above [4, 5].

The objective of the present study is to verify the possibility of active sensing diagnostics using FBG sensors. A cross-ply CFRP having visible damage was used as the material to be monitored. Plate waves were propagated through an intact area or a damage area and were detected with FBG sensors. The influence of the existence of damage on FBG sensor response was investigated.

A schematic diagram of the experimental setup employed is shown in Fig. 1. The monitored material was a $290 \times 190 \times 1$ mm^3 cross-ply CFRP plate in which a 65×10 mm^2 visible damage had been produced by ball drop impact. The damage included matrix cracking, fiber breaking and delamination was spread through the thickness. An FBG sensor was attached on the surface of CFRP using adhesive for strain gauges. A PZT pulser was put on two places. One was such that the plate wave generated with the pulser passed the damage area before it reached the FBG sensor; the other was where the plate wave passed through intact area before it reached the FBG sensor. Distance from the FBG sensor to the PZT pulser was 90 mm. Two types of PZT pulser that generates extensional or flexural plate wave were used. Input signal to the pulser was a 10-cycle toneburst and the frequency was set at the resonant frequency of pulser.

A broadband light source whose output wavelength ranged from 1520 to 1620 nm was used. Broadband light was conducted to an FBG sensor via an optical circulator. Light reflected from the sensor goes backwards through the optical circulator and then travels to an FBG filter. Light transmitted through the filter was converted into voltage signal with a photodetector. The photodetector signal was recorded at a sampling rate of 25 MHz and was averaged in data acquisition of 512 times. Both FBG sensor and filter employed in the experiment had a gauge length of 10 mm and their Bragg wavelengths in strain free state were 1550.183 and 1550.173 nm, respectively. Reflective curves of the sensor and the filter are shown in Fig. 2.

Fig. 3 shows FBG sensor response to a flexural plate wave along with the pulser signal. We note here only the first 10-cycle response since the pulser was driven by 10-cycle signal. The amplitude of response in intact area increases during the first 3 cycles and then becomes almost constant. Compared with the response in intact area, the amplitude of response propagated through damage area attenuates nearly by half. The waveform shows a different behavior from the pulser signal: the amplitude increases during the first 5 cycles and decreases in the following 5 cycles. Difference in waveform between the response and the pulser signals is introduced by dispersion. The experimental results demonstrate that damage causes large dispersion.

Fig. 4 shows the frequency characteristics of pulser signal and response signals in the first 10-cycle. Frequency characteristics of both response signals agree well with that of pulser signal. The existence of damage has little influence on frequency characteristics of response to flexural wave although it affects the response waveform.

Fig. 5 shows pulser signal and response curves to extensional plate wave. Compared with the response pause to a flexural plate wave shown in Fig. 3, the response signal to extensional plate wave has a higher SN ratio. The amplitude of response increases with axial strain to which the FBG sensor is subjected. The extensional wave causes larger change in the axial strain, thus giving larger amplitude signals. In response to plate wave propagated through intact area, the amplitude gradually increased during the first 10-cycle response and then decreased rapidly. On the other hand, the response signal to plate wave propagated through damage area demonstrated a significant fluctuation in

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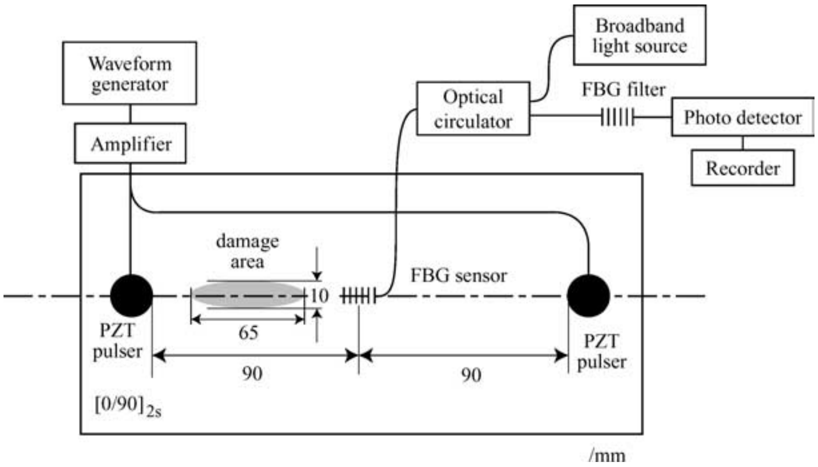

Figure 1 A schematic of experimental setup.

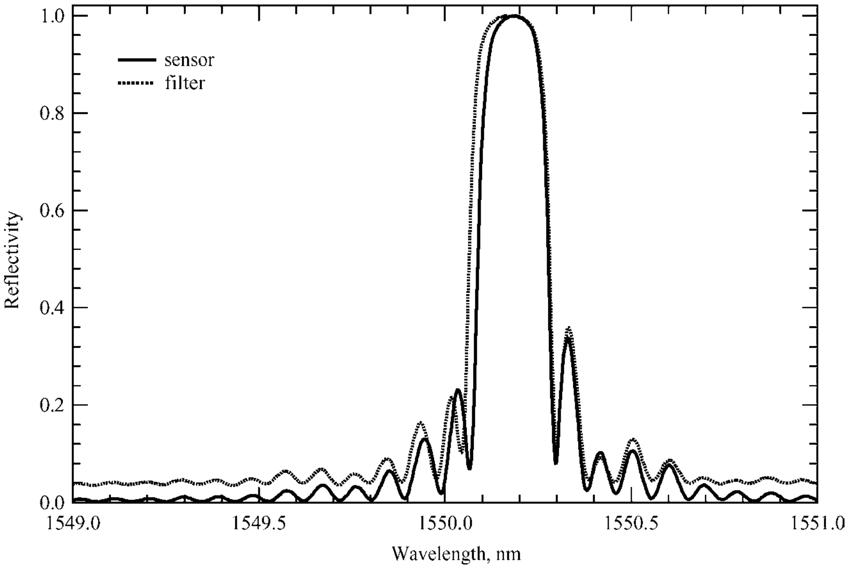

Figure 2 Reflectivity of FBG employed in the experiment.

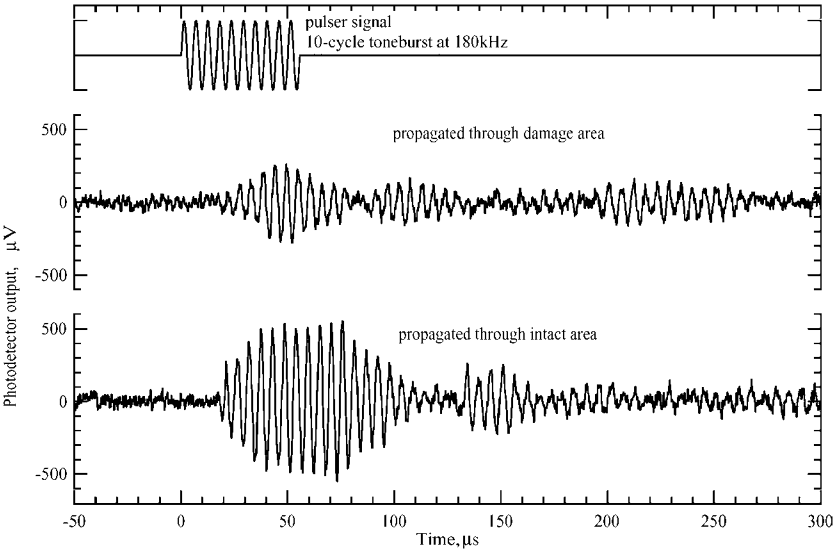

Figure 3 FBG sensor response to flexural plate wave.

amplitude during the first 10-cycle. Furthermore, the amplitude dropped by 10% or less in comparison to the case in intact area.

Frequency characteristics of the first 10-cycle response to extensional plate wave are shown in Fig. 6. Response to plate wave propagated through intact area has similar frequency characteristics to pulser signal. On the other hand, response to plate wave propagated through damage area has different frequency characteristics in which some peaks appear in the lower

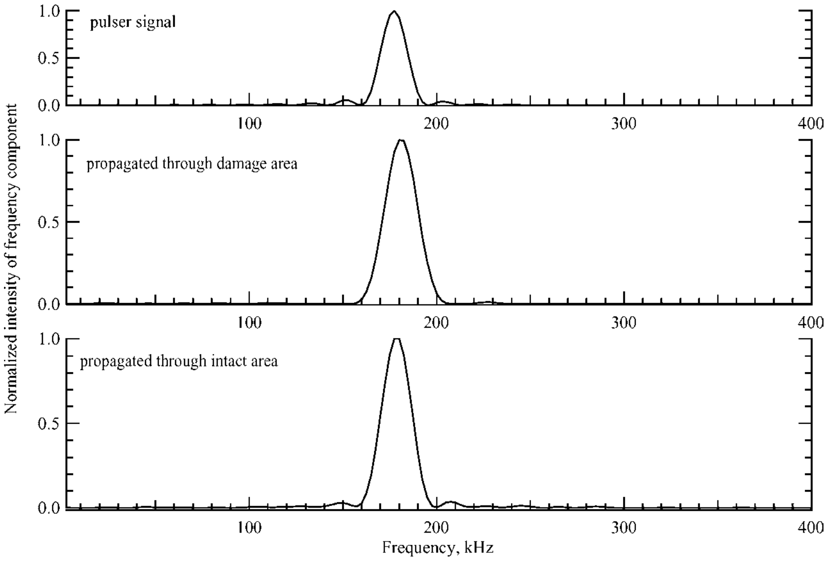

Figure 4 Frequency characteristics of FBG sensor response to flexural plate wave.

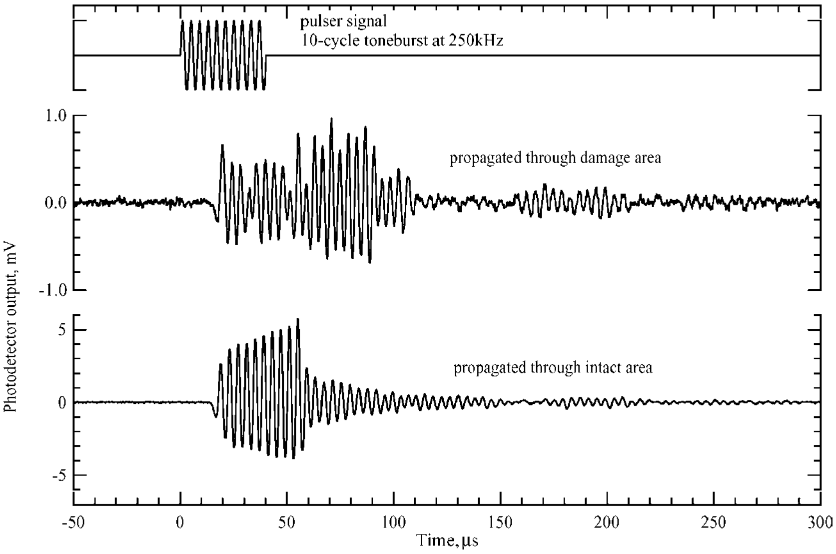

Figure 5 FBG sensor response to extensional plate wave.

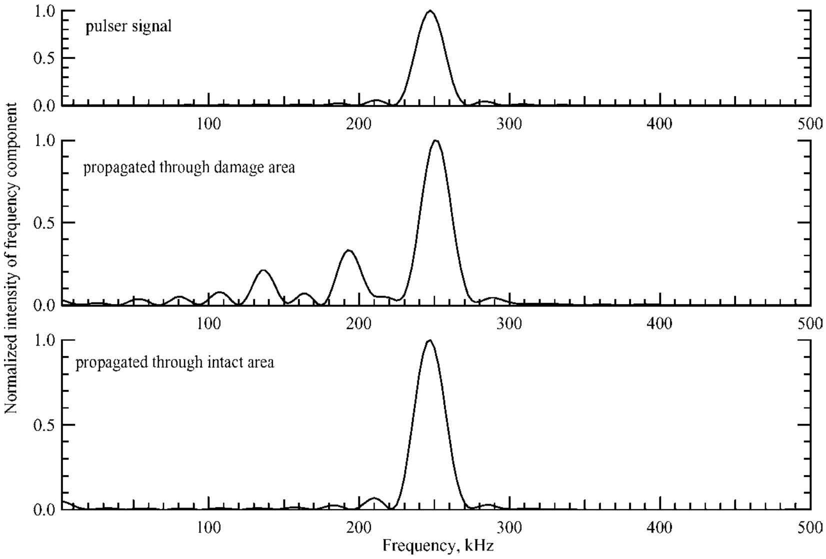

Figure 6 Frequency characteristics of FBG sensor response to extensional plate wave.

frequency band. In detection of extensional plate wave, the existence of damage affects both waveform and frequency characteristics of the response signal.

These experimental results prove the possibility of damage detection using FBG sensor in active sensing diagnostics. Extensional plate wave is suitable for diagnosing input because the response signal has a high SN ratio. The existence of damage causes the response signal to have different waveform and frequency characteristics from the pulser signal. The response amplitude is considerably attenuated when a plate wave passes through a damage area.

References

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