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Detection of Acoustic Emission with Fiber Bragg Grating Sensors

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This paper presents detection of acoustic emission with fiber Bragg grating (FBG) sensors. A piezoceramic pulser was used to generate acoustic waves. The pulser was attached on the surface of an aluminum plate and an FBG sensor was attached on the reverse surface just under the pulser. Two kinds of waveform were sent to the pulser: spike and tone burst waves. Light reflected from the FBG sensor was demodulated using a FBG whose Bragg wavelength was close to that of the sensor. The FBG demodulator converts change in wavelength of the light reflected from the FBG sensor into change in light intensity. Response of the FBG sensor to the acoustic emission (AE) was compared to that of a PZT AE sensor. The FBG sensor demonstrated a higher sensitivity in wider frequency range than the PZT AE sensor used conventionally.
Key words: fiber Bragg grating sensors, acoustic emission, smart structures, NDE

1. INTRODUCTION

Structures having the function both to inspect their integrity with sensors and to control damage propagation with actuators are referred to as "smart structures" [1]. FBGs have been promising sensors used in smart structures. This is because FBG sensors have many advantages such as electromagnetic immunity, high resolution as well as multiplexibility [2].

FBGs are periodic perturbation of the refractive index along the fiber which is formed by exposure of the core to an intense optical interference pattern. When broadband light is transmitted to the FBG, a narrowband spectrum is reflected with a central wavelength known as the Bragg wavelength while other wavelengths are transmitted onward through the fiber. The Bragg wavelength is determined by the refractive index of the core and the grating period. Both the refractive index and the grating period of the FBG vary with strain and temperature the FBG is subjected to. Hence, strain can be evaluated by measuring the Bragg wavelength under constant temperature condition [3].

In many studies hitherto reported the Bragg wavelength was measured with an optical spectrum analyzer [4-7]. The analyzer usually scans at a low rate of 1Hz although it provides precise measurement of the Bragg wavelength. Owing to its slow scanning rate, dynamic strain change cannot be detected using the analyzer.

It has been reported that strain can be measured in real time by demodulating the light reflected from FBG sensors with an FBG whose Bragg wavelength is close to that of the sensor [8, 9]. So far, dynamic strain monitoring using FBG sensors is not well investigated. In the present study, AE detection with FBG sensors was attempted by utilizing the FBG demodulation technique.

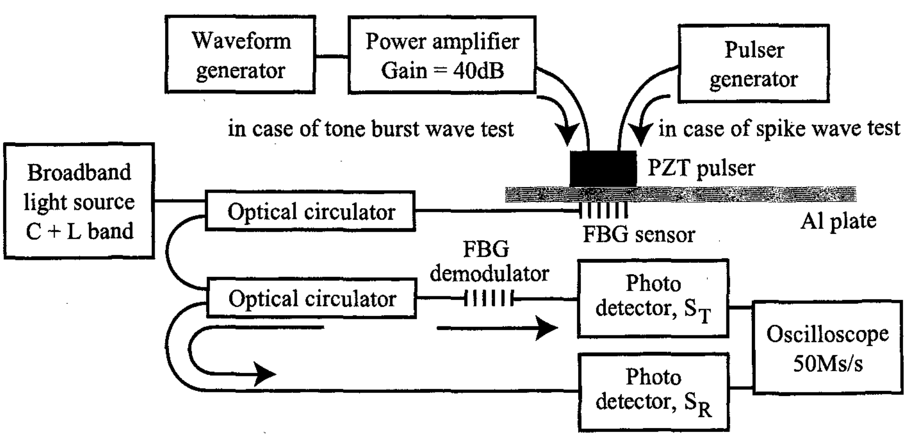

Fig. 1 Experimental setup of AE measurement using FBGs.

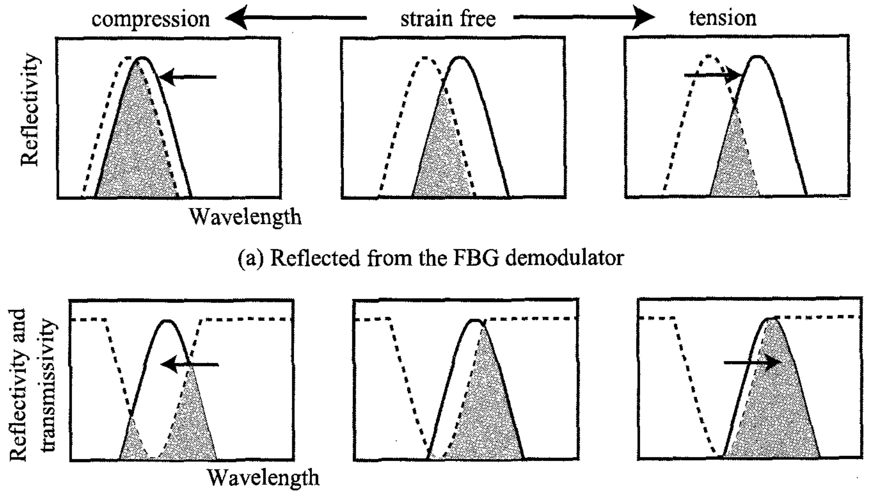

Fig. 2 Schematics illustrating change in intensity of the demodulated light with varying strain.

2. PRINCIPLE OF REAL-TIME STRAIN MONITORING USING FBGs

Consider the optical system shown in Fig. 1. Broadband light is sent to an FBG sensor via an optical circulator. The light reflected from the sensor goes backwards through the optical circulator and then enters an FBG demodulator. The transmitted and reflected light of the demodulator is converted into voltage signal with a photo diode.

Assuming that the FBG sensor has a slightly longer Bragg wavelength than the FBG demodulator. Figure 2 (a) and (b) illustrate change in intensity of reflected and transmitted light of the demodulator with varying strain to which the FBG sensor is subjected. Solid lines in Fig. 2 show the reflectivity of the FBG sensor. The Bragg wavelength corresponds to the central wavelength of the reflective curve. Dotted lines in Fig. 2 (a) and (b) delineate the reflectivity and transmissivity of the FBG demodulator, respectively. Shaded area in Fig. 2 represents intensity of the demodulated light.

The Bragg wavelength of FBG sensor shifts to a shorter wavelength when the sensor is compressed. Then, overlapping area of the two reflectivity curves grows larger compared to strain free state. That means the intensity of light reflected from the demodulator rises when the sensor is compressed. It is obvious from the same notion that intensity of the light transmitted through the demodulator declines when the FBG sensor is compressed. When the FBG sensor is subjected to tension, the intensity of reflected and transmitted light of the demodulator decreases and increases, respectively. Change in intensity of the demodulated light can be measured in real time using photo detectors.

3. EXPERIMENTAL PROCEDURE

An experimental setup employed in the present study is shown in Fig. 1. Two kinds of waveform, spike and tone burst waves, were sent to a PZT pulser. A spike wave was emitted from a pulse generator (PAC, C-101-HV). In case of tone burst wave test, a 5-cycle Gaussian windowed sinusoidal tone burst wave with a central frequency of 180kHz was created by an arbitrary waveform generator. The tone burst wave was transmitted to the PZT pulser through a power amplifier. The pulser was a resonant type PZT device (Panametrics, X1019) whose resonant frequency was 180kHz and diameter was 38.1mm. The pulser was attached on the surface of an aluminum plate 3mm thick.

An FBG sensor was attached on the reverse surface of the aluminum plate just under the pulser using strain gauge cement. The light reflected from the sensor entered an FBG demodulator. The reflected and transmitted signals of the demodulator were recorded into a digital oscilloscope at a sampling rate of 50MHz and with an averaging process of 512 times. AE measurement with a PZT sensor was performed in order to compare the response of FBG and PZT sensors. The PZT sensor (Panametrics, X1019) which was the same PZT device used as the pulser was attached on the same position where the FBG sensor had been attached.

Reflectivity of the FBG sensor and the demodulator employed is shown in Fig. 3. Bragg wavelengths of the sensor and the demodulator in strain free state were 1550.206 and 1550.182nm, respectively.

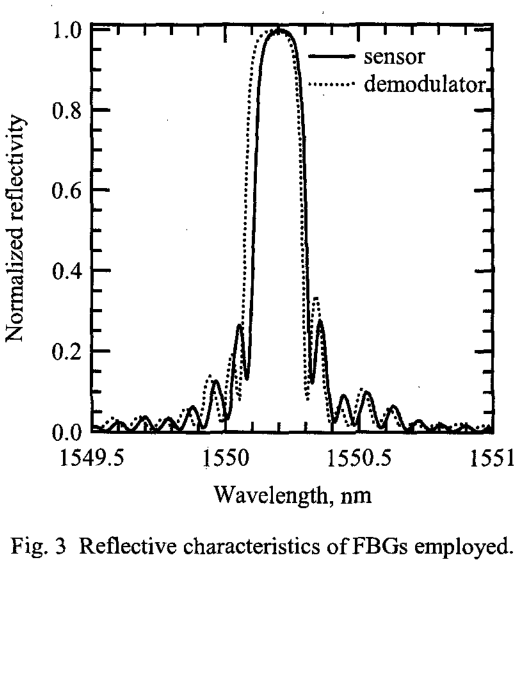

Fig. 3 Reflective characteristics of FBGs employed.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Response to spike wave

Response of PZT and FBG sensors to spike wave is shown in Fig. 4. The PZT sensor responded notably for about 15μs to the spike wave and then the signal continued to fluctuate insignificantly. The minor fluctuation would result from residual vibration. Though both of the optical transmitted and reflected signals seemed to demonstrate similar behavior to the PZT sensor signal, the initial response of optical signals to spike wave was different. The transmitted signal showed positive rising behavior while the reflected signal responded inversely. Considering from the polarity in the initial response, the FBG sensor must have been stretched by spike wave and then subjected to compression and tension alternately.

Reflected and transmitted signals have shown opposite phase relation throughout the response. It can be inferred from the opposite phase relation between these signals that the signal obtained by subtracting the reflected signal from the transmitted signal would have a higher signal-noise ratio than the reflected or transmitted signal. Hereafter, the signal obtained by subtracting the reflected signal from the transmitted signal is referred to as the processed signal. As shown in Fig. 4, the processed signal shows similar behavior to the transmitted signal.

Figure 5 shows the frequency domain representation of the responded signal of both sensors to spike wave. The intensity of individual frequency component was normalized by the highest-intensity component. The PZT sensor signal had relatively higher

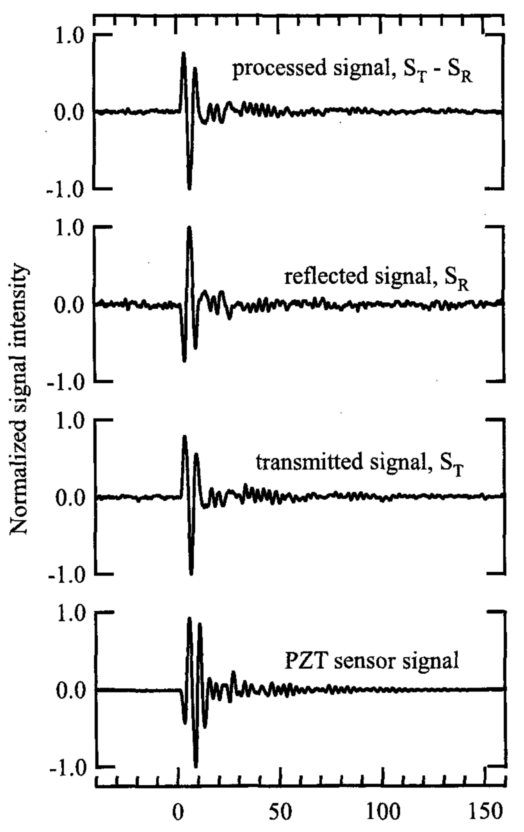

Fig. 4 Response of FBG and PZT sensors to spike wave.

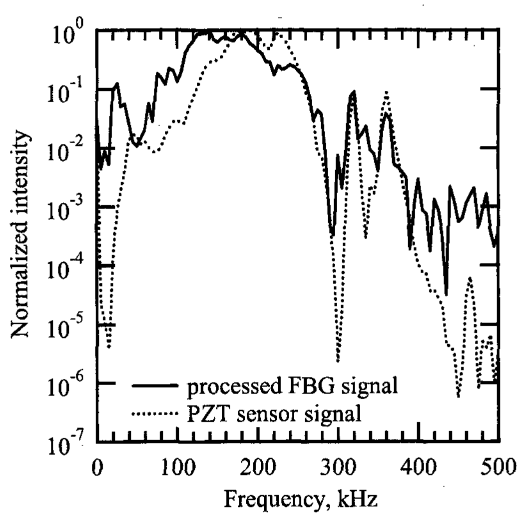

Fig. 5 Frequency analysis on signals responded to spike wave.

frequency components over 10^{-1} ranging from 130 to 260kHz. In higher frequency range over 400kHz, the normalized components were fairly small less than 10^{-4}. The processed FBG sensor signal had high frequency components over 10^{-1} ranging from 70 to 260kHz, which was wider frequency band than the PZT sensor. In higher frequency range over 400kHz, there was no noticeable decrease in component intensity as observed in PZT sensors. It can be said from these results that FBG sensors have wider sensitive frequency band than the PZT sensor.

4.2 Response to tone burst wave

Response of PZT and FBG sensors to tone burst wave is shown in Fig. 6. The PZT sensor demonstrated strong response to the 5-cycle tone burst wave and the oscillation continued over 130μs. The transmitted and reflected signal of FBG demodulator showed a similar behavior to PZT sensor signal but the remaining response after 5 cycles rapidly attenuated. Phase relation between the transmitted and the reflected signals had kept to be opposite during the response. The first 5 cycles of processed signal shows good reproduction of the signal sent to the pulser.

All signals were analyzed by fast Fourier transforms and the results were shown in Fig. 7. The first 5 cycles of each signal were analyzed since the 5-cycle tone burst wave was sent to the pulser. The signal sent to the pulser had a central frequency of 180kHz and the frequency range where the intensity of components reduced by half, Δf was 60kHz. The PZT sensor signal had a central frequency of 175kHz and its Δf was 50kHz. All the optical signals peaked at 180kHz and their Δf were 45kHz.

Frequency components less than 40kHz of the transmitted signal had small intensity. These frequency components would result from nonlinearity of the transmitted signal intensity to change in strain the FBG sensor is subjected to. No low frequency components with small intensity were observed in the processed signal. The signal process subtracting the reflected signal from the transmitted signal seems to be an effective method to cancel the nonlinearity of FBG sensor response to strain change.

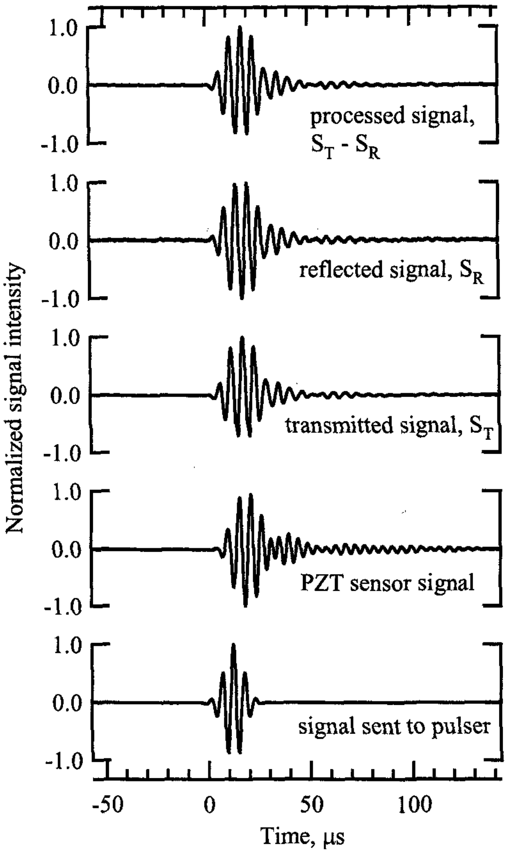

Fig. 6 Response of FBG and PZT sensors to tone burst wave.

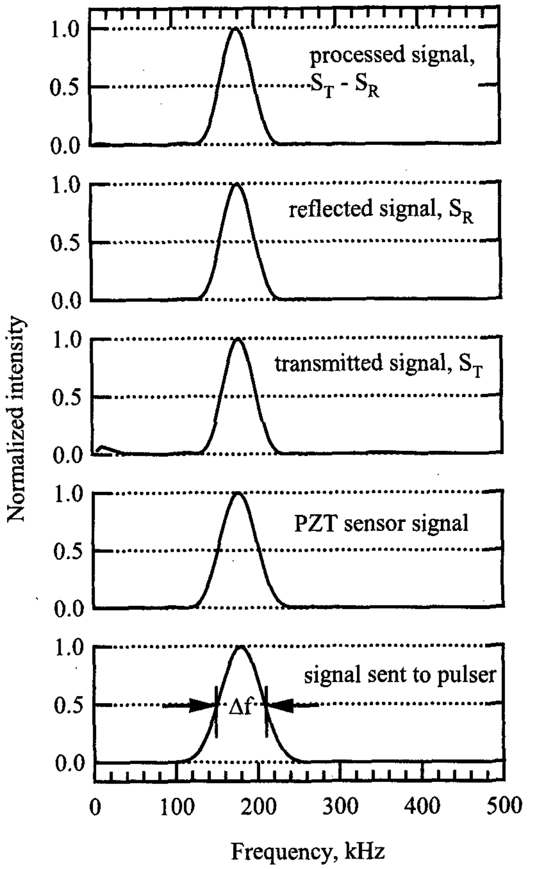

Fig. 7 Frequency analysis on signals responded to tone burst wave.

5. CONCLUSIONS

Detection of acoustic emission with FBG sensors was investigated. FBG sensors could detect acoustic emission generated with piezoceramic pulsers through demodulating technique using FBGs. The processed signal obtained by subtracting the reflected signal from the transmitted signal of the demodulator provides more precise reproduction of the original acoustic emission wave. FBG sensors proved to be effective to detect acoustic emission.

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