Structural Health Monitoring in Composite Structures Using Fiber Optic and Piezoelectric Sensors

Chun-Gon Kim[a], Hyung-Joon Bang[a], and Jeongho Han[a]

[a] *Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology, 373-1 Kusung-dong Yusung-gu, Daejeon 305-701, South Korea*

1. INTRODUCTION

The health monitoring techniques providing real-time diagnostics of smart composite structures can be helpful in keeping the composite structures sound during their service. Recently, fiber optic sensors and piezoelectric transducers (PZT) are widely used to detect ultrasonic signals in structural health monitoring. For a FBG sensor system, to detect acoustic emission (AE) signals from structural damage, an interrogation method of high frequency sensing must be used. In general, most high frequency FBG systems have low multiplexing capability, and conversely, most multiplexed FBG systems have low frequency ranges [1-2]. In this paper, we present a high frequency detectable stabilized FBG vibration sensor system.

On the other hand, Lamb wave method is utilized in an active sensing system using piezoelectric transducers or hybrid transducers system, which are used for generation and reception of Lamb waves. In this paper, a discontinuity owing to thickness change was identified and localized for a composite plate with thickness change using thin PZTs bonded on the surface of the structure under consideration of a structural health monitoring system.

2. EXPERIMENT

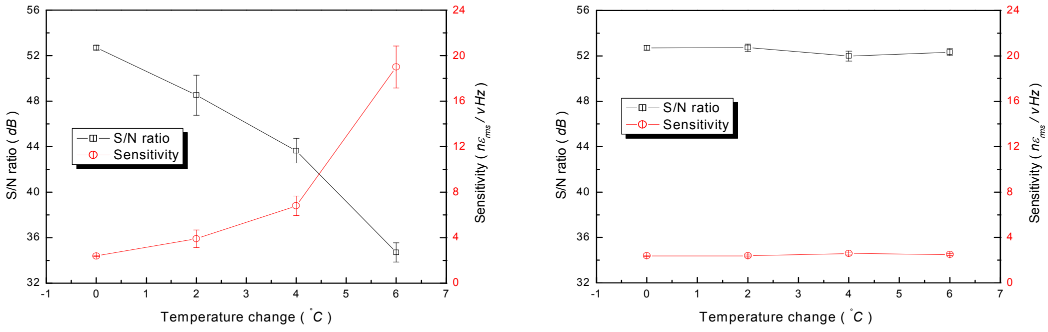
Development of Stabilized FBG Vibration Sensor System – By controlling the filtering position using a closed loop controller with a tunable fiber Fabry-Perot filter, we adjusted the wavelength of the demodulator at the operation point in order to maintain maximum sensitivity of the FBG vibration sensors.

We tested the performance of the stabilization controlling unit by measuring the sensitivity of FBG vibration sensors in a thermal chamber. Temperature was raised to an initial state of 36 ºC in advance and naturally cooled down to 30 ºC in the thermal chamber and the sensitivity of the FBG sensor was measured and compared between the stabilization controlled case and uncontrolled case. Finally we conducted multi-point vibration tests to validate the multiplexing performance of the in-line FBG sensors.

Signal Characteristics of Lamb Waves in Composite Plate - Whereas, in the active sensing system using the Lamb wave method, rectangular shape PZTs were used in order to simplify the signal analysis. The test specimen with square type was manufactured so that the length of tapered region was 2 mm and the gradient was about 1:2, influencing to Lamb wave propagation [3]. Identification of a tapered region was possible by comparing the signals received by a pair of transducers bonded at each uniform thickness region, when they mutually transmitted Lamb waves. The signals acquired within each uniform thickness region were compared with the one obtained from the Lamb waves propagating across the tapered region to localize the tapered region.

3. DISCUSSIONS

Development of Stabilized FBG Vibration Sensor System –Figure 1 provides a comparison of sensitivity and signal to noise ratio (SNR) measurement of the FBG vibration sensor system between the results obtained for the stabilization controlled case and uncontrolled case. In the uncontrolled case, Fig. 1(a), the slope of the SNR plot steeply diminished as the temperature difference increased from the initial condition; therefore, the sensitivity representing the noise level of the output signal of the FBG became poorer as the environmental temperature changed. On the contrary, we could maintain SNR and sensitivity of 52.43 *dB* and 2.46 *nanostrain/√Hz* , respectively, in the stabilization controlled case, because the filtering wavelength of the FFP filter was continuously controlled so as to be tuned to the operation point of the FBG spectrum.



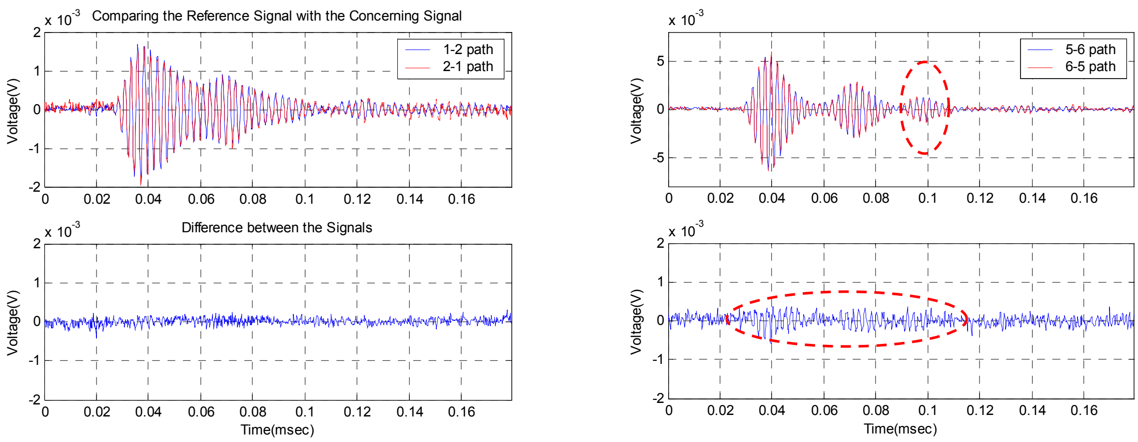
(a) uncontrolled case. (b) stabilization controlled case.

Fig. 1 Signal to noise(S/N) ratio and sensitivity measurement.

In the multi-point vibration test, Two FBG sensors were simultaneously excited with ultra sonic frequencies of 50 *kHz* and 100 *kHz*, and we can successfully demodulate two different input signals from two FBG sensors simultaneously without inducing any interference using the fiber Fabry-Prot demodulator with narrow free spectral range.

Signal Characteristics of Lamb Waves in Composite Plate - Figure 2(a) presents two signals received at a pair of PZT transducers in the thin region, when they mutually transmitted Lamb waves. By simply subtracting a signal from the other, there is no difference between them as anticipated. The same result is obtained in the thick region.

Figure 2(b) presents the Lamb wave responses acquired in actuator-sensor paths across the tapered region, PZT5-PZT6 and PZT6-PZT5, when they each transmitted Lamb waves to the other. Unlike the case in the uniform thickness region, a distinguished signal from noise was shown in the difference between two signals (marked as dashed circle in Fig. 2(b)). The third wave packets in Fig. 2(b) (marked as dashed circle), which are not appeared in Fig. 2(a), are related with the tapered region. These wave packets were occurred by interference of the waves propagating along the 3 different paths; transmitter-right edge-left edge-receiver, transmitter-left edge-discontinuity-receiver, and transmitter-discontinuity-right edge-receiver. By the analysis of the possible paths of interest, including reflections, it was possible to localize the discontinuity in this simple case. However, when structural health monitoring considered, a systematic method, applicable to practical applications, is needed.



(a) (b)

Fig. 2. Comparing the signals and the subtracted (a) in the uniform thickness region; (b) across the tapered region

REFERENCES

1) Betz D. C., Thursby G., Culshaw B. and Staszewski W. J., "Acousto-Utrasonic Sensing Using Fiber Bragg Gratings," *Smart Materials and Structures,* **12**(2003): 122-128.
2) Takahashi N., Yoshimura K. and Takahashi S., "Detection of Ultrasonic Mechanical Vibration of a Solid Using Fiber Bragg Grating," *Japanese Journal of Applied Physics*, **39**(2000): 3134-3138.
3) Younho Cho, Estimation of Ultrasonic Guided Wave Mode Conversion in a Plate with Thickness Variation, IEEE Transaction on ultrasonics, ferroelectrics and frequency control 47 (2000) 591-603