2010

Spatial Performance of Acousto-Ultrasonic Fiber Bragg Grating Sensor

Graham Wild
Edith Cowan University

Steven Hinckley
Edith Cowan University

10.1109/JSEN.2009.2038232
This article was originally published as: Wild, G., & Hinckley, S. (2010). Spatial Performance of Acousto-Ultrasonic Fiber Bragg Grating Sensor. IEEE Sensors Journal, 10(4), 805 - 806. Original article available here

Spatial Performance of Acousto-Ultrasonic Fiber Bragg Grating Sensor

Graham Wild, *Student Member, IEEE*, and Steven Hinckley, *Member, IEEE*

***Abstract*—In this letter, we present results for the spatial performance of a Fiber Bragg Grating (FBG) sensor to continuous-wave acousto-ultrasonic (AU) signals. The FBG AU sensor is an intensity sensor, using a Transmit Reflect Detection System. The AU sensor was used to receive actively generated continuous-wave ultrasonic signals from a PZT transducer. We present results showing the received signal strength as a function of longitudinal, lateral, and angular separation in small aluminum panels. Measurements were taken for distances of less then 100 mm and at angles from 0 to 90° between the sensor and the transducer. These results show no direct dependence between the received signal strength and the spatial separation, in the range considered. Only variations due to interference were observed.**

***Index Terms*—Acousto-ultrasonics, fiber Bragg grating, optical fiber sensing, structural health monitoring.**

I. Introduction

DAMAGE generated by high energy impacts, specifically in aerospace vehicles, can be significant. The detection of Acoustic Emissions (AEs) is a current area of research for Aerospace Vehicle Structural Health Monitoring (SHM), with applications to the detection and monitoring of micrometeorite or space debris impacts [1]. Although the passive detection of AEs is the primary function of these SHM systems, Acousto-Ultrasonic (AU) based SHM is required for active damage monitoring and location [2].

The use of Fiber Bragg Grating (FBG) sensors for the detection of ultrasound has been established in the literature [3]. Due to the high frequencies, detection of ultrasound with FBGs is typically limited to edge filter detection. Typically intensity based FBG sensors for the detection of acoustic signals require significant amplification of either the received signal [4], or the ultrasonic source [5]. The FBG sensor using the TRDS previously reported for the detection of through thickness ultrasound [6] had improved signal strength without the use of an amplified ultrasonic source, or signal amplification. We present results of the FBG AU sensor using the TRDS for the detection of guided waves ultrasound to characterize the spatial performance of the sensor.

II. Experiments

The experimental setup for measuring the spatial performance of the FBG AE sensor with the TRDS is shown in Fig. 1. Details of the aluminum panels mounting and spatial separations considered are shown in Fig. 2.

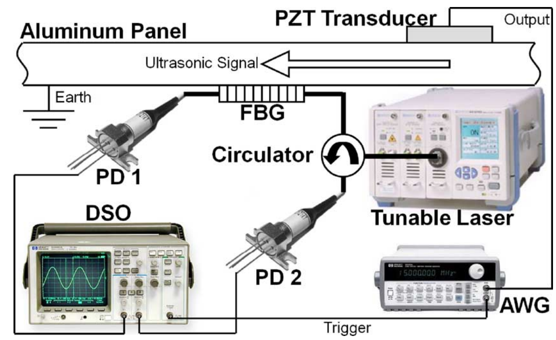

Fig. 1. Experimental setup for FBG sensing system using the TRDS to detect the actively generated acousto-ultrasonic signals.

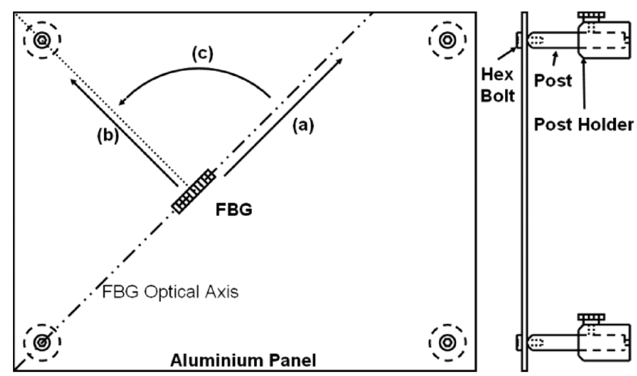

Fig. 2. Configuration of aluminum panel, showing (a) direction of longitudinal separation, (b) lateral separation, and (c) arc of bearing.

The acoustic signals were actively generating by a PZT transducer, via an arbitrary waveform generator. The PZT was coupled to the upper surface of the aluminum panel (170 mm × 200 mm × 1.5 mm), and the FBG was coupled to the under surface of the panel. The tunable laser was connected to the FBG via a circulator, which directed the signals from the FBG to the photoreceivers. The difference between the two received signals was then displayed on a digital storage oscilloscope.

The PZT transmitter was set to the through thickness resonance, 108.8 kHz, previously measured [6]. The wavelength of the tunable laser was adjusted to give the maximum signal strength. The digital oscilloscope was set to average the signal 16 times to remove the small amount of flicker observed. First, bearing measurements were taken, with a separation of 80 mm. The PZT transducer was initially located at a bearing of 90°, which corresponded to a lateral separation of 80 mm. The transducer was moved along the arc (c) in Fig. 2 in 15° increments to a bearing of 0°, which corresponded to a longitudinal separation of 80 mm. The process was then repeated several times to give an average signal and standard error of the received signal at each angle. Next, lateral displacement measurements were

Manuscript received October 29, 2009; accepted November 28, 2009. Current version published March 10, 2010. The associate editor coordinating the review of this paper and approving it for publication was Prof. William Tang.

The authors are with the School of Engineering, Optics Research Laboratory, Edith Cowan University, Joondalup, 6027, Perth, WA, Australia (e-mail: g.wild@ecu.edu.au; s.hinckley@ecu.edu.au).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/JSEN.2009.2038232

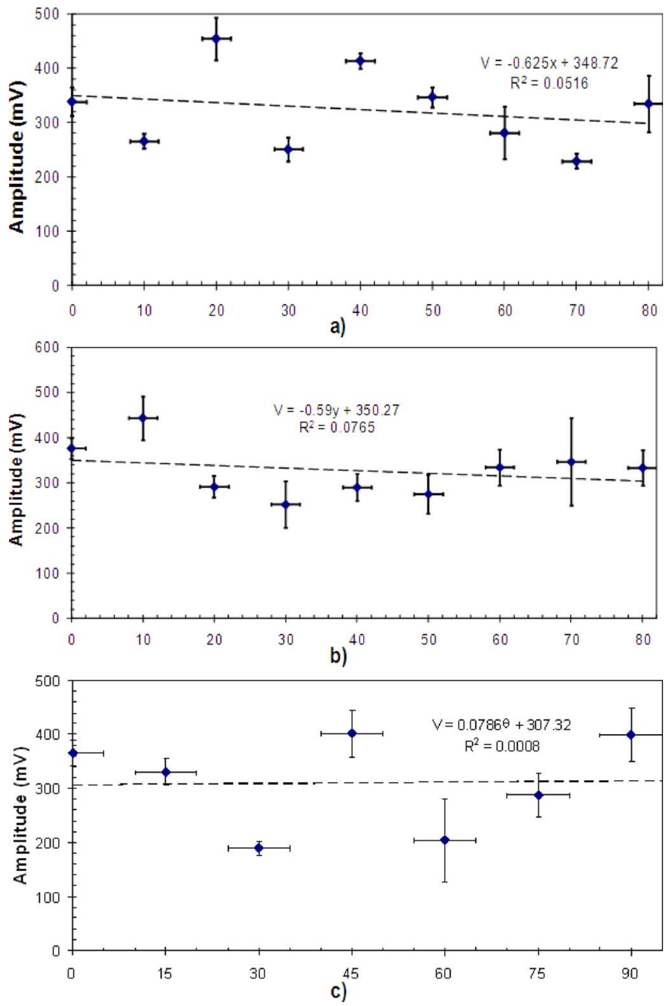

Fig. 3. Average signal strength as a function of (a) longitudinal, (b) lateral, and (c) angular separations. The standard error of the trials was used for the error bars. (a) Longitudinal Separation (mm). (b) Lateral separation (mm). (c) Angle (degrees).

taken. The transducer was again set to 80 mm. The transducer was moved along line (b) in Fig. 2, in 10 mm increments, to a lateral separation of 0 mm. As before, several trials were taken to give an average signal and a standard error for each value of lateral separation. Finally, longitudinal separation measurements were taken. Here, the procedure for the lateral separation was repeated, but along line (a) in Fig. 2.

III. Results

The results for all three separations, shown in Fig. 3, show no direct dependence between the received signal and the separation, for the ranges considered, which is demonstrated by the insignificant correlation coefficients (R^2). Although FBG ultrasonic receivers do have a strong directional dependency, especially for detecting AEs [4], the fact that continuous wave ultrasonic signals can be utilize in AUs means the directional dependence of FBGs can be overcome.

As the transmitter was moved relative to the FBG receiver, a large amount of variation was observed in the signal strength measured, shown by the scatter in the graphs. This is due to edge reflection within the aluminum panel, resulting in the location of constructive and destructive interference of the ultrasonic signal.

Future work will look at frequency domain analysis, using continuous wave AU signals, for damage detection. As with previous work using frequency domain analysis [7], a sweep sinusoidal signal will be used. The sweep rate will be determined from the transient response of the FBG AU receiver, giving a quasi-continuous wave AU signal. This may also involve optimizing the placement of both the FBG receiver and the PZT transmitter, taking into consideration the interference effect of the ultrasonic signal.

IV. Conclusion

In conclusion, we have investigated the spatial performance of a Fiber Bragg Grating (FBG) acousto-ultrasonic sensor. The results presented for lateral and longitudinal separation between the FBG and the source suggest that there is little to no direct dependence of the received signal from the FBG on the separation, for continuous wave acoustic signals within the ranges considered. However, interference effects were responsible for the signal variations observed.

References

[1] D. C. Price *et al.*, "An integrated health monitoring system for an ageless aerospace vehicle," in *Structural Health Monitoring 2003: From Diagnostics & Prognostics to Structural Health Management*, F. K. Chang, Ed. Lancaster, PA: DEStech Publications, 2003, pp. 310–318.
[2] W. Staszewski, C. Boller, and G. Tomlison, *Health Monitoring of Aerospace Structures: Smart Sensor Technologies and Signal Processing*. West Sussex: Wiley, 2004.
[3] D. J. Webb *et al.*, "Miniature fibre optic ultrasonic probe," in *Proc. SPIE*, 1996, vol. 2839, pp. 76–80.
[4] I. Perez, H. L. Cui, and E. Udd, "Acoustic emission detection using fiber Bragg gratings," in *Proc. SPIE*, 2001, vol. 4328, pp. 209–215.
[5] D. C. Betz, G. Thursby, B. Culshaw, and W. J. Staszewski, "Acousto-ultrasonic sensing using fiber Bragg gratings," *Smart Mater. Struct.*, vol. 12, no. 1, pp. 122–128, 2003.
[6] G. Wild and S. Hinckley, "A transmit reflect detection system for fibre Bragg grating acoustic emission and transmission sensors," in *Lecture Notes in Electrical Engineering – Smart Sensors and Sensing Technology*, S. C. Mukhopadhyay and G. S. Gupta, Eds. Berlin, Germany: Springer, 2008, pp. 183–197.
[7] C. Biemans, W. J. Staszewski, C. Boller, and G. R. Tomlison, "Crack detection in metallic structures using broadband excitation of acousto-ultrasonics," *J. Intel. Mat. Syst. Str.*, vol. 12, no. 8, pp. 589–597, 2001.