FBG/Intensity Based Hybrid Fiber Optic Sensor for Simultaneous Measurement of Strain and Temperature

Seong-Yong Jeong, Sang-Jin Choi, and Jae-Kyung Pan
Dept. of Electrical Eng. and Smart Grid Research Center
Chonbuk National University, Jeonju-si, Jeonbuk, 54896 Korea
e-mail: jsy50541@jbnu.ac.kr, sang_jin@jbnu.ac.kr, pan@jbnu.ac.kr

***Abstract*—We propose and experimentally demonstrate a hybrid fiber optic sensor (FOS) using fiber Bragg gratings (FBGs) and intensity based FOS for measuring the temperature and the strain simultaneously. Experimental results showed the simultaneous measurement performance of the strain and the temperature for the proposed FOS, which are in good agreement with those measured using commercial sensors. The proposed hybrid FOS has the advantages of low cost, simple structure, and remote multipoint sensing characteristics.**

Keywords- Hybrid FOS; simultaneous measurement; intensity based FOS; strain free FBGs

I. INTRODUCTION

Techniques for simultaneously measuring the strain and the temperature using fiber optic sensor (FOS) have been developed and considerable interested in the concomitant use of different forms [1]. Various discrimination methods to measure the strain and the temperature separately using fiber Bragg grating (FBG) have been reported [2]. FOSs for measuring the strain and the temperature simultaneously can be classified into hybrid FOS and integrated FOS. The hybrid FOSs are the combined FBG and long period grating (LPG) method [3] and the FBG/Fabry-Perot (F-P) cavity method [4]. The integrated FOSs are the combination of three sensors which consists of a polarimetric sensor, photonic crystal fiber, and FBG [5] and the combination of Mach-Zehnder interferometers and temperature insensitive photonic crystal fiber [6].

Recently, we had reported an intensity based FOS, which consists of general FBGs and intensity based FOS head for measuring the only strain [7]. In this paper, we propose and experimentally demonstrate a hybrid FOS using strain free FBGs instead of the general FBGs for measuring the strain and the temperature simultaneously, based on our previous work [7].

II. THE PROPOSED HYBRID FOS STRUCTURE

The proposed hybrid FOS for measuring the strain and the temperature simultaneously is shown in Figure 1, which consists of strain free FBGs and an intensity based FOS. The light from broadband light source (BLS) enters through hybrid FOS via ports ① and ② of an optical circulator (OC). The reflected spectra by strain free FBGs return to PD via an OC and a tunable F-P filter. The tunable F-P filter transmission spectrum is changed by the applied sawtooth wave. The overlapping power of $I_{FBG}(\lambda)$ and $I_{FP}(\lambda)$, $P(\lambda)$, can be expressed as follows:

$$P(\lambda) = \int_{-\infty}^{+\infty} I_{FBG}(\lambda) \times I_{FP}(\lambda + \lambda')\, d\lambda' \qquad (1)$$

where $I_{FBG}(\lambda)$ is the FBG reflection spectrum and $I_{FP}(\lambda)$ is the F-P filter transmission spectrum. To measure the temperature using FBG Bragg wavelength shift, we propose an adequate signal processing algorithm, which is shown in LabVIEW program of figure 1. The separated signals are detected as sharp peaks corresponding to FBGs Bragg wavelengths. They determine the corresponding tunable F-P filter driving voltages, which use to determine the Bragg wavelengths.

To measure the strain using the intensity based FOS, we used our previous FOS structure [7]. When the optical power of reflection spectrum from FBG_1 and FBG_2 are $P_1(\lambda)$ and $P_2(\lambda)$, respectively, the measurement parameter X can be expressed as follows [7]:

$$X = \frac{\int P_2(\lambda)\, d\lambda}{\int P_1(\lambda)\, d\lambda} = \beta \cdot H^2 \qquad (2)$$

where H is the transfer function and β is the calibration factor. The calibration factor, β, is determined when an intensity based FOS head has no loss. The transfer function, H, in (2) can be obtained from β and X. When the strain is applied to intensity based FOS head, the optical fiber bending loss corresponding to the applied strain occurs. The occurred optical power loss makes to change X and H. The applied strain can be obtained by using the H. Based on the above FBG Bragg wavelength detection algorithm and the intensity

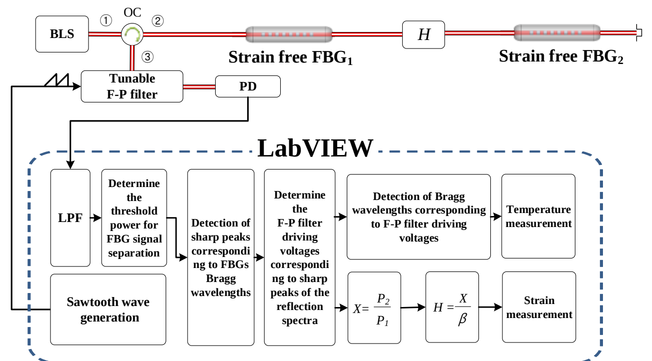

Figure 1. Schematic diagram for the proposed hybrid FOS structure. BLS: broadband light source, OC: optical circulator, PD: photodetector.

 ISBN: 978-1-61208-581-4

based FOS operating principle, the proposed hybrid FOS structure could have the ability of measuring the temperature and the strain simultaneously.

III. Experimental Results

To show the performance of the proposed hybrid FOS, we implemented a proposed hybrid FOS in Figure 1 using an intensity based FOS and two strain free FBGs. Two strain FBGs, FBG_1 and FBG_2, have a full width at half maximum (FWHM) of 0.1 nm, a gauge factor of 9.7 pm/℃, and Bragg wavelengths of 1553.1 nm and 1553.8 nm, respectively.

Firstly, to show the temperature measurement performance for the proposed FOS, we measured the temperature with the signal processing unit in Figure 1 and compared with the commercial FOS (I-MON 512E, Ibsen Photonics). Figure 2 shows the measured wavelength according to the temperature with the proposed FOS and the commercial FOS. As shown in Figure 2, the measured results of the proposed FOS have a good agreement with those of the commercial FOS. The FBG_1 and FBG_2 average errors for the proposed FOS from the reference curve based on the specification of strain free FBGs were 0.013 nm and 0.011 nm comparing with the commercial FOS errors 0.032 nm and 0.001 nm, which showed the same error range.

Secondly, to show the strain measurement performance for the proposed FOS, we measured the strain with the intensity based FOS in Figure 1 using a universal testing machine (5982 INSTRON). Figure 3 shows the measured strain by using the intensity based FOS comparing with those of the extensometer. The %strain determined by using H^2 has a good agreement with the measured %strain using an extensometer. To get the relationship between the two measured results, linear curve fitting was used, which showed the RMSE value of 0.002 and R-square value of 0.9956. The average difference of between %strain of the extensometer and one of the intensity based FOS were 0.003 %strain and standard deviation were 0.002 %strain. Also, we measured the H^2 in Figure 1 according to the varying temperature from -10 to 50 ℃ with step of 10 ℃ five times to confirm the temperature influence of the intensity based FOS. The standard deviations of the measured temperature at each temperature are less than 0.789E-04, which means little temperature influence of the proposed intensity based FOS.

From the above experimental results in Figures 2 and 3, we may consider that the proposed hybrid FOS has the ability measuring the strain and the temperature simultaneously.

IV. Conclusions

We have proposed and experimentally demonstrated a hybrid FOS structure using the intensity based FOS and the strain free FBGs. To demonstrate performance, we measured the temperature and the strain, which are compared with the commercial sensors. The average errors for the measured temperature and strain showed acceptable range of errors comparing with those of the commercial sensors. Also, we confirmed that the proposed intensity based FOS has little temperature influence. Further work under development is focusing on applying our proposed hybrid FOS with the measuring the strain and the temperature simultaneously for structure health monitoring.

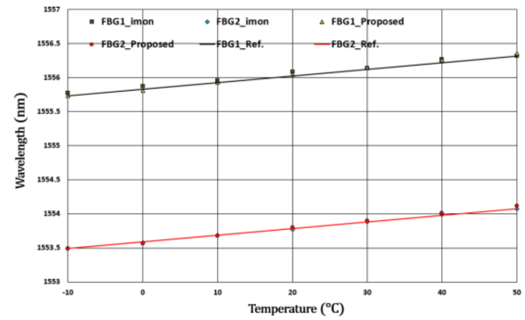

Figure 2. Measured Bragg wavelength FBGs vs the temperature with the proposed FOS and the commercial FOS.

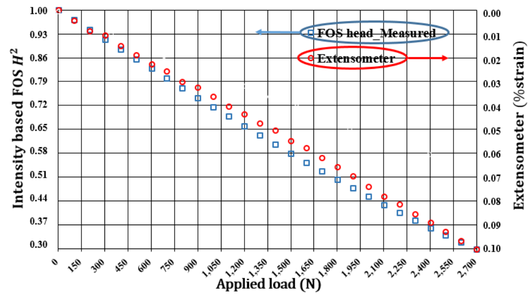

Figure 3. Measured the squared transfer function, H^2, and %strain according to applied load

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2016R1D1A1A09917117).

References

[1] A. Othonos and K. Kalli, Fiber Bragg Gratings: Fundamentals and Applications in Telecommunications and Sensing, Artech House, pp. 330-331, 1999, ISBN:0-89006-344-3.

[2] Y. Zhao and Y. Liao, "Discrimination methods and demodulation techniques for fiber Bragg grating sensors," Optics and Lasers in Engineering, vol. 41, pp. 1–18, July 2004, doi:10. 1016/SO143-8166(02)00117-3.

[3] C. Berrettoni, C. Trono, V. Vignoli, and F. Baldini, "Fibre tip sensor with embedded FBG-LPG for temperature and refractive index determination by means of the simpler measurement of the FBG characteristics," Journal of sensors, vol. 2015, pp. 1-8, Mar. 2015, doi: 10.1155/2015/491391.

[4] Q. Lin, et al., "High integrated FP/FBG sensor for simultaneous measurement of high temperature and strain," IEEE photonics technology letters, vol. 26, pp. 1715-1717, Sep. 2014, doi:10.1109/LPT.2014.2331359.

[5] M. Ramakrishnan, G. Rajan, Y. Semenova, and G. Farrell, "Hybrid fiber optic sensor system for measuring the strain, temperature, and thermal strain of composite materials," IEEE Sensors Journal, vol. 14, pp. 2571-2578, Aug. 2014, doi:10.1109/JSEN.2014.2306892.

[6] M. Najari, A. M. Javan, and N. Amiri, "Hybrid all-fiber sensor for simultaneous strain and temperature measurements based on Mach-Zehnder interferometer," Optik, vol. 126, pp. 2022-2025, Oct. 2015, doi: 10.1016/j.ijleo.2015.05.066.

[7] S. J. Choi, Y. C. Kim, M. H. Song, and J. K. Pan, "A self-referencing intensity-based fiber optic sensor with multipoint sensing characteristics," Sensors, vol. 14, pp. 12803-12815, July 2014, doi:10.3390/s140712803.