Multiplexed reflective-matched optical fiber grating interrogation technique

Yage Zhan (詹亚歌), Shaolin Xue (薛绍林), and Qinyu Yang (杨沁玉)

College of Science, Donghua University, Shanghai 201602

Received November 2, 2006

The multiplexed-reflective matched fiber grating interrogation technique was presented in this paper. The interrogation technique was based on the use of two (or more) wavelength-matched fiber Bragg gratings (FBGs) to receive the reflected signal from the sensing FBG. The two (or more) matched gratings were arranged parallelly and used as filters to convert wavelength into intensity encoded information for interrogation. Theoretical and experimental results demonstrated that the interrogation system is immune to the source fluctuation and cross-sensitivity effect between temperature and strain, and also can enlarge the dynamic range.

OCIS codes: 060.2370, 050.2770, 060.4230.

Optical fiber Bragg grating (FBG) sensors are attracting considerable interest for applying as sensing elements, because of their intrinsic nature and inherent wavelength-encoded operation[1,2]. This feature allows for a straightforward determination of the wavelength shift reflected by the sensing element. This shift can be determined with monochromators or optical spectrum analyzers, albeit quits slowly. However, it is not feasible to use instruments of this type for practical applications because of their size and weight and the frequent need for recalibration. So most interrogation techniques developed to date rely on optical filtering methods, such as bulk optical edge filters, scanning fiber Fabry-Perot filters, wavelength-division fiber couplers, and acousto-optic tunable filters etc[3,4].

The reflective-matched FBG sensing interrogation technique has been proposed and applied in recent years, which based on only one matched FBG and operated as a band-pass filter to interrogate the signal of the FBG sensor. This kind of interrogation system is fast, simple, and low cost. But limited by the bandwidth of the common FBG, the dynamic range of this novel interrogation system is small and also there is two-value problem in practical use. On the other hand, one should add additional hardware to solve the source fluctuation and cross-sensitivity effect between temperature and strain[5,6].

In this paper, the novel multiplexed reflective-matched FBG sensing interrogation technique is theoretically and experimentally investigated. The results demonstrated that the interrogation system is immune to the source fluctuation and cross-sensitivity effect between temperature and strain, and also can enlarge the dynamic range.

In the traditional reflective-matched FBG interrogation technique, there is only one matched Bragg grating used as filters to reflect the signal returned from the sensing FBG for interrogation. The spectrum of FBG can be modeled as a Gaussian distribution of wavelengths. The optical intensity received by photo detector (PD) is proportional to the convolution of the two spectra function, namely the value of area of the hatching region in Fig. 1[7].

In our multiplexed reflective-matched FBG interrogation technique, two (or more, and for simpleness there are two matched FBGs in our experiment) FBGs are arranged parallelly and used as reflective wavelength-matched FBG to interrogate the FBG strain (or temperature) sensor, as shown in Fig. 2. The signal reflected from the reflective matched FBGs is received by corresponding PD (PD_1 or PD_2) simultaneously.

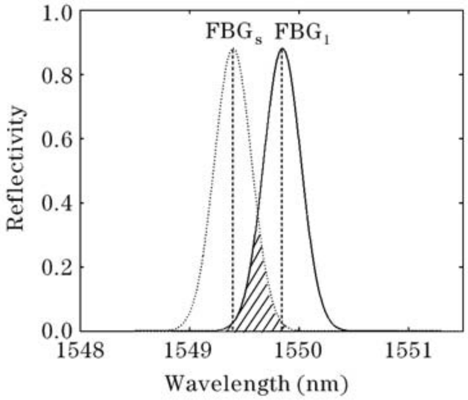

Fig. 1. Schematic spectra of matched and sensing FBG in conventional interrogation scheme.

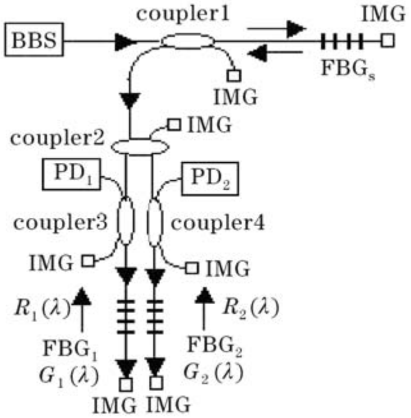

Fig. 2. Schematic diagram of the Bragg grating fiber sensor demodulation system. BBS: broadband source; IMG: index matched gel.

Similar to the principle of traditional reflective-matched interrogation scheme, the optical intensity that each PD can receive is proportional to the convolution of the spectrum functions of the corresponding matched FBG and the sensing FBG.

The parameters of the matched FBGs are determined according to the sensing FBG. The spectra of all the FBGs are approximately identical, namely the reflectivity and the 3-dB bandwidth of them are equal. The Bragg wavelengths of the two matched FBG (λ_1, λ_2) and the sensing FBG (λ_s) are arithmetic progression. The wavelength difference of them is equal to the 3-dB bandwidth of them. According to the strain measured, the wavelengths should meet the relationship

$$\lambda_1 < \lambda_2 < \lambda_\mathrm{s} \quad \text{(negative strain)}, \tag{1}$$

$$\lambda_1 < \lambda_\mathrm{s} < \lambda_2 \quad \text{(positive and negative strain)}, \tag{2}$$

$$\lambda_\mathrm{s} < \lambda_1 < \lambda_2 \quad \text{(positive strain)}. \tag{3}$$

For example, in the experiment only positive strain to be measured, the wavelengths should meet Eq. (1). Figure 3 shows schematic spectra and wavelengths of sensing FBG and the two matched FBG. When the strain is smaller, FBG_1 matches the sensing FBG but FBG_2 mismatches the sensing FBG. When the strain becomes larger, FBG_2 and the sensing FBG are more matched. When the strain is too large, FBG_1 and FBG_2 all mismatch the sensing FBG.

Schematic diagram of experiment setup is shown in Fig. 2. In the system, two matched FBGs (FBG_1 and FBG_2) are used to interrogate the FBG strain sensor. The PDs are connected to a computer and the signals can be processed by the computer directly. The three FBGs have approximately identical spectra. The 3-dB bandwidths of them are all 0.3 nm. The wavelengths of the sensing FBG, FBG_1, and FBG_2 are 1549.7, 1550, and 1550.3 nm respectively. The reflectivities of them are all 95%. The sensing FBG was glued to the bridge model. We give the bridge positive strain by adding weight in its end.

The outputs of the PDs (PD_1 and PD_2) are shown in Fig. 4. In sections of AE (strain section AB) and BH (strain section BN), PD_1 and PD_2 all increase with the increase of strain. In sections of GC (strain section MC) and FD (strain section CD), PD_1 and PD_2 all decrease with the increase of strain. This indicates that there is a linear response (of PD_1 or PD_2) in any section of the whole dynamic range.

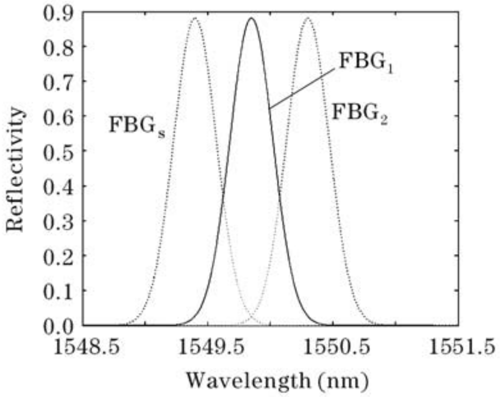

Fig. 3. Spectra of sensor FBG and the two paralleled reflective-matched FBGs.

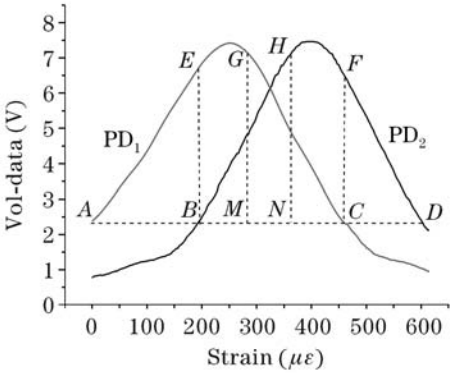

Fig. 4. Results of large scale strain measurement.

By combining PD_1 and PD_2 and also the ratio of them, one can know the accurate strain, meanwhile there is no two-value problem. The ratio of PD_1 to PD_2 is independent of the strain to be measured and independent of the intensity of source. So the error due to source fluctuation can be eliminated[8]. One can know the detailed deduction by Ref. [8].

It is also indicated that the dynamic range of the multiplexed reflective-matched interrogation technique is more than 0—600 $\mu\varepsilon$ and the dynamic range of traditional reflective-matched interrogation technique is 0—220 $\mu\varepsilon$ (to eliminate two-value problem, only single sideband can be used). Obviously, the dynamic range of the former is much larger than that of the latter. The dynamic range of the former depends on the amount of the matched FBG. The more the matched FBG, the larger the dynamic range. So the dynamic range of the multiplexed reflective matched interrogation technique can be enlarged by increasing the amount of matched FBG.

To discriminate the cross-sensitivity between temperature and strain, there needs additional hardware in the traditional interrogation technique but there does not need additional hardware in the novel reflective matched interrogation technique. Because the temperature sensitivity difference between FBG_1 and the sensing FBG and the temperature sensitivity difference between FBG_2 and the sensing FBG are equal to each other. So after calibration by preprogramming and integrating the signal difference between PD_1 and PD_2, the cross-sensitivity effect between temperature and strain of the sensor can be identified.

The multiplexed reflective-matched FBG interrogation technique is also suited for other measurand, such as temperature. The principle is same as above-mentioned.

In conclusion, the novel multiplexed reflective-matched FBG interrogation technique is an innovational technique based on the mature and traditional reflective-matched technique, so it is very simple and cheap, meanwhile it is fast and low cost. It can avoid automatically the two-value problem that accompanies with the traditional reflective matched FBG sensing interrogation scheme. It also can enlarge the dynamic range in a large degree, eliminate the error induced by the source fluctuation, and discriminate the cross-sensitivity between temperature and strain.

Y. Zhan's e-mail address is zhanyg@dhu.edu.cn.

References

1. F. Lin, H. Cai, Z. Xia, J. Geng, G. Chen, R. Qu, and Z. Fang, Chin. J. Laser (in Chinese) **32,** 549 (2005).
2. W. Zhang, G. Kai, Q. Zhao, S. Yuan, and Y. Dong, Acta Opt. Sin. (in Chinese) **22,** 999 (2002).
3. Y. Zhao and Y. Liao, Opt. Lasers Eng. **41,** 1 (2004).
4. Y. Rao, Opt. Lasers Eng. **31,** 297 (1999).
5. M. Guo, D. Jiang, and H. Yuan, Piezoelectrics & Acoustooptics (in Chinese) **28,** 390 (2006).
6. T. Wei, X. Qiao, and H. Wang, Acta Photon. Sin. (in Chinese) **35,** 1199 (2006).
7. A. B. L. Ribero, L. A. Ferreira, J. L. Santos, and D. A. Jackson, Appl. Opt. **36,** 934 (1997).
8. H. Cai, Z. Xia, J. Geng, Y. Zhang, and H. Cui, Proc. SPIE **5279,** 450 (2004).