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High resolution and wide scale fiber Bragg grating sensor interrogation system

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ABSTRACT

This paper demonstrates a high resolution and wide scale fiber Bragg grating sensor interrogation system based on fiber Fabry–Perot tunable filter (FFP-TF) and Fabry–Perot ITU filter (FPIF). By automatic control of the driving voltage of the FFP-TF, the wavelength of the laser can be tracked to the −3 dB reflectivity spectrum of the FBG. Using FPIF as the reference channel, the measurement resolution of the system is improved by wiping out the nonlinearity of the FFP-TF. A high resolution of better than 2 pm within wide strain measurement range was verified by experiments.

1. Introduction

Fiber Bragg gratings (FBGs) have been widely applied in optical sensors and optical communications due to their promising performances with electro-magnetic immunity, compactness, remote sensing, ease of fabrication and wavelength selectivity [1–4]. The aerospace and wind turbine blade industry have now started using fiber-optical sensors as they can survive lighting strikes and have a very high fatigue tolerance [5].The next generation strain sensors at the $10^{-13}\varepsilon\ \mathrm{Hz}^{-1/2}$ level using a fiber Bragg-grating resonator has also been reported [6]. Due to its low insert loss and low threshold power, FBG used as an optical switching has also been reported [7–9].

FBG has fiber-based wavelength-encoded characters and in order to increase measurement speed for dynamic strain, a number of suitable wavelength detection schemes have been proposed and implemented [10–17]. Commonly, interrogation methods such as MEMS tunable filtering [10], FBG filtering [11], Fabry–Perot filtering (F–P) [12,13], tunable lasers [14,15], and distributed feedback laser [16,17] are used. However these techniques suffer from the same disadvantages: high cost and complexity. Tunable filter and laser based methods have wide measurement range and resolution, but its precision will deteriorate as interrogation speed increases. Ratio-metric wavelength measurement is a simple, high speed and cost effective scheme, but its full scale resolution is limited by its measurement range. Few researchers have dedicated themselves to the investigation of how to increase interrogation resolution and measurement scale using dynamic auto-scan method.

In this paper, a new design of an interrogation system for both wide scale and high resolution dynamic strain gauge is presented. A high gain flatness C-band ASE (erbium amplified spontaneous emission) source and a narrow line bandwidth F–P filter are used. The output wavelength of the F–P filter is locked to the −3 dB reflectivity spectrum of the FBG by dynamic auto-scan and tracked with the change of the wavelength of the FBG. The field programmable gate array (FPGA) is used to get high speed and resolution.

2. Experimental procedures

Fig. 1 shows a schematic diagram of the experimental setup. One uniform FBG with high reflectivity of 0.96 is adopted on the dynamic strain gauge. The center wavelength and full width half maximum (FWHM) of FBG is 1550 nm and 0.18 nm. One dynamic strain stage is designed with one piezoelectric transducer (PZT) used. One side of the FBG is attached to the fixture while the other side is fixed on the translator. The relative wavelength difference changes linearly as driving voltage increases because the PZT is chosen within the linear region. A C-band ASE (erbium amplified spontaneous emission) source (L80M, produced by Beihang University) is used. The ASE can provide 10 mW and high gain flatness (lower than 1 dB) for the light source. Light from the ASE passes through the FFP-TF (OFTF-CL,

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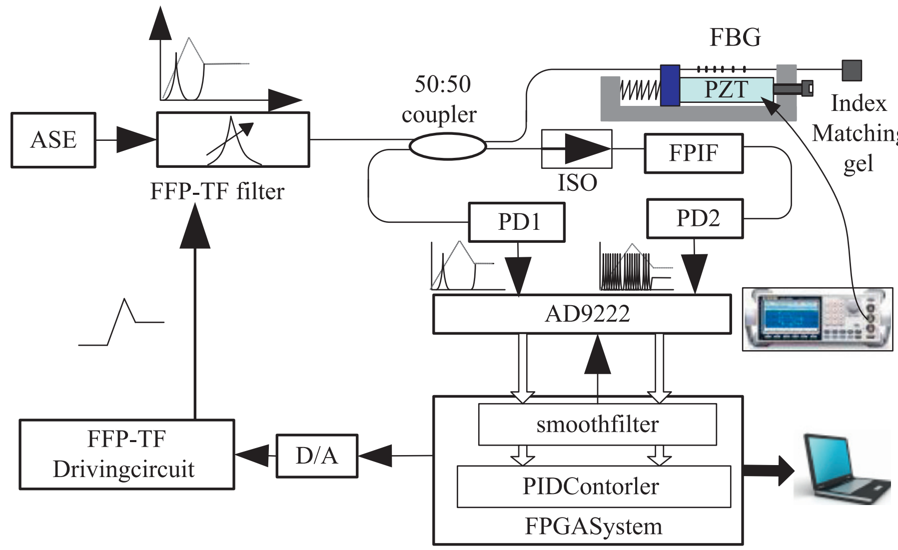

Fig. 1. Experimental setup for dynamic auto-scan strain interrogation system.

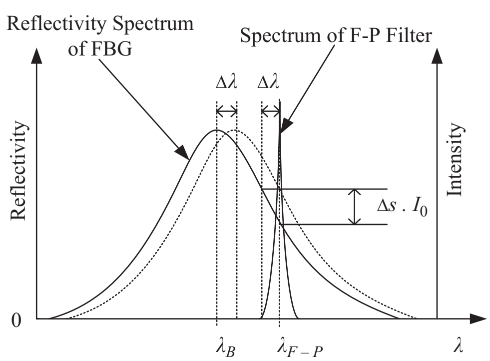

Fig. 2. Principle of the interrogation system.

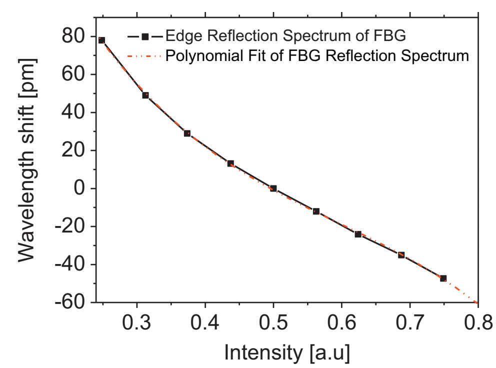

Fig. 3. Polynomial fitting results of FBG (intensity versus wavelength shift).

produced by OE Inc., narrow line-width spectrum lower than 0.01 nm), and is directed to the FBG strain sensor and FPIF (Fabry–Perot ITU filter) via a 2×2 directional coupler. The FFP-TF driving voltage is adjusted to cover the wavelength range of 1545–1555 nm. Light reflected from the FBG (1550 nm) is detected by PD1, and the transmission spectrum of the FPIF is detected by PD2. The smooth filtered AD9222 (20 M samples/s and a 12-bit resolution) output results are processed as the centroid peak calculation is susceptible to noise and works poorly for low signal to noise ratio (SNR) [18]. When the peak locations of the FPIF transmission spectrum are determined with centroid peak finding methods, the FBG auto-locking −3 dB position wavelengths are given by interpolating function.

The dynamic strain measurement procedure starts with a linear scanning process, and then enters into −3 dB dynamic auto-tracking process. The above two channel smooth filtering, centroid peak finding calculations and auto-tracking processing are all finished by Field Programmable Gate Array (FPGA), produced by Xilinx Inc.

The interrogation principle depends on the intensity modulation of a narrow line-width FFP-TF output laser. The reflection or transmission spectrum curve of an FBG moves when the strain is induced by vibration or acceleration, as shown in Fig. 2 [16]. The three polynomial fitting coefficient of determination of FBG intensity versus wavelength shift is about 0.9997, and has a strong linear relationship from the intensity 0.4–0.6, as shown in Fig. 3. The polynomial equation is described by Eq. (1). The FFP-TF driving voltage will not change from the intensity 0.45–0.55; otherwise the auto-tracking process will be triggered. The wavelength shift caused by temperature and the relation between FFP-TF tuning voltage and wavelength change is measured during positive linear scanning process before dynamic strain is applied

$$\Delta\lambda_I = 264 - 1077\times I + 1519\times I^2 - 851\times I^3 \quad (1)$$

where $\Delta\lambda_I$ is the wavelength deviation from the −3 dB edge of the FBG, and I is the intensity.

3. Results and discussion

3.1. Dynamic scanning result of FBG

Fig. 4(a) shows the reflection spectrum of the FBG that is scanned with triangular signal and then entered into the −3 dB auto-tracking process. The scanning scale will cover the dynamic strain measurement range and wavelength mark point of FPIF. The FPIF can provide equidistant multi-wavelength reference for the purpose of decreasing the measurement error [19]. Fig. 4(b) shows the multi-passbands of the FPIF with a spacing of 100 GHz and one easy-to-find wavelength mark (red dotted line) that is produced by one narrow pass-band