Optics & Laser Technology 67 (2015) 159–163

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Alternative interrogation method for a dual laser sensor based on fiber Bragg gratings to measure temperature using the fundamental beating frequency intensity

O. Méndez-Zepeda, S. Muñoz-Aguirre*, G. Beltrán-Pérez, J. Castillo-Mixcóatl

Facultad de Ciencias Físico-Matemáticas, Benemérita Universidad Autónoma de Puebla, 18 sur y Av. San Claudio, Col. San Manuel, CU, C.P. 72570 Puebla, México

ARTICLE INFO

Article history:
Received 20 August 2014
Received in revised form
11 October 2014
Accepted 16 October 2014
Available online 7 November 2014

Keywords:
Fiber Bragg grating
Fundamental beating frequency
Optical fiber laser sensor

ABSTRACT

In this work we present an alternative interrogation method for a dual sensor based on a fiber laser used to measure temperature in two remote locations simultaneously. The dual laser consisted of two Fabry–Perot cavities each conformed by two fiber Bragg gratings (FBG). For each cavity, one FBG was used as the reference and the other one as a sensing element. The sensing element interrogation was performed by the quantification of the fundamental beating frequency (FBF) intensity, which was calculated using the fast Fourier transform algorithm. The laser emissions were centered at 1549 and 1556 nm, while the lengths of cavities were of 300 and 400 m, which corresponds to FBFs of 334 and 258 kHz, respectively. The quantification of the temperature was calculated from the difference between the FBF values of both cavities. Such difference describes a geometrical plane in function of the two sensing FBGs temperatures. Consequently, it was possible to achieve temperature measurements in a range of 25–28 °C for the two sensors.

1. Introduction

In general, the sensors based on fiber Bragg gratings (FBG) require methods or techniques for measuring the spectral shifts that the Bragg wavelength (λ_B) presents when the FBG is in contact with some physical variable such as strain or temperature variations. Then, in order to detect and measure the changes of such variables through spectral shifts it is required expensive equipment such as the optical spectrum analyzer (OSA) [1], electrical spectrum analyzer (ESA) [2], tunable lasers [3], and different systems such as Sagnac filters [4,5], tunable Fabry–Perot filters [6], Mach–Zehnder interferometers [7,8], among others. Therefore, it is required to develop detection and measurement techniques that are economical and easy to implement.

On the other hand, the measurement of two or more variables with the same setup using FBGs becomes difficult and expensive, although the development of some sensors that perform physical variables measurements through the quantification of FBGs reflection or transmission spectra shifts have been reported. For instance, some works use the time division multiplexing (TDM) [9], arrayed waveguide gratings (AWGs) demultiplexer [10], while another employs the wavelength-division multiplexing (WDM) technique [11] or in the case of Lu et al. that report a simultaneous discrimination of axial strain and temperature FBGs through the wavelength shift [12]. In general, all the works above mentioned use complicated experimental setups.

Other laser sensors based on FBGs cavities involve the use of the determination of the fundamental beating frequency (FBF) shifts to quantify the physical variables. For instance, a sensor principle based on the measurement of the beating frequency shifts, which are provoked by birefringence changes, has been reported. In this category we can find the polarimetric fiber laser sensors, which require two orthogonal polarization modes to generate polarization mode beating as the sensing signal [13–16]. They focus mainly in the determination of the FBF shifts. In a previous work we have reported that there exists a relationship between the output laser intensity and the overlapping region of two FBGs reflection spectra caused by one FBG stretching as result of a physical variable [17]. It was also found that the output optical power variations were linear in relation to the sensing FBG stretching. However, if this setup is used to evaluate more than one variable simultaneously, it would not be possible to discriminate the variables through the optical power intensity, since the total response is the combination of both intensities; if there is an intensity variation it would not be possible to know which cavity is the one that provokes such variation. The cavity discrimination would be possible if the output optical power of the dual laser were analyzed in the frequency domain, in such case,

* Corresponding author. Tel.: +52 222 2295500x2176; fax: +52 222 2295636.
E-mail addresses: smunoz@fcfm.buap.mx, mezeos9@yahoo.com (S. Muñoz-Aguirre).

http://dx.doi.org/10.1016/j.optlastec.2014.10.014
0030-3992/

the response of each sensor would be identified from the FBF corresponding to each cavity.

The last affirmation is based on the fact that the length of a laser cavity determines the beating frequencies between any pair of resonance modes inside the cavity that can be calculated from Equation (1).

$$\nu_q = q\frac{c}{2d} \quad q = 1, 2, 3, \ldots \tag{1}$$

where c is the light speed inside the cavity and d is the cavity length. For the particular case when $q=1$ (beating between two adjacent modes), the FBF is given by Equation (2).

$$FBF = \Delta\nu = \frac{c}{2d} \tag{2}$$

From here, if two cavities with different length are used, it can be expected that each laser emission can be identified by their FBF value according to Equation (2). On the other hand, if the dual laser output is analyzed in the frequency domain, each FBF intensity change as a function of the laser power intensity which depends on the FBGs spectra overlapping. It is important to mention that the quantification and identification using the FBF intensity has not been used so far and that its implementation would decrease cost and make the interrogation setup simpler, especially when the system is used to measure two variables simultaneously.

In this work we propose an alternative simple method to interrogate a dual temperature sensor, where each sensor was set in a different location. The interrogation was performed by the determination of the FBF intensities of a multilongitudinal dual laser, which has a few advantages for sensing applications over the above mentioned schemes. First, the laser cavities were constructed with commercial elements, avoiding the use of special FBG written in the erbium doped fiber (EDF) and the polarization states control that are quite sensitive to fiber bends and twists, which must be avoided especially when the physical variable produces small changes in the birefringence. Secondly, a large cavity provides much higher laser power than single-mode lasers, and hence a higher SNR can be obtained. Furthermore, our scheme can be used as a dual and remote sensor since the standard fiber that conform part of the cavity can be installed far away from the system. On the other hand, the FBF can be measured with a conventional data acquisition (DAQ) card, without using expensive equipment such as the optical or electrical spectrum analyzers (OSA and ESA, respectively).

2. Experimental

The experimental setup is shown in Fig. 1. The dual fiber laser consisted of two Fabry–Perot cavities with lengths of 300 and 400 m, respectively, constructed with FBGs and standard optical fiber SMF28 (Corning). Both cavities share 7 m length of EDF as the gain medium. These lengths are important since the fiber can be installed far away from the interrogation system and it would allow using the sensors in two remote locations. Furthermore, the FBF values of long cavities are in the order of hundreds of kHz, which is not so high frequency and it can be measured using conventional electronic circuits. The gain medium was pumped by a laser diode (26-8052-100, JDSU) with a wavelength of 980 nm, which was adjusted to an output optical power of 35.5 mW and was coupled to the EDF through a wavelength division multiplexer (WDM). Each cavity was constructed with two FBGs (Bragg Photonics Inc.), one of them was the reference element (FBG-R) and the other one was the sensing element (FBG-S). The two reference elements were FBG-R1 (λ_B=1549 nm, reflectivity of 58%) and FBG-R2 (λ_B=1556 nm, reflectivity of 58%), while the sensing elements were FBG-S1 (λ_B=1546 nm, reflectivity of 58%) and FBG-S2 (λ_B=1553 nm, reflectivity of 59%). Without any excitation all the FBGs λ_B are different and there is not laser emission since there is not conformed any cavity. However, when the spectrum of the FBG-S starts overlapping over that of FBG-R, provoked by a physical variable, the cavity is set and the laser intensity starts and it changes as a function of the spectral overlapping of the FBGs in each cavity. Moreover, if we try to measure temperature with this FBGs, we need a very high temperature variations, since the spectral shifts of the FBGs are quite slight (approximately 10 pm/°C). For this reason, the system needs an initial condition of spectra overlapping which results in an initial dual emission that is reached when we apply a stretching on the sensing FBG through a micrometer screw, which is not shown in the scheme of Fig. 1 since it was used only to set such initial condition. It is important to mention that this initial stretching does not affect the FBF, since it is a stretching of a few tens of micrometers in hundreds of meters of the total cavity length. After reaching this initial condition, we can start to measure temperature variations. The temperature of each FBG-S was controlled by a Peltier cell and only a portion of 4 cm of the fiber that contains the FBG was exposed to temperature changes. This was performed for each cavity. The signal conditioning electronic circuit was composed of a conventional photodiode (FGA10, detection range from 800 to 1800 nm) and a transimpedance amplifier, which provides an output voltage in the range from 1.2 to 4.8 V dc and a bandwidth of 500 kHz. These values were adequate for the frequency range that we were measuring in our system, whose maximum frequency was around 334 kHz. Finally, the obtained signal was digitalized using a DAQ card (PCI-1712, ADVANTECH) with a sampling rate of 1 MS/s and a 12-bit resolution. This signal was analyzed using the FFT algorithm to determine its spectrum in the frequency domain and then to determine the frequency value and amplitude of the FBF. The data acquisition procedure was as follows: a measurement of 2^{22} samples (during approximately 5 s) was performed and the obtained data vector was segmented in sub-vectors of 2^8, since the FFT algorithm works better with data sets of 2^n sizes. Then, the FFT was calculated in order to determine the FBF intensity for each segment. Finally, the behavior of the FBF intensity in function of the FBG-S temperature was studied.

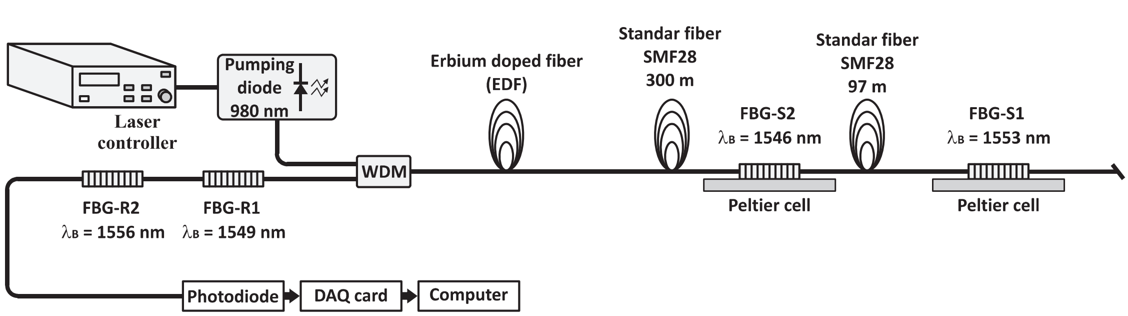

Fig. 1. Experimental setup.