Multipoint sensor based on fiber Bragg gratings

O. Méndez-Zepeda*, S. Muñoz-Aguirre, G. Beltrán-Pérez, J. Castillo-Mixcóatl
Facultad de Ciencias Físico-Matemáticas, BUAP
Av. San Claudio y Rio Verde, Col. San Manuel, C.P. 72570, Puebla, Puebla, México
E-mail: mezeos9@yahoo.com

Abstract. In some control and industrial measurement systems of physical variables (pressure, temperature, flow, etc) it is necessary one system and one sensor to control each process. On the other hand, there are systems such as PLC (Programmable Logic Control), which can process several signals simultaneously. However it is still necessary to use one sensor for each variable. Therefore, in the present work the use of a multipoint sensor to solve such problem has been proposed. The sensor consists of an optical fiber laser with two Fabry-Perot cavities constructed using fiber Bragg gratings (FBG). In the same system is possible to measure changes in two variables by detecting the intermodal separation frequency of each cavity and evaluate their amplitudes. The intermodal separation frequency depends on each cavity length. The sensor signals are monitored through an oscilloscope or a PCI card and after that acquired by PC, where they are analyzed and displayed. Results of the evaluation of the intermodal frequency separation peak amplitude behavior with FBG stretching are presented.

1. Introduction

Industrial processes require monitoring and control of different physical variables (temperature, pressure, flow, etc.) in different places in a production line. Such task can be performed through programmable logic controls (PLC) which can process several signals simultaneously. However, in this case is necessary one sensor for each variable, and it should be pointed out that they are quite expensive. For this reason the development of a multipoint sensor is required to measure multiple variables.

The fiber Bragg gratings (FBG) are employed as a detection element in multipoint sensors; their operation principle is based on the variation of Bragg wavelength (\(\lambda_B\)), which changes with temperature and strain variations. Some authors have reported the development of sensors based on FBGs with different operation principles such as: the time division multiplexing (TDM) which is used to identify the FBG when the reflection time of a light pulse for every FBG is measured [1]; waveguide grating demultiplexer with FBGs, where the measurement of temperature is proportional to the wavelength shift of the FBG transmission spectrum and the waveguide that is excited [2]. Another work uses a pulsed laser of multiple wavelengths with an FBG array, which has an individual response to a temperature threshold [3]. Another method employs FBG multiplexed with some polymer coatings that respond to environment parameters (temperature, salinity) changing the Bragg wavelength [4] and finally another technique employs the wavelength division with Sagnac loop filters detecting the Bragg wavelength with a photodetector for each FBG [5].

Published under licence by IOP Publishing Ltd
The disadvantages of those interrogation methods are the expensive equipment employed such as the optical spectrum analyzer (OSA), and the use of polymer coatings which makes the sensor construction complicated. Furthermore, some systems are quite complex when they use acousto-optic modulators, Fabry-Perot tunable filters, Sagnac loop filters, high frequency photodetector, among others.

In a previous work, FBGs have been employed to make a fiber laser cavity where the laser output intensity behavior was studied and applied as a water flow sensor [6]. The sensor principle was based on optical power measurement which is proportional to FBG stretching. However when there are more than one FBG it is not possible to identify the FBG that is operating just using the optical power.

In the present work, the construction of a multipoint sensor is proposed. The sensor employs a fiber laser with two Fabry-Perot cavities, and the operation principle consists in quantifying the intermodal separation frequency and its spectrum amplitude for each laser cavity. Such amplitude is proportional to the stretching of a sensing FBG (FBG-S). The frequency is determined by $\Delta \nu = c / 2L$, where $\Delta \nu$ is the intermodal separation frequency, $c$ is the light speed and $L$ is the cavity length. For this reason, each FBG can be identified by its own intermodal separation frequency. On the other hand, since the FBG-S stretching changes the spectrum amplitude, the variable under measurement can be quantified.

2. Experimental setup

The system setup that was used in the characterization of intermodal separation frequencies of the fiber laser with two cavities is shown in Figure 1. The fiber laser consists of a 980 nm pumping diode (Thorlabs) which provides a maximum optical power of 100 mW, in this case, a pumping power of 37 mW was employed. 6.8 m of erbium doped fiber was used as gain medium. The two Fabry-Perot cavities laser were built up by three FBGs (Bragg Photonics), one of them was used as reference (FBG-R) and the others as sensors (FBG-S1 and FBG-S2), whose lengths where of 130 and 500 m, respectively.

The output signal was obtained from the 10% port of one 90-10 coupler, the signal was detected with a photodiode FGA10 (Thorlabs), and it was converted to voltage with an operational amplifier (LM358) in current-voltage converter configuration. The analogical signal was monitored by an oscilloscope (Tektronix) and the protocol RS232 was implemented to acquire the signal and process it applying the Fourier Fast Transform (FFT) through an algorithm in MATLAB. This was performed to determine graphically the frequency components of each cavity. Finally, the same method was employed to characterize the system with the two cavities together. The grating FBG-S1 and FBG-S2 were stretched by a micrometric screw in a range of 0-0.28 mm with increments of 10 µm in order to cause changes in the peak amplitude of the intermodal separation frequency spectrum and were monitored graphically with the algorithm implemented in MATLAB.

3. Results

The characterization of both cavities was performed simultaneously with the purpose of observing...
their intermodal separation frequencies in the same optical signal. Figure 2 shows the result of these measurements where the main peaks are located at the frequencies of 200 and 800 kHz, respectively. For these peaks, there is no distortion of the signal, and it is possible to discriminate the intermodal frequencies for each cavity. Therefore, it is possible to have more than one cavity in the same system where each cavity would correspond to a given sensor. Thus, it is possible to perform the identification of the intermodal frequencies of the fiber laser by means of a simple system and recognize the sensor that is operating in a certain moment. There is also the possibility of quantifying the behavior of the peak.

On the other hand, the characterization of each cavity was performed based on the stretching of the gratings independently, the results are shown in Figure 3. It can be observed that there are changes only in the amplitude of the peak, while the frequency remains constant. The amplitude increases probably due to that the number of modes increases as the overlapping area of both gratings spectra occurs. In addition, it can be observed that the behavior of the increasing amplitude of the peak for the cavity with 200 kHz (Figure 3a) is not regular due the fact that the shape of the FBG reflection spectrum is irregular; moreover there is some noise inside the cavity. Therefore, it is important to use an FBG with a regular spectrum shape as is the case of the cavity 2, which has a regular behavior as is shown in Figure 3b. Therefore, it can be said that is possible to quantify the stretching caused by an external physical variable via the FFT measuring the amplitude of the main peak of the intermodal separation frequency spectrum.

To observe the difference between voltage variations and amplitude changes of intermodal separation frequency peak, in Figure 4a the variation of the optical power converted to voltage is shown. It presents a lineal behavior with a correlation coefficient of $R^2 = 0.9930$. In the Figure 4b the intermodal separation frequency peak amplitude changes due to the FBG stretching are shown. The curve presents large fluctuations maybe due to some variations in the sensor signal. Then it is possible just to identify some points at the beginning, in the middle and at the end of the graphic. Therefore, it can be identified three levels of the sensor response. This is due to the fact that the signal is quite noisy ($R^2 = 0.9137$).
In order to evaluate the behavior of the intermodal separation frequency peak amplitude with another method, the signal was acquired with a PCI1712 DAQ card and processed by the FFT algorithm. The measurement of the spectrum peak was performed 512 times and the average was calculated to eliminate the noise in the sensor signal, the complete process was done in 11 seconds. Figure 5 shows the results for this method. There is a linear behavior of the spectrum amplitude changes in function of the FBG stretching with a correlation coefficient of $R^2 = 0.9701$. Thus, it can be said that with this method the spectrum amplitude behavior is similar to the optical power measurement showed in Figure 4a. Therefore it can be said that the measurement of peak amplitude through the FFT is suitable to quantify the FBG stretching.

4. Conclusions
In the present work the study of the behavior of the peak amplitude of the intermodal separation frequency spectrum was performed in the frequency domain through FFT as an interrogation method of an FBG in a laser sensor.

The characterization of a two Fabry-Perot laser cavities formed by FBGs was performed. The cavity signals process was done via an analysis with the FFT through an algorithm implemented in MATLAB. It was determined that the intermodal separation frequencies in the cavities with lengths of 500 and 130 m were 200 and 800 kHz, respectively. Moreover, it was shown that exists a linear correspondence between the amplitude of the peak and the stretching of the grating, finding a correlation coefficient of $R^2 = 0.9137$, when an oscilloscope was employed in the acquisition of the signal.

![Figure 4](image1.png)

**Figure 4** (a) Voltage variations caused by FBG stretching and (b) amplitude changes of intermodal separation frequency peaks.

![Figure 5](image2.png)

**Figure 5** Behavior of the peak amplitude of the intermodal separation frequency spectrum when the signal was acquired with a PCI-1712 DAQ card.
Furthermore, when both cavities are included in the same system, the intermodal separation frequencies for each of them can be observed. Therefore it is possible to discriminate the changes that the detected variable suffers in the corresponding cavity.

Finally, the algorithm in MATLAB to process and acquire signals through the PCI1712 DAQ card was implemented. The acquisition time was 11 seconds and the correlation coefficient was improved to a value of $R^2 = 0.9701$. Such value is quite close to that of the optical power behavior, when the voltage variation against the FBG stretching with a correlation coefficient of $R^2 = 0.9930$ is measured. The results showed that this kind of process of the signal is the adequate to determine the signal behavior in accordance to the FBG stretching.

5. References

[1] W. Wu and X. Liu, "Fiber Bragg Grating Sensors Interrogation System Using Arrayed Waveguide Gratings Demultiplexer," in *Asia Communications and Photonics Conference and Exhibition*, Technical Digest (CD) (Optical Society of America, 2009), paper WL27.

[2] W. Wu and X. Liu, "Fiber Bragg Grating Sensors Interrogation System Using Arrayed Waveguide Gratings Demultiplexer," in *Asia Communications and Photonics Conference and Exhibition*, Technical Digest (CD) (Optical Society of America, 2009), paper WL27.

[3] Q. Sun, D. Liu, J. Wang, H. Liu, L. Xia, and P. Shum, "Multi-Point Temperature Warning Sensor Using a Multi-Channel Matched Fiber Bragg Grating," in *National Fiber Optic Engineers Conference*, OSA Technical Digest (CD) (Optical Society of America, 2008), paper JWA27.

[4] L. Men, P. Lu, and Q. Chen, "Fiber Bragg Grating Sensor for Simultaneous Measurement of Multiple Parameters," in *Conference on Lasers and Electro-Optics/International Quantum Electronics Conference*, OSA Technical Digest (CD) (Optical Society of America, 2009), paper CMNN3.

[5] Chang-Seok Kim, Tae Ho Lee, Yun Sik Yu, Young-Geun Han, Sang Bae Lee and Myung Yung Jeong, “Multi-point interrogation of FBG sensors using cascaded flexible wavelength-division Sagnac loop filters,” *OPTICS EXPRESS* VOL 14 No. 19 (2006) pp. 8546-8551.

[6] M. Durán-Sanchez, G. Beltrán-Pérez, J. Castillo-Mixcóatl, S. Muñoz-Aguirre, M. Méndez-Otero et al., “Experimental study of the fiber laser output intensity behavior and its application to a water flow sensor”, Sens. Actuators B: 123 (2006) 816.