Interrogation System Intensity Coded for Bragg Gratings Based Sensors

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Abstract

This work shows results obtained from the application of an interrogation system intensity coded proposed for Bragg gratings based sensors. The demodulation system employs a Bragg grating written in a high birefringence optical fiber with two bands centered at 1549.7 and 1550.2 nm, besides photo-detectors as transducers devices. The demodulation system performance was tested with the help of an angle position sensor. The measured experimental data are compared to computational simulations. A linear response of the sensing head to the screw turns was observed, with a sensitivity of 0.36 nm/turn. In the experiment, for the sensor head characteristics and a 0.5 nm spectral range between the HiBi-FBG bands, a maximum angular interval of 198° was measured which corresponds to 0.55 turn in the screw.

Introduction

A Bragg grating in an optical fiber is a periodic modulation of the core refractive index, obtained when the fiber is exposed to an ultraviolet interference pattern with adequate periodicity and intensity. The technology for fiber Bragg gratings (FBG) production in optical fibers was greatly developed after Hill et al [1] discovered the photosensitivity of this type of waveguides. Along the last years, an intensive research has been devoted to the application of such photorefractive devices in both optical communication systems and optical sensors. In the sensing field, the electromagnetic immunity and the electrical passivity make the FBG a very attractive option for sensors that must work in inflammable environments. Besides these features, its reduced size and the possibility for integration in optical links make them a versatile choice for fast and remote monitoring. Although FBG sensors can be designed to measure a range of physical parameters (e.g. temperature, mechanical stress, curvature, pressure), almost all of the interrogation systems relate the change in the measurand to the Bragg wavelength reflected by the Bragg grating. The majority of these interrogation systems is based on tunable Fabry-Perot and acousto-optic filters or interferometers systems, and so requires expensive components and equipments to the measurements. For this purpose, some demodulation systems that relates the measurand with the optical power was proposed [2,3,4,5]. In this work, we present an interrogating system for Bragg gratings based sensors that uses, besides the sensing grating, an extra Bragg grating written in a high birefringence fiber (HiBi-FBG). The light intensities reflected by the two bands of the HiBi-FBG, associated with the slow and fast axis of the fiber, are measured with two optical detectors and can be related to the parameter under measurement.

Experimental Setup

For the experiment, a sensing head was assembled by attaching a FBG ($\Delta\lambda$= 0.18 nm FWHM, λ_{Bragg}= 1548.9 nm at 21 °C) with glue on a steel sheet that could be bent with the aid of a screw. By turning the screw a stress was applied to the FBG, resulting in a wavelength shift of the grating reflection peak due to the applied force. This sensing head was firstly characterized with an OSA (Anritsu, MS9710B, 0.1 nm resolution, ±5 pm of wavelength stability) to verify its wavelength response to the applied stress, so that the data could be compared to the ones obtained with the proposed setup. The experimental setup used for the intensity measurements is shown in figure 1. A LED (Superlum Pilot 2) is coupled to port 1 of an optical circulator and illuminates the sensing FBG at port 2. Light reflected from this grating illuminates, via port 1 of a 2x2 optical coupler, a HiBi-FBG at port 4. This grating presents two bands centered at 1549.7 nm and 1550.2 nm, each of one with a bandwidth of approximately 0.13 nm. Light reflected from this FBG is coupled, via port 2, to a fiber polaryzer controller (Thorlabs FPC031) and then is split in two beams with a cube beamspliter (Thorlabs PBS3). By means of a careful adjust of the polarization state, each of these two beams becomes associated to the light reflected by one of the bands of the HiBi-FBG and is measured by the photo-detectors PD1 or PD2, as these two beams present polarization states mutually perpendicular. When the sensing FBG evolves towards higher wavelengths between the two HiBi-FBG peaks, the transmitted beam intensity (associated with the lower-wavelength HiBi-FBG peak, for example) experiences a decrease, while the reflected beam intensity (associated with the higher-wavelength HiBi-FBG peak) experiences an increase. For a specific screw angle position, the ratio of the two intensities is uniquely related to this position, and can be used to determine the angle.

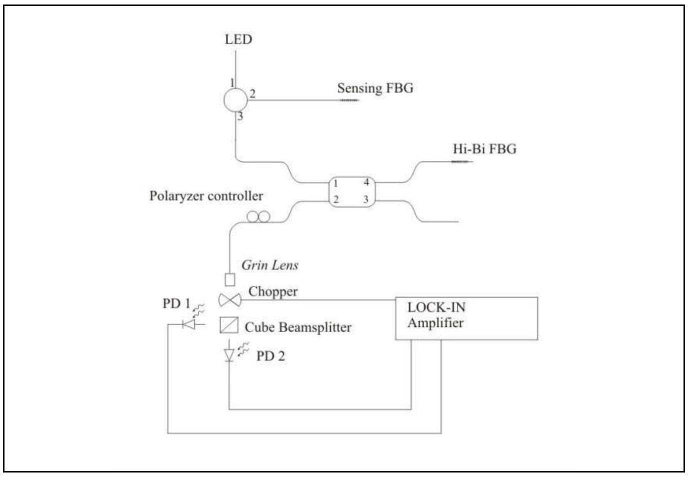

Figure 1: Experimental setup of the interrogation system intensity coded.

Results and Discussion

In order to verify the sensing head response as the screw was turned, the central wavelength of the sensing FBG reflection band was measured with the OSA for several screw angle positions, and the results are shown in figure 2. To minimize errors, this wavelength was determined by fitting a Gaussian curve to the experimental spectrum. The operation range of the sensing head that presents a linear behavior of the wavelength shift with a 0.36 nm/turn sensitivity, shown in that figure by the solid line. This linear behavior also shows that the sensor head is not inducing a chirp in the grating by bending the sensing FBG. The nonlinear behavior observed in the initial curve portion may be associated with the fact that the fiber was not glued under tension on the steel sheet of the sensing head, only becoming stressed after the two first turns in the screw. It also needs to be emphasized that neither the bandwidth nor the reflectivity of the sensing grating were changed during the whole experiment.

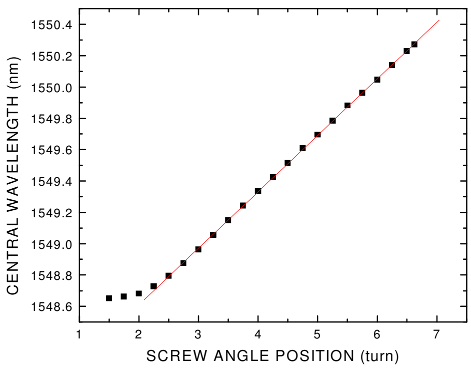

Figure 2: Wavelength response of the sensing FBG in the sensor head to the applied stress as the screw was turned.

To simulate the performance of the interrogation system, both the sensing and the HiBi gratings were connected to ports 3 and 4 of a 2x2 coupler with the LED in the port 1, and the result spectrum for each angle position of the screw was recorded with the OSA in port 2. For each spectrum, three Gaussians curves were fitted to the experimental points to approximate the measured spectral shapes of the FBG bands [4]. A typical spectrum obtained is shown in figure 3, where it also can be seen a diagram of the assembly in the inset. One can see from figure that the fitted Gaussian curves provide an efficient adjust to the FBG reflection bands. By turning the screw of the sensing head, the sensing FBG covers the whole wavelength range where the HiBi-FBG operates.

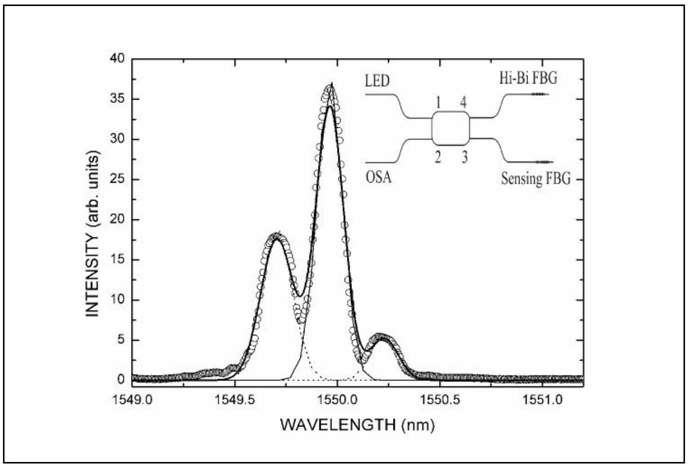

Figure 3: Typical spectrum obtained for a specific screw angle position. The experimental points (open circles) were adjusted by three Gaussians curves (HiBi- doted, sensing- solid lines), and the bold solid line represents the resultant fitted curve.

For the HiBi-FBG, all the adjusting parameters (off-set, central wavelength, bandwidth and area under the curve) were determined and kept constant for each screw angle position. For the sensing FBG the only variable parameter was the central wavelength for each screw angle position. The adjusted equation for the sensing FBG was then multiplied by each equation that represents each one of the HiBi-FBG bands, and the area under the two resulting curves was calculated. These areas are associated with the beam intensities I_R and I_T reaching the photo-detectors PD1 and PD2, when the complete setup shown in figure 1 is used. The resulting intensities ratio I_T/ I_R is shown in figure 4 for several screw angle positions. As it can be seen from that figure, to a particular angle position, there is a characteristic ratio value that can be used to calibrate the instrument. However, this unique association only occurs when the sensing FBG central wavelength is in the spectral range between the central wavelengths of the HiBi-FBG reflection bands (indicated by the two vertical lines in the figure).

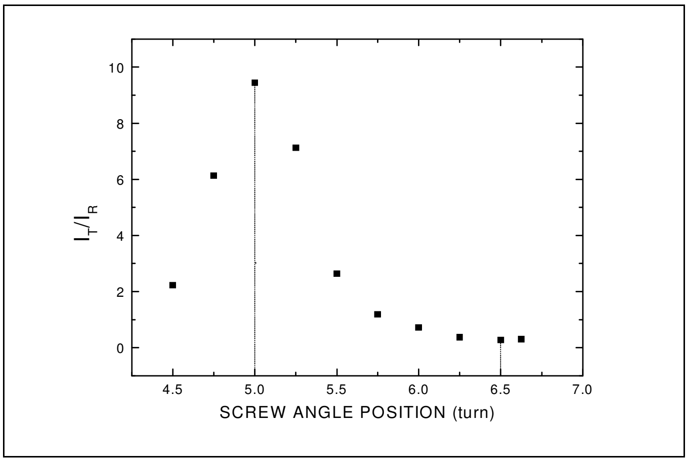

Figure 4: Ratio of the areas obtained in the simulation of beams for several screw angle positions in the sensing head.

The simulated results were experimentally verified using the setup shown in figure 1. In this experimental apparatus, light intensities reaching the photo-detectors 1 and 2 correspond to the beams reflected and transmitted by the cube beamspliter, respectively. By adjusting the light polarization state with the polaryzer controller, it is possible to associate the transmitted beam with the lower wavelength band of the HiBi-FBG, and the higher wavelength band with the reflected beam. Figure 5 shows the ratio of the measured intensities for several screw angle positions in the head sensing (the FBG used here was fixed at a different position on the steel sheet from that one used to collect the data presented in figure 4). The two vertical lines stand for the useful spectral range of the instrument, where each angle position is uniquely associated with a specific ratio value of intensities.

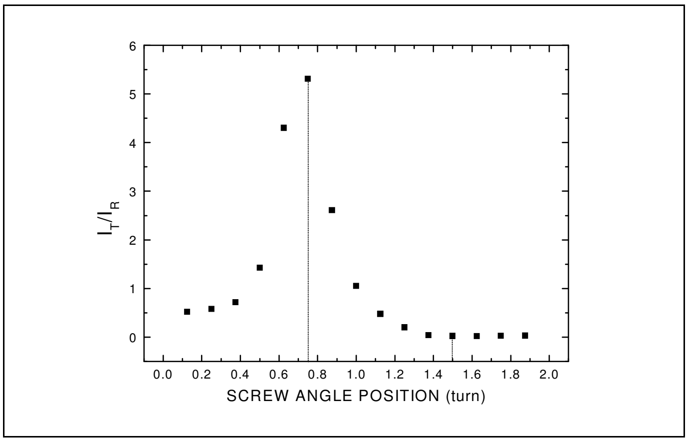

Figure 5: Ratio of the intensities between the transmitted and reflected beams for several screw angle positions in the sensing head, obtained with the experimental setup of figure 1.

Conclusions

In this work, we presented an alternative interrogation system for Bragg gratings based sensors that can be used to replace the conventional expensive systems. The system is intensity coded, and relies on the ability of a cube beamspliter to separate the two orthogonal polarization states reflected by an auxiliary Bragg grating written in a HiBi fiber. The ratio between the measured intensities of these two beams, uniquely associated to a specific value of the measurand, allows performing a calibration of the instrument. The proposed demodulation system was employed in a sensor head built with a sensing FBG and designed to measure angle positions. The maximum operation interval of the demodulation system is limited basically by the spectral range of the HiBi-FBG employed and by the FBG sensor head sensitivity. A linear response of the sensing head to the screw turns was observed, and in the first sensing head configuration the FBG showed a sensitivity of 0.36 nm/turn. In this experiment, for the spectral range of the 0.5 nm between the HiBi-FBG bands and the sensor head characteristics, a maximum angular interval of 198° was measured which corresponds to 0.55 turn in the screw. Finally, the experimental results of this work showed that the demodulation system proposed presents a good performance for measuring angle positions and can be applied in other detection systems that use a FBG sensor.

Acknowledgements

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