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Fibre Bragg grating structure in a braid twisted configuration for sensing applications

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Abstract

A fibre Bragg grating structure arranged in a twisted configuration is proposed for sensing applications. The characteristics of the sensing head for measuring temperature, longitudinal strain and transverse load are analysed. It is shown that this configuration is particularly applicable for transverse load measurement. In this case a resolution of 0.002 N $mm^{-1}Hz^{-1/2}$ was achieved.

Keywords: fibre Bragg grating, optical sensing.

1. Introduction

Optical fibre sensors are nowadays considered a natural replacement technology in several sensing applications [1]. The advantages of optical fibre sensors are well known and have been widely described in the literature. In situations where fibre sensors offer new capabilities, such as remote sensing and multiplexing or distributed sensing, fibre sensors appear to have a distinct edge over other competing technologies. This is particularly true when Bragg grating based fibre sensors are considered in view of their highly favourable characteristics [2].

Fibre Bragg gratings (FBGs) are simple, intrinsic elements, which can be photo-inscribed into the core of the optical fibre, and they have all the advantages normally attributed to traditional optical fibre sensors. Any change in fibre properties, induced for example by strain or temperature, which varies the effective refractive index or grating period, will change the Bragg wavelength. One of the most important advantages of FBG sensors is that the measurand information is wavelength encoded, i.e., the sensed information is encoded directly into wavelength, which is an absolute parameter; therefore the output signal does not depend on the input light level and losses along the optical system.

Most of the work on fibre Bragg grating sensors has focused on the use of these devices for providing quasi-distributed point sensing of strain and temperature. Due to its practical importance, solutions oriented to the simultaneous measurement of these two physical parameters have also been extensively researched [3]. There are, however, cases where the measurement of transverse load is needed as well as the measurement of longitudinal strain and temperature. In those situations the proposed solutions are not easily expandable to fulfil this requirement.

The single measurement of transverse load has been demonstrated using different sensing head concepts, relying for example in the use of Bragg gratings written in high birefringence (Hi-Bi) fibres [4], in the utilization of a long period grating with a transmission spectrum that splits and shifts due to the induced birefringence caused by transverse load [5], in the proper arrangement of a pair of long period gratings [6], or considering two optical fibres in a twisted configuration [7].

Within this path, several configurations with different levels of performance have been developed for simultaneous multi-parameter measurement. As examples of configurations proposed for the simultaneous measurement of strain, temperature and transverse load, one can report the use of a superstructure fibre grating whose narrowband spectral peaks have different sensitivities to temperature and strain, while the broadband peak splits due to the induced birefringence caused by transverse load [8]; with the same objective, a sensing head based on two FBGs superimposed in the same position

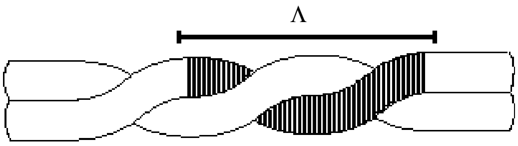

Figure 1. Sensing head geometry.

of an internal elliptical cladding (IEC) Hi-Bi fibre was also implemented [9].

The twist of optical fibres is a well-known concept that has been adapted to different measurement applications. The optical power intensity modulation in a twisted single-mode fibre was the basis of an entire class of fibre based strain sensors [10]. More recently, a sensing head for simultaneous measurement of strain and temperature based on two fibre Bragg gratings arranged in a twisted (helicoidal) configuration was demonstrated [11]. The same geometry was also used for simultaneous measurement of three parameters [12].

In this work we propose a novel sensing head relying on the utilization of one fibre Bragg grating in a braid twisted configuration for sensing applications. In particular, the configuration was tested to measure the temperature, longitudinal strain and transverse load.

2. Experimental details

To perform this experiment, the sensing head structure shown in figure 1 was implemented. The two optical fibres were fixed at one point and braid twisted with a period of ∼10 mm, which corresponds approximately to the FBG length. The FBG was written in a single-mode fibre (SMF 28) by UV exposure through a uniform phase mask (an excimer laser operating at 248 nm was used). An FBG with resonance peak localized around $\lambda_B = 1557$ nm was obtained. To prevent the grating from breaking under the twist process, it was recoated using Desolite 950–200. An erbium-doped broadband source was used to illuminate the sensing head through a standard 3 dB coupler. The spectral shift of the FBG resonance and the optical power were measured using an optical spectrum analyser and an optical photodetector.

To calibrate the sensing structure, temperature (T), longitudinal strain (ε) and transverse load (L) changes were sequentially applied. For temperature characterization, the sensing head was placed in a tube furnace and submitted to increasing values of temperature, at constant longitudinal strain and transverse load. The corresponding results are shown in figure 2. As expected, the Bragg resonance has a linear response to variations of temperature, while the peak power of the Bragg signature is not affected by this parameter. The temperature sensitivity is $\Delta\lambda/\Delta T = (9.89 \pm 0.01)$ pm °C^{-1}, the expected value at this operating wavelength, determined by the temperature dependence of the refractive index and the thermal expansion of the fibre material.

For the measurement of longitudinal strain, the sensing head was fixed between two displacement stages, and specific strain values were applied, using a calibrated micrometer. The measurements were performed at constant temperature

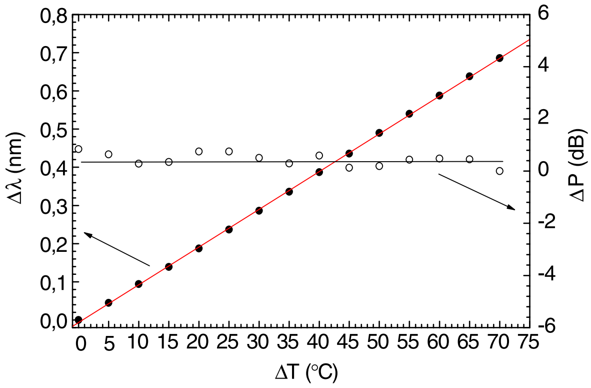

Figure 2. Wavelength shift and peak optical power of the Bragg signature versus temperature.

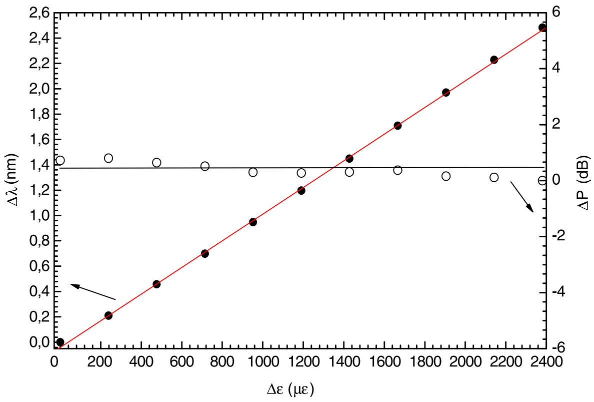

Figure 3. Bragg wavelength shift and optical power versus longitudinal strain.

(room temperature) and without transversal strain. Figure 3 shows the results obtained. Again, the peak power of the Bragg signature is essentially unaffected by the application of longitudinal strain, while the Bragg wavelength shifts due to the physical elongation of the sensor (and corresponding fractional change in grating period) and the change in fibre refractive index (photoelastic effect). The obtained longitudinal strain sensitivity, $\Delta\lambda/\Delta\varepsilon = (1.05\pm0.07)$ pm$/\mu\varepsilon$, also coincides with the expected value for the operating wavelength.

To characterize the effect of transverse load on the Bragg grating signature, the sensing head was sandwiched between two horizontal plates, and different weights were placed on top of them. A second set of twisted fibres was placed parallel to the grating arrangement in order to avoid tilting of the upper plate while the load was being applied. The measurements were performed at constant temperature (room temperature) and constant longitudinal strain. Figure 4 shows the change in the Bragg wavelength of the grating as a function of transverse load (L), which is defined as *force applied*$/2\ell$, with ℓ being the length of the upper plate. As can be observed, the optical power decrease is followed by a broadening of the resonance peak. This is quantified in figure 5, which shows the transverse strain induced wavelength shift and peak power variation of the Bragg signature. In particular, for the case

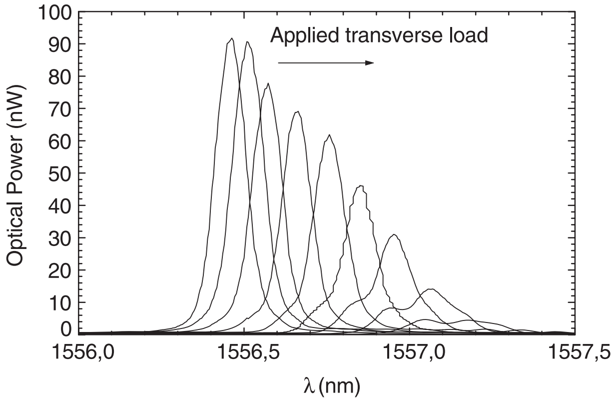

Figure 4. Spectral response of the sensing head to transversal strain.

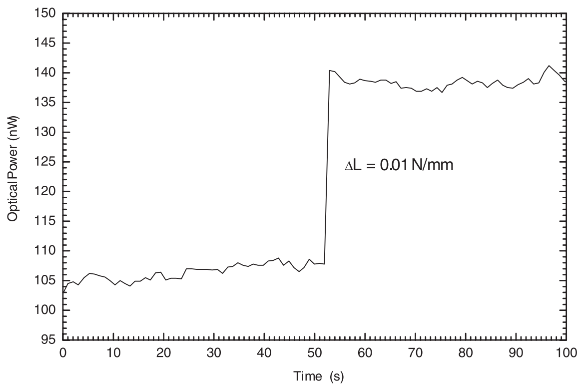

Figure 6. Evaluation of the sensing head resolution for the measurement of transversal strain.

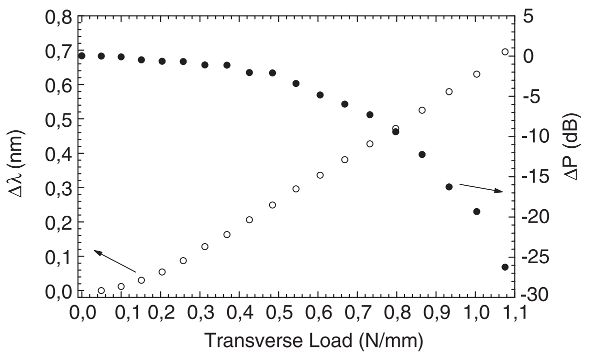

Figure 5. Bragg wavelength shift and optical power versus transversal strain.

of the optical power, there is a non-linear behaviour. For the case of wavelength shift reading, at low transverse load values there is a noticeable non-linear behaviour which is attributed to the plastic properties of the fibre coating. However, when the transverse load increases this effect becomes residual, and for $\Delta\lambda/\Delta L$ it becomes a dependence which is approximately linear, with a value $\Delta\lambda/\Delta L \approx (0.69\pm0.01)$ nm (N mm^{-1})$^{-1}$.

The results given in figure 5 also show that the transverse load applied to the sensing head originates a shift in the Bragg wavelength far greater than the one associated uniquely with the Poisson ratio. The interpretation is that the twisting of two fibres converts the radial transverse load into longitudinal strain to some extent. For not too large loads, it was found that this transverse load induced strain adds to the longitudinal strain directly applied, which causes the two scale parameters to become turns independent (Bragg wavelength shift versus transverse load; Bragg wavelength shift versus applied longitudinal strain).

To assess the system resolution relative to the measurement of transverse load, the effect of this measurand on the Bragg signature peak power was selected. A transverse load step change with amplitude of 0.01 N mm^{-1} was applied to the sensing head, resulting in the sensor response shown in figure 6. From the magnitude of the peak power variation relative to the rms amplitude of the noise fluctuations, a transverse load system resolution of 2×10^{-3} N mm^{-1} is obtained.

Given the fact that the sensing head is sensitive to temperature, longitudinal and transversal strain, these parameters can now be simultaneously discerned using the matrix method [2]. For temperature and longitudinal strain we have the same optical power response, and in this case it is not possible to use the matrix method for simultaneous measurement. However, temperature and transversal strain lead to different wavelength and peak optical power changes, so the matrix method can be employed, and this configuration is therefore suitable to be used as a new sensing head for the simultaneous measurement of these physical parameters.

3. Conclusion

This work has described a sensing head based on an FBG arranged in a braid twisted configuration. The dependence of the resonant wavelength and peak power of the Bragg signature under variations of temperature, longitudinal strain and transverse load was investigated. For temperature and longitudinal strain the sensitivity values obtained are similar to those relative to a single straight fibre Bragg grating. For the case of transverse strain, a resolution of 2×10^{-3} N mm^{-1} was achieved. These results make feasible the utilization of this sensing structure for the simultaneous measurement of the parameter pairs (temperature, transverse strain) and (longitudinal strain, transverse strain).

A positive feature of the proposed sensing structure it is its ability for integration into composite material layouts.

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