Embedded Fiber Bragg Grating Transducer for Concrete Structures

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1. INTRODUCTION

The photonic sensing technology is an area of very rapid growth and increasing interest nowadays. This is due in part to devices such as Fiber Bragg Gratings (FBG), whose inherent characteristics make them very suitable for different sensing fields such as civil engineering, aeronautics or medicine just to mention a few[1,2]. Among the characteristics that make these devices so versatile, one can find their electromagnetic immunity due to the fact that they are made of dielectric material, both their low size and weight, and their ability to be multiplexed in the same fiber. Even more important is the fact that the information is wavelength encoded and so it is not altered by the attenuations of the transmission channel. This last characteristic transforms these devices into very reliable ones. A new FBG-based transducer for monitoring civil engineering structures is presented in this paper. It is able to monitor both strain and temperature at the same time, giving then very useful information about the actual behaviour of their host structure. These transducers were fully characterized and tested in laboratory in order to evaluate their performance. The paper is organized as follows: first of all a brief theoretical introduction to FBG is given, and after that the design of the transducer is discussed, then the characterization process as well as its results are presented, and at the end the final laboratory test in a well-known structure is described.

2. TRANSDUCER

2.1 Description

A periodic modulation of the index of refraction in the core of an optical fiber is known as Fiber Bragg Grating (FBG) [3]. The behavior of this structure under a broadband light illumination consists on reflecting a narrowband portion of this light's spectrum, whereas the rest of the light propagates through the fiber without suffering any distortion. The central

wavelength at which the light is reflected is called the Bragg wavelength. It depends on the period of the grating obeys the following equation:

$$\lambda_B = 2n\Lambda \quad (1)$$

where n is the effective refraction index of the fiber core and Λ is the grating period.

The FBG can be used as a transducer due to the fact that its λ_B is sensitive to external parameters such as temperature, strain, etc. This sensitivity is mathematically expressed by the following equation:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - p_e)\epsilon_{AX} + (\alpha + \xi)\Delta T \quad (2)$$

where p_e is the photoelastic effective coefficient, α is the thermal expansion coefficient and ξ is the thermo-optic coefficient of the optical fiber. The measured magnitudes ϵ_{AX} and ΔT are the axial strain and the temperature change respectively. So, it is possible to detect the wavelength change in λ_B and to obtain the measurement of temperature and/or strain from it.

Fig.1. Diagram of a FBG strain and temperature transducer able to be embedded in concrete .

In order to measure simultaneously strain and temperature it is necessary to discriminate whether the change of the wavelength in the FBG is due to a variation in the strain or in the temperature. One option is to isolate the FBG from one of these parameters, then the measurement would only be affected by the other parameter. But this solution presents a important drawback, this is that only the measurement of one parameter is allows.

The first step is to choose the proper material to make the transducer of, so it would be compatible with concrete in the sense that its durability in an alkaline environment must be high. Also its mechanical characteristics have to be as similar as possible to those of the concrete. The final chose was a methacrylate-like material.

The design must allow the traction/compression force of concrete to be transferred undistorted to the FBG. This is achieved making two heads at the ends of the transducer's body.

To simultaneously measure strain and temperature it was decided to use two FBG [4] at different Bragg wavelengths (taking advantage of the capability of wavelength multiplexing (WDM) of these devices). One of them is fixed in the middle of transducer being sensitive to both strain and temperature, whereas the other is let loose, so it is only temperature sensitive. The scheme of the designed transducer is shown in figure 1.

Fig. 2. Transducer Strain characterization.

2.2 Transducer Characterization

Prior a real use of these transducers would be possible, it is necessary to characterize them. As this transducer is meant to measure two parameters, two different characterizations, one of temperature and other of strain are needed. With the first one the temperature sensitivities of the two FBG's are obtained. These are different because one of the FBG's is fixed and so it is also affected by the thermal expansion of the transducer's body, meanwhile the other is free. The temperature characterization was made using the climatic chamber Hygros-15. The transducer was subjected to different thermal cycles. On the other hand the strain sensitivities

are obtained with the other characterization process. To perform the strain characterization a machine that is used to test the resistance of the materials was employed. One of these coefficients, the one belonging to the loose FBG, must be null or as near to zero as possible to permit a good discrimination. This can be seen in the figure 2.

3. LABORATORY DEMONSTRATION

Before starting the use of the transducers in real structures, it becomes necessary to demonstrate in a laboratory that they can actually be embedded in concrete and are able to measure the strain and temperature of their host concrete structure.

The best demonstration is to embed a set of transducers in a theoretically well-known structure (a concrete beam in this case) and apply a force until it cracks. Four transducers were embedded in a concrete beam whose physical dimensions were 0,2x0,3x5,6 m. In order to make the demonstration it was necessary to test if the designed transducers were able to measure positive (traction) and negative (compression) strain. Thus four transducers were installed in the center of the beam: two in the upper part (Upper transducers) and two in the lower part (Lower transducer). An scheme of the position of the transducer in the beam is shown in figure 3.

Fig. 3. Scheme of position of transducer in concrete beam .

The transducers were firmly attached to the metallic structure of the beam, but placed in such a way that its deformation did not affect the strain measurement of the transducer, as shown in figure 4.

Fig..4. Photograph of a transducer attached to the metallic structure

To obtain an homogeneous deformation of the beam the load was applied and distributed between two points centered in the beam and separated 1.5 m one another. Applying the load this way, the strain will be more or less constant in the center part of the beam. Thus the two upper transducers will give similar measurements and the two lower as well. When loading the beam, a positive strain in its lower side and a negative strain on its upper side are generated.

The four transducers had FBG's with different Bragg wavelengths. It was possible to interrogate all transducers at the same time using a single FBG interrogation unit. It is able to measure up to 32 FBG with different Bragg wavelengths between 1530 nm and 1570 nm.

In order to monitor the applied load, an electric load transducer was placed. It gave a voltage proportional to the load. A digital voltmeter, controlled by a notebook computer using a GPIB protocol, was utilized to acquire this voltage. The FBG interrogation unit was controlled by this same notebook computer using a digital acquisition PCMCIA card.

Figure 5 shows the relationship between the measurement of strain given by the FBG transducers and the applied load. In the graphic both the measurement of a lower transducer and of an upper transducer are shown. As expected, the lower transducer gave positive strain whereas the upper transducer gave negative one. Both graphics have two distinguishable zones. The first one is a zone where the relationship between the strain measurement and the applied load is more or less linear. That is due to the fact that in this range of loads the

behavior of the material is linear, but if the load keeps on increasing the concrete beam will reach the zone of plastic behavior, and so the strain measurements will not be linear anymore, with respect to the applied load.

During the experiment the temperature inside of the concrete beam was almost constant.

Fig. 5. Strain measure of two transducers of concrete beam.

4. CONCLUSIONS

A new design of a strain-temperature transducer based in FBG's has been presented. This transducer is able to be embedded in concrete based structures for measure simultaneously temperature and strain. The transducer has been completely characterized and tested in the laboratory. According to the results obtained , it is possible to affirm that the behavior of the transducers are apt to be used like strain and temperature transducer in concrete structures.

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