COMPARATIVE STUDY OF STRUCTURES TEMPERATURE MONITORING USING FBG ARRAY AND DISTRIBUTED SENSING IN REAL TIME

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ABSTRACT: The present study aims to characterize the spectral parameters of optical fibers and single mode optical fiber sensors as well as to highlight two complementary methods of measurement: one based on the variation of the central wavelength of FBGs (Fiber Bragg Gratings) that are located in fixed positions within the fiber and the other based on Optical Frequency Domain Reflectometry (OFDR). The results may provide complex information in the case of a structure that is monitored. The distributed sensor method provides the temperature and mechanical stress variations throughout the fiber length. At some points inside a thermally controlled chamber, we found that the temperature differs due to its uneven distribution. Optical fibers calibration and measurements were carried out in the Photonics Investigation Laboratory (CETAL, NILPRP) through various assemblies and configurations in the spectral range 800-1670 nm.
KEYWORDS: optical fibers, sensors, distributed, temperature.

1. INTRODUCTION

We hereby describe and analyze two complementary methods of measurement: one based on FBG (Fiber Bragg Gratings) sensors with fixed spatially distribution within a single mode optical fiber and the other based on the distributed sensing. Parallel results can provide complex information about measured structures. The Optical Frequency Domain Reflectometry (OFDR) will provide a full temperature distribution while the FBGs will show temperature variations more precise with higher frequency. The study aims to demonstrate both advantages and disadvantages of two main measurement techniques based on optical fiber sensors. As secondary target of this study was to prove the different temperature dispersion within a climatic chamber by comparative methods. In some points the temperature is higher than in others, even if the chamber is set to gradually heat up under constant parameters. The uneven distribution in the thermal chamber is demonstrated within this work, with the aim to help choosing the correct measurement methods, for industrial, space or automotive applications. Performing experimental assemblies, at laboratory scale, the properties of fiber optics were determined in several configurations. The fiber optic sensor is a sensor that uses fiber optics either as a sensing element ("intersecting sensors") or as a signal switch from a sensor to an electronic component that processes signals ("extrinsic sensors"). Compared to traditional sensors, the sensors using fiber optics offer several advantages such as immunity to electromagnetic interference, the possibility of multiplexing and high fatigue limits. Fiber optic sensors are intended to be bonded to the surfaces of different materials, welded or poured directly into the wet mixture. Due to their very small dimensions and weights they can be used for locations or measuring points that are not easily accessible. They are particularly used to monitor the technical state of large structures (structural health monitoring), both for indoor and outdoor applications. FBG are made by exposing the core of a single-fiber fiber to UV radiation using ultraviolet light intensity. The exposure produces a permanent increase in the refractive index of the fiber core. At each refraction change, a small amount of light will change. All reflected light signals are coherently combined with high reflection at a certain wavelength where the actuation period is about half the wavelength of the input length. These are called the Bragg state, and the wavelength at which this reflection occurs is called the Bragg wavelength. [1] Light signals at wavelengths other than the Bragg wavelength, which do not correspond to the phases, are essentially transparent. The working principle is shown in figure 1.

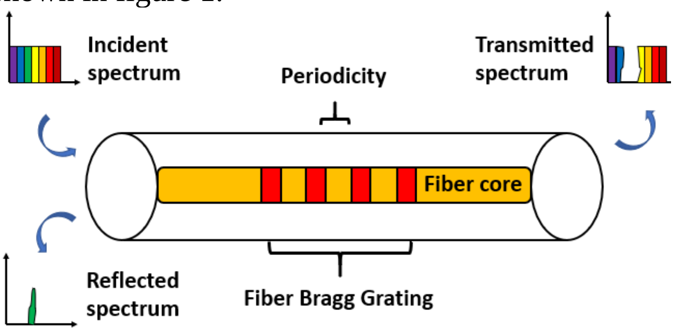

Fig. 1. Working principle of Fiber Bragg Gratings

Therefore, light propagates through the sensor with negligible attenuation or variation of the signal. Only those wavelengths that satisfy the Bragg status are affected and strongly reflected. The central wavelength of the reflected component satisfies the relationship 1: [2]

$$\lambda_{refl} = 2n\Lambda \quad (1)$$

where:
n – refractive index;
Λ – Fiber Bragg Gratings refraction rate [nm].

Distributed sensors allows real-time continuous measurements over the entire length of the fiber-optic cable. Compared to traditional sensors that measure at predetermined points, the distributed sensor is not based on manufactured sensors, but uses only the bare fiber as sensing element without additional transducers in the optical path. The interrogator works according to a radar type process: it sends a series of pulses to the fiber and records the return of the naturally dissipated signal against time. In this sense, the distributed sensor measures at all points along the fiber. Because fiber is the sensor, it is also a cost-effective method, which can be easily used even in the toughest and most unusual environments. Sensor distribution is usually used to obtain temperature, voltage or acoustic data. [10]

Optical fibers (OF) are made of pure glass (silica) as thin as human hair. OF consists of two parts: the inner core and the outer plating. The coating is a glass layer made of glass with a lower refractive index to maintain the orientation of the light inside the core. Both sides are encapsulated by a single layer or more layers of primary polymer coating to protect and facilitate handling. There are two main types of fiber optics according to communication application standards. These are single mode, intended for long distance communications and multiple modes for short-term communications. Multi-mode fibers have a larger core (45 to 50 microns) than single-mode fibers (8-10 microns), allowing the propagation of multiple modes of illumination. The typical diameter of the fiber optic is 125 µm which increases up to 250 µm if the thickness of the standard acrylic layer would be considered. In general applications, multi-mode fibers are usually used for temperature detection, while single-mode fibers are mainly used for distributed acoustic detection or voltage detection. [7]

Long Period Grating (LPG) couples light from a diffusion mode to one-way propagation modes, where it loses due to absorption and dissipation. The coupling from the diffusion mode to the propagation modes is wavelength dependent, so that we can achieve a selective spectral loss. It is a fiber optic structure with periodically variable properties along the fiber, so that the conditions for the interaction of several co-payment modes are fulfilled. The period of such a structure is of the order of a fraction of a millimeter. [8]

LPFGs couple co-propagation modes with close propagation constants; therefore, the period of such grating can considerably exceed the wavelength of the radiation propagation in the fiber. Because LPFG is much longer than wavelength, LPFGs are relatively simple to manufacture. Since LPFGs include co-payment modes, their resonances can only be observed in the transmission spectra. The transmission spectrum has dips at wavelengths corresponding to single mode fiber resonances. Depending on the symmetry of the disturbance that is used to write LPFG, different symmetry modes can be coupled. For example, the cylindrical symmetrical grids couple the symmetrical LP0m modes of the fiber. The microband grids, which are antisymmetric with respect to the fiber axis, create a resonance between the basic mode and the asymmetric LP1m modes of the core and the plywood. The working principle is shown in figure 2. [6]

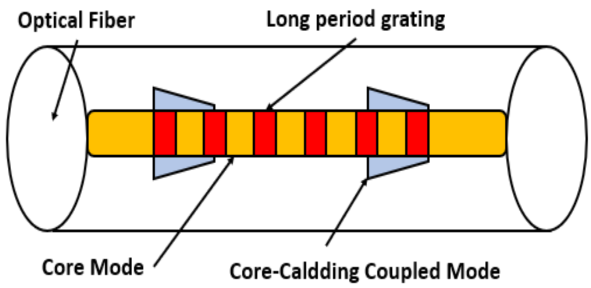

Fig. 2. Working principle of Long Period Gratings

Long-lasting grating has a wide variety of applications, including band rejection filters, gain flattening filter and sensors. Different barriers have been designed with complex structures: barriers combining several LPFGs, LPFGs with superstructures, cracked barriers and apodization barriers. Various LPFG based devices have been developed: filters, sensors, fiber dispersion compensators, etc. [8]

2. EQUIPMENT AND FEATURES

In the present work, the main equipment utilized consisted in optical spectrum analyzers and optical interrogators designed for telecom wavelength. The "Luna" OBR 4600 is designed for component testing, short-run network tests, and problem identification and troubleshooting. Also, the OBR 4600 allows a sampling resolution of up to 10 µm.
The detection has a dual display that allows the user to simultaneously view both a top temperature chart and section details of that graph at the bottom. Can

store and display up to 5 routes (two routes in top-desk analysis). In figure 3 is presented a picture of LUNA OBR 4600. [3]

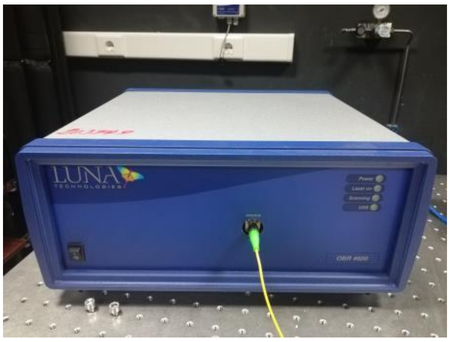

Fig. 3. Luna OBR 4600

The characteristics of the equipment Luna OBR 4600 can be found in table 1:

Table 1. Luna OBR 4600 characteristics [3]

Mode		**30 m**	**70 m**	**2000 m**
Subregion scanned		**1 or 2 m**	**1 or 2 m**	**80 m**
Wavelength Range	3,2 nm	-	-	0,15 Hz
	5 nm	3,7 Hz	2,9 Hz	-
	20 nm	1,8 Hz	1,2 Hz	-
	80 nm	0,5 Hz	-	-
Best Sampling Resolution		10 µm	20 µm	0,25 mm

The "Micron Optics SM125", optical interrogator, has a static and reliable sensor module. The Sensing Interrogator is equipped with a high-powered, low-noise laser made with Micron Optics' patented Fiber Fabry-Perot Tunable Filter technology.
The SM125 Interrogation Center uses full spectral scanning and data storage, delivering high-precision measurements, a wide range of use and flexible software. In figure 4 is presented a picture of MICRON OPTICS sm 125. [4]

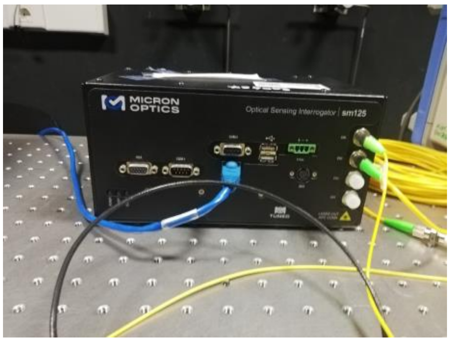

Fig. 4. MICRON OPTICS sm 125

The characteristic of the equipment MICRON OPTICS sm 125 can be found in table 2:

Table 2. MICRON OPTICS sm 125 characteristics [4]

Number of optical channels	4
Scan frequency	2Hz
Wavelength range	1510-1590 nm
Wavelength stability; accuracy	1pm
Dynamic range	50 dB

The single mode fiber is a fiberglass with a diameter of 8.3 to 10 µm that has a single transmission mode. It has a relatively narrow diameter, whereby only one mode will usually propagate at a wavelength of 1310 nm or 1550 nm. It has a bandwidth greater than fiber in several modes, but requires a light source with a narrow spectral width. Single mode fiber offers up to 50 times higher transmission than multiple modes.
The core is small and the only light wave eliminates virtually any distortion that could result from overlapping light pulses, providing minimal attenuation of the signal and transmission speeds. One-mode fiber provides up to 50 times more transmission than multi-mode transmission. [5] [9] In figure 5 are presented the differences of working principle between single-mode and multimode.

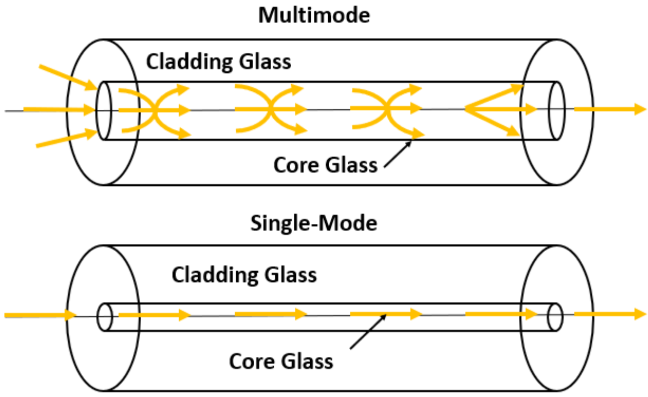

Fig. 5. Difference between single-mode fiber and multimode fiber

The core is small and the only light wave eliminates virtually any distortion that may result from superimposed light impulses, providing minimal attenuation of the signal and transmission speeds. [5] [9]

3. EXPERIMENTAL METHODOLOGY

The current study targets a laboratory setup, containing several measurement equipment (described earlier in the paper), a heating chamber, type Memmert UE300, two FBG sensors centered at 1550 nm and one single mode optical fiber, 4 meters long utilized for the distributed sensing inside the chamber. The single mode fiber was measured with the Luna OBR 4600, and the other two FBG (Fiber Bragg Gratings) sensors were interrogated with the Micron Optics SM125. The FBGs are mounted on a metallic structure to demonstrate its temperature monitoring inside the climatic chamber. The operation principle is shown in figure 6.

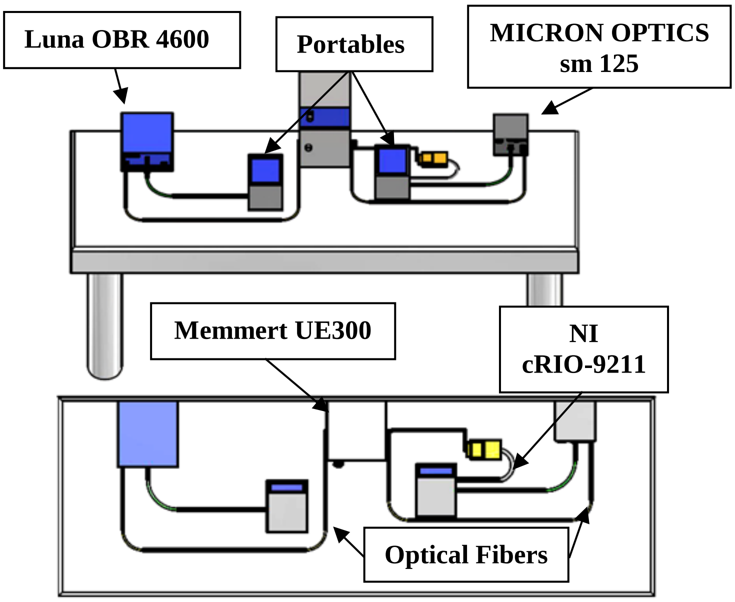

Fig. 6. Operation chart

Both optical fibers are inserted into the Memmert UE300. Temperature was induced via a Labview VI to the heating chamber and monitored constantly with a J-Type thermocouple controlled by a NI-CRIO 9211 acquisition board. The mounting optical fiber on metallic structure is shown in figure 7.

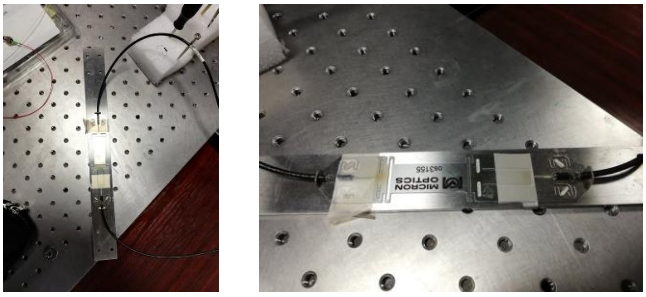

Fig. 7. Mounting optical fiber on metallic structure

The setting of a reference value was performed with the NI cR-9211 thermocouple for measuring ambient temperature. Measurement was found to be 23°C. Subsequently, it was desired to gradually warm the oven temperature by 10°C until the temperature reached 62°C. The arrangement of optical fibers in Memmert UE300 at laboratory level is shown in figure 8.

Fig. 8. Arrangement of optical fibers in Memmert UE300

4. RESULTS AND DISCUSSIONS

To track the behavior of the measured structures at the gradual rise in temperature, the Micron Optics sm125 interrogator was used to monitor the central wavelength change of the two gratings in real time. When the temperature rises up, both instruments automatically store the data in the computer.

Data then is processed and compared. On the Luna OBR 4600 date was manually stored when the temperature reached the required threshold. With these data, we compared how the measured structures reacted to the temperature rise. Parallel results from the two devices can provide complex information about measured structures. Simple fiber will provide full temperature distribution. At some points, due to unequal distribution in the oven, the temperature may be higher than in others. The results of experiment are display in charts that are presented in figures 9 to 14.

In figure 9 is presented the variation of relative temperature in function of length:

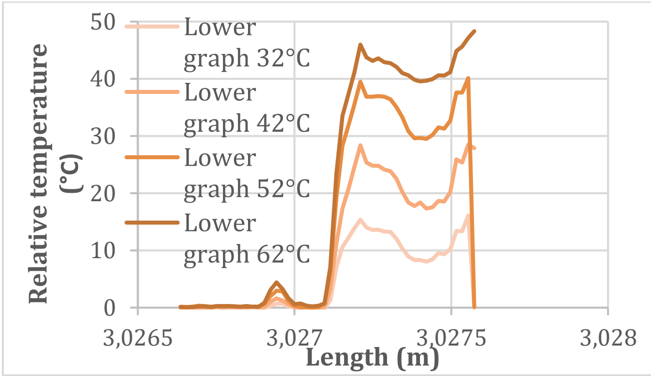

Fig. 9. The thermal modification indicated by optical fiber by the distributed sensor method

In figure 10 is presented the modification in center wavelength with the controlled heating:

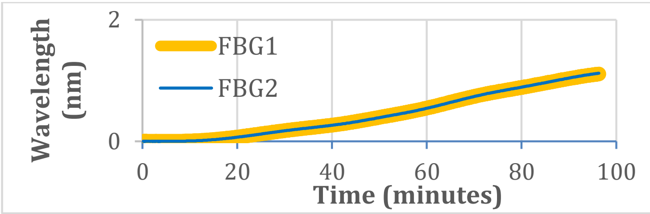

Fig. 10. Modification in center wavelength of the two FBG sensors, with their controlled heating at the level of the oven

In figure 11 is shown the uniform thermal change that is measured with a thermocouple of type J:

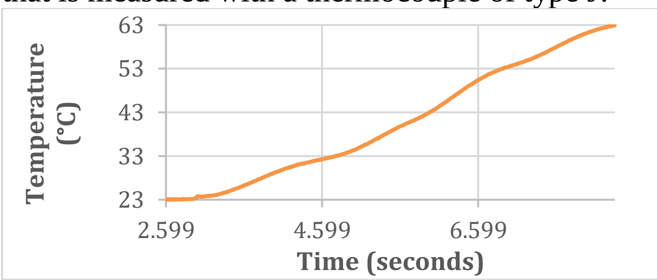

Fig. 11. Thermal change indicated by type J thermocouple

In figure 12 is presented a screenshot of transmission obtained with the LUNA OBR 4600:

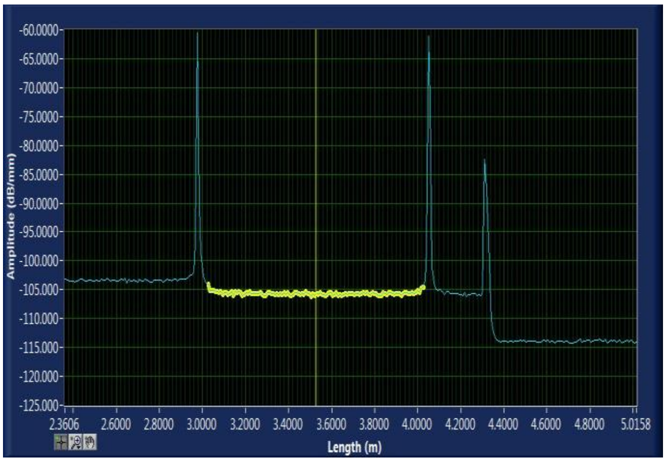

Fig. 12. Single mode fiber optic transmission obtained with the LUNA OBR 4600 optical reflectometer

Figure 13 shows the validation of the method in the case of three temperatures:

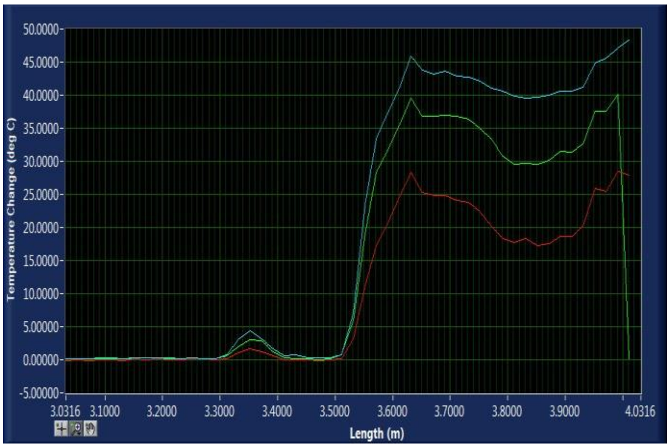

Fig. 13. Fiber temperature distribution in the case of three temperatures - method is validated by the data recorded by the thermocouple

Figure 14 shows the spectral characteristics of three FBG sensors:

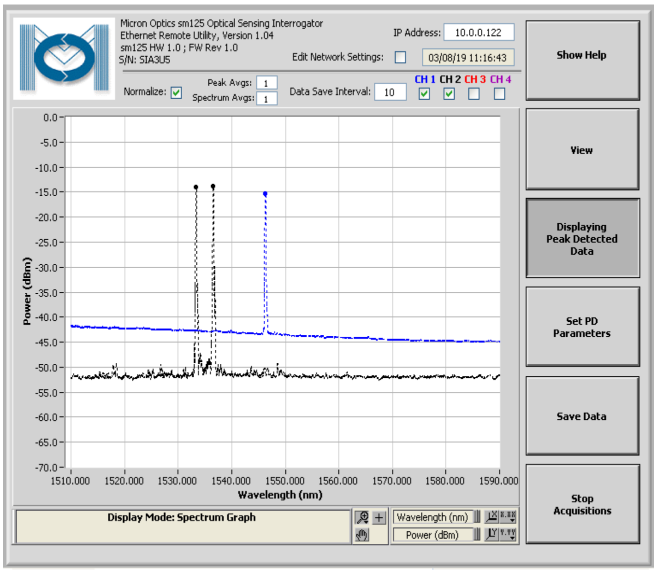

Fig. 14 The spectral characteristics of three FBG sensors used in the installation: two multiplexed (black) and one on another channel of the optical interrogator (blue)

5. CONCLUSIONS

Different temperatures in the oven were highlighted, which can be seen in the graphs by the elevated ascents and descents because its distribution is uneven. Although with a FBG (Fibre Bragg Gratings) sensor we can measure locally with high frequency and high accuracy, with distributed measurement technique, we can obtain information on temperature variation and mechanical stresses over a larger area. Research in the field consists of determining the specific properties of the optical fibers of the various productions and paralleling a result for a comparison with those obtained so far.

In this mode it can be determined that this type of fiber optic is suitable for structural monitoring (SHM).

6. REFERENCES

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