Multipeak Treatment of FBG Sensor Signal

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MULTIPEAK TREATMENT FOR FBG SENSOR SIGNAL

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ABSTRACT

Fiber Bragg Grating (FBG) sensors are increasing their importance in Structural Health Monitoring (SHM) of composite materials. They excel at reduced size, electromagnetic immunity and corrosion resistance. Furthermore, they are sensitive to strain and temperature, allowing the record of both parameters simultaneously.
For the case of composite materials, FBG sensors can be bonded to part surface or embedded within the CFRP plies prior to curing. During the last one, embedded sensors are exposed to high pressure, vacuum and temperature. These conditions modify fiber optic section, causing the degradation of the reflected signal. The received spectrum widens and shows multiple peaks for the same sensor, making signal treatment a complex task.
In this paper, an algorithm for peak recognition and monitoring is presented and validated. Embedded sensors included in different set-ups are study through different loading conditions during mechanical testing.

KEYWORDS : *Fiber Bragg Grating, Birefrigence, Fiber Optic Sensor, SHM.*

INTRODUCTION

Structural Health Monitoring (SHM) techniques for composite materials are in continuous development and growth, due to the rise of the use of these materials in applications as aerospace sector. Among the several techniques available for SHM, Fiber Bragg Grating sensors (FBG) present excellent properties to be integrated in composite structures [1].

The methods to attach FBG sensors are bonded to the surface or embedded within the CFRP plies prior to curing process. Embedded sensors are exposed to curing conditions, which modify the fiber cross-section from circular to elliptic. This change induces birefringence effects in the core, and two orthogonal polarization axes are develop in the plane of the sensor, each one with a different index of refraction [2-4]. The number of reflected wavelengths by the sensor (peaks) is equal to the number of refractive indices existing in the fiber. According to the shape acquired by the deformed section of the fiber, two or more different refractive indices appear.

The aim of this study is to determine a multipeak treatment strategy and analyzing the influence of various peaks in the strain records of the FBG sensors. An algorithm has been designed and validated in the following sections.

1 EXPERIMENTAL

1.1 Materials

Carbon Fiber Reinforced Polymer (CFRP) samples were manufactured by means of hand lay-up and autoclave curing. 12 samples were prepared with dimensions of 250 x 25 mm for tensile and flexion, and 150 x 100 mm for compression tests. The stacking sequence of the laminate was [45,-

45,0,90,90,90,90,0,-45,45], and the resulting thickness was 1.95 mm. In each specimen, a FBG was embedded between the first and the second ply. The optical fiber was always aligned parallel to the greatest dimension of the specimens.

1.2 Mechanical testing

Mechanical tests have been carried out using a universal testing machine Zwick Z100 and a SM 125 optical sensing interrogator (Micron Optics). Bragg optical sensors OS 1100 (Micron Optics) with a wavelength range between 1510-1590 nm were used in this study.

Three different loading configurations were tested: (i) tensile, (ii) compression and (iii) flexion.

1.2.1 Tensile

Tests were performed in the elastic regimen up to 15 kN and varying the displacement rate between 0.5 and 2 mm.min^{-1}.

1.2.2 Compression

A maximum load of 10 kN was fixed and the displacement rate was increased from 1 to 2mm.min^{-1}. Tests were carried out using an anti-buckling test tool.

1.2.3 Flexion

In this case, the displacement rate was selected at 1 mm.min^{-1} meanwhile the maximum load was varied from 15 to 50 N.

1.3 Data Processing

Data treatment in embedded sensors with multiple reflected peaks requires using specific tools for analysis, extraction and comparison of information. For this reason, an algorithm has been developed in order to identify and follow the peaks during the tests.

The main actions performed by this algorithm are:

- Relative maximums localization at reflected signal by the sensor (Figure 1).

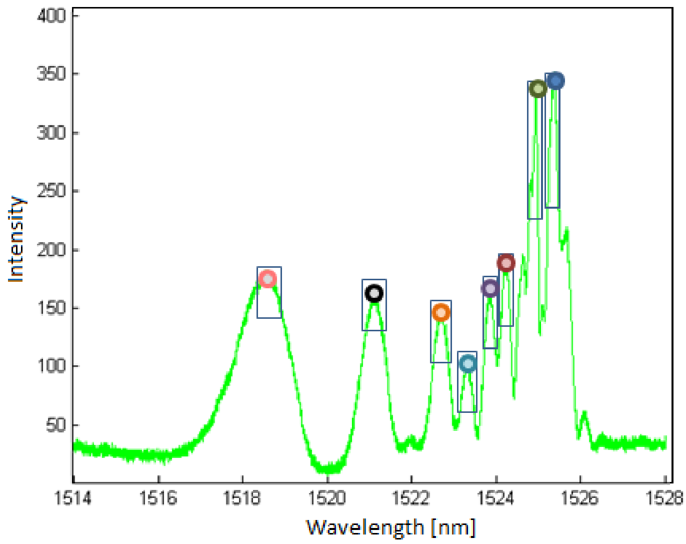

Figure 1: Example for maximum peaks localization at reflected signal (different peaks are identified by coloured circles).

- If the number of peaks remains constant between two different instants, strains are calculated from each peak.
- If not, the application of an automatic algorithm for peak detection is performed, which identifies the new peaks and those which are maintained and even the ones disappearing. The algorithm is based on three criteria:

  (i) Multiple peak detection with different intensity: in order to identify multiple peak signals with different intensities (I), the relative amplitude variation between time instants *(t)* and *(t-1)* of the different signals ("i" and "j") is calculated as (Figure 2.a):

$$\Delta \,\mathrm{Re}\, lative \quad Intensity \; = \frac{I(t)_j - I(t-1)_i}{I(t-1)_i}. \tag{1}$$

  This relationship will be close to 0 if the same peak is traced and >0 for different peaks.

  (ii) Wavelength: Multiple peaks amounts different wavelength (W) positions during the tests. The objective of this criterion is to identify each developed peak by the relative wavelength variation for each peak ("i" and "j") at time *(t)* against previous instant *(t-1)* (Figure 2.b):

$$\Delta \,\mathrm{Re}\, lative \quad Wavelength \; = \frac{W(t)_j - W(t-1)_i}{W(t-1)_i}. \tag{2}$$

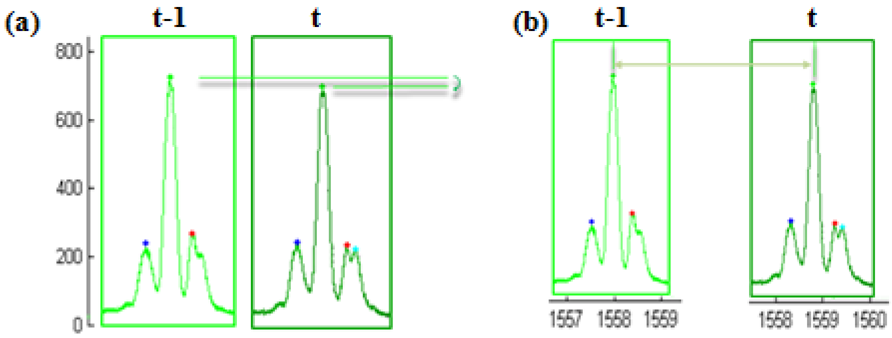

Figure 2: Representation of analysed criteria: Relative (a) Intensity and (b) Wavelength variation.

  (iii) Slope: in this case the slope of the wavelength vs. force curve is analysed. Equation (3) calculates the difference of the slope of all the peaks ("i" and "j") between the time *(t)* and *(t-1)* (Figure 3). If comparing different peaks, an important modification of the calculated slope will be expected:

$$\Delta \,\mathrm{Re}\, lative \quad Slope \; = \frac{S(t)_j - S(t-1)_i}{S(t-1)_i} - \frac{S(t-1)_i - S(t-2)_i}{S(t-2)_i}. \tag{3}$$

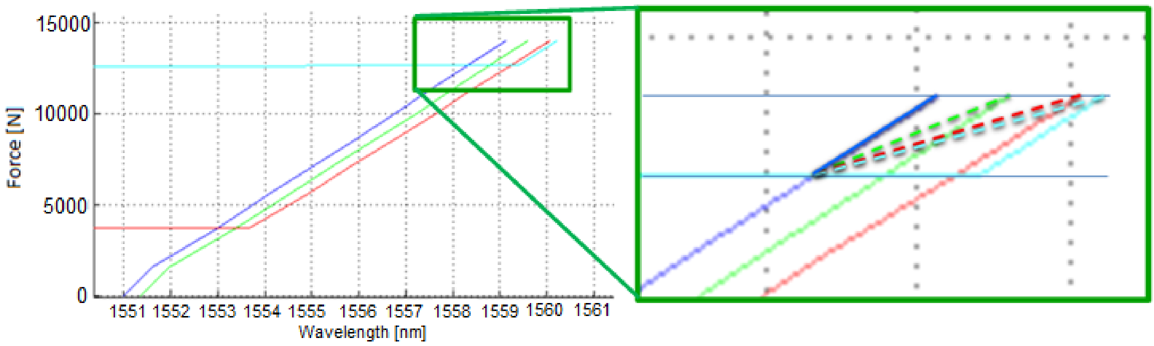

Figure 3: Representation of analysed relative slope variation.

2 RESULTS AND DISCUSSION

2.1 Tensile

Figure 4 shows the reflected wavelength by the embedded sensor during tensile testing. Before loading, the sensor presented two reflected peaks related with its deformation during pressuring in autoclave. The number of reflected peaks grows when increasing the applied load, being 4 at maximum test load. At this point, the highest peak decreased its intensity by 37% with respect to the unloaded condition. Finally, the reflected signal comes back to the initial shape when the load is removed.

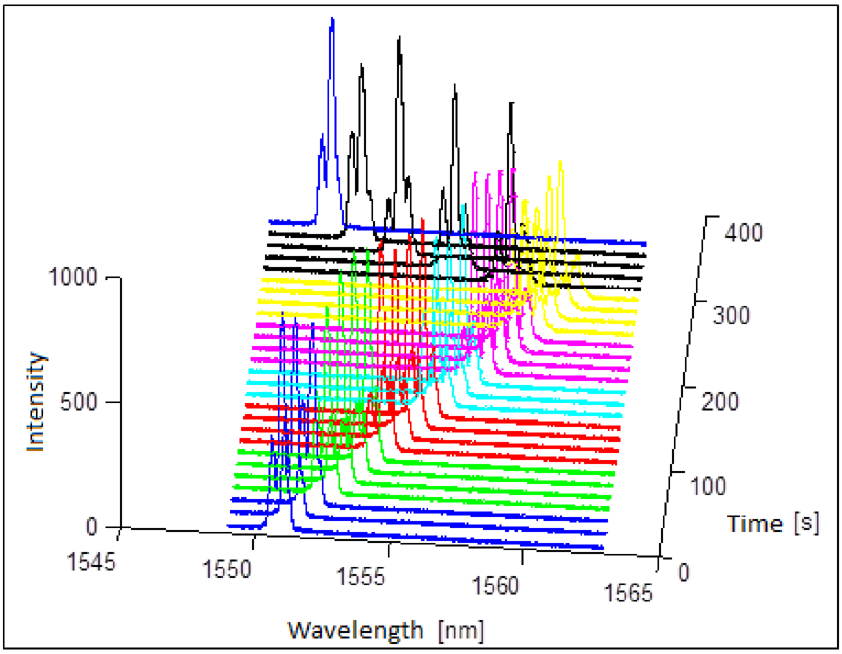

Figure 4: Wavelength variation during tensile test (Maximum load=15 kN @ 2 mm.min^{-1}).

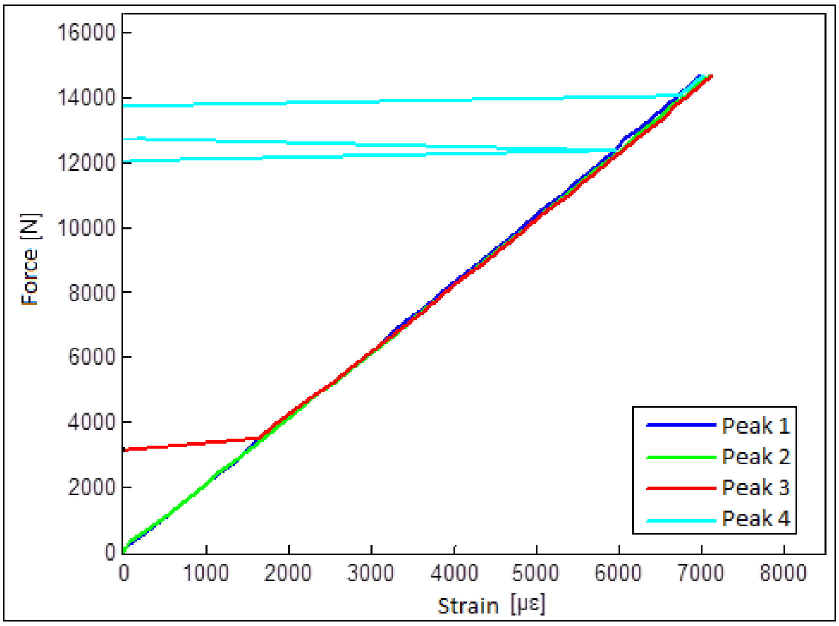

Figure 5: Force vs. strain records obtained during tensile testing by the different analysed peaks (max. load =15 kN @ 2 mm.min^{-1}).

Strains recorded during testing and calculated from each peak are presented in Figure 5. It can be observed that the recorded force vs. strain signal is overlapped for all developed peaks. Initially, only the peaks 1 and 2 are reflected by the sensor. The Peak 3 appeared at 3,540 N and maintained until maximum load of 15 kN. An additional peak appeared at 5,930 N but disappeared after few milliseconds. The last was raised again at 6,720 N and remaining until maximum load (Peak 4).

2.2 Compression

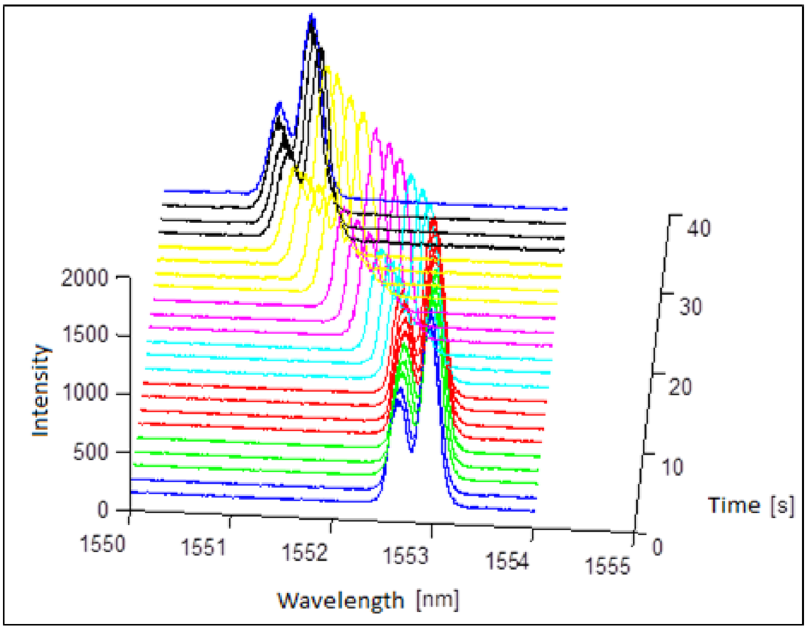

Figure 6: Wavelength variation during compression test (Maximum load=10 kN @ 2 mm.min^{-1}).

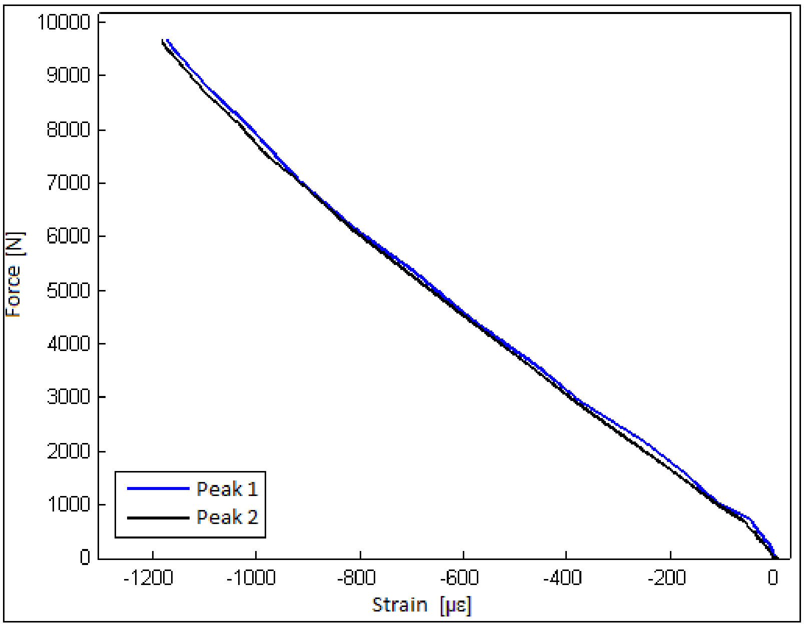

Figure 7: Force vs. strain records obtained during compression testing by the different analysed peaks (max. load =10 kN @ 2 mm.min^{-1}).

A 3D representation of the wavelength vs. time is presented in Figure 6. Two peaks are identified for the embedded sensor, with significant difference in intensity (47%). During loading, the amplitude of the first peak is reduced by 10.2%,, meanwhile the intensity of the second one grows by 1.8%. Due to the compression load, the reflected wavelength decreases from the initial value.

Force vs. strain records are presented in Figure 7, where a good correspondence between the measurements of peaks 1 and 2 is observed. The relative strain difference at maximum load (10 kN) amounts only 0.01%.

2.3 Flexion

During flexion tests, tensile and compressive loads are produced. In this sample the embedded sensor was situated in compressed region, therefore a reduction of wavelength signal recorded by the optical sensor is observed during testing (Figure 8). Similarly to the previous example, only two peaks were registered in the data records. The intensity of the both peaks remains constant along the test.

In Figure 9, a good correlation for stress vs. strain is observed. The appearance of other peaks has not been developed when increasing load.

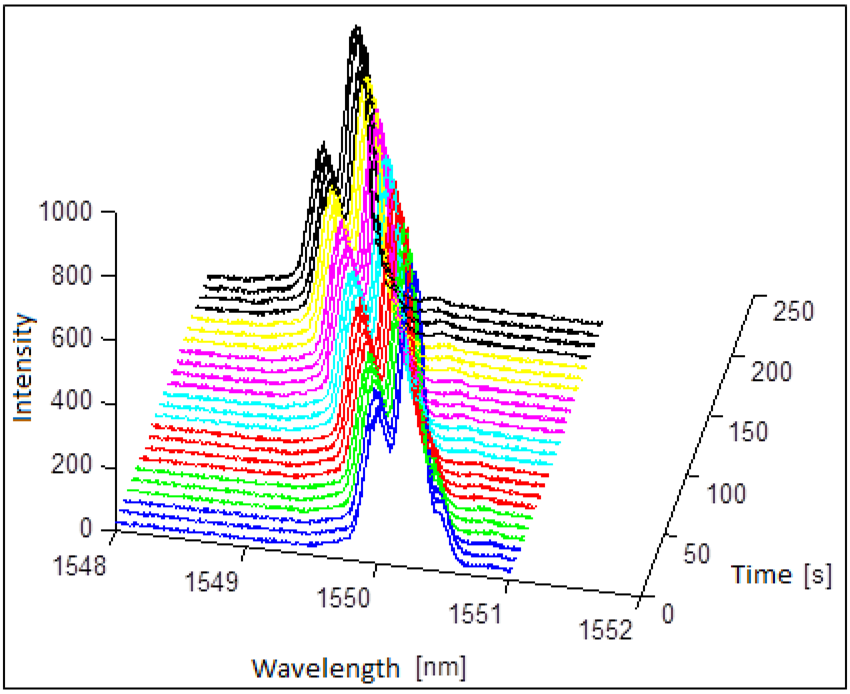

Figure 8: Wavelength variation during flexion test (Maximum load=18 N @ 1 mm.min^{-1}).

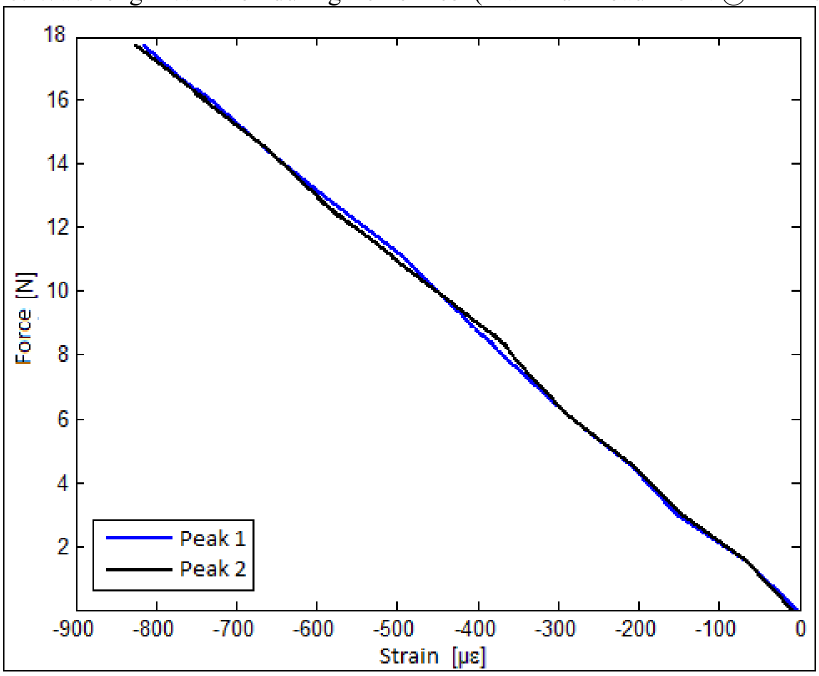

Figure 9: Force vs. strain curves obtained during flexion testing by the different analysed peaks (max. load =18 N @ 1 mm.min^{-1}).

CONCLUSIONS

Embedded FBG sensors are exposed to curing process where ambient conditions (combination of temperature, pressure and vacuum) deform fiber optic cross-section, increasing the number of reflected peaks.

As a general rule, it has been observed that when increasing the applied load; a reduction of the intensity in the reflected signal is registered.

For the case of tensile tests, the reduction of intensity together with the apparition of other peaks is observed. For those cases, the evaluation of the recorded data requires of specific processing algorithm, which was developed and evaluated in this work. The last one, allows the identification of all peaks and their tracing along the tests.

Since in all case, small differences in the wavelength (< 9 nm) are registered between the peaks, the tracking of strain is independent from the selected peak. In all cases, the peak should remain visible during the whole test.

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