Dynamic damage detection of a cantilever carbon beam using a FBG array inscribed in polymer gradient index multimode CYTOP fibre

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Abstract: In this paper we report on the use of a multiple-FBG array inscribed in gradient index multimode CYTOP POF using an efficient femtosecond laser inscription method. The FBG array was mounted across the cantilever as a quasi-distributed sensor and the time-depended wavelength information of each particular FBG-point sensor was recovered using a commercial spectrometer, designed to operate at 1550nm. We adjusted the degree of damage detection by using different weights suspended in the middle of the flexible beam.

1. Introduction

Fibre Bragg grating (FBG) sensors in polymer optical fibres (POFs) are typically inscribed in polymethyl methacrylate (PMMA) or cyclic olefin copolymer (TOPAS) materials [1-4]. The key advantage is the very high strain response offering a large wavelength tuning range that can exceed 75 nm, because of the low Young's modulus [5-6]. However, the material losses in both cases are exceptionally high in the near infrared, a wavelength range that is desirable as it offers a compatibility with the majority of optical fibre components, and commercial sensor demodulators. The high optical losses adversely affect FBG sensor applications in PMMA and TOPAS to short distances of a few tens of centimetres. As a result their use for advanced applications, such as multiple FBG sensor arrays, is limited. Bearing this in mind we have focused on other polymer optical fibres based on the polymer CYTOP that is available as a gradient index multimode fibre. CYTOP has excellent transparency at 1550nm allowing for the development of FBG sensing arrays in POF that are tens of metres in length [7]. All the CYTOP POFs that are commercially available are multimode fibres, and FBG inscription in multimode fibres introduces a multi-peak spectrum because of grating-core mode coupling [8-9]. This effect causes difficulties with respect to the interrogation of the FBGs. To overcome this potential hurdle we have used a femtosecond laser inscription method to record FBGs in CYTOP multimode optical fibre by carefully controlling the grating depth, width and length we are able to avoid many of the multiple modes that are typically measured for FBGs in multimode optical fibres [10-11]. We apply this inscription method for the development of a simple interrogation scheme that is used for dynamic health monitoring of a cantilever carbon helicopter air-blade beam. We use a multiple-FBG array inscribed in gradient index multimode CYTOP POF using the aforementioned, efficient femtosecond laser inscription method. The FBG array was mounted across the cantilever as quasi-distributed sensor and the time-depended wavelength information of each particular FBG-point sensor was recovered using a commercial spectrometer, designed to operate at 1550nm. We adjusted the level of the detected "damage" by using different weights suspended in the middle and at the end of the beam.

2. Experimental details and Results

A femtosecond laser system (HighQ laser femtoREGEN) was used for the inscription of the FBG array. The fibre sample was mounted to an air bearing stage system (Aerotech) for accurate computer controlled translation on two axes during the inscription process. Six FBGs were inscribed in a multimode gradient index CYTOP polymer fibre and the reflection spectrum of the FBG array is shown in Fig. 1. The FBGs were inscribed using the plane-by-plane femtosecond laser inscription method [10]. Each grating consisted of 300 planes with the pitch between two consecutively planes ~2.2-μm. Small variations of the grating period were used for the inscription of the rest of the gratings in the FBG array. The fibre had a 62.5-μm core diameter, a cladding layer of 20-μm and an additional polyester and polycarbonate outer cladding to protect the fibre. The total length of the fibre strand was ~1m and the physical distance between the FBGs was 3-cm.

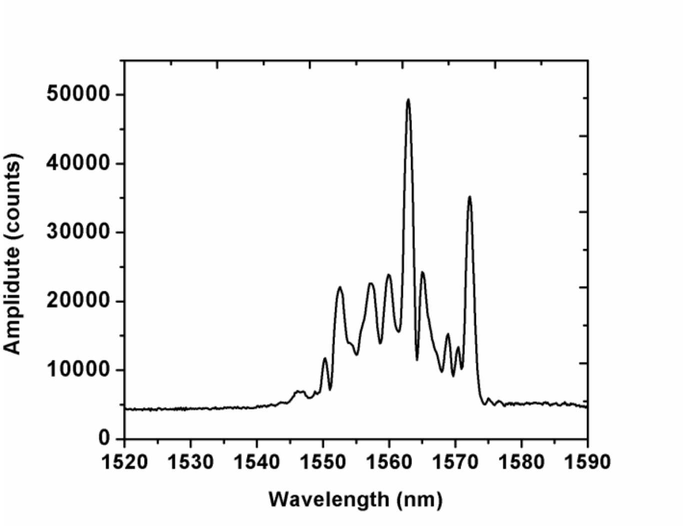


Figure 1: Multiple-FBG array reflection spectrum inscribed in multimode gradient index CYTOP polymer fibre using the plane-by-plane femtosecond laser inscription method.

The multiple FBG array was mounted on a carbon cantilever beam with total length 320-mm, as shown in Fig. 2. A broadband light source (Thorlabs ASE730) was used to illuminate the polymer array and the reflection spectrum was measured through a circulator with a commercial spectrometer (IBSEN I-MON 512 High speed). Note that the coupling between the multimode polymer fibre and the single mode silica was realized using a 3-D manual translation stage and index matching gel was used between the fibres to reduce Fresnel reflections.

The cantilever beam was fixed at one end and the other end was left free to perform a free-vibration motion. We interrogated the response of the FBG array and we recovered the time-dependent wavelength information of each FBG separately for the period of the fluctuation; examples of the raw time-dependent data are shown in Fig. 3. The results for each particular FBG were normalized and the shape of the beam during the vibration was recovered. Note that the FBG array was placed on the beam and covered only part of the beam, as shown in Fig. 2 (red line).

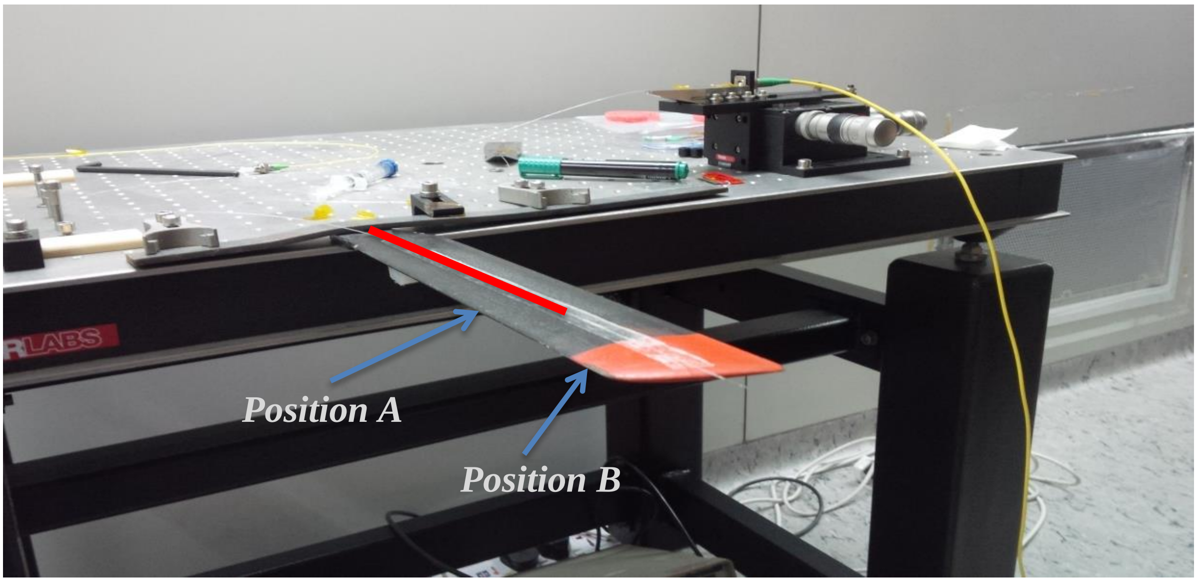
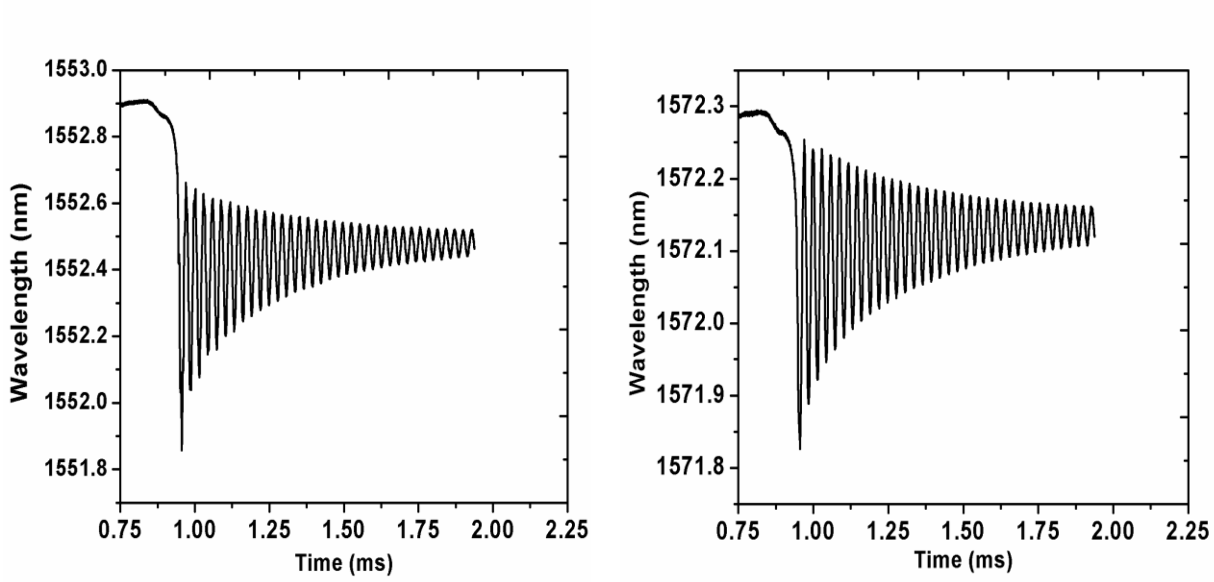


Fig. 2: Experimental setup for damage detection of a cantilever beam using a multiple FBG array inscribed in a multimode gradient index multimode CYTOP fibre.



(a) (b)

Fig. 3: Time-dependent wavelength information data for two FBGs as recovered using a commercial spectrometer (IBSEN I-MON 512 High speed).

We attempted to mimic the introduction of some degree of “damage” on the beam by adding weights to various positions on the beam. We adjust the position of the “damage” to the beam by changing the position of the weights, for example position A and position B, as shown in Fig. 2. The results for each case were normalized and the shape of the beam was extracted and compared with and without weights. In Fig. 4 we observe the fluctuation of the beam with no load (black line), with the load at position A (red line), and with the load at the position B (blue line). From the results it is clear that when the weights are placed close to a FBG point sensor the wavelength shift indicates a change at that location; conversely far from the FBG point sensors there is poor recovery of information by the FBG point sensors.

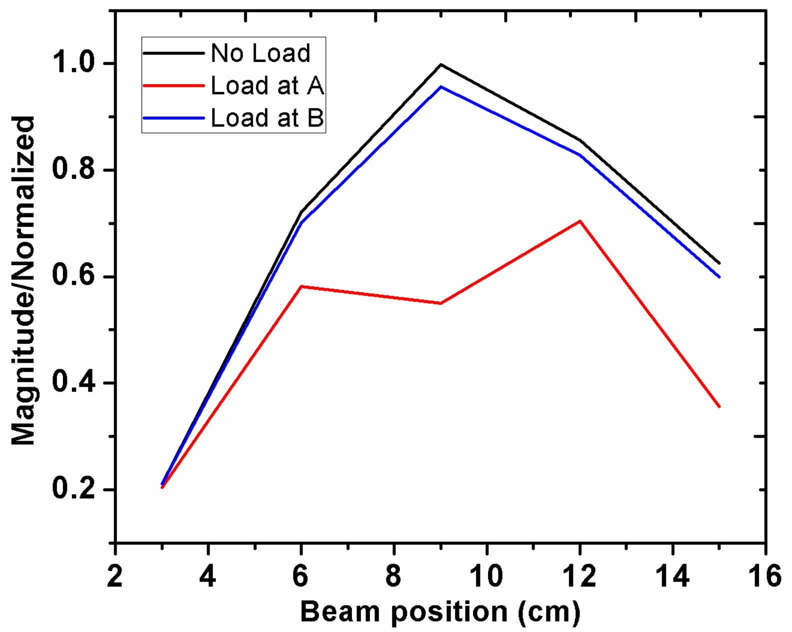


Fig. 4: Comparison between the beam shapes of the cantilever when weights are placed at different positions on the beam.

3. Conclusion

We report on the inscription of a multiple FBG array in gradient index multimode CYTOP fibre using a femtosecond laser inscription method. The FBG array was mounted on a cantilever beam and used as quasi-distributed sensor for the monitoring of the vibration response of the beam. The time-depended wavelength information was recovered for each particular FBG point sensor and the shape of the beam during the vibration was recovered. Finally, we introduced some degree of “damage” on the beam by using different weights suspended in middle of the beam and we compared the results with and without load to identify the position of the damage.

4. Acknowledgements

The authors want to thank Ultra 555T LAE Ltd. for their support.

6. References

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