A Review on the Development of Bragg Grating Sensors at CEFET-PR and University of Aveiro

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ABSTRACT

A review of current activities in the development of fibre optic Bragg grating (FOBG) sensors under a joint agreement of Brazilian and Portuguese Institutes is presented. Numerical simulation, experimental development, calibration procedures and application results are presented for sensors in mechanical, electrical and biomedical engineering.

Keywords: Gratings, Fibre Optics, Sensors

1. INTRODUCTION

It is well known that Fibre optic Bragg grating (FOBG) devices play an increasing role in the development of new products and services both in telecommunications and sensing applications. FOBG are strong, reliable and low cost fibre devices and they offer the increased advantage of being in-fibre written. This means that no coupling of light between the fibre and the device is required, reducing the overall cost and providing better power management due to smaller coupling losses. Apart from that, FOBG also present their resulting signal – when subject to a proper measurand – encoded as a frequency shift, which means that absolute measurements are possible without the need of frequent calibration or referencing.[1]

FOBG are extensively used to measure strain and temperature, as those parameters shift the spectral band of the reflected light due to photo elastic and thermo optic effects. Strain measurements are of particular importance in several engineering applications like, aerospace, mechanical structures, composites, biomedical ... [2,3]

When light is launched into a fibre core to pass through a Bragg grating, some wavelengths will be reflected by the periodic index variation. Generally, the reflected light will be out of the phase and tend to cancel except when the wavelength satisfies the Bragg reflection condition. In this case, the reflected light adds constructively and can form a reflective peak in the backward propagating beam. The Bragg wavelength of a grating, λ_B, is given by

$$\lambda_B = 2 n_e \Lambda \tag{1}$$

where Λ is the periodicity of the index variation, and n_e the modal effective index in the fibre core. The shift in the Bragg wavelength, due to traction and compression of the grating structure and changes in the effective index, can be expressed in term of the Silica photo-elastic tensor components, p_{ij}, and of the longitudinal and transversal strain, ϵ_z and ϵ_t. When only longitudinal strain, ϵ_z, is considered to act on the grating, plus the effect of a temperature variation, ΔT, it can be shown that

$$\frac{\Delta\lambda_B}{\lambda_B} = \{(1 - (\frac{n^2}{2})[p_{12} - \nu(p_{11} + p_{12})]\}\epsilon_z + (\alpha + \eta)\Delta T = [1 - p_e]\epsilon_z + (\alpha + \eta)\Delta T \tag{2}$$

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where ν is the Poisson ratio, p_e is the effective photo-elastic constant, $p_e \approx 0.22$, α and η are, respectively, the thermal expansion and the thermo optic coefficients for Silica glasses.

As it can be seen from Eq. 2, the measurement of strain or temperature is done by measuring the corresponding spectral shift in the peak position of the reflection band from the FOBG. This can be accomplished easily by several means as, e.g., Optical Spectrum Analysers (OSA), tuneable spectral filters and tuneable lasers, fixed frequency reference filters, ...

2. INFRASTRUCTURE

At the Physics Department of University of Aveiro a phase mask illuminated interferometer, operating at the UV wavelength of $244\,nm$ is assembled. With guaranteed $150\,mW$ CW output from a frequency doubled Ar ion laser, FOBG can be written in hydrogen pre loaded fibres in a few minutes. Similar results are obtained when using commercial, pre sensitised fibre optics samples. The set-up is being updated in order to allow writing longer Bragg gratings due to their importance to the telecommunications applications, but that will also allow better sensing devices to be recorded. We expect a complimentary set-up to be assembled at CEFET-PR, but the relevant operational characteristics will not be so good as the Portuguese one, due to economical constraints in Brazil. Another phase mask interferometer is also available at the Institute of Advanced Studied (IEAv), with similar characteristics, apart from the UV wavelength at $257\,nm$. Complimentary facilities include, hydrogen loading chambers (UA, IEAv), optical characterization facilities (UA, IEAv, CEFET-PR), temperature and stress sweep over the grating (UA, CEFET-PR), strain measurements using Universal Test Machines (CEFET-PR).

3. STRAIN MEASUREMENTS

The main application of FOBG in strain measurement at our group is the study and control of power cable deformation.[4] Multi FOBG sensors are glued to multi wire aluminium electrical cables with steel core, to monitor the strain over individual conductors. With multiplexed FOBG that measurements can also be done at different locations along the cable. Individual transducer calibration processes have been developed using the FOBG alone or the FOBG glued to metallic test probes. Strain studies are made using a MTS Universal Stress Test Apparatus.

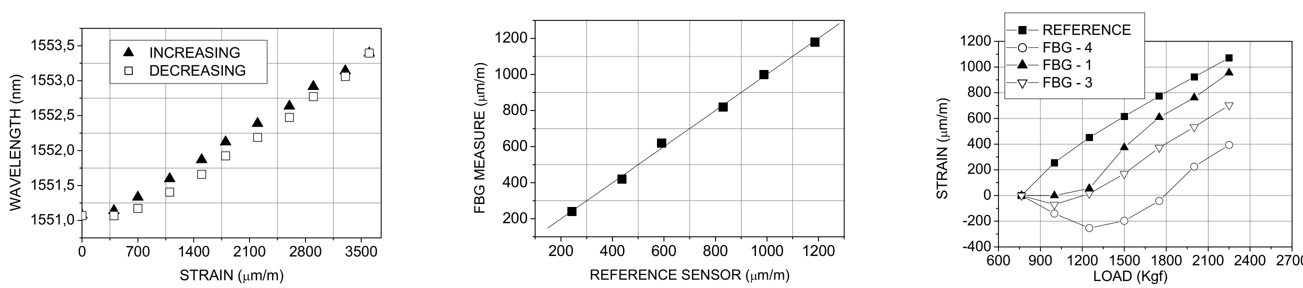

Figure 1. Strain studies in power cables using FOBG sensors: left - individual FOBG calibration process; centre - FOBG measured strain in a test probe against the measurements of the reference sensor in the MTS apparatus; right - Measurements of strain over individual conductors in a multi wire electrical cable using FOBG.

Figure 1 shows some of the obtained data. The graph on the left displays the calibration procedure of an individual FOBG transducer, when subjected to elongation imposed by precision screw micrometers and measured by a traceable 'clip gauge' (MTS Inc.). Results are incorporated in the calibration curve of the respective transducer. The central graph shows the linearity of a typical FOBG sensor glued to a metallic test plate and subjected to controlled strain. Linearity is determined by the recorded values of that transducer against the measurement done by the (traceable) electric sensors of the MTS apparatus. The graph on the right of that figure shows results from another measurement, made on a $12\,m$ long electrical power cable mounted in a standard (Brazilian norm) elongation bench. The individual FOBG sensors attached to the cable show that the strain on each conductor is, for the initial pre-stretching process displayed, quite different from the average strain measured by the reference sensor in the bench. This behaviour in the bench measurement is caused by the central (Steel) strength element, whose strain dependence is quite different from that of the Aluminium conductors.

To extend the applications of FOBG sensing in mechanical, electrical and civil engineering there are two main branches that can be followed: the study of dynamic processes through the measurement of vibration spectra from the bodies under study and the measurement of multi axis stress acting on such subjects.

Vibration can be detected as a differential strain measured by a suitable pair of FOBG attached to the test body. Several schemes are published and the choice is more related to the range and amplitude of the movements to be detected and to the assembly of a convenient set-up with the FOBG.

As for multi axis stress, that is a key point in structural engineering.[2,3] The use of multi FOBG sensors, orthogonaly oriented, shall be avoided because it becomes too bulky. One possibility is to develop FOBG in high birefringence fibres, so that the measurement of the transversal components of strain can be done by a single transducer, while a second one, a few millimetres apart in the same fibre, can measure the longitudinal component. FOBG in HiBi fibres have already been obtained at our group[5] and further results are also being presented at this conference.[6]

4. BIOMEDICAL APPLICATIONS

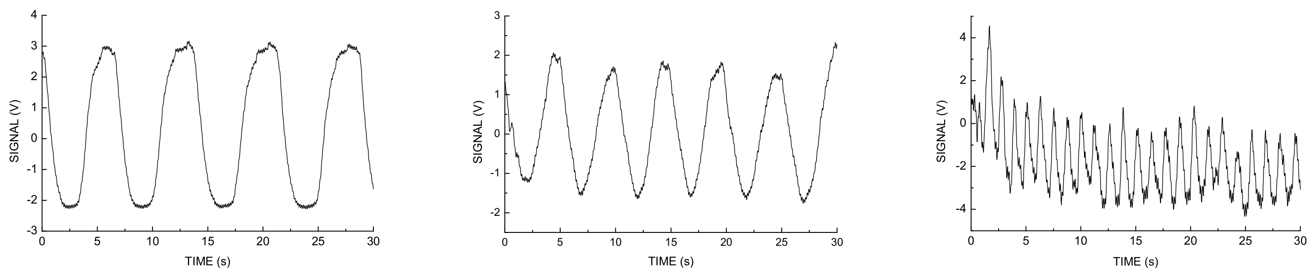

Figure 2. Respiratory signal from a 26 year old male: left - normal volume, centre - inspiratory volume reduced to 150 ml, right - further reduction to 60 ml.

Biomedical sensing is one of the most important areas for the application of Fibre Optics Sensors. FOBG share with other fibre sensors the small dimensions and low weight, that insures superior comfort for the patient, chemical inertness, electrical isolation, ... As an example we refer to the measurements of the respiratory signal and corresponding frequency spectra of human beings, using a FOBG to detect the chest movement. When the patient inhales or exhales, the chest deformation is perceived by the FOBG as a periodic strain modulation, and the corresponding shift in the peak position of the FOBG reflection band can be used to trace and measure the dynamic characteristics of the respiratory process. The main advantage of such sensor is its dielectric nature, which avoids electromagnetic pick-up and noise from disturbing signals. This means that the sensor can be used to trigger electrically assisted ventilation apparatus that uses electrical pulses on the chest to synchronize the respiratory process. The FOBG sensor[7] is mounted on a elastic belt around the patient's chest and can detect signals with frequency components up to, approximately, 10 Hz. Fig. 2 shows acquired signals from a patient under normal, slow breathing in rest position (left graph) and the corresponding changes when the inspiration volume is restricted to 150 ml and 60 ml (centre and right graphs, respectively). The later situation is close related to the acute respiratory arrest that can be caused by trauma in the thorax region.

It is possible, from the acquired signals, to obtain the frequency spectra, using common FFT algorithms. Results for the signals previously mentioned are displayed, respectively, in Fig. 3. The main frequency peak is clearly observed, as well as it displacement to higher frequencies as the inspiration volume is reduced. Other small components are present, yet not identified. It shall be mentioned that other muscular movements in the pectoral zone can also be superimposed in the signal. In fact, a clear demonstration of this effect was shown with the patient turning the arms. The high frequency signals from the arm's revolution can be observed in superimposition to the respiratory signal[8] and the frequency components are completely discernible.

Future applications in Biomedical engineering include the development of tissue compatible extensometers to be used as monitors for bone fracture consolidation, intracavity pressure monitor and multi sensor structures for study of the walking process during physiotherapy and recovery.

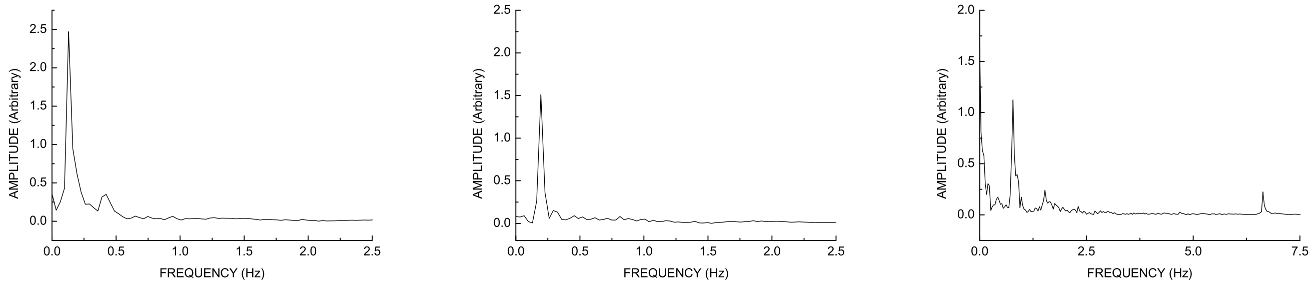

Figure 3. Frequency spectra of the respiratory signals from a 26 year old male: left - normal volume, centre - 150 ml volume, right - 60 ml volume.

5. CONCLUSION

FOBG represent a viable and economically alternative for several sensing problems in countries like Brazil and Portugal. It is possible to increase FOBG writing in normal and HiBi fibres, and to develop transducers and sensors to applications that include the study of dynamic aspects as structure vibration (civil and electrical engineering subjects), biomedical monitoring and control and biofeedback during the walk (orthopaedics).

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