Proposed Interrogation System Applied to a FBG Opto-Mechanical Accelerometer

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Abstract

In this work, an analysis of a proposed opto-mechanical setup to the implementation of a Fiber Bragg Grating (FBG) tri-axial accelerometer applied to military purpose is made. The detection scheme aims to minimize the thermal drift and the transverse and axial accelerations coupling effects on the final measurements, and those influences are estimated as well as the signal intensity change that is sensed by the detector.

Introduction

Accelerometers are largely employed in military and industrial applications such as vibration monitoring, inertial navigation and feedback of unstable aerodynamical structures. They are defined as devices that are capable of generating an electrical signal proportional to the acceleration of the surface in which they are attached to.

In modern days, the most common accelerometers are based on piezoelectricity. Other possible configurations include accelerometers based upon micromachines and fiber Bragg gratings (FBG).

In order to implement a FBG accelerometer, it is necessary to use a pre-stressed fiber Bragg grating, which is attached to an inertial mass. Setups like this can be purchased nowadays, but optimized to industrial applications where the interrogating system is isolated from vibrations. For military applications, these systems must allow that the interrogator travel together with the vehicle, passing through the same conditions as the sensor.

In this work, a FBG accelerometer is modeled for military applications. In order to satisfy the rigorous military standards, the thermal drift and coupling between the different transverse and axial accelerations are minimized. The mechanical setup consists of an inertial mass supported by six fibers, each containing a FBG, as illustrated in Figure 1.

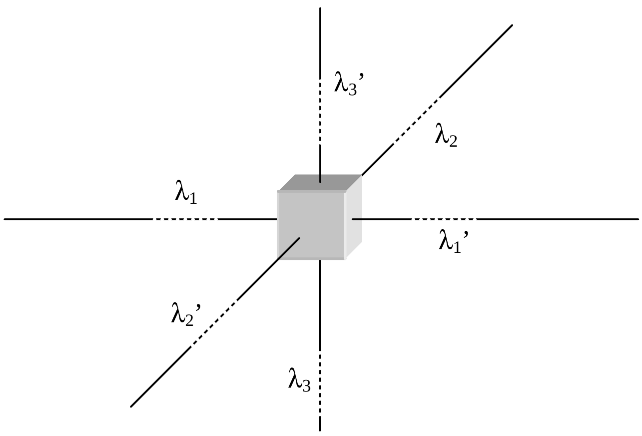

Figure 1: accelerometric mass supported by six FBGs.

Initially, it is assumed that the peak wavelength of the reflectivity spectra of each grating follow the expression below [1]:

$$\lambda_{Bragg}(\varepsilon) = \lambda_{Bragg} + \lambda_{Bragg}\, S_z\, (1 - p_e) \qquad (1)$$

where Sz is the strain of the fiber in its axial direction, λ_{Bragg} is the peak wavelength of the FBG reflectivity spectrum, and pe is the elastic-optical coefficient of the used fiber. Measurements in our fibers indicate that (1 – pe) is about 0,76 ε^{-1}.

The next step is to calculate the axial strain of each FBG, considering the effects of the six fibers and the acceleration of the system. The final expression is obtained as,

$$m\alpha = \left(6 - \frac{4L}{\sqrt{\Delta L^2 + L^2}}\right)\frac{\Delta LAE}{L} \qquad (2)$$

with m being the inertial mass, a the axial acceleration, ΔL the fiber strain in the axial direction, L the initial length of the fiber in the absence of external forces, E the Young's module for silica, and A the cross-section of the used fiber. For small strains, ΔS_z is given by,

$$\Delta S_z = \frac{\Delta L}{L} = \frac{m\alpha}{2AE} \qquad (3)$$

where ΔS_z is the axial fiber strain subject to the fiber axial acceleration a. It is assumed that the initial lengths of all six fibers are the same. Considering the geometrical setup and the fiber constants [2], the relation between the transverse and axial strain can be assumed constant, for small displacements.

$$\left|\frac{S_{trans}}{S_{axial}}\right| = 8{,}7\ 10^{-3} \qquad (4)$$

where S_{trans} is the transverse strain of the fibers, and S_{axial} is the axial strain of the fiber. Many of the parameters being used in this simulation are based upon practical data that has been obtained through our measurements in FBG. sensors. The initial strain of these gratings is equivalent to an acceleration of 40 G. In this analysis, it is considered that the gratings with reflectivity peak wavelengths λ_i are displaced approximately by 0.5nm from gratings with reflectivity peaks at λ_i', i = 1, 2, 3. This wavelength shift is necessary in the setup of Figure 2, allowing positive and negative accelerations be measured.

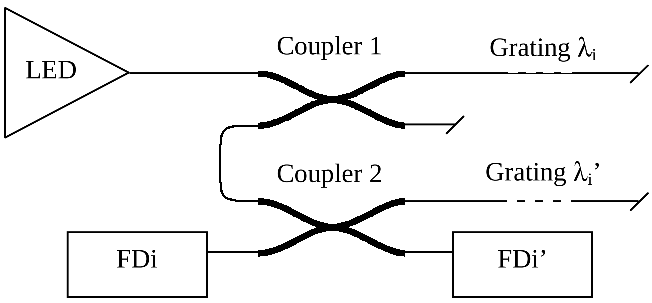

Figure 2: Basic schematic of the interrogating system for the FBG.

Notice that the grating pairs λ_i, λ_i' are assembled in the same axis as the accelerometric mass. In this situation, both of them will be submitted under the same variations in temperature and to the same strain due to the transverse acceleration. Because the reflectivity peaks of the gratings are very close, the induced wavelength shift caused by these external mechanical forces will be approximately equal.

Simulations

Figure 3 shows the reflectivity spectra of the FBGs that will be employed in our simulations. Their spectra are positioned to maximize the response linearity of the system in the desired operational range.

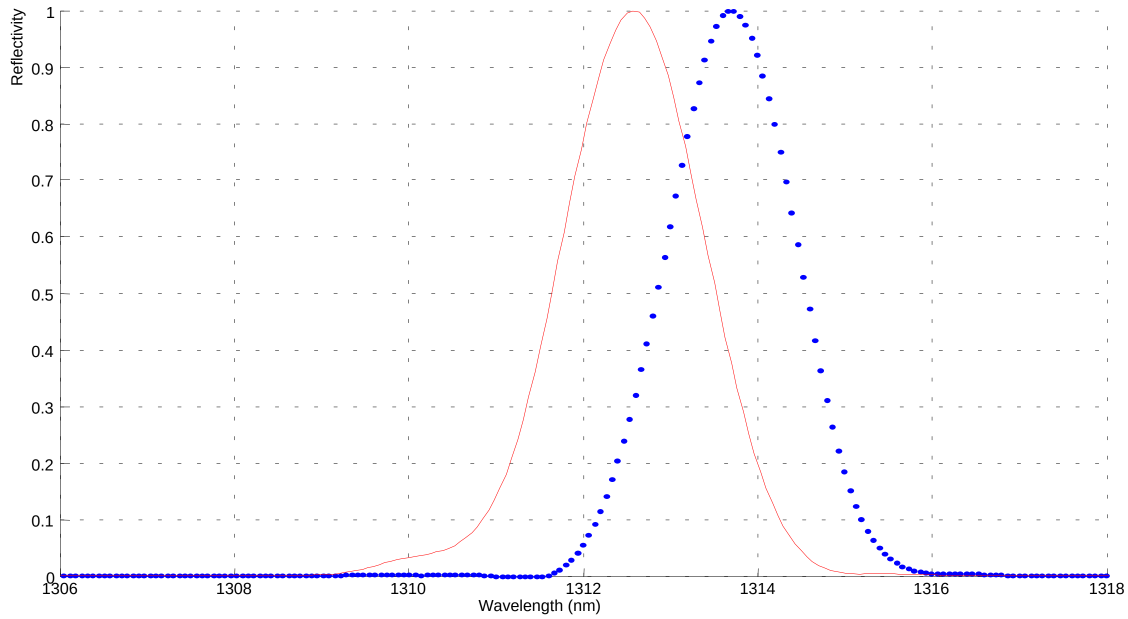

Figure 3: Reflectivity spectra of the gratings employed in the simulations.

Considering the transverse and axial acceleration effects, the new FGBs reflection wavelength were calculated and, using then, the optical power in photodetector FD1 was estimated. With the same principle, the thermal analysis of the system was made, considering the operation range of 0^oC to 100^oC. The axial acceleration, transversal acceleration and the thermal analysis are in figures 4, 5 and 6, respectively.

In these conditions, it is assumed that: maximum value of acceleration 40G; accelerometric mass 1.5g; fiber diameter of 125mm; Young modulus of the fiber 7 $10^{10}N/m^2$.

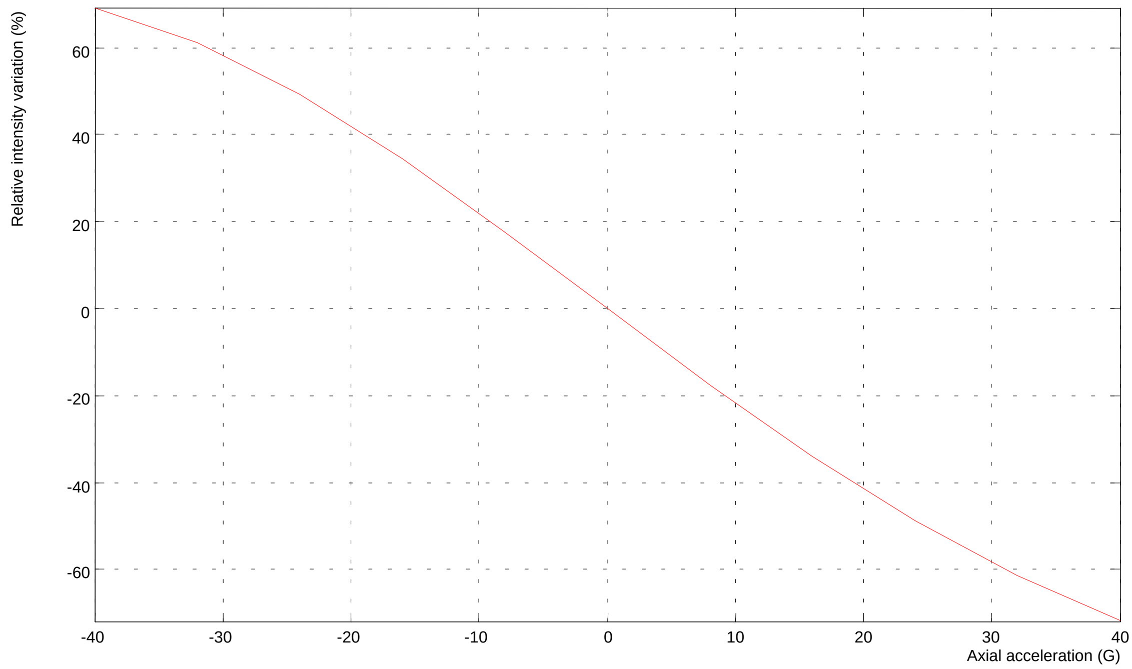

Figure 4: Variation of the relative intensity in respect to the axial acceleration.

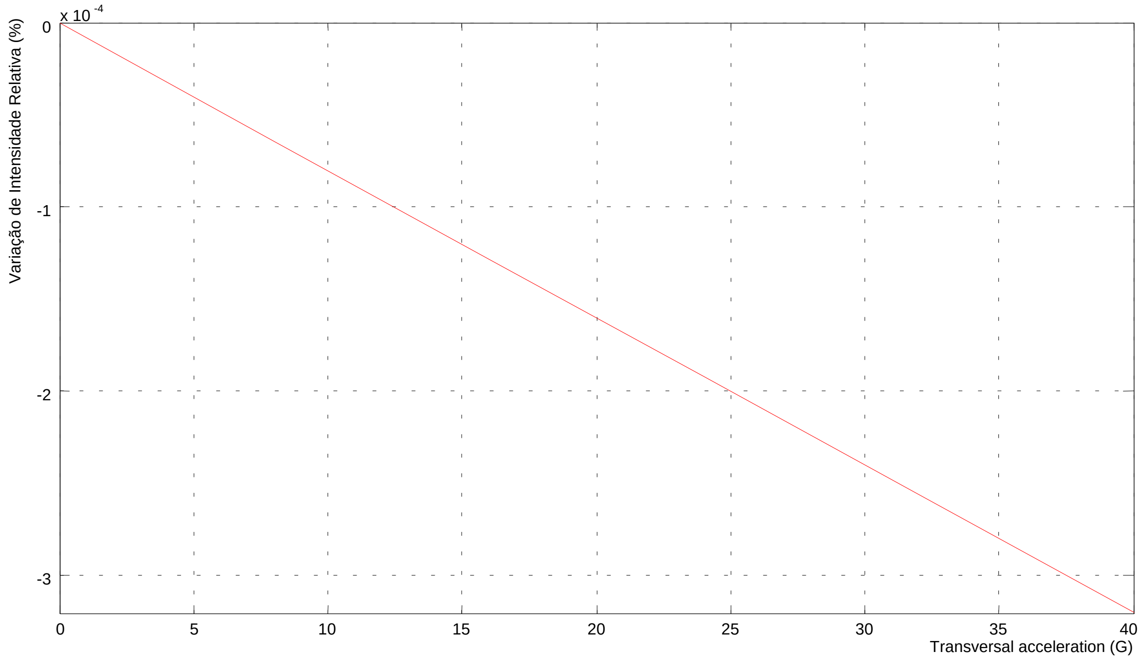

Figure 5: Variation of the relative intensity in respect to the transversal acceleration.

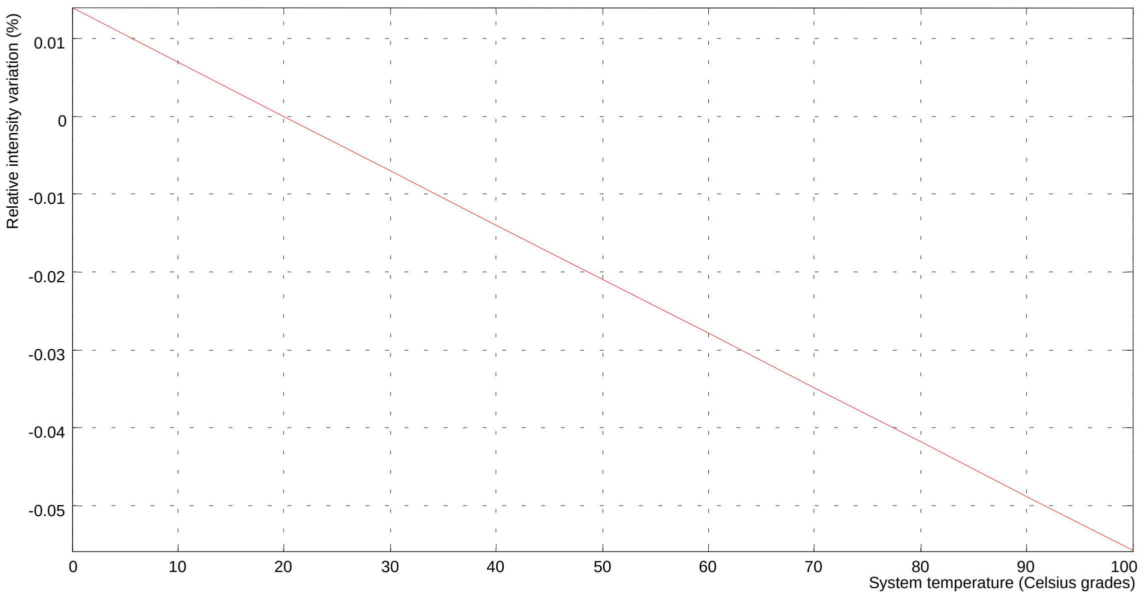

Figure 6: Variation of the relative intensity in respect to temperature.

Interpretation of the results

The plots in Figure 6 show that, for a change in temperature of 100°C, the variation of the relative intensity must be in the order of 0,07% and that, compared with temperature changes, the influence of the transverse accelerations is negligible (on the order of 3,5 10^{-4}%). By monitoring the temperature in this sensor to compensate its effects, it is possible to improve the quality of the sensor.

The follow system expressions can be used for a relation between the photodetector voltage and the system acceleration:

$$a_i = \alpha_i(V_i) - \beta_i (V_j) + \chi_i (V_k) - \phi_i \Delta T \qquad (5.a)$$

$$a_j = \alpha_j(V_i) - \beta_j (V_j) + \chi_j (V_k) - \phi_j \Delta T \qquad (5.b)$$

$$a_k = \alpha_k(V_i) - \beta_k (V_j) + \chi_k (V_k) - \phi_k \Delta T \qquad (5.c)$$

where i, j and k are the FBGs axis, V_i, V_j and V_k are the voltages in the photodetectors of the interrogator system of the FBGs in axis i, j and k. α, β, χ and ϕ are look up tables that may be catalogued experimentally. In the proposed set up, the system may be linear for accelerations below 10G, so α, β, χ and ϕ may be considered linear functions.

Conclusions

In this work, we have analyzed the optic-mechanical setup proposed to the implementation of a three-axis accelerometer, with a setup which minimizes the effects of the transverse accelerations in the measurement of axial ones and spurious effects induced by temperature. We have estimated the influence of these factors in the axial readings, and the variation of the light signal that reaches the photodetectors of the system. By adequately processing the measurement data, these spurious effects can be compensated.

The next step will be to fabricate this system and determine all parameters in our model. Finally, a digital system will be implemented for the acquisition and processing of the data of acceleration, allowing a future optimization of the accelerometer.

References

[1] A. Othonos, K. Kalli, *"Fiber Bragg Gratings: Fundamentals and Applications in Telecommunications and Sensing"*, Boston Artech House (1999).

[2] R. M. Cazo, *"Sistemas Interrogadores de Sensores Baseados em Grade de Bragg"*, Instituto de Estudos Avançados (2001).