Experimental validation of a quasi-distributed polarimetric vibration sensor

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A quasi-distributed optical fiber vibration sensor based on the light polarization properties is presented and experimentally validated. This system is based on the combination of several mechanical transducers (MTs), which transform applied vibrations into polarization state variations by crushing the fiber, with fiber Bragg gratings (FBGs), which reflect light from the different sensing positions of the fiber. A polarizer is also used to transform the polarization variations in easily measurable power variations. We show that this sensor can provide the vibration spectrum in a quasi-distributed manner.

Introduction

Vibrations are of high importance as they are an indicator of the health of civil structures and industrial machines. Modifications in a vibration spectrum can be considered as alarm signals for structural problems and vibration sensors can then prevent damages and avoid serious consequences. Even if many kinds of vibration sensors are available (accelerometers, ...), vibration sensors based on optical fiber technology are particularly interesting due to their ability to provide quasi-distributed and distributed information along the optical fibre with only one interrogating element. Optical fibre sensors have also the advantages of being usable in harsh environments (EM-disturbed, humid, high temperature...) in which conventional sensors are limited. In this paper, the state of polarization (SOP) is chosen as the measurand as it can provide multi-point information and is sensitive to external perturbations. The general principle of a polarimetric vibration sensor is that a vibration modifies the birefringence properties of the fiber and induces a SOP modification. A polarizer then transforms this SOP variation into a power modification which is observable on an oscilloscope. Different polarimetric vibration sensors have been previously developed [1, 2]. The originality of our work is that vibrations are here induced via the crushing of the optical fiber over a 3 mm length by a mechanical transducer (MT) [3] and no longer simulated as the stretching of a fiber section wounded around a piezoelectrical crystal (PZC) which expands with an applied voltage [1]. This paper is divided as follows. In the first section the working principle of the proposed sensor is given and in the second section the quasi-distributed measurement technique is described.

Working principle of the proposed multi-point sensor

The proposed sensor is depicted in Fig.1. Light is emitted from a broadband source (here, an Amplified Spontaneous Emission (ASE) source) and is launched into the fibre under test (FUT) through a circulator and a polarizer which fixes the input SOP. During its propagation along the FUT, considering the case of N=3 sensors, the lightwave is successively reflected by 6 FBGs with different Bragg wavelengths λ_{ij} (i=1, ..., N, depending on which sensor is considered and j=1,2, depending on the position of the FBG within the sensor): λ_{11} = 1582.5 nm and λ_{12} = 1571.5 nm (S_1), λ_{21} = 1560.8 nm and λ_{22} = 1550.6 nm (S_2), λ_{31} = 1540.3 nm and λ_{32} = 1530.9 nm) (S_3).

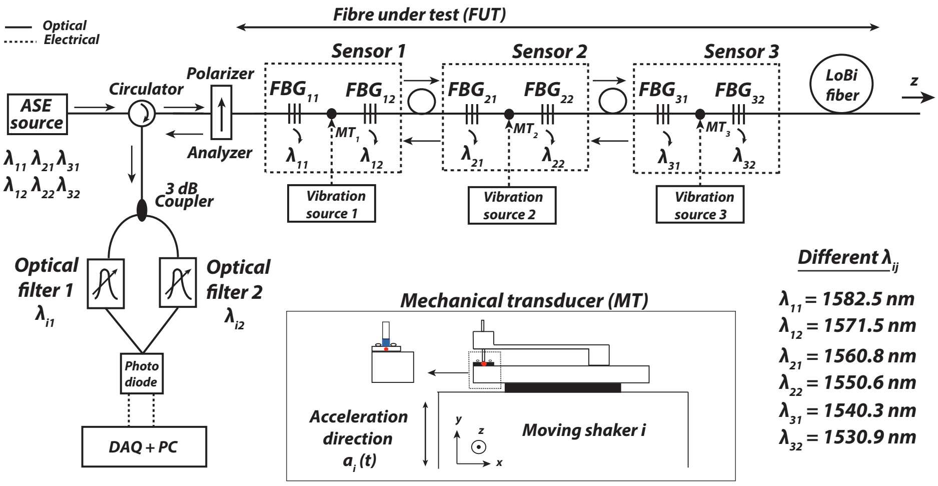

Figure 1: *Experimental setup (plain lines: optical links; dashed lines: electrical links ; MT: mechanical transducer ; S_i: sensor i ; FBG: fiber Bragg grating ; DAQ: data acquisition card ; inset: mechanical transducer used to induce birefringence in the fibre*

As shown in Fig. 1, these FBGs are placed in pairs around one MT, constituting one sensor S_i (i=1,...,N). The MT used is shown in the inset of Fig. 1 and is made of a vibrating beam and a rigid base. The base is screwed on the vibration source (shaker), while the beam is free to move at one of its extremities (the other extremity is screwed on the base). A second screw, whose edge is covered with rubber and is in contact with the fibre, is placed at this free extremity. The direction of this second screw is transversal to the fibre propagation axis z. When the shaker vibrates, the inertia of the beam, via the presence of the second screw, induces a crushing of the optical fibre over a 3 mm length and modifies the birefringence (phase retardance between the polarization eigenmodes). Ref. [3] shows that this phase retardance depends linearly on the applied acceleration.
The reflected signals are guided back to the polarizer which transforms the SOP variations into power variations. These contributions are splitted by a 3dB coupler and reach two tunable optical filters which are adjusted so as to select the signals reflected at λ_{i1} and λ_{i2}. The contributions are electrically converted, acquired with a data acquisition card (DAQ) and displayed on a PC. Even if the present sensor is able to measure vibrations in a quasi-distributed manner [2], it appears that when the SOP is modified at a position z, by a MT, it is also modified between that position and the fibre end. This means that one frequency applied on one sensor S_j (j=1,..., N-1) is also observed in the frequency spectrum of the sensors S_k (k=i+1,...,N), resulting in artefacts. To distinguish these artefacts from vibrations that are really applied on one MT, the phase shift between the electrical signals corresponding to the two FBGs surrounding this MT are measured. If this phase shift differs from 0°, this means that a vibration is applied on the MT while if this shift is equal to 0°, no vibration is applied. Under some assumptions, a phase shift can only correspond

to a SOP modification due to the vibration applied on the MT between the two adjacent FBGs. These assumptions are that extra polarization modifications elsewhere in the setup are negligible. This is the reason why we use a Low-Birefringence fibre (whose intrinsic birefringence is equal to 4.10^{-9}, i.e. 25 times smaller than in a singlemode fibre, meaning that the SOP does not practically change between two adjacent FBGs). Moreover, these adjacent FBGs are as close to each other as possible (here, 30 cm). On the other hand, FBGs used have low birefringence (5.10^{-6}), so that the SOPs are not practically modified when transmitted and reflected by these FBGs [3]. Finally, the wavelength separation between each FBG (10 nm) is such that the SOP evolutions are not significantly different for two adjacent wavelengths.

Quasi-distributed measurement technique

Using the experimental setup described in Fig. 1, we first acquire the signals guided back from the 6 FBGs, then we calculate, for each FBG, the magnitude spectra of the converted signals and finally, for each frequency contribution in the magnitude spectra and each pair of FBGs surrounding one MT, we calculate the phase difference. Based on the value of the phase shift (cf. previous section), we can deduce if a vibration is really applied or not on a specific transducer. This method is illustrated with the following example: a 300 Hz sine vibration is applied on MT_1, a 240 Hz and a 175 Hz sine vibrations are applied on MT_2 and a 110 Hz and a 300 Hz (MT_3) are applied on MT_3. The magnitude spectra of the 6 signals are given in Fig. 2.

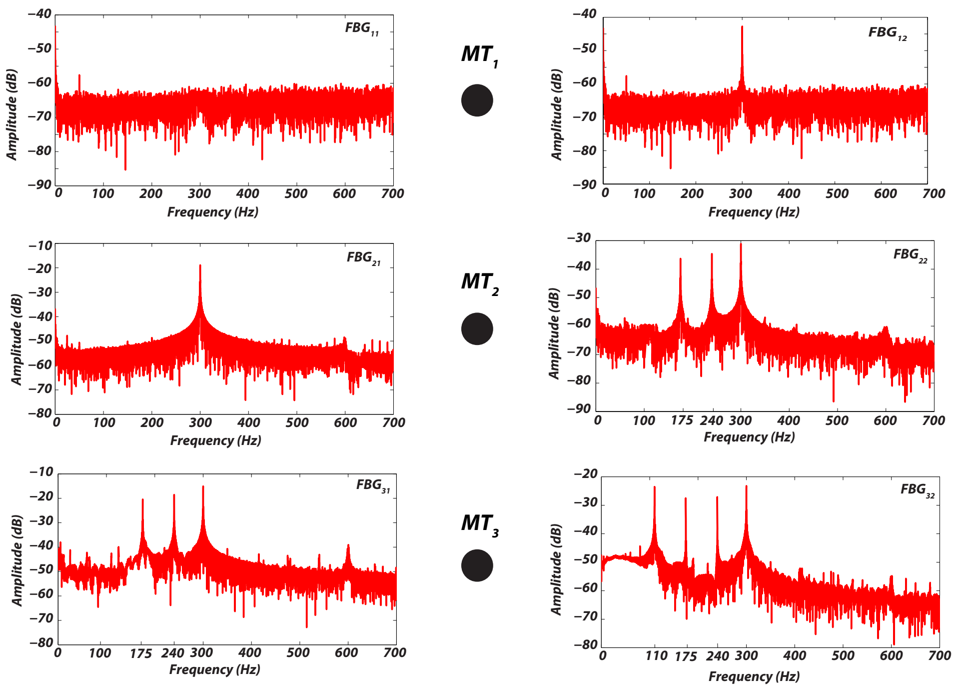

Figure 2: *Magnitude spectra of the signals coming from the different FBGs*

This figure shows that from the magnitude spectra, we can only deduce the presence of frequencies on a sensor S_i (i=1,...,N) if these frequencies are not applied on a previous shaker S_k (k=1,..., i-1). As explained in the previous section, we then calculate, at the different frequencies of the magnitude spectra, the phase shift between the signals coming from two FBGs surrounding the same MT. Table 1 gives the phase shifts for the four applied frequencies.

	110 Hz	175 Hz	240 Hz	300 Hz
MT_1 (FBG_{11} - FBG_{12})	–	–	–	–
MT_2 (FBG_{21} - FBG_{22})	–	–	–	$\Delta\phi$ = -0.5°
MT_3 (FBG_{31} - FBG_{32})	–	$\Delta\phi$ = 0.1°	$\Delta\phi$ = 0.5°	$\Delta\phi$ = -40°

Table 1: *Distinction between artefacts and really applied trequencies at the different MTs*

For some frequencies, the phase shift is not calculated as the vibration frequency can be unequivocally determined from the magnitude spectra (Fig. 2). We can see that depending on the fact that the vibrations are applied or not on the different MTs, the phase shifts are close to 0° (the difference with the ideal value of 0° is due to the uncertainties during the FFT process, to noise and to the slight influence of intrinsic birefringence) or are totally different from that value. Using this two-step method the frequency spectra can be univocally recovered at the different sensing positions.

Conclusion

In this paper, we presented a quasi-distributed polarimetric vibration sensor based on the use of mechanical transducers, which transform the vibration in an SOP modification, and FBGs, which reflect light from different sensors. A particular focus has been made on the problem of similar frequencies, which require, in addition to the calculus of the magnitude spectra of the obtained electrical signals, the measurement of the phase difference. We showed that it was then possible to recover the vibration frequency spectrum in a quasi-distributed manner.

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