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String Model Resonator High Accuracy Measurement For F B G Sensors

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***Abstract*: Fibre Bragg grating (FBG) sensors are widely accepted as strain and vibration monitoring devices for advanced composite mechanical structures.This paper describes a string resonator that is used for the interrogation system of a Fiber Bragg Grating (FBG) strain sensor. For several years now, civil engineers have been collaborating with researchers in the field of optoelectronics, in efforts to develop fiber optic sensing and monitoring systems for civil engineering structures. Optoelectronics are the core of the telecommunications industry and are an important part of sensing in the aerospace industry. In the last ten to twenty years, optoelectronic technology has emerged in the fields of civil engineering, manufacturing and biomedicine, etc., in products such as fiber optic sensors.The strain on the fiber piece is calculated from the measured frequency based on that the natural frequency of a string is a function of the applied absolute strain. Existing research considered a fiber as a string, but a fiber is not a string in the strict sense due to its bending stiffness, thus the fiber should be modeled as a beam accompanied with an axial force. In the vibration modeling, the relationship between the strain and the natural frequency is derived, and then the resonance condition is described in terms of both the phase and the mode shape for sustaining resonant motion. Several experiments verify the effectiveness of the proposed model of the fiber.**

Keywords: Smart structure,resonator fiber Bragg grating sensor, Tunable Optical Filter,beam model, Demodulation technique, string model.

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I. INTRODUCTION

Fiber Bragg Grating (FBG) is an optical fiber element, which is fabricated to show periodic change of the refractive index of the fiber core and reflects a narrow band of wavelength, called Bragg wavelength, when illuminated with a broadband light source. The principle of a FBG sensor is based on the fact that the Bragg wavelength of the sensing element shifts when strain or temperature change arises in the element. FBG sensors provide advantages such asn distributed sensing using only single fiber line, ease of insertion and attachment, self referencing capability independent of the total power level of the source and the loss of coupler or connection, high sensitivity, electromagnetic interference immunity, and multiplexing capability . With wavelength interrogating method using Fiber Fabry Perot (FFP) filter, a real-timeIn this work, a robust modeling of the string resonator is conducted, considering the stiffness of the string. A string resonator is designed and implemented to evaluate the effectiveness of the proposed model and the actual performance of the strain measurement system. The concepts of smart materials (SM) and structures are on the verge of becoming technological realities. The idea of mechanical, civil and aerospace engineering structures, which can react or adapt their characteristics due to signals from embedded sensors, has generated much interest in the engineering community. In addition, FBGs have the advantages of being absolute, linear in response, interrupt immune and of very low insertion loss that is why they can be multiplexed in series along a single mode fibre. The key point of these devices is related to their wavelengthencoded nature, since the sensed information (temperature or strain) is encoded directly into wavelength, which is an absolute parameter providing reproducible measurements despite intensity fluctuation and optical losses (bending, ageing of connectors). However, an issue with these sensors lies in the detection of the small wavelength shift of the reflected signal due to strain changes[10]. In the last years, several interrogation techniques have been developed involving interferometer detection, passive and active optical filtering.

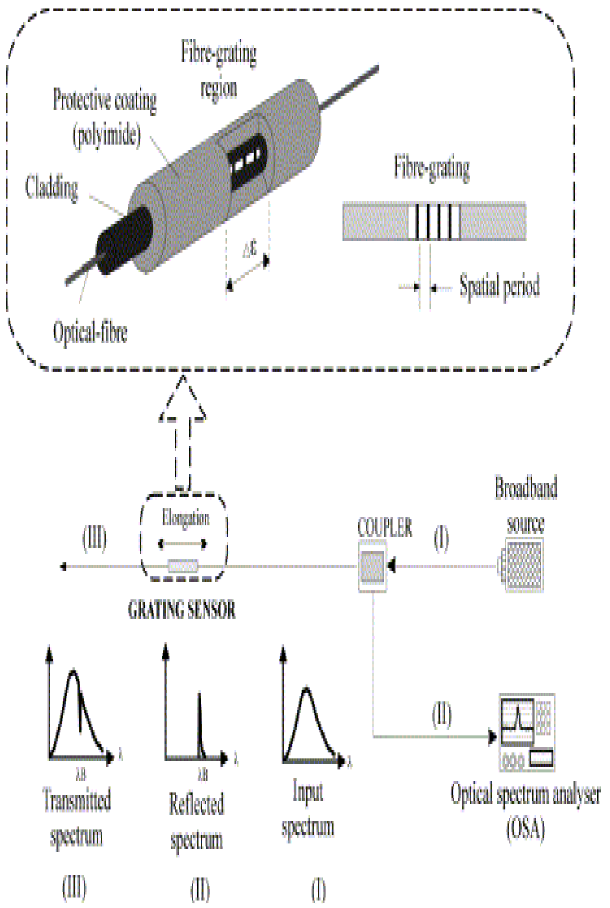

Figure 1: FBG strain measuring system

Transient dynamic vibrations are aroused by impacting a free-falling steel ball on a steel cantilever. Figure 1 displays the steel cantilever, in which both the IBFBG and TBFBG are attached in the closest distance between their axes of fibers that is, diameter of a optic fiber (0.125 mm) – to measure the longitudinal strains along almost the same line, and the resistance strain gauge is bonded symmetrically to the underside from both the FBGs to serve as a strain reference. In such an arrangement, comparisons between the IBFBG and TBFBG can be made, and the reference strains obtained from the resistance strain gauge are used to demonstrate that dynamic calibrations of an IBFBG by using a resistance strain gauge are reasonable.

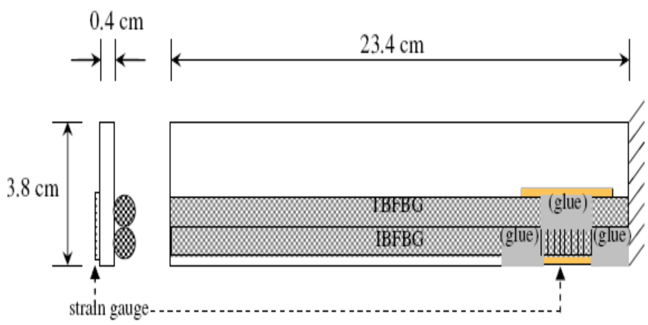

Figure 2 - The cantilever of rectangular cross section, both the IBFBG and TBFBG strain sensors.

Modeling/simulation:

For the simulation purpose we used the IFO_Gratings . The specification of the testing fiber Bragg grating is given in Table 1.

No.	Specifications	
1	Center wavelength at 25c (nm)	1560.03
2	FWHM (nm)	0.27
3	Reflectivity (%)	95
4	Grating length (mm)	5.0
5	Fiber type	SMF-28 compatible

Table 1: Specification of the tested fibre Bragg grating.

Calculation of Reflectivity: The Reflectivity is obtained by keeping the grating length constant and varying the index modulation amplitude of the grating (n), getting the Table 2 and the plot are shown in Figure . A negligible change in reflectivity may be observed by changing in index modulation from 0.0001 and 0.0008. The reflectivity (R) may be calculated from the transmission characteristic curves. The average value of Reflectivity is 99%.

Smart structure

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A structure is an assembly that serves an engineering function. It is reasonable to expect that all engineering design should be smart, and not dumb. But one can still make a distinction between smartly designed structures and smart structures. The latter term has acquired a specific technical meaning over the last few decades. A smart structure is that which has the ability to respond adaptively in a pre-designed useful and efficient manner to changes in environmental conditions, including any changes in its own condition; the response is adaptive in the sense that two or more stimuli or inputs may be received as anticipated and yet there is a single response function as per design. Smartness ensures that the structure gives optimum performance under a variety of environmental conditions. While structures with some degree of smartness have been designed from times immemorial, the current activity and excitement in this field derives its impetus from the level of sophistication achieved in materials science, information technology, measurement science, sensors, actuators, signal processing, nanotechnology, cybernetics, artificial intelligence, and biomimetics.

Tunable Optical Filter

Optoplex's **Tunable Optical Filter**, also known as **Optical Tunable Filter or Tunable Bandpass Filter**, is an integrated module, consisting of micro optics and electronics. When receiving a stream of optical signals of a plurality of wavelengths from the Input-Port (IN), the 2-port **tunable optical filter** directs a selected channel to the Output-Port (OUT). The selected channel can be varied (tuned) within the operating wavelength (frequency) range by a remote command sent through the built-in control PCB and firmware. Filters are the basic building blocks within frequency converting systems such as receivers and tuners. At microwave frequencies (1 GHz and above), filters are composed of high-Q resonators such as printed transmission line, suspended rods, or dielectric pucks. Depending on the media used to create these resonators, excellent performance can be achieved with Qs in the hundreds for printed lines to tens of thousands for dielectric resonators. The need for frequency tenability within broadband receiving and transmitting systems usually necessitates switching of multiple fixed-tuned circuits. The use of tunable filters and resonators can significantly simplify complexity and reduce losses within complex multiband systems.

Beam Model

The beam model used is the single-celled composite beam model of Rehnfield [3]. While the model is quite simple; use of it is somewhat dubious.

First of all, the blade I am designing is double-celled. Only the trailing part of the blade (the spar and the skin behind the spar) are modeled structurally. The skin ahead of the spar produces quite a bit of torsional stiffness; however, it is expected that careful design using coupling behavior of composites will offset the added stiffness.

Second, Rehnfield's model only applies to thin-walled beams. The spar, however, is not thin walled. In fact, the spar about as thick as the thinner airfoils themselves.

Despite the doubtfulness of the model, it offers the simplest analysis, and so is used for the very early preliminary design.

Rehnfield's model relates seven generalized forces to seven generalized strains. The force vector is

$$F=[N_x,Q_y,Q_z,M_x,M_y,M_z,Q_w]$$

N_x represents an axial force, Q_y and Q_z shear forces, M_x twisting moment, M_y and M_z bending moments, and Q_w a generalized warping force.

String model

The closed string model in the background gravity field is considered as a bi Hamiltonian system in assumption that string model is the integrable model for particular kind of the background fields. The dual nonlocal Poisson brackets (PB), depending of the background fields and of their derivatives, are obtained. The integrability condition is formulated as compatibility of the bi-Hamiltonity condition and the Jacobi identity of the dual Poisson bracket.
The bi-Hamiltonian approach [1–3] to the integrable systems was initiated by Magri [4] for investigation of the integrability of the KdV equation. A finite dimensional dynamical system with $2N$ degrees of freedom xa, $a = 1, . . . , 2N$ is integrable, if it is described by the set of the n integrals of motion

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$F1, \ldots, Fn$ in involution under some Poisson bracket (PB) $\{Fi, Fk\}$PB = 0. The dynamical system is completely solvable, if $n = N$. Any integral of motion (or any linear combination of them) can be considered as the Hamiltonian $Hk = Fk$.

Experimental results

The functional diagram of automatic string resonator is shown in Fig.2. The flexure stage of the string resonator is composed of two elastic hinges of notch type [7]. One flexure is for fiber stretching with a piezo actuator, PZT1, and another is for excitation motion, PZT2.

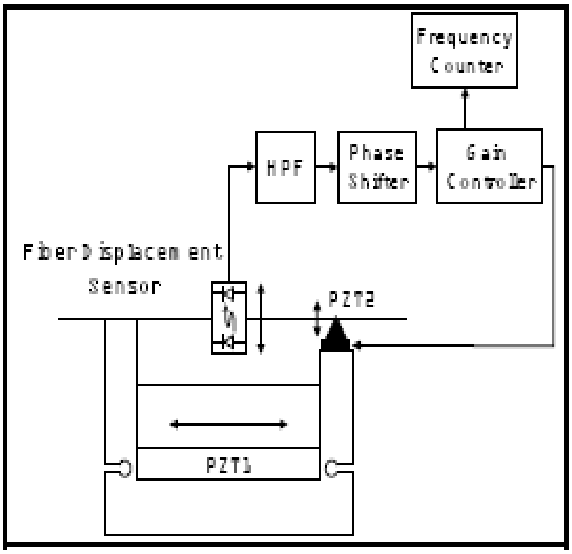


Fig. 3 Functional diagram of string resonator

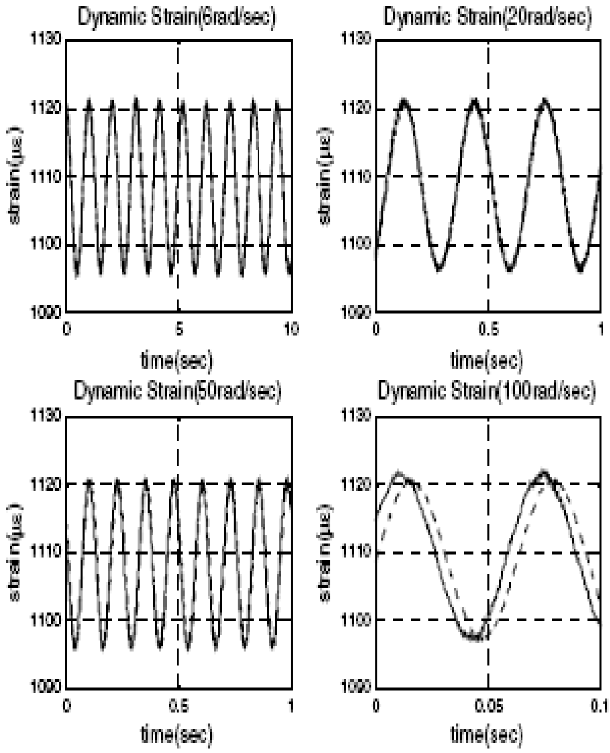
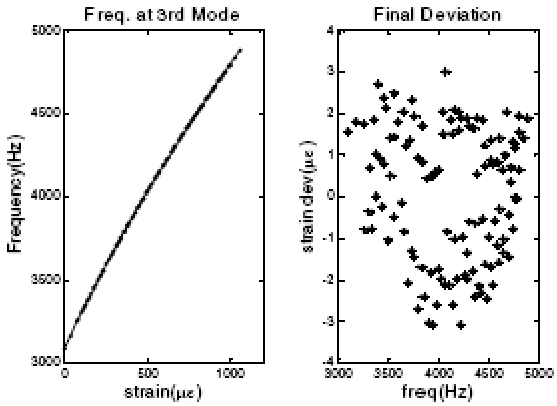


Fig. 4 Response to dynamic strain

Frequency response of the 3rd mode with respect to a dynamic strain is measured for input signal with the amplitude of 25με. The frequencies of the strain input were changed from 1Hz to 16 Hz, Fig.7. For frequencies smaller than 8Hz, excellent locking capability is achieved, with an accuracy of ~3 με and almost no phase difference.



Response to small step strain at 3rd mode

We did another measurement by applying a 250-Hz ramp signal to a cylindrical PZT on which some part of the MZI arm was tightly wound and glued. Figure 3(a) is the output interferogram with the MZI path

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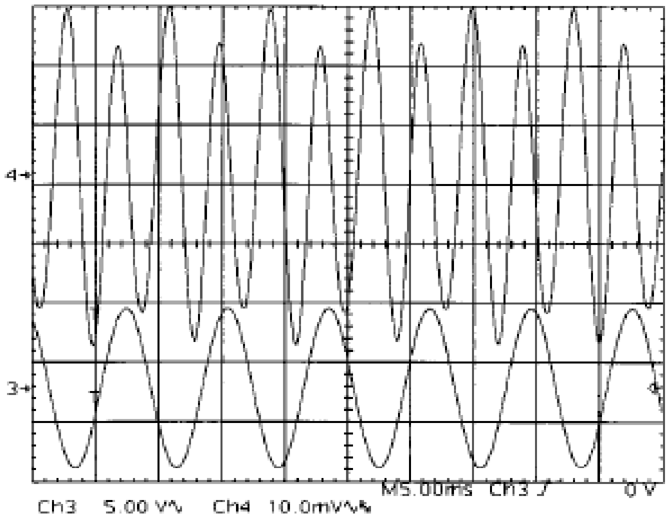
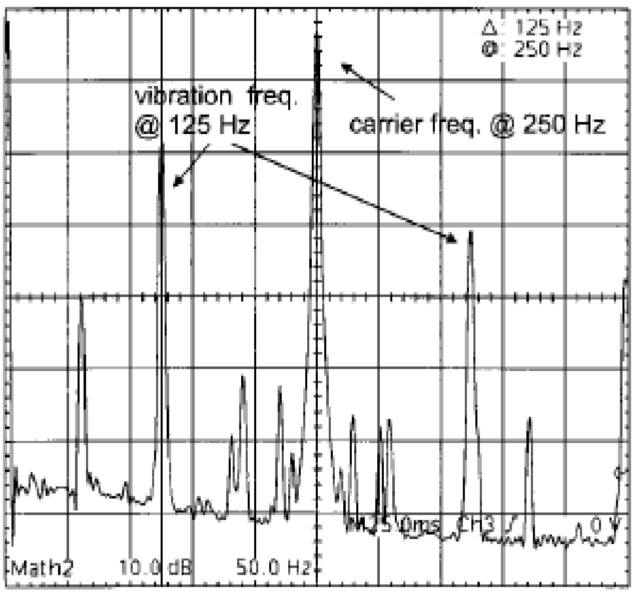
difference modulation. The envelope of the carrier frequency 250 (Hz) was modulated by the dynamic strain signal 125 (Hz). The mean amplitude of the interference signal denotes the strength of bias strain ~static strain!, and the periodic deviation of the envelope makes it possible to measure the amplitude and the frequency of the applied dynamic strain with proper signal processing. Figure 3(b) is the power spectrum of the interferogram of Fig. 3(a).



(a)

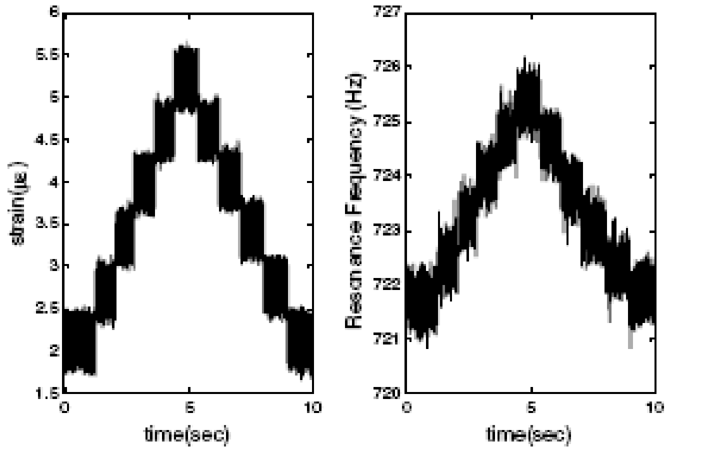


(b)

CONCLUSION

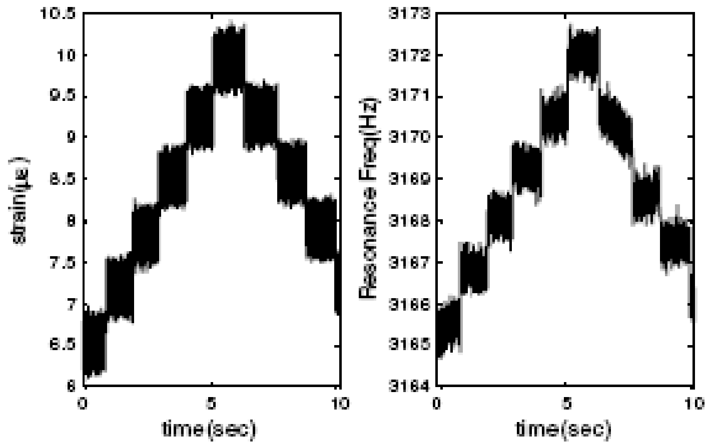
By the analysis, the measuring scheme for the absolute strain was established, from which the string resonator for the locking filter interrogation system was implemented. The measurement system of 3rd mode detection provides the sensitivity of three times compare with 1st mode, the accuracy of 3με, and the quasi-static resolution of ~0.1με which are better than 1st mode. For dynamic strain it provides accuracy of ~3με below than 8Hz input. Consequently, the performance of the string resonator for the absolute strain measurement with high sensitivity and high accuracy can be advanced by the design improvement of the flexure and the novel scheme for resonance detection of 3rd mode.

We also demonstrated the feasibility of interferometric dynamic-strain measurement with the dual-grating sensor. The fast response and temperaturediscriminating characteristics of the technique greatly improve the practicality of fiber grating sensor implementations for structural monitoring applications.



(a)

Response to small step strain at 1st mode



(b)

Response to small step strain at 3rd mode

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