Sensors and Actuators A 205 (2014) 79–85

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Modified cantilever beam shaped FBG based accelerometer with self temperature compensation

Mohd. Mansoor Khan [a,*], Nishtha Panwar [b], Ravi Dhawan [b]

[a] International Institute of Information Technology, Hyderabad 500032, India
[b] CSIR-Central Scientific Instruments Organisation, Chandigarh 160030, India

ARTICLE INFO

Article history:
Received 4 July 2013
Received in revised form 24 October 2013
Accepted 26 October 2013
Available online 6 November 2013

Keywords:
Fiber Bragg Grating (FBG)
Cantilever beam
Temperature compensation
Accelerometer

ABSTRACT

This paper focuses on Fiber Bragg Grating (FBG) based accelerometer design. The accelerometer structure consists of inertial mass supported by an L-shaped modified cantilever beam having non-uniform cross section area connected to base by a thin neck element which acts as strain concentrated centre hence an optimum zone for FBG sensors placement. It has a working bandwidth below the structure's natural frequency and responds linearly to vibrations. The parameters for the structure design have been optimised on *SolidWorks 2012* platform. Experimental trials yield sensitivity of 46 pm/g for frequency below 50 Hz and 306 pm/g for frequency above 150 Hz. A mathematical model for the accelerometer structure's natural frequency modes is also presented with detailed analysis for different combinations of inertial mass-frame assembly.

1. Introduction

Accelerometers are the prime devices for vibration and shock monitoring in civil engineering structures such as bridges, dams and buildings against damages caused by earthquakes, collisions, explosions, and fatigue, or due to heavy traffic or strong winds. This calls for the need to identify structural damage and to monitor its evolution by development of structural health monitoring (SHM) techniques, which are useful tools for applications in civil engineering infrastructures and aeronautical platforms [1,2]. Conventional electronic sensors used for vibration measurements are piezo-electric, piezo-resistive or capacitive based [3–5]. The response of these sensors is typically processed by a signal amplifier and converted to a voltage change for detection and acquisition. Limitations arise due to their intrinsic susceptibility to electromagnetic interference (EMI) and lack of multiplexing capability that result in undesired noisy signals and high labour cost when implementing large scale sensor networks. An FBG based accelerometer offers several advantages over its electronic counterpart such as immunity to EMI radiation, high sensitivity, multiplexing and distributed sensing capability [6–9]. Several techniques on FBG based accelerometer have been reported, which include embedded type, beam plates based and cantilever based designs [10–14]. Sensitivity of ~100 pm/g has been reported for a frequency range up to 110 Hz for a typical L-shaped uniform cantilever beam accelerometer [12]. Sensitivity of 200 pm/g was reported using a vertical taut fiber grating for a particular arrangement with 0.5 kg inert mass, making the sensor bulky adding negativity to its design [18].Of the various types of FBG based accelerometer designs, it is the cantilever shaped beam that gives highest sensitivity and can be tailored to suit the bandwidth and sensitivity requirements for various applications [12–14].

FBGs are intrinsic fiber elements in photosensitive fibers where index of refraction in the fiber core is periodically modulated by illuminating with UV light (Fig. 1) [15,16]. Since the phase difference between adjacent reflections is dependent on the wavelength; this implies that the overall reflection from such a medium would be strongly wavelength dependent, according to the Bragg condition [17] as given in Eq. (1).

$$\lambda_B = 2n_{eff}\Lambda \tag{1}$$

Here Λ is the pitch of the grating, n_{eff} is the effective refractive index of the core and λ_B is the Bragg wavelength. When light from a broadband source is launched in FBG, the Bragg wavelength λ_B defined by the above equation is missing from the transmitted spectrum. This Bragg wavelength undergoes a shift if the effective refractive index or the grating periodicity gets changed due to some external perturbation [17]. The general sensing scheme of FBG based accelerometer is shown in Fig. 2.

In this paper a modified cantilever beam based FBG sensor accelerometer is theoretically modelled and designed for desired range of frequency of operation. A necked shaped leaf spring

* Corresponding author at: Centre for VLSI Design and Embedded Systems (CVEST), International Institute of Information Technology, Gachibowli, Hyderabad 500032, Andhra Pradesh, India. Tel.: +91 4066531301; mobile: +91 9652379040.
E-mail address: mansoorkhan2020@gmail.com (Mohd.M. Khan).

0924-4247/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.sna.2013.10.027

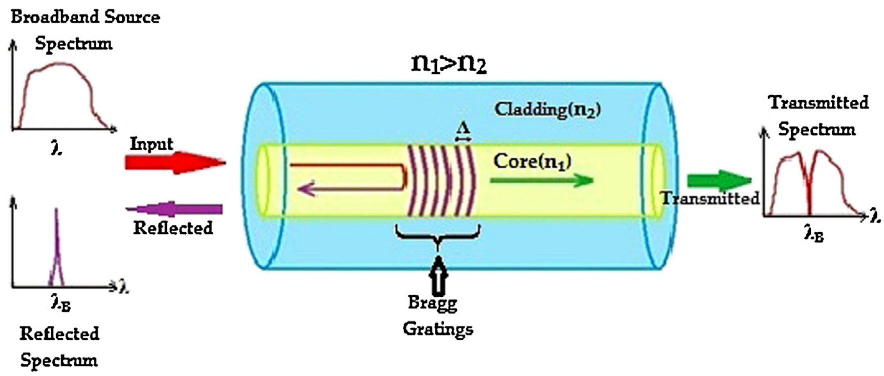

Fig. 1. Schematic of FBG and its spectral response.

Fig. 2. Sensing scheme of FBG based accelerometer.

integrated with inertial mass is numerically simulated using Finite Element Method on *SolidWorks 2012* platform to achieve enhanced strain sensitivity. After parametric optimisation, the desired prototype is developed for experimental trials to establish the FBG based accelerometer performance. The obtained design uses temperature compensation mechanism by attaching two FBGs of the same batch in the opposite direction, hence cancelling out the temperature effects.

2. Theory

An accelerometer is a device that detects accelerations (vibrations) on certain objects. For an FBG based accelerometer, it is necessary that load variations impose strain changes on FBG thereby resulting in wavelength shifts in the reflected spectrum of light [19,20]. By interpreting the changes in the reflected light the actual acceleration levels can be found [9]. In this paper, a cantilever beam with non-uniform cross section area which increases linearly along its length, shown in Fig. 3, is considered to measure vibrations uniaxially. The design offers several advantages like maximum in-axis sensitivity due to minimum in-axis inertia (sectional modulus) and minimum cross axis sensitivity due to maximum cross axis inertia (sectional modulus). Moreover, it provides easy and safe placement of FBG written optical fibers which otherwise have a strong tendency to break if placed on sharp edges.

2.1. Theoretical estimation of natural frequency of operation

The beam considered in Fig. 3(a) is modelled as an Euler–Bernoulli beam i.e. a beam subjected to pure bending. The partial differential equation of vibration for the Euler–Bernoulli beam has the form described by Eq. (2) [21],

$$\frac{\partial^2 y}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left(\frac{EI(x)\partial^2 y}{\rho A(x)\partial x^2}\right) \tag{2}$$

where, $I(x)$ is the area moment of inertia of cross section of beam along its neutral axis as a function of x, $A(x)$ is the Area of cross section of beam along its neutral axis as a function of x, E is the Young's Modulus of beam's material, ρ is the density of beam's material, 2 h is the end cross-section height of cantilever, l is the length of cantilever and b is the cross-sectional breadth of cantilever.

If X is a modal function expressing the mode of vibration as a function of x, then the deflection of cantilever beam y can be described as

$$y = X\cos\,(\omega t) \tag{3}$$

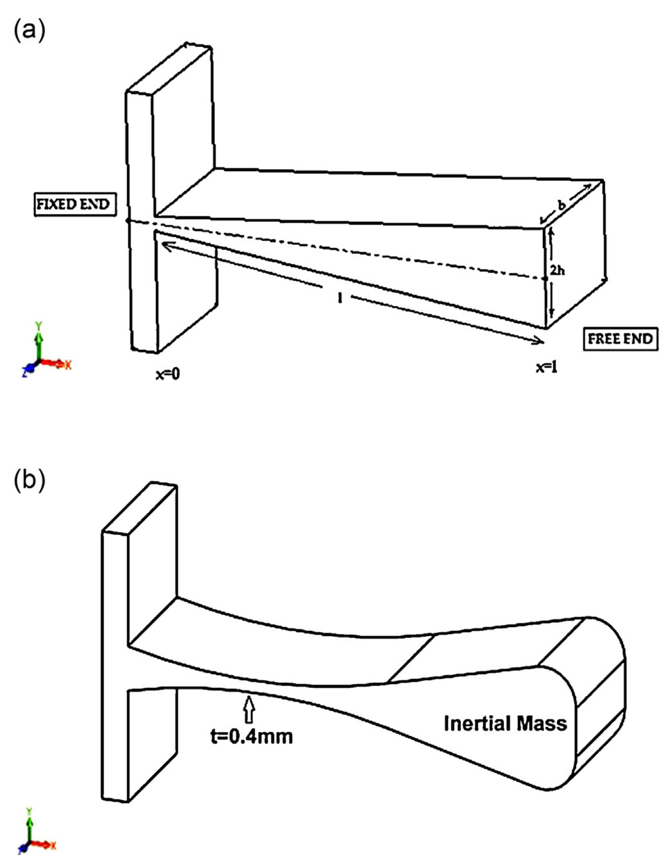

Fig. 3. (a) Cantilever beam with increasing cross section area (b) Modified cantilever beam.