Fiber Bragg Grating based two-dimensional Accelerometer

SharathUmesh[1], Resmi Ravi Kumar[2], Shweta Pant[3], Sundarrajan Asokan[4]
Dept of Inst and Applied Physics[1, 3], Dept of Optoelectronics and Com[2], Robert Bosch Centre for Cyber Physical Systems[4]
Indian Institute of Science[1,3,4], Sarabhai Institute of Science and Technology[2]
Bangalore 560012[1,3,4], Kerala, India

***Abstract*—Fiber Bragg Grating (FBG) sensors have become one of the most widely used sensors in the recent times for a variety of applications in the fields of aerospace, civil, automotive, etc. It has been recently realized that FBG based accelerometer's performance meets and/or exceeds that of traditional sensors. The present work is about the development of a novel, real-time, dynamic two dimensional Accelerometer employing FBG sensors. The proposed FBG Accelerometer works on the principle of inertial mass acceleration which in turn produces strain variations on the adjoining cantilevers, obtained using the FBG sensors bonded over it. The proposed device facilitates compact size and low fabricating cost along with the inherent advantages of FBG sensor, making it an effective device for measuring acceleration.**

Keywords-Fiber Bragg Gratings, fiber optic sensor, 2-D Accelerometer

I. INTRODUCTION

Accelerometers are principal devices employed for vibration and shock monitoring in civil engineering structures such as bridges, buildings, dams etc against damages caused by collisions, earthquakes, explosions, fatigue, heavy traffic or strong winds [1]. Accelerometers have also proved their worth in Aerospace, Automobiles, Defense and Medical sectors. Usually, accelerometers are pendulum based devices, working as a spring-mass system, where the inertial mass is attached to the accelerometer base by an elastic spring. The movement of the base, caused by an external stimulus, imposes a movement of the mass relatively to the base, which is proportional to the effect of external stimulus [2]. In the traditional accelerometers, the inertial mass movements are measured by piezoelectric, piezo resistive or capacitive elements. The response of these sensors are typically processed by a signal amplifier and converted into voltage change for detection and acquisition of the measurand. However, these devices, when applied on a large scale, need a huge number of wires and will be affected by electromagnetic interferences, constraining the methodology to be employed.

Fiber Bragg Grating (FBG) based Accelerometers are a growing field of research as they possess several advantages over the conventional electrical accelerometers such as immunity to EMI radiation, high sensitivity, multiplexing and distributed sensing capability [3-7]. FBG based accelerometers[8] are technologically evolving, making them suitable for a variety of vibration measurements including structural health monitoring of civil structures and seismic wave detection [9].The purpose of the present study is to develop atwo dimensional accelerometer based on FBG sensors, with the data acquired in the form of dynamic strain variation, which is an indicator of the acceleration. The direction of movement of the mass evaluates the direction of acceleration. The use of FBG sensors brings potential advantages such as compact dimensions, low fatigue and ultra-fast response, making the proposed FBG accelerometer an effective means for recording acceleration.

II. PRINCIPLE OF FBG TECHNOLOGY

Fiber Bragg Gratings (FBGs) are intrinsic sensing elements which are produced by inscribing a refractive index modulation along the core of a photosensitive fiber [10- 11]. When a broad band light is launched into a fiber with FBG sensor, one particular wavelength (λ_B), which satisfies the following Bragg condition (1), is reflected and other wavelengths are transmitted through the fiber. The wavelength of light reflected from the grating structure is given by

$$\lambda_B = 2n_{eff}\Lambda \quad (1)$$

Here, n_{eff} is the effective refractive index of the fiber and Λ is the periodicity of the grating fabricated.

III. MATERIALS AND METHODS

A cubical mass made of aluminium material of dimensions 30mm×30mm×30mm (length × height × thickness) is employed as inertial mass. The cantilever beams of aluminium material with dimensions of 40mm×10mm×2mm whose one end is fixed to the inertial mass (on adjacent sides) and the other end is fixed onto a pillar beam of dimension 10mm×31mm×10mm. Two FBG sensors (FBG1 and FBG2) are bonded individually over these cantilevers as shown in Fig. 1, in order to obtain the strain variation over it. The pillars along with the mass-cantilever system are enclosed on the top and bottom by aluminium plates with dimension 80mm×80mm×3mm which constitutes to form the FBG accelerometer device as shown in Fig. 2. The working principle involves transduction of acceleration into strain variation on the adjacent cantilever beams which is obtained by the FBG sensors. Horizontal vibrations are transferred from the bottom plate of the FBG accelerometer to the pillars, allowing it to move in the direction of vibration. The inertial mass tends to remain in the state of rest when compared to the movement of the pillars, producing strain

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variations on the cantilever beams. Hence the relative movement of the bottom plate with respect to the inertial mass is in opposite direction when compared with the direction of acceleration motion. The strain on the adjacent cantilever beams acts as an indicator of the amplitude of acceleration. Furthermore, any vertical vibrations are negated by arresting the movement of the inertial mass in vertical direction, by the aluminium plates on either side.

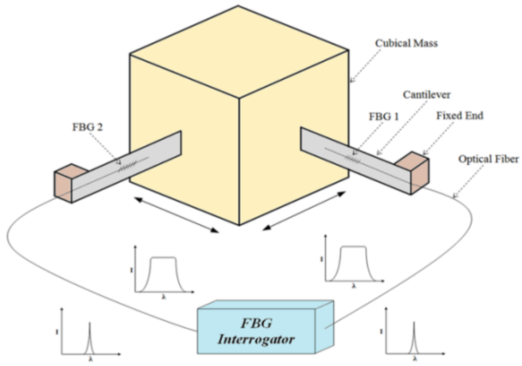

Figure 1. Schematic diagram of FBG based accelerometer.

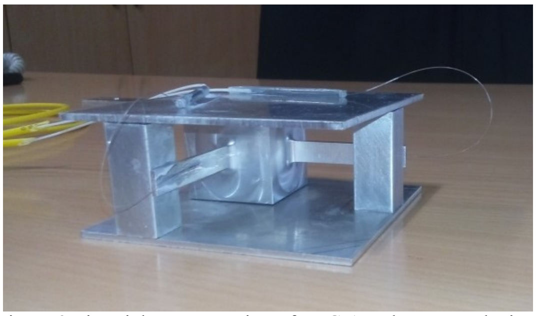
Figure 2.Pictorial representation of FBG Accelerometer device.


(a)


(b)

Figure 3. Experimental setup for vibration testing of FBG based accelerometer (a) Accelerometer placed on vibration table.
(b) Enlarged image of fixation of the accelerometer device to the vibrating plate.

IV. Experimental Methodology

The developed FBG accelerometer device is mounted on a vibration shake table (LDS by Brüel & Kjaer) as shown in Figure 3, capable of producing vibrations of frequency from 5 Hz to several hundred Hz. Sinusoidal excitations with the acceleration of 1 g and 2 g at frequencies 5 Hz and 10 Hz are applied, respectively. Consequentially, during the initiation of the vibrational motion, the inertial mass remains in the state of rest with respect to base plate motion, imposing strain variations on FBG which results in shift in Bragg wavelength. Further the sinusoidal vibrations on the base will be transferred to the inertial mass which in turn will start vibrating. This movement creates sinusoidal strain variations on the cantilevers. The peak-to-peak wavelength shift of two FBGs is monitored by using micron optics interrogator (MOI) system with a resolution of 1 pm and sampling frequency of 1000 Hz.

For each of the applied sinusoidal stimulus, the shift in Bragg wavelength is obtained and sensitivity in terms of wavelength shift per unit change in velocity is evaluated. All vibration testing experiments are performed at constant room temperature. For a sinusoidal motion, the magnitude of acceleration (A) can be calculated by using equation (2) where, f is the frequency of acceleration, D is the displacement and g is acceleration due to gravity (9.8 ms^{-1}) experienced by the specimen under sinusoidal motion.

$$A=2\pi^2f^2/Dg \qquad (2)$$

V. Results And Discussion

The designed FBG based two dimensional accelerometer device is able to measure both, the magnitude and direction of acceleration. Magnitude may be obtained from the shift in reflected Bragg wavelength whereas for direction of acceleration, the possible movement of accelerometer is divided into four quadrants as shown in Fig. 4. The two axes i.e. Axis 1 and Axis 2, of the device are equipped with two FBG sensors, FBG1 and FBG2 respectively over the corresponding cantilevers 1 and 2. The direction of acceleration is determined based on the type of initial strain (compressive or tensile) of the vibration, experienced on the two FBG bonded cantilevers as explained below through two trials. In Trial 1, the acceleration is put along the axis 1 and the response of the device is observed. Similar trial is carried out with axis 2, mentioned as trial 2. The individual response of the FBG sensors in the developed accelerometer is shown in Table 1.

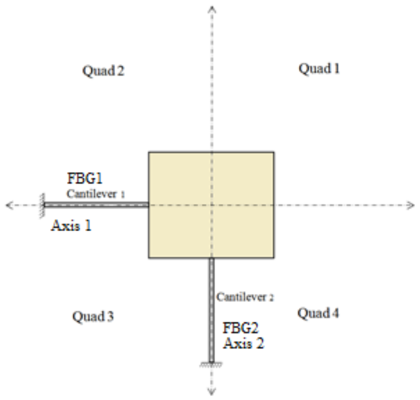

Figure 4. Top view of FBG based Accelerometer.

Initial Base Plate Movement	Inertial mass relative movement	FBG 1	FBG 2
Quad 1	Quad 3	Compression	Compression
Quad 2	Quad 4	Tension	Compression
Quad 3	Quad 1	Tension	Tension
Quad 4	Quad 2	Compression	Tension

Table 1. FBG sensors response for acceleration.

A. *Trial 1 (acceleration along axis 1)*

The motion of the base plate and its effect on FBG1 and FBG2 are shown when it is experiencing acceleration along axis 1, in either left or right orientation. Fig. 5 shows the responses of two sensors when acceleration occurs at 10 Hz frequency. If the force is exerted towards Quadrant 4, the base plate move towards the same side but mass tends to remain at rest which in turn makes the relative movement on the mass in the opposite direction (Quadrant 2) imposing strain changes on corresponding sensor. Hence, FBG 1 undergoes compression and FBG 2 undergoes tension simultaneously. Similarly, FBG 2 undergoes compression and FBG 1 undergoes tension simultaneously when acceleration force is towards Quadrant 2. It can be seen in figure that the response of FBG 2 is higher in amplitude than FBG1 due to bending effect on cantilever 2.

B. *Trial 2 (acceleration along axis 2)*

In this trial, acceleration is provided along axis 2 (upwards and downwards) and its effect on the FBG sensors is focused. When the acceleration acts towards Quadrant 1, movement of the base plate is towards the same direction and the inertial mass pushes the cantilever in the opposite direction (Quadrant 3) by which both FBG1 and FBG2 undergo compression simultaneously. If the force exerted is toward Quadrant 3, the base plate move towards the same direction but the inertial mass tends to be in rest which creates strain in opposite direction. Hence both the sensors undergo tension simultaneously. Also, the response of FBG 1 is observed to be higher in amplitude than FBG 2 due to the bending effect on cantilever 1, as shown in Fig. 6 (vibrations at 5 Hz).

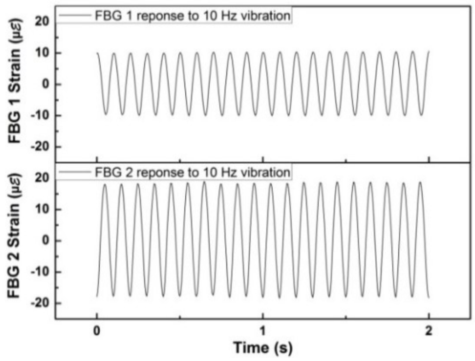

Figure 5. Response of the FBG accelerometer sensors to 10 Hz at 1g.

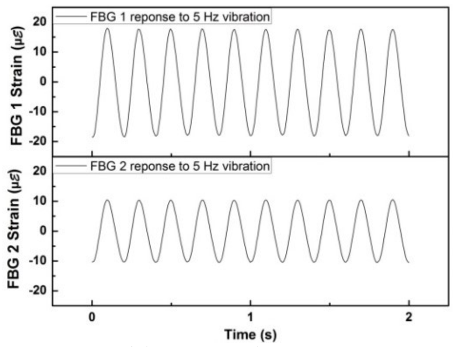

Figure 6. Response of the FBG accelerometer sensors to 5 Hz at 1g.

Sensitivity of a sensor is defined as the change in output of the sensor per unit change in the parameter being measured. For the developed accelerometer device, a strain variation of 38µƐ is observed individually on both the cantilever for a displacement of 19.85mm as observed from the Fig. 5 and 6. Hence, sensitivity of the device is evaluated to be 1.914µƐ/mm.

CONCLUSION

A novel, cantilever based, two dimensional accelerometer device employing FBG sensors has been designed and developed having a sensitivity of 1.914µƐ/mm. Moreover, the device has been validated through the vibration shake table and a good agreement in both, amplitude as well as frequency measurement is observed. This device can be employed in various fields for sensing low acceleration seismic signals and also in other civil engineering applications for high sensitivity vibration measurement. Along with the magnitude, the direction of the force can also be found from the responses of the sensors. Future considerations may include few optimizations such as thickness of cantilever can be reduced or the dimensions of inertial mass can be increased to maximize the sensitivity.

REFERENCES

[1] K. M. Mansoor, P. Nishtha and D. Ravi, "Modified cantilever beam shaped FBG based accelerometer with self-temperature compensation", Sensors and Actuators A, vol.205, pp.79– 85, 2014.

[2] A. Paulo, V. Humberto and P. Andre, "Uniaxial fiber Bragg grating accelerometer system with temperature and cross axis insensitivity", Measurement, vol.44, pp.55–59,2011.

[3] X. Zhang, Q. Rong, H. Sun , S. Yang, L. Yuan and M. Hu, "Low-frequency fiber Bragg grating accelerometer based on a double-semicircle cantilever", Optical Fiber Technology,vol.20,pp.190–193,2014.

[4] Q.Liu, X. Qiao, Z. Jia, H. Fu, H. Gao, and D. Yu,"Large Frequency Range and High Sensitivity Fiber Bragg Grating Accelerometer Based on Double Diaphragms", IEEE SENSORS JOURNAL, vol.14, no. 5, May 2014.

[5] N. Basumallick, P. Biswas, K. DasguptaandS. Bandyopadhyay,"Design optimization of fiber Bragg grating accelerometer for maximum sensitivity", Optical Fiber Technology,vol.194,pp.31–39,2013.

[6] K. Ni, C.CChan, X. Dong andL. Li,"Temperature-independent accelerometer using a fiber Bragg grating incorporating a biconical taper", Optical Fiber Technology,vol.19, pp.410–413,2013.

[7] A. Stefani, S. Andresen, W. Yuan, N. Herholdt-Rasmussen, and O. Bang, "High Sensitivity Polymer Optical Fiber-Bragg-Grating-Based Accelerometer", IEEE PHOTONICS TECHNOLOGY LETTERS, vol.24, no. 9, May 1,2012.

[8] N. Basumallick, I.Chatterjee, P. Biswas, K. DasguptaandS. Bandyopadhyay, "Fiber Bragg grating accelerometer with enhanced sensitivity", Sensors and ActuatorsA,vol.173(1),pp.108– 115,2012.

[9] J. Wu,V. MasekandM. Cada, "The Possible Use of Fiber Bragg Grating based Accelerometers for Seismic Measurements", IEEE,2009.

[10] K. O. Hill and G. Meltz, "Fiber Bragg Grating Technology Fundamentals and Overview", J. Lightwave Technol., vol. 15, pp. 1263–1276, 1997.

[11] G. Meltz, W. W. Morey, and W. H. Glam, "Formation of Bragg Grating in Optical Fibers by a Transverse Holographic Method", Opt. Lett., vol. 14, pp. 823–825, 1989.