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Constrained Restoring Force FBG-based Accelerometer

[1]Suneetha Sebastian , [1]Sai Prathyusha Malla, [2]Sreejith A, [1]S Asokan
[1]*Department of Instrumentation and Applied Physics, Indian Institute of Science, Bangalore-12, India*
[2] *International School of Photonics, Cochin University of Science and Technology, Cochin-22, India*
e-mail address: sasokan@iisc.ac.in

Abstract: We propose a FBG-based accelerometer design which comprises of a spring mass system resting on a diaphragm. Theoretical sensitivity of 68.88 pm/g was obtained which matches the simulated sensitivity of 67.31 pm/g.
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1. Introduction

FBG based accelerometer finds applications in fields which are prone to electromagnetic interference due to its immunity to the same. The constrained restoring force model consists of a spring and diaphragm with one end of the fiber fixed on a spring and the other is fixed at the case. The mass is made to oscillate in the vertical directions with the help of a thin diaphragm. The spring can also be replaced by a metal bellow.

In this case, the spring-mass system acts as a transducer and converts the applied acceleration to strain in the FBG sensor. Depending on the location of the FBG, it either gets compressed or elongated leading to a negative or a positive change in refractive index. The fiber is pre-tensioned to prevent the chirping of the fiber grating.

In this work, theoretical equations for determining the sensitivity of the model have been derived. Also, an attempt has been made to simulate the results using COMSOL Multiphysics software. This model is first of its kind and is expected to reduce cross-sensitivity due to the diaphragm attached to the mass.

2. Theory

The restoring force (F) for a small displacement ($\triangle x$) is given by

$$F = -K_b \triangle x = -K\epsilon L \text{ (by Hooke's Law)} \tag{1}$$

where K is the spring constant, ϵ is the strain and L is the initial length of the spring. Due to acceleration being applied on the vertical direction, the mass will press into the diaphragm causing a deflection ω_F. The restoring force sets the mass to rise to its normal position. The deflection it causes will be given by ω_r. By using elastic theory [1-3], we have:

$$\omega_F = \frac{A_S R^2}{16\pi D} F_0 \text{ and } \omega_r = \frac{A_S R^2}{16\pi D} F \tag{2}$$

where F_0= ma and F are the accelerated inertia mass force and the elastic reaction force respectively, D is the bending rigidity, R radius of the diaphragm and A_s numerical coefficient. As the net deflection will result in a strain in the fiber, we have:

$$\epsilon = \frac{A_S R^2 m}{L(16\pi D + A_S R^2 K_b)} a \tag{3}$$

So the sensitivity coefficient S of the model is written as,

$$S = \frac{\triangle\lambda_B}{a} = (1 - P_e)\lambda_B \frac{A_S R^2 m}{L(16\pi D + A_S R^2 K_b)} \tag{4}$$

where $\triangle \lambda_B$ is the bandwidth of the reflective spectrum and K_b is a constant. For a spring of spring constant 890.625 N/m and a copper diaphragm of thickness 0.5 mm, we get sensitivity S = 68.88 pm/g.

3. Simulations

COMSOL Multiphysics has been used to simulate the model (fig.1). The modules primarily used are the Solid Mechanics module and the Electromagnetic waves, Frequency Domain (ewfd) module. FBG has modelled using the ewfd module and the strain has been coupled to the refractive index using the Solid Mechanics module. After application of the proper constraints and running a stationary and boundary mode analysis on the optical fiber, the effective modal index n_i and the principal strain can be obtained.

We know that from bragg condition,

$$\lambda_B = 2n_i\Lambda_i \tag{5}$$

where n_i is the effective modal index and Λ_i is the grating pitch.

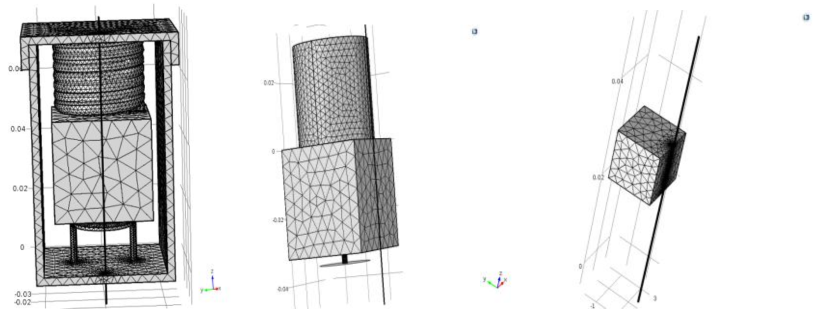

Fig 1: Simulation of the model in COMSOL Multiphysics

When fiber is strained on application of a non-zero acceleration, this strain results in a shift in the Bragg wavelength. Let it be denoted by λ_B'. Thus, we have

$$\lambda_B' = 2n_i'(\Lambda_i + \Delta\Lambda); \vartriangle \Lambda = \Lambda_i \epsilon_i \tag{6}$$

where n_i' is the refractive index with stress optic effect and ε_i represents the principal strain that can be obtained from the COMSOL model.

Then the change in wavelength is given by

$$\vartriangle \lambda_B = \lambda_B' - \lambda_B \tag{7}$$

This change in wavelength can be plotted against the corresponding acceleration values and the slope of this graph gives the sensitivity of the model. Following the above procedure to simulate the model the change in wavelength for various accelerations has been calculated.

Under fixed constraints, the simulations have been finished for accelerations ranging from 1g to 10g in steps of 1g. The change in wavelength is calculated using equations 5-7 and plotted against their corresponding accelerations (Fig 2). From the graph (Fig. 2), it is noted that the system shows a linear response and its sensitivity (from the slope) is 67.31 pm/g which matches with theoretically calculated sensitivity.

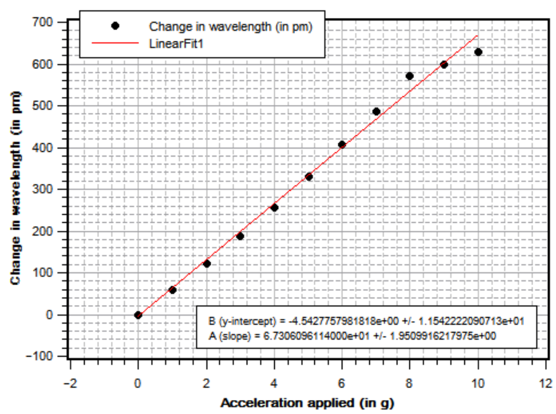

Fig 2: Change in wavelength plotted against the applied acceleration simulated in COMSOL Multiphysics

4. Conclusion

In this work, a theoretical model has been developed for the constrained restoring force based FBG accelerometer. By using COMSOL Multiphysics software, the model has been simulated. Theoretical value of the sensitivity and the sensitivity value obtained from simulations seems to be in close correlation. The model will provide reduced cross sensitivity due to the diaphragm attached to the model. Reduced cross sensitivity provided by the model will be further verified through experiment in the near future.

5. References

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