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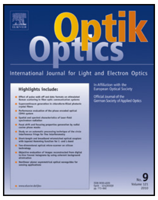

A novel fiber Bragg grating acceleration sensor for measurement of vibration

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ABSTRACT

A novel fiber Bragg grating (FBG) acceleration sensor for measurement of vibration is proposed. The sensor is fabricated by embedding a FBG into an aluminum cylinder, in which the optical wave propagated is coupled with the strain wave when the vibration is applied on the aluminum cylinder. The wavelength shifts of the FBG are proportional to the vibration acceleration. Employing FBG interrogation system, the wavelength shifts are converted into the change of optical power to achieve vibration measurement. Experiments indicate that the FBG acceleration sensor provides a flat frequency response from 800 Hz to 5000 Hz and sensitivity of 5.3 mV/g at 3000 Hz. The linear characteristic is good and the coefficient of determination is better than 0.996. In addition, the accuracy of the sensing system and the effect of temperature are investigated.

1. Introduction

Compared with conventional sensors, FBG based sensor offers important advantages such as EMI immunity, high sensitivity and multiplexing capabilities [1], so it has been used widely in many fields [2–4]. With the development of engineering vibration testing technology, the FBG sensors enjoy great popularity in industrial and civil engineering applications [5,6]. Vibration acceleration measurement is a common method for vibration monitoring. The cantilever structure is generally applied in FBG acceleration sensors due to the simple structure and stable performance [7–11], different sensing characteristic can be obtained through the variation of the cantilever's shape or size. Despite that, its frequency band is narrow due to the restriction of resonance frequency; at the same time, its bulk confines its application in many fields. To solve this problem, researchers proposed other structures and carried out extensive studies in widening bandwidth [12,13], increasing sensitivity [14–16], eliminating the influence of temperature [17,18], multiplexing technology [19], etc.

Based on the principle of the optical wave coupled with strain wave [20], an FBG acceleration sensor with a novel structure is proposed in this paper. Compared with the previous FBG acceleration sensor, the sensor proposed in this paper has many advantages such as wide frequency band, small size, simple structure, etc. The experiments indicate that the FBG acceleration sensor provides a flat frequency response from 800 Hz to 5000 Hz and sensitivity of 5.3 mV/g at 3000 Hz.

This paper demonstrates the structure and operation principle of the FBG acceleration sensor, and conducts a series of experiments to investigate the amplitude-frequency response, measurement accuracy, linear characteristic and temperature characteristic.

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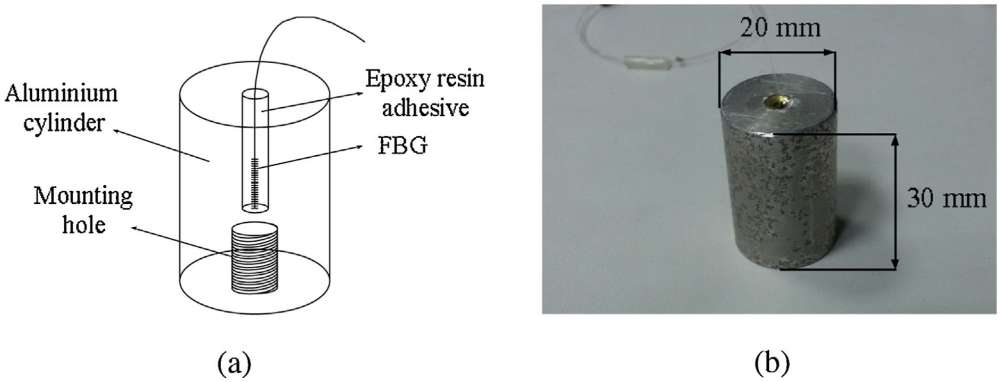

Fig. 1. (a) Structure diagram and (b) image of the FBG acceleration sensor.

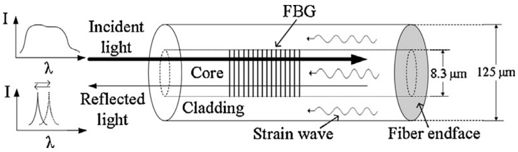

Fig. 2. Schematic diagram of working principle of the FBG acceleration sensor.

2. Sensor fabrication and principle

FBG acceleration sensor taken into consideration in this work consists of a standard FBG written in single mode fiber coated by aluminum cylinder with the cylinder diameter of 20 mm and the height of 30 mm. To fix the FBG in the aluminum cylinder, epoxy resin adhesive is filled between the FBG and aluminum cylinder. At the bottom of the aluminum cylinder, a mounting hole is set to fix the sensor on the object to be measured. Fig. 1 shows the structure diagram and image of the FBG acceleration sensor.

When the bottom of the aluminum cylinder is excited by vibration acceleration, an external force is applied onto the bottom. A mechanical deformation is produced according to the elastic properties of the aluminum, which generates a strain wave propagating along the fiber axis, as is shown in Fig. 2. When the strain wave acts on the FBG, it couples with the optical wave propagated in it, causing the changes of FBG's optical parameter, which further causes Bragg wavelength shifts proportional to the amplitude of the strain wave. Employing FBG interrogation system, the shifts of Bragg wavelength are converted into the changes of optical power, which reflect the vibration acceleration. Based on the above principle, only the vibration acceleration or its component, whose direction is consistent with the FBG axis, can be detected.

When vibration acts on the bottom of the sensor, the normal stress applied on the bottom of the cylinder can be expressed as:

$$\sigma_c = F/S \tag{1}$$

where F is the force applied on the bottom of the cylinder, its direction is vertical to the axis direction of the sensor, and S is the area of the bottom. The axis strain of the cylinder is as follows:

$$\varepsilon_c = \sigma_c/E_c = \frac{F/S}{E_c} \tag{2}$$

where E_c is the elastic modulus of the cylinder. Replacing F in Eq. (2) with the expression $F = ma$, ε_c can be expressed by:

$$\varepsilon_c = \frac{m/S}{E_c} \cdot a \tag{3}$$

where m is the mass of the sensor and a is the vibration acceleration. From Eq. (3) we can see that the axis strain of cylinder is proportional to the vibration acceleration.

The axis strain in the cylinder is transferred to the FBG through the shear strain [21]. The relationship between the strain of FBG and the cylinder is given by [22]

$$\varepsilon_f(z) = \varepsilon_c \left[1 - \frac{\cosh(kz)}{\cosh(kL)}\right] \tag{4}$$

where ε_f represents the strain in the FBG which is transferred from the cylinder, L is the length of the fiber embedded in the cylinder, k is a constant related to the diameter, elasticity modulus of the fiber, epoxy resin adhesive and cylinder, z stands