A high performance compact vibration sensor based on fiber Bragg grating

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A high-performance compact vibration sensor based on fiber Bragg grating (FBG) is designed. The acceleration sensitivity of the FBG vibration sensor is measured to be larger than 30 pm/g. From 10 Hz to 250 Hz, a quite flat frequency-response curve can be obtained with additional damping, which suppresses the resonance peak effectively. A phase-generated carrier (PGC) demodulation technique realized by compact reconfigurable input and output (RIO) system is applied in our sensing system.

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A lot of advantages like anti-electromagnetic interference, adaptability to harsh environment and high-capacity, long-term data retention owing to all-optical signal acquisition and transmission make Fiber vibration sensor superior to traditional electromagnetic ones. Compared to intensity-type[1,2] vibration sensor and interferometric-type[3–6] vibration sensor, fiber Bragg grating (FBG) vibration sensor has some advantages, such as small size, light weight, high accuracy, and large dynamic range. Especially, the wavelength demodulation technology provides us independence of general optical path loss and large multiplexing capacity. As a result, FBG vibration sensor has attracted extensive attention from military and industry fields[7–12]. In this paper, we design a vibration sensor based on FBG, and its high performance is investigated employing a compact reconfigurable input and output (RIO) system.

The basic theory of measuring acceleration is that the reflection or transmission wavelength of FBG is dependent on the grating period and the effective index, which can change with outside vibration. The FBG is carefully glued to compose a forced vibration system together with the oscillator as illustrated in Fig. 1. The system frequency response can be obtained by means of kinetic equation of the system[13]:

$$\left|\bar{H}\right| = \frac{1}{\omega_0^2\sqrt{\left(1-q^2\right)^2 + 4\xi^2 q^2}}, \tag{1}$$

$$\xi = \frac{\delta}{\omega_0}, q = \frac{\omega}{\omega_0}, \tag{2}$$

where ω is angular frequency of acceleration, ω_0 is natural frequency of the system, ξ is damping ratio, and δ is relative damping factor determined by the material damping factor and the weight of the oscillator.

Hence, the mechanical parameters of the system are optimized to make that the system has a relatively higher natural frequency, and a wider frequency response range. The structure is installed and protected in a shell, which is sealed and filled with silicone oil to introduce additional damping. When q is large enough, the strain produced on FBG can be written as

$$\varepsilon = \frac{a_0 a}{bl\omega_0^2}, \tag{3}$$

where a_0 is acceleration amplitude. Apparently, the larger strain produced on the FBG, the higher acceleration sensitivity can be obtained. In our design, a FBG with reflection peak wavelength of 1546.9 nm and linewidth of about 0.1 nm. The FBG is pre-stretched to produce 0.1 nm wavelength shift during curing procedure. Red copper is employed for oscillator and duralumin for other parts of our sensor head. In addition, the viscosity of silicone oil is about 500 cs. This sensor head has dimension of only 70 × 40 × 15 mm³.

The scheme of FBG vibration sensing system is illustrated in Fig.2. A standard accelerometer is used to quantize the acceleration of the vibration platform where the FBG senor head is mounted. The commercial

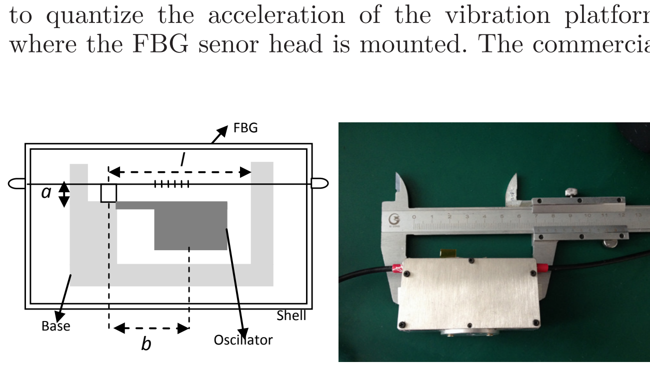

Fig. 1. Design of FBG sensor head.

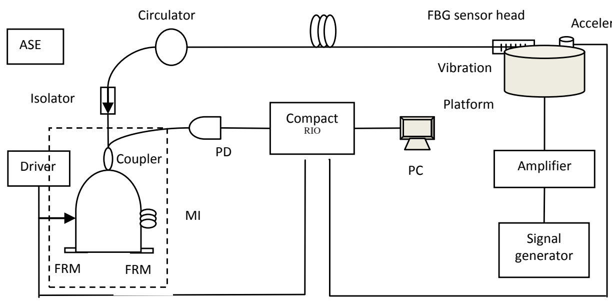

Fig. 2. The scheme of FBG vibration sensing system.

piezoelectric accelerometer (model: LC0109) has a sensitivity of 100 mV/g, and measuring range of 50 g. The reflection spectrum of the FBG is changed according to the vibration signal. The narrow bandwidth of only 0.1 nm of the FBG enables us to obtain high sensitivity. Then, an unbalanced Michelson interferometer with optical path difference of 5 mm will convert the shift of the frequency or wavelength into the shift of phase. A phase generated carrier algorithm[14] is used for demodulation, which introduces a large phase shift outside the signal band to detect small phase shifts and eliminate fading caused by large environmental drifts. Here, we apply compact RIO by National Instruments to realize real-time phase-generated carrier (PGC) demodulation for FBG sensing[15].

The accelertion signal frequency is tuned from 10 Hz to 250 Hz. From the frequency spectrum (Fig. 3), we can see the ground noise is about 0.001 pm/$\sqrt{\text{Hz}}$, which is dependent on the system electrical noise as well as ambient noise. The acceleration sensitivity of the same FBG vibration sensor head without and with silicone oil is measured. It is about 35 pm/g and 30 pm/g without and with additional damping separately. Hence, the equivalent noise acceleration is calculated to be about 33 μg/$\sqrt{\text{Hz}}$. The frequency response of FBG vibration sensor is obtained and drawn in Fig. 4. As we can see, the curve of sensor without damping has an obvious resonance peak at around 130 Hz. Filling oil increases the damping parameter and can suppress the resonance effectively. However, it brings in little sacrifice of sensitivity.

A high-performance compact vibration sensor based on fiber Bragg grating is reported. The acceleration and frequency response are tested and compared without and with silicone oil inside the sensor head. Using PGC demodulation technique realized by compact RIO system, the acceleration sensitivity of the FBG vibration sensor is measured to be larger than 30 pm/g, and the testing results illustrate that the damping can help suppress the resonance peak effectively. The frequency response curve with damping is quite flat in the range of 10 Hz to 250 Hz.

Fig. 3. Time-domain and frequency-domain signal test.

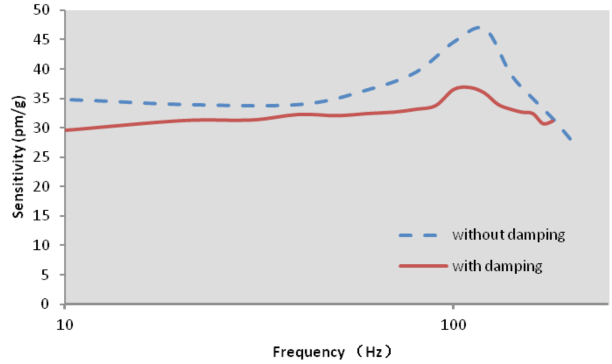

Fig. 4. Frequency response of FBG vibration sensor.

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