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Reliable high sensitivity FBG geophone for low frequency seismic acquisition

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ABSTRACT

A fiber Bragg grating (FBG) based geophone is designed for low-frequency signal detection. It has high acceleration response of about 60 dB re pm/g in a low frequency range of 5–60 Hz. However, the basic sensing principle of stretching FBG requires much more delicate and reliable packaging design and technology. Especially the high sensitivity at low frequency challenges the reliability in packaging, transportation and installation of sensor. To guarantee normal operation in field test and practical application, an acceleration amplitude restriction is added in the mechanical design of the FBG geophone. Then a series of environmental and reliability tests have been proceeded with online or offline monitoring of its working performance, including high & low temperature test, vibration test, shock test and tensile test, strictly according to National standard and Oil & Gas Industry Standard. The experimental results indicate that our FBG geophone meet the criterion of oil and gas industry product and is capable of field application. Finally, in the filed blasting tests, the seismic cross-section profile was obtained by use of FBG geophone array which shows the advantage in low frequency signal acquisition compared to conventional move-coil geophone.

1. Introduction

Low frequency seismic waves have weaker attenuation and scattering, and higher energy during equivalent depth propagation compared to high frequency seismic waves, which is relatively intact with increasing depth of target exploration stratum [1]. In geophysical exploration, seismic low frequency signal detecting is crucial to learn the earth's interior structure, thereby enhancing the capability of deep exploration and geological disaster forecast [2–3].

Fiber Bragg grating (FBG) based geophone has attracted much attention for potential application in micro-seismic monitoring in petroleum exploration, physical oceanography and perimeter security [4–6]. Compared to interferometric fiber-wound geophone, the FBG geophone has small size, high multiplexing capability and high resolution [7–9].

The lab of photonics gas/oil logging and detecting of Xi'an Shiyou University has done many research on fiber grating acceleration vibration sensor, including cantilever beam structure [10] and drum-type [11]. A FBG acceleration sensors based on flexure hinge structure was reported with a frequency response range from 10 Hz to 240 Hz [12]. A flextensional fiber Bragg grating-based accelerometer for low frequency vibration measurement was reported to have a broad and flat response over low frequencies ranging from 1 to 10 Hz, and a high sensitivity of 410.7 pm/g [13].Theoretical and experimental results show that the structure of accelerometer is stable by using L-shaped rigid beam, which has good performances in detection of low-frequency vibration signals with flat response from 20 Hz to 70 Hz and the sensitivity of about 220 pm/g [14].

The FBG sensors reported are mostly concentrated on theory, design and experiment in lab. However, the practical or engineering application requires much more delicate and reliable packaging design and technology, considering that the basic sensing principle of FBG based accelerometer is transferring vibration into central wavelength drift by stretching FBG. Especially the high sensitivity at low frequency challenges the reliability in packaging, transportation and installation of sensor in engineering application. The FBG based vibration sensor was designed with restrict of vibration amplitude within 90 μm to realize shock resistance [15].

In this paper the FBG geophone we design for low-frequency signal detection has high acceleration response of about 60 dB re pm/g in a low frequency range of 5–60 Hz. To guarantee normal operation in field

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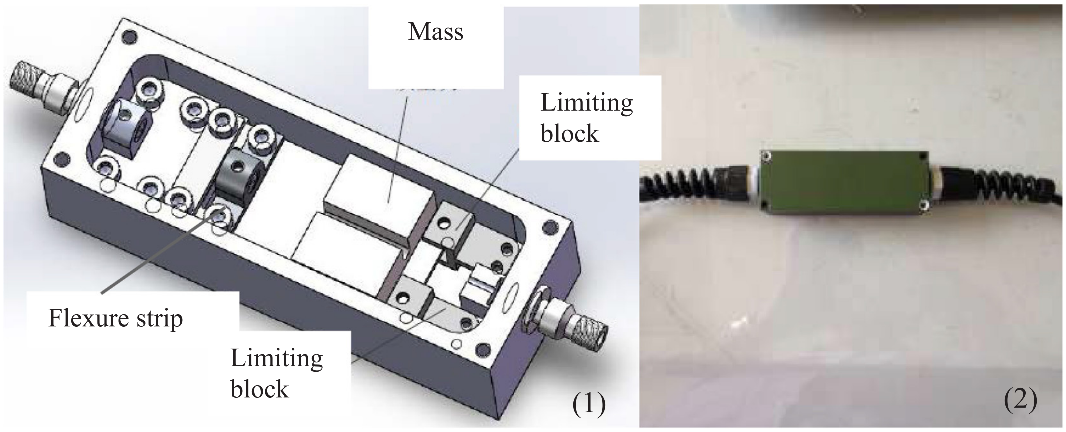

Fig. 1. (1) 3D assembly drawing and (2) photograph of FBG based geophone.

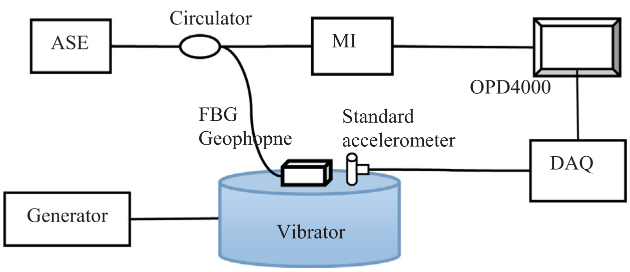

Fig. 2. Schematic diagram of the test system.

test and practical application, a series of environmental and reliability tests are carried out for FBG geophone, referring to China Standards of Petroleum and Natural Gas Industry, including temperature test, vibration test, shock test and tensile test. The FBG geophone array with good consistency had been used in field test and obtain seismic profiling successfully.

2. Design of FBG geophone

The FBG based geophone applies cantilever beam structure to transfer vibration acceleration into axial strain of FBG, as shown in Fig. 1. The acceleration response of FBG geophone is depended on the stiffness of the flexure strip and the quality of the mass. The acceleration sensitivity S of single element of FBG geophone equals the ratio of wavelength change $\Delta\lambda$ to acceleration a, which is proportional to the quality of the mass m and inversely proportional to of the elasticity K of the spring strip, as described in Eq. (1) where h is the transfer function of the mass and the fiber. The resonant frequency f_0 is contrary to

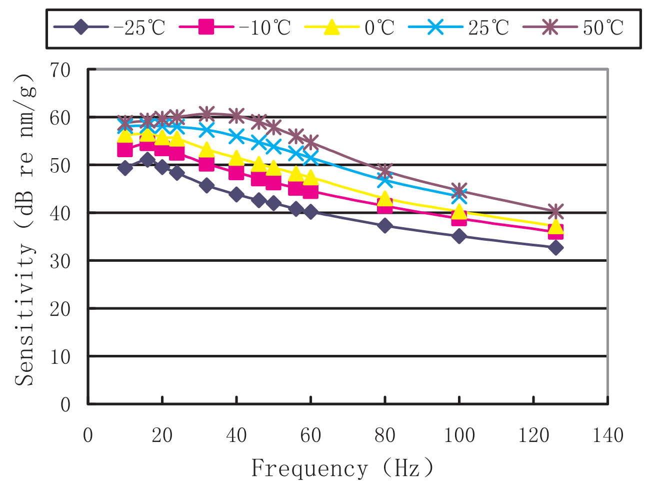

Fig. 4. Frequency response of FBG geophone under different temperature.

sensitivity derived from Eq. (2) [15]. According to cantilever beam theory [16–17], the sensitivity is restricted to the response bandwidth. To realize high sensitivity at low frequency, the FBG based geophone is designed to be about 60 dB at 5–60 Hz. the resonant frequency is designed to be around 55 Hz.

$$S = \frac{\Delta\lambda}{a} \propto h\frac{m}{K} \quad (1)$$

$$f_0 = \sqrt{K/m} \quad (2)$$

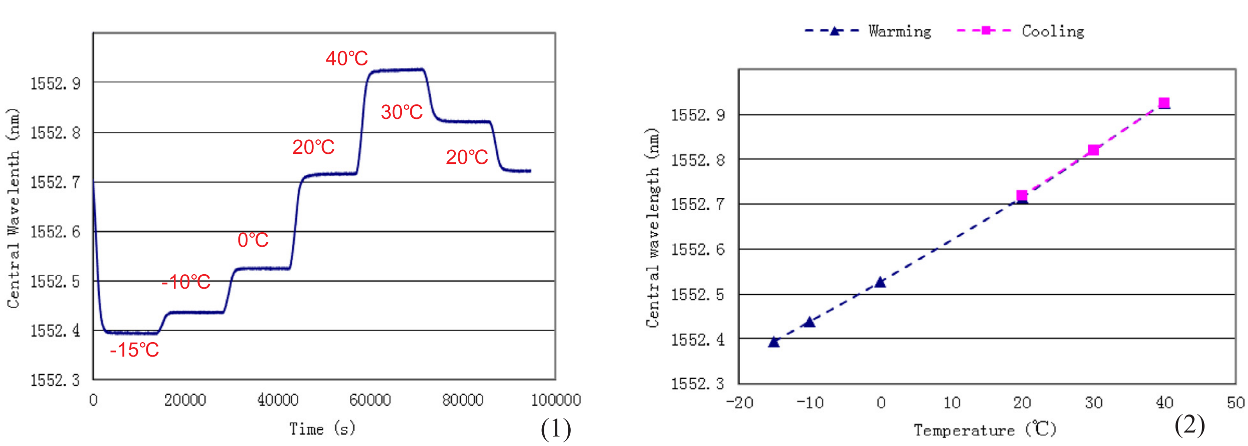

Fig. 3. (1) Monitoring of reflected central wavelength every 30 s of FBG geophone; (2) analysis of the temperature parameter of FBG geophone.