Field test of a 16 channel high sensitivity FBG geophone array

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Abstract. In this paper we report the development and field test of a 16 channel high sensitivity fiber Bragg grating (FBG) geophone array for oil and gas exploration application. A high sensitivity FBG geophone is designed, and its sensitivity is about 1000pm/g. The wavelength change of the FBG geophone is interrogated by using interferometric demodulation method, and the demodulation system noise is below 10⁻³pm/√Hz. And the minimum detectable seismic signal is below 1μg/√Hz. We are presenting field test results for the FBG geophone and comparing its performance with regular exploration geophones. In comparison, FBG geophone has the advantages of higher signal-to-noise ratio and better low-frequency response. This work shows that using FBG technology to develop geophone for oil and gas exploration is both advantageous and feasible.

1. Introduction

In recent years, fiber optic geophones have attracted considerable research interest. This is due to their advantages of low noise floor, high sensitivity, large dynamic range, immunity to electromagnetic interference, extreme robustness and reliability, and high temperature performance [1-6]. Their applications in oil and gas exploration, structural health monitoring, intrusion detection are attracting more and more interest.

In this paper we report the development and field test of a very high sensitivity 16 channel FBG geophone array for oil and gas exploration application.

The paper is arranged as follows. Section 2 describes the principle and performance of FBG geophone array. Section 3 describes the field test and results analysis. Then the conclusion and acknowledgments is given.

2. Principle and performance of FBG geophone array

Principle of FBG geophone sensing is illustrated in Fig. 1. The mass is mounted at the end of the L type cantilever beam as the inertia sensing component. The fiber grating is pre-stretched over the cantilever beam. When the FBG geophone sense the seismic signal, the mass moves relative to the
housing, the FBG is stretched or shrunk, resulting in the strain change and then the reflection wavelength of the FBG is changed. The wavelength shift \( \Delta \lambda \) is proportion to the strain change \( \Delta \varepsilon \),

\[
\frac{\Delta \lambda}{\lambda} = 0.78 \cdot \Delta \varepsilon
\]  

where \( \lambda \) is the FBG wavelength, the factor 0.78 accounts for stress-optic coefficient. The photo of two packaged FBG geophone is illustrated in Fig 2.

The output of the FBG geophone is injected into an unbalanced Michelson interferometer (MI). Then the wavelength shift \( \Delta \lambda \) of FBG is converted into phase shift, the interferometer phase shift \( \Delta \phi \) is given by

\[
\Delta \phi = \frac{4\pi n L}{\lambda^2} \Delta \lambda
\]  

where \( L \) is the fiber path imbalance in the MI (\( L = 5 \) mm), \( n \) is the effective refractive index of the interferometer fiber. To eliminate the signal-fading caused by the initial phase shifts of the MI, a 5kHz sinusoidal voltage signal is applied to the piezoelectric tube (PZT) cylinder in one arm of the MI, then the phase modulation carrier is generated.

Dense wavelength division de-multiplexer (DWDM) is used to split off the MI output signals. The outputs of the DWDM are received by InGaAs PIN photodiode detection circuits. The analog outputs of the circuits are sampled by multi-channel A/D converter with 24bit resolution and 50kSPS. At the same time, the 5 kHz PGC carrier signal generated by D/A converter is also sampled. The digital PGC demodulation algorithm is adopted to recover the signals \( \Delta \phi(t) \).
The frequency response of the FBG geophone is tested and the result is shown in Fig. 5. The sensitivity of the FBG geophone is about 1000 pm/g. The system noise level of FBG geophone in the frequency range from 3 Hz to 500 Hz is shown in Fig. 6. It can be observed that the system noise level is about $10^{-3}$ pm/√Hz (60dB re pm).

$$\text{NEA} = \frac{\phi(f)}{S_a(f)}$$

where $\phi(f)$ is the noise floor of the FBG geophone system, $S_a(f)$ is sensitivity of FBG geophone. The acceleration sensitivity is 1000 pm/g and the noise floor is $10^{-3}$ pm/√Hz @ 40 Hz. According to Eq. (3), the noise equivalent acceleration is 1 μg/√Hz @ 40 Hz.

3. Field test and analysis

The field test was performed to detect seismic signals in Shengli oilfield. In the field test, 16 FBG geophones are installed on the ground together with the piezoelectric geophone geophones, as shown in Fig. 7. The 16 FBG geophones are wavelength multiplexed and the space between them is 12.5 m. Seismic signals are stimulated by explosions in a 40 m deep well. The received signals of the two types of geophones are recorded by seismic signal acquisition instrument and FBG geophone system separately. The received signals of FBG geophones are converted into SEG-D format to compare.

Figure 5. Frequency response of a FBG geophone.

Figure 6. The noise level of system.

Figure 7. Photos of field test in Shengli oilfield: Piezoelectric (blue) and FBG (green) geophones.

Figure 8. The received signals of 16 Piezoelectric (left) and FBG (right) geophones.
Figure 9. Seismic profile of Piezoelectric geophones.

The results show that the FBG geophones have higher signal-to-noise ratio and better low-frequency response than piezoelectric geophone, as shown in Fig.8. The reflections of FBG geophones are better and more continuous.

In order to analyze the data acquisition reliability of two geophones, multi shot point data superposition is adopted, and the ability of describing underground targets is analyzed. As can be seen from the seismic profile contrast in Fig.9 and 10, target layers of FBG geophones are clearer. And the signal to noise ratio of FBG geophone is better than piezoelectric geophone.

4. Conclusion

In this paper we report the field test results of a 16 channel FBG geophone array in Shengli oilfield, China. The performance of FBG geophones are tested both in laboratory and the field test. Comparison of seismic signals received by the two geophones is given. In comparison, FBG geophone has the advantages of higher signal-to-noise ratio and better low-frequency response. This work shows that using FBG technology to develop geophone for oil and gas exploration is both advantageous and feasible.

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