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Abstract. The possibility of detection of weak seismic waves in sea-ground interface by fiber-optic interferometric seismometer is experimentally demonstrated. High sensitivity of the seismometer to acceleration 10^{-7} m/s^2 is provided by application of original multiturn fiber-optical sensing element. Long term stability of the seismometer operation is provided by feed-back control of the interferometer working point.

Introduction

Detection of weak seismic waves in sea-ground interface is important but challenging task which solution can bring a practical benefit to investigation of a sea shelf. Seismometers which are commonly used for seismic detection in fact measure a displacement of mass caused by seismic wave. In its turn optical interferometry has always been considered as one of the most sensitive techniques for measuring mechanical displacements [1]. The sensitivity of classical homodyne interferometer is limited by shot noise of the photoelectrons in a photodetector and can be extremely high: the theoretical minimal detectable displacement is 1.1×10^{-16} m/Hz$^{1/2}$ for 10 mW of detected laser power at the wavelength of 500 nm [2]. Use of optical fiber in interferometers can provide development of compact and immune to EMI seismometer with low intrinsic noises. Moreover sensitivity of fiber-optic (FO) sensors can be additionally increased if multiturn sensing elements are used. As a result a combination of high interferometric sensitivity with long optical path length can provide a measurement of displacements with resolution up to 10^{-13} m in a wide frequency band. It opens opportunities for detection of weak seismic waves in sea-ground interface by fiber-optic interferometric seismometer.

Experiment

In our work the fiber-optic accelerometer on the basis of a Mach-Zehnder Interferometer was used as the seismometer. Among existing interferometers the Mach-Zehnder Interferometer (MZI) has one of the simplest schemes and can be easily used as a base for fiber-optic sensors.

The scheme of fiber-optic seismometer is shown in Fig. 1. Its base is a fiber-optic Mach-Zehnder interferometer. CW optical radiation from a laser (1) with power 1 mW is coupled by means of fiber-optic Y-splitter (3) into two single-mode optical fibers which work as signal and reference arms of the interferometer. Afterward the signal and reference waves are combined at the second Y-splitter (7). The result of an interference is registered by photodetector (8).

In order to maintain the interferometer output signal in the quadrature we used an approach based on active phase control. Here, the optical fiber in the interferometer reference arm is coiled to a piezoelectric cylinder (4) operated as a phase modulator (PM). PM is driven by feed-back voltage which, in its turn, is determined by DC level of the interferometer output signal. The latest is directly related to the interferometer working point position. So the working point drift being occurred is compensated by additional phase shift produced by PM.

When the interferometer is in quadrature, its output signal U_0(V) is linearly proportional to acceleration amplitude a_0 (m/s^2). For the particular scheme of the seismometer represented in Fig.1 the sensitivity to acceleration has reached the level 10^{-7} m/s^2. Such high sensitivity was provided by using a multiturn sensing element in the interferometer's signal arm [3, 4].

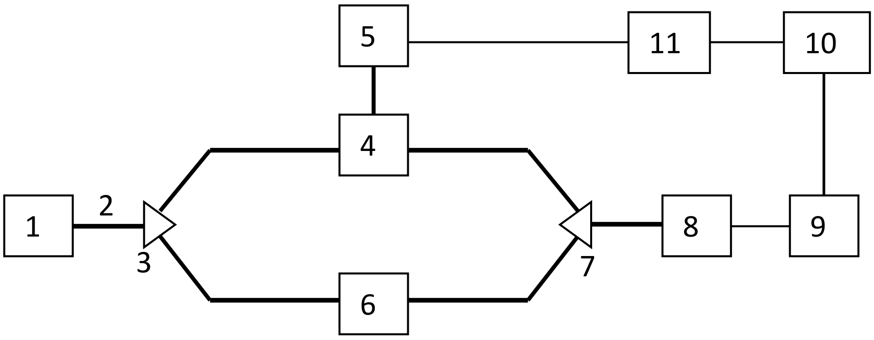

Figure 1. Scheme of the seismometer on the basis of a fiber-optic Mach-Zehnder interferometer. 1 – DFB-laser; 2 – optical fiber; 3, 7 – fiber-optic Y-splitters; 4 – phase modulator; 5 – amplifier; 6 – multiturn sensing element; 8 – photodetector; 9 – ADC; 10 – personal computer; 11 – DAC.

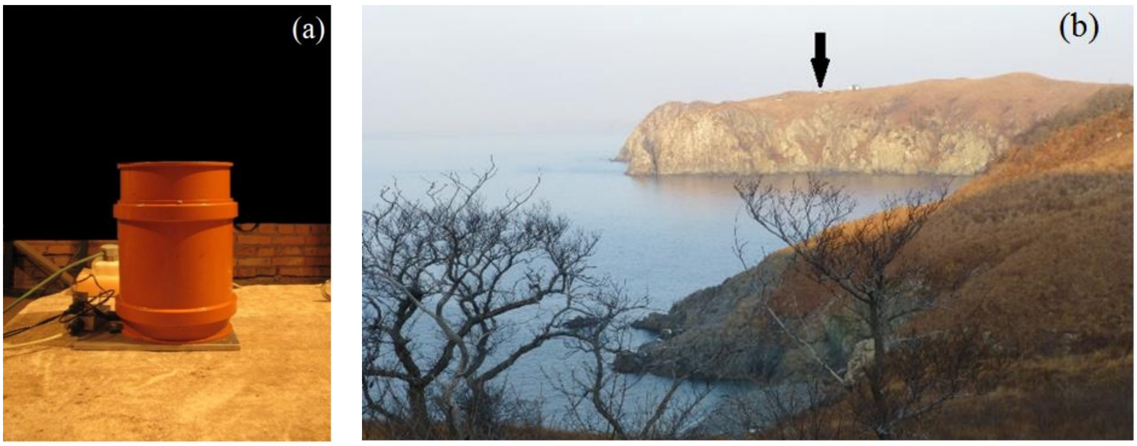

Figure 2. The fiber-optic interferometric seismometer (a) and place of its installation on a shore rock – shown by arrow (b)

For the experimental testing, the described fiber-optic seismometer was installed in sea-ground interface, in particular on the rock at 75 m above sea level (Fig.2). The seismometer was mounted at concrete base in a wind-proof room at a depth of 2 m.

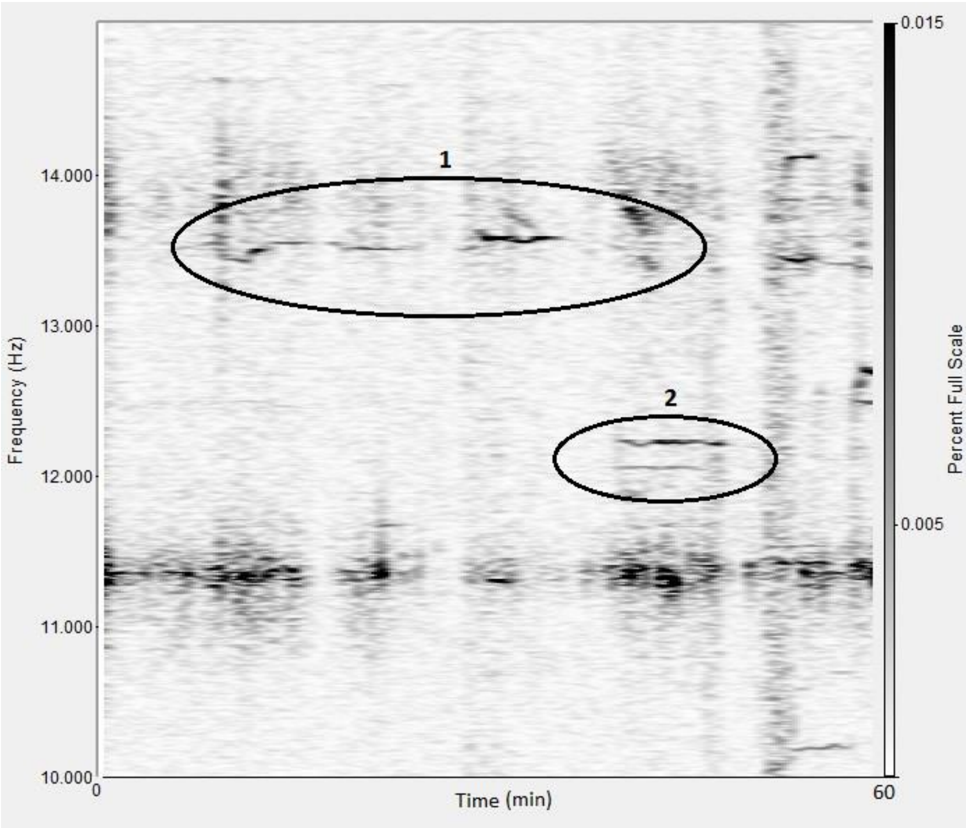

Figure 3. Part of time evolution of Fourier spectrum of the seismic signals produced by heavy-tonnage vessel (1) and small-size high-speed boat (2).

During the measurements (1 hour) two types of the marine vessels – heavy-tonnage vessel (HTV) and the small-size high-speed boat (HSB) – were running at the distance between 3 and 8 km apart from the rock. Fig.3 shows the time evolution of Fourier spectrum of the seismic signals detected by the seismometer. As seen there are noticeable signals which correspond to serial passing of both vessels: HTV – from 5 to 45 min, and HSB – from 35 to 52 min.

Thus, in this work we have experimentally demonstrated possibility of detection of weak seismic waves coming through the sea-ground interface by fiber-optic interferometric seismometer mounted at shore rock.

Acknowledgments
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References

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