A NEW VERTICAL SEISMOMETER BASED ON THE MOIRE TECHNIQUE

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ABSTRACT

This paper describes a new optical seismic sensor for geophysical applications. Following the work done Institute Advance studies in Basic sciences in Zanjan, we have built a new vertical short period seismometer based on the Moiré technique. This seismometer consisting of a spring-suspended mass whose position is monitored using the moiré technique. A pair of gratings in relative displacement, magnifies the amplitude of the displacement of the oscillator inside the seismometer. The intensity of a light beam passing through the moving moiré fringes changes with time, and a detector converts these power fluctuations to a voltage signal. This voltage signal gives the time-series of the ground motion. We derive the theoretical response of the moiré readout system. The natural frequency of our sensor is 8 Hz and the damping factor is 0.65. Also, a 12 bit A/D device is used to digit the analog responses of optical seismometer. We compare the actual response of the moiré seismometer and a conventional seismometer (6TD Guralp, 0.1 Hz). Comparisons with conventional seismometers show that, in terms of both noise and signal fidelity, the optical approach is quite viable. Also, our sensor has some additional advantages.

INTRODUCTION

Seismometers are instruments that record ground vibration during the propagation of elastic waves in the earth. These sensors are based on damped oscillation of an inertial-pendulum system. The pendulum is an inertial proof mass attached to a spring. The frame of the sensor is fixed to the ground. During ground shaking, the movement of the mass is delayed relative to the movement of the frame. A damping mechanism restores the mass to its equilibrium position after a small transient perturbation. In most seismic sensors, the readout system consists of a moving coil-transducer that converts the motion of the mass to voltage signal. These electromagnetic systems have some disadvantages, for example they are susceptible to environmental EM noise. So, scientists have been looking at using optical methods. Optical approaches have some advantages respect to the other techniques that are higher signal to noise ratio, sensitivity, and precision, and etc. Recently, scientists used Michelson interferometry as a readout system in seismometery.

In this work, we introduce a novel optical seismic sensor that is based on the moiré technique. The moiré technique has found many applications in the measurement of very small displacements light beam deflections. Moiré pattern is defined as a series of dark and bright patterns formed by the superposition of two regular gratings. Our design is based on a mass-spring system and moiré readout system. We have attached two gratings to the mass and the frame of the instrument. The mass motion amplitude is amplified by the moving moiré patterns. In comparison with conventional sensors, our optical technique is free of EM noise, and the power of the output signal is easier to calibrate.

MOIRÉ TECHNIQUE

Moiré technique is based on the interference obtained when two transparent plates such as tow gratings are covered with equally period. If one of the plates is held over one another, they can be aligned so that no light will pass through or so that all light will pass through. Now, if one of the plates is placed over the other, and their lines have a small angel together, appear a new periodic structure that called moiré pattern (Fig. 1). The period of moiré pattern dm is larger than the period of gratings d. When one of the gratings moves d in perpendicular direction of grating's lines, it makes moiré pattern moves dm (Eq. 1). Therefore the use of moiré technique magnifies the small displacements.

$$d_m = \frac{d}{2\sin(\theta/2)}. \tag{1}$$

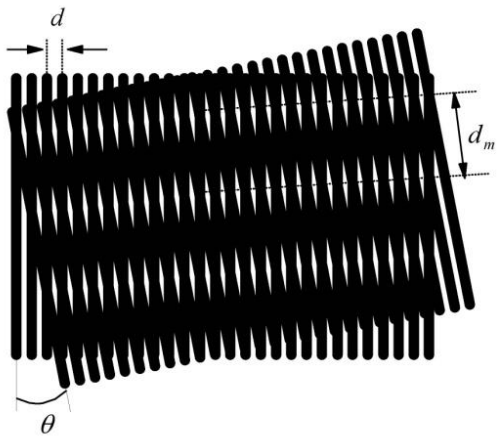

Figure 1. Moiré pattern obtained by superposition two grating with equal period that their lines have a small angel (θ).

Moiré readout system can measure amplitudes in the micron scale. In comparison with some techniques such as electromagnetic readout systems, our optical technique is free of EM noise, and the power of the output signal is easier to calibrate.

INSTRUMENT DESIGN

To make our seismometer, we have been used a mass-spring system as an oscillator and moiré system to monitor the suspended-mass motions. The schematic diagram of our sensor is shown in figure 2. We used the springs of a commercial geophone (SE-10) to build our oscillation system that has a natural frequency of 8 *Hz*. Also, to make moiré pattern we use a pair of similar gratings (20 line per millimeter) that one of them is fixed to the suspended mass and another one is fixed to the seismometer frame. The gratings are installed near together without any physical contact, which the planes of the gratings are parallel together and the lines of gratings have small angle (less than 6^o) respect together. Due to a typical impulse, the gratings displace respect to each other, and as a result the moiré fringes are moved with a magnification of more than ten times. To detect and record of fringes movements or finally seismic pulses we used a diode laser (1 mW) was placed in front of one of the gratings, and a light-detector faced the laser source from the opposite side. Also, a narrow vertical slit was placed in front of the detector to narrow the light beam. The diode, the detector, and the slit were all fixed to the instrument frame. The diode laser beam passes through the moiré pattern then the narrow slit and finally detect by the light sensor.

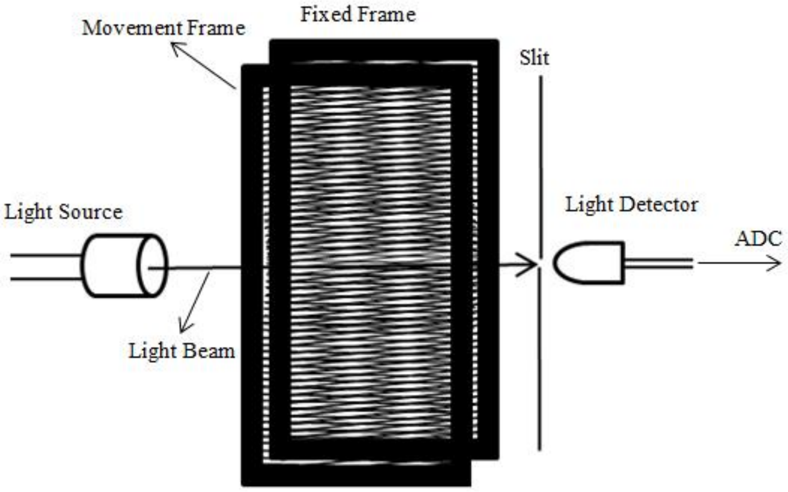

Figure 2. The schematic diagram of optical seismometer.

Due to a seismic pulse received by our sensor, the moiré fringes pass through the laser light and the intensity of the light on detector varies as a result. The detector records these variations as a time series. The output of the light detector is electric voltage, with amplitude proportional to the amplitude of ground motion. As we know, the damping in seismometer is very important to detect seismic pulses. Our damping system is based on viscose oil. The damping factor is 0.72. Also, a 12 bit ADC device is used to digit the analog responses of optical seismometer. Figure 3 shows our instrument.

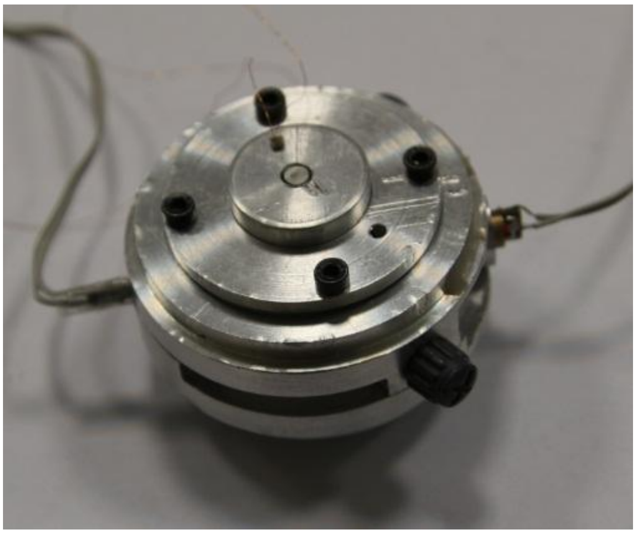

Figure 3. The optical seismometer based on the moiré technique.

EXPERIMENTAL RESULTS

We carried out some experiments to investigate the performance of our optical seismometer. We subjected our seismometer (8 Hz) and a calibrated commercial seismometer (model: CMG- 6TD, 0.1 Hz, produced by Guralp company) to identical impulses and comparison their responses. İn this procedure, both seismometers were exposed to many impulses and these experiments carried out in a non-isolated environment to having environmental vibrations, too. In this case, we were able to study the response of our sensor in real conditions. We used a 12 bit ADC with a sampling frequency of 100 *Hz*. So, the sampling rate for both is similar. Figure 4 shows the both response of optical and 6TD seismometer to some identical impulses in a real and similar condition. As we can see, our sensor response has a good agreement with 6TD response.

Also, it is observed that, the first motions in optical sensor traces are clearer than those in 6TD output and beside this, the signal to noise ratio in optical seismometer responses is more than conventional seismometer which is very important in seismometery. These results well illustrated in figure 5. The damping constant of our seismometer is 0.72 that is a bit larger than 6TD (*h*=0.68), so that we can see in both time series. Also, the power spectrum for both sensors responses has been investigated. Figure 6 shows the power spectrum of identical traces of sensors. It is visible that, the sensitivity of our sensor in higher and mid frequency is more and in lower frequency less than 6TD. Also, figure 7 shows the noise response of both optical and conventional seismometer that we can see the well response of our sensor to seismic noise and pulses.

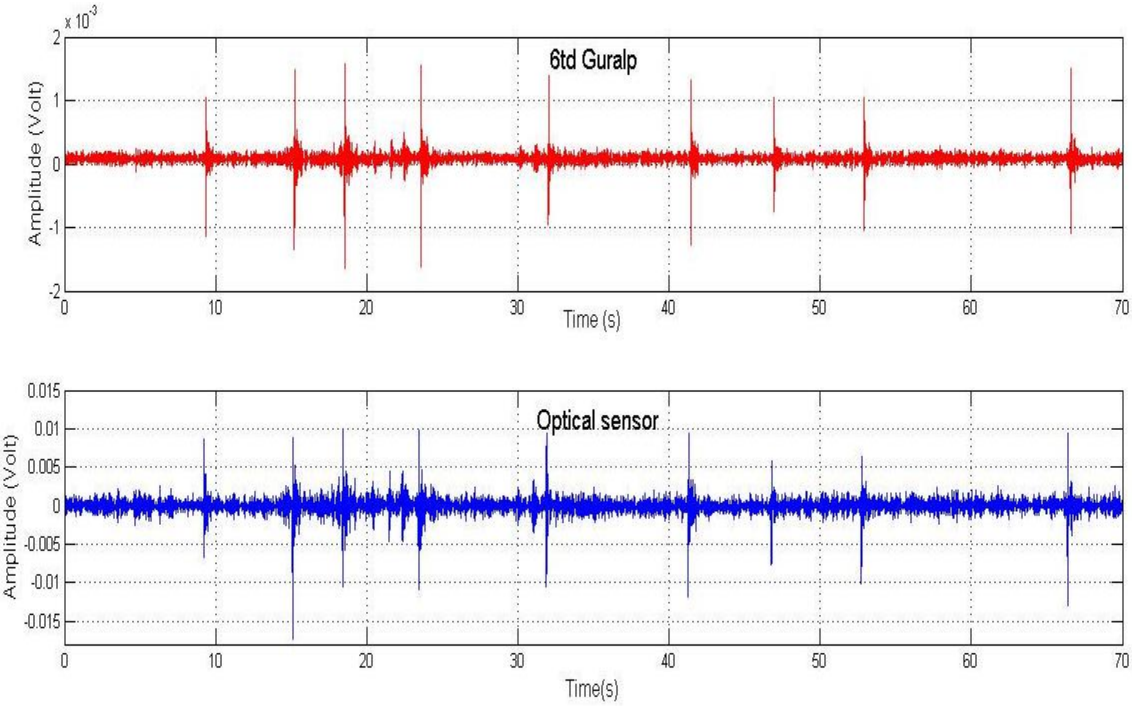

Figure 4. The output of optical seismometer (8 Hz) and 6TD Guralp (0.1 Hz) in similar conditions.

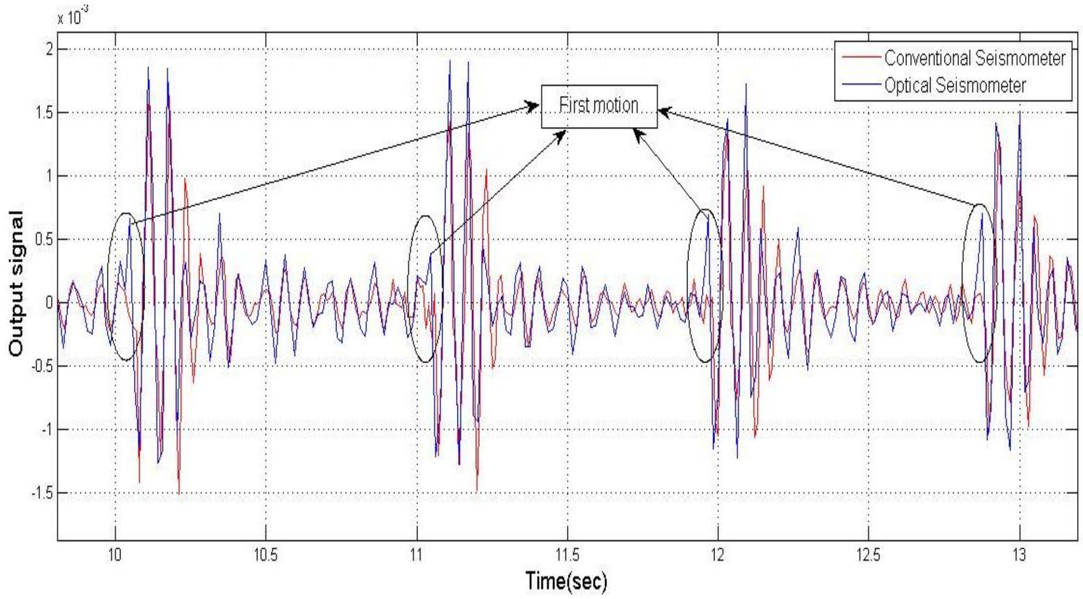

Figure 5. The conventional and optical seismometer output signals which are superimposed. The first motions in optical seismometer output are clearer in comparison with the 6TD output. The first motions of both outputs are shown by ellipses.

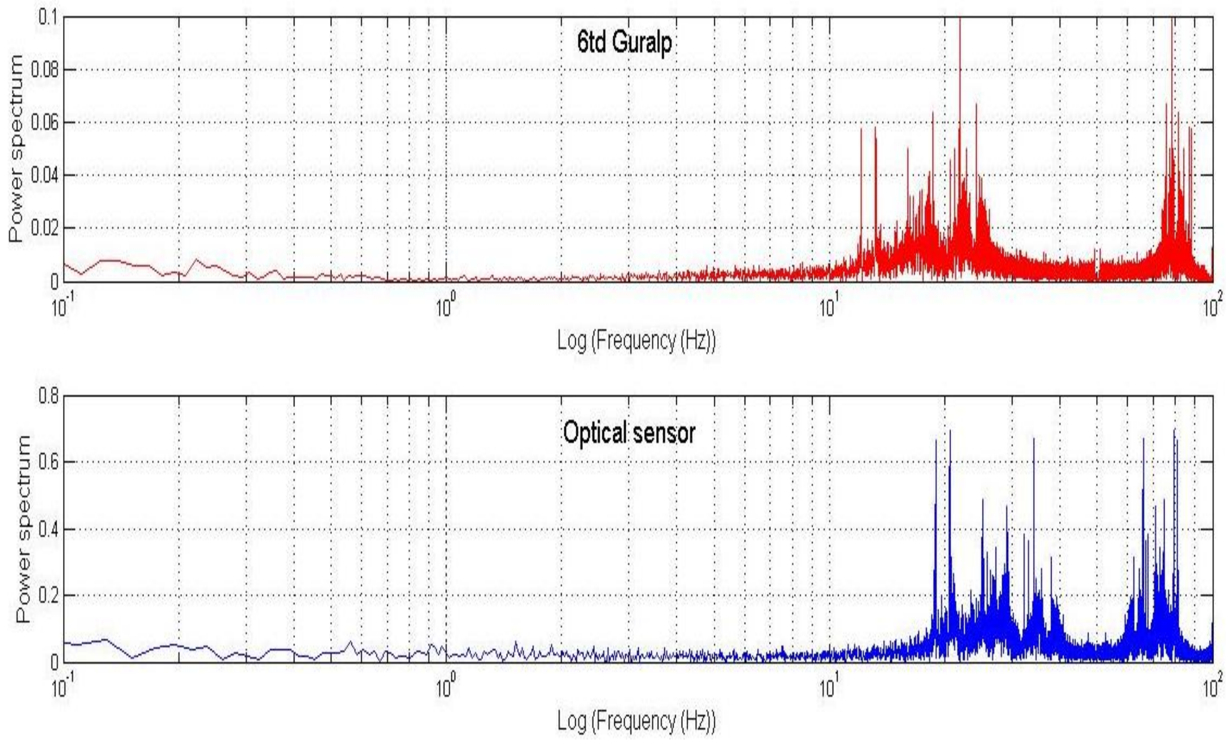

Figure 6. The power spectrum of optical and 6TD seismometers

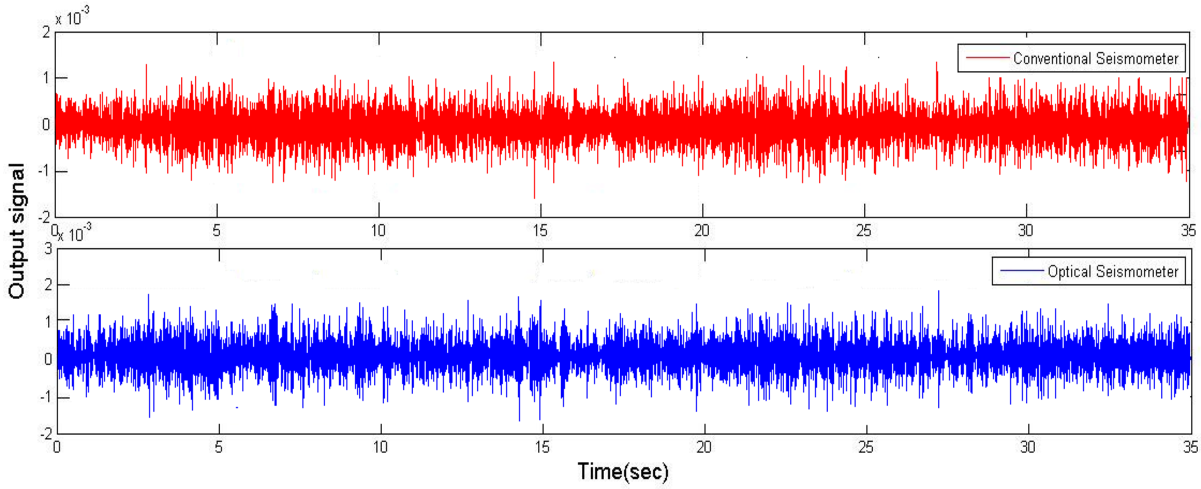

Figure 7. Noise response of optical and 6TD seismometers

CONCLUSIONS

In this paper we have described a new optical seismic sensor based on the moiré technique developed for geophysical applications. Adding an optical element to a vertical seismometer allowed us to monitor its mass position with high resolution. This sensor is a short period seismometer with natural frequency of 8 Hz. Preliminary tests, performed on our seismometer and a conventional seismometer, are reported and discussed in this paper. The results show the good performance of our seismic sensor. Furthermore, our sensor has some advantages. Its output is largely free of EM noise. Also, it is easier to install, and insensitive to environmental conditions such as temperature fluctuations. In our sensor, we can vary the sensitivity by varying the gratings period, and the angle between the rulings of the gratings. Also we can amplify the output signal of sensor by enhancing the power of light source and enhancing the proportion of signal to noise ratio. Research is continuing in the development of this optical seismometer to other types of seismometers in resonance frequency.

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