A novel three-component optical seismometer based on the moiré technique

Anooshiravan Ansari, Shamseddin Esmaeili

International Institution of Earthquake Engineering and Seismology, Tehran, Iran

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Abstract

We have built a new three components optical seismometer. The oscillation systems consist of a spring-suspended mass which its position is monitored by moiré technique. A pair of similar gratings have been used that one of them is fixed to the suspended mass and another is fixed to the seismometer frame. The gratings are installed close to each other with no physical contact, with the planes of the gratings parallel to each other and their lines making a small angle with one another to form the moiré pattern. A narrow beam of a laser diode passes through the moiré patterns and the beam power is detected by a light detector. Due to a typical impulse, the second grating is displaced with respect to the first grating, and as a result the moiré fringes are moved with a magnification of more than ten times. So, the detector output is a time series of the mass displacements. The response of the optical seismometer was validated through comparison of recorded waveforms with those obtained by Guralp CMG-6TD seismometer. Comparisons show that, in terms of both noise and signal fidelity, the optical approach is quite reliable.

Introduction

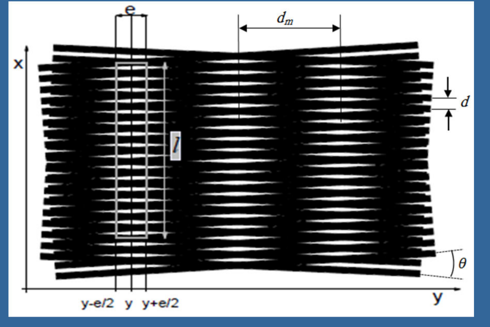
Seismometers are instruments that record ground vibration during the propagation of elastic waves in the earth. These sensors are based on damped oscillation of an inertial-pendulum system. The pendulum is an inertial mass attached to a spring. The frame of the sensor is fixed to the ground. During ground 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 for using optical methods. Optical approaches have some advantages in comparison with the other techniques, these are, higher signal to noise ratio, sensitivity, and precision. Recently, scientists used Michelson interferometry as a readout system in seismometery (Zumberge et. al. 2010).

In this work, we introduce a novel three-component optical seismometer that is based on the moiré technique. The moiré technique has found many applications in the measurement of very small displacement 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 and moiré readout systems. 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

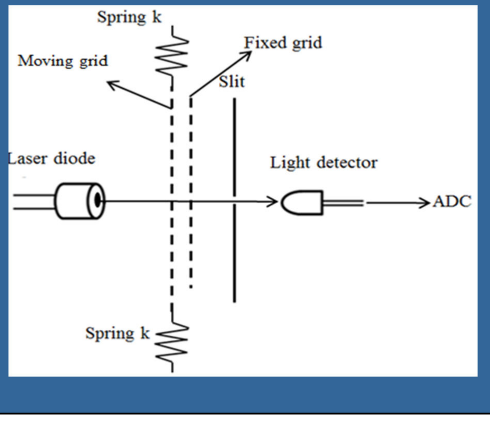
Moiré technique is based on the interference obtained when two transparent plates such as two gratings are covered with equally period. If one of the plates is held over one another, they can be aligned so that no light will pass through or so that all light will pass through. Now, if one of the plates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

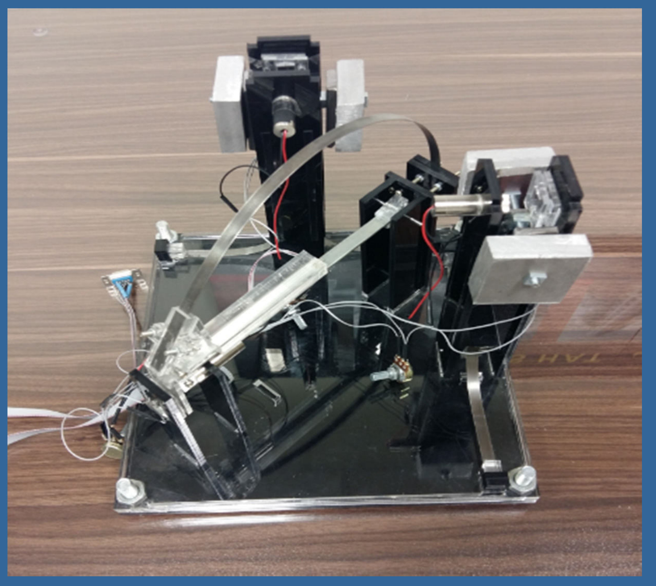
$$d_m = \frac{d}{2\sin(\frac{\theta}{2})}$$



The average intensity of a light beam (*I*) through a slit of width *e* oscillating with angular velocity ω in front of the fringes is:

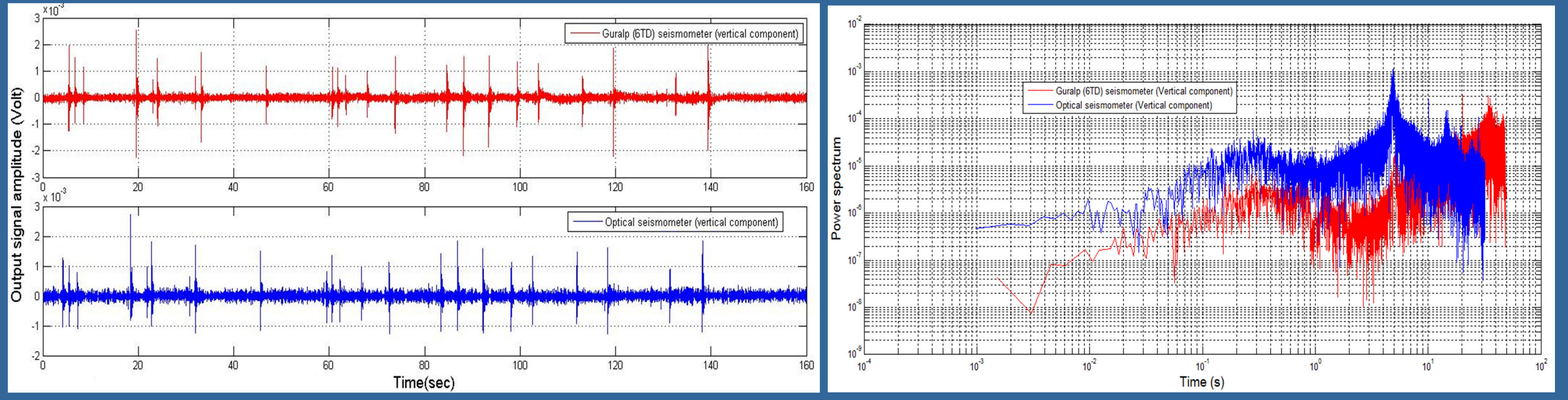
$$\bar{I}(t) = I_0 l\left[\frac{1}{4} + 2\sum_{n=1}^{+\infty} a_n^{\,2}\,\mathrm{sin}\,c\left(\frac{\pi ne}{d_m}\right)\cos\left(\frac{2\pi n\left(A\exp(-\gamma t)\sin(\omega t+\varphi)\right)}{d_m}\right)\right]$$

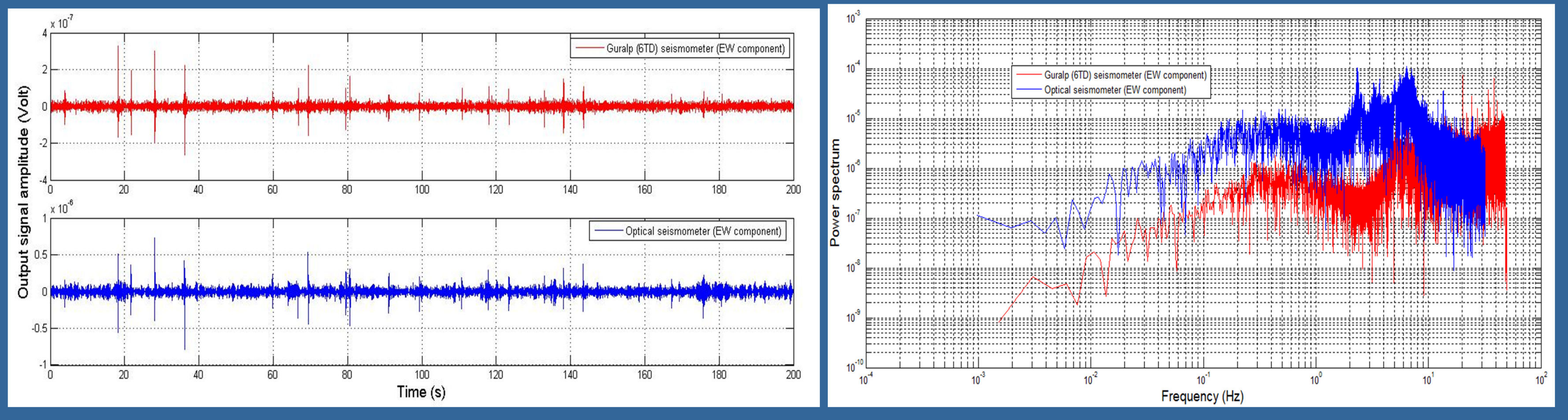


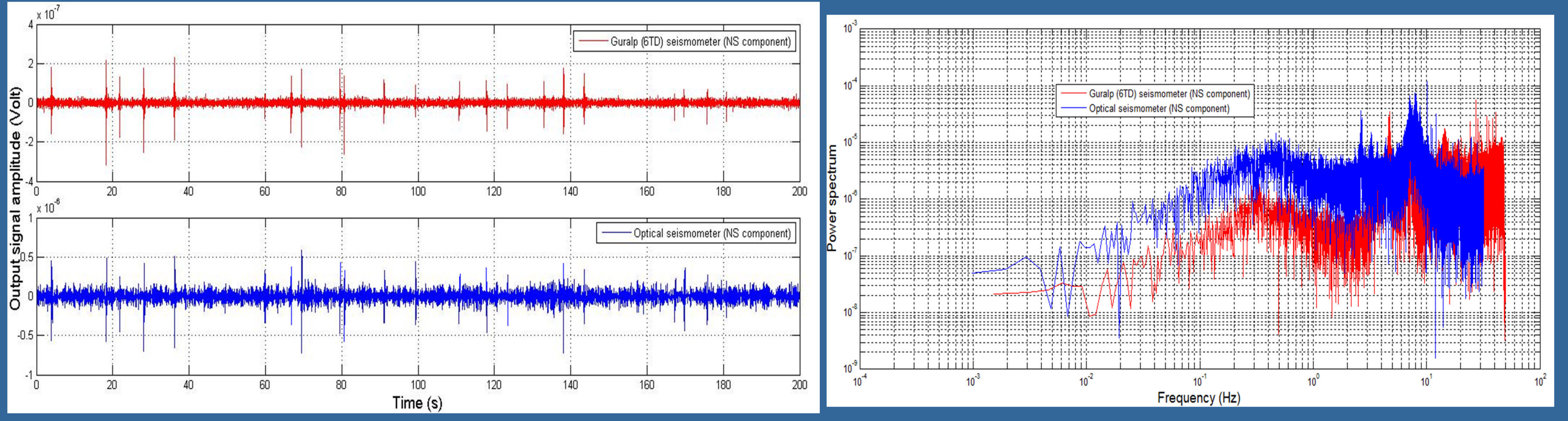


Experimental results

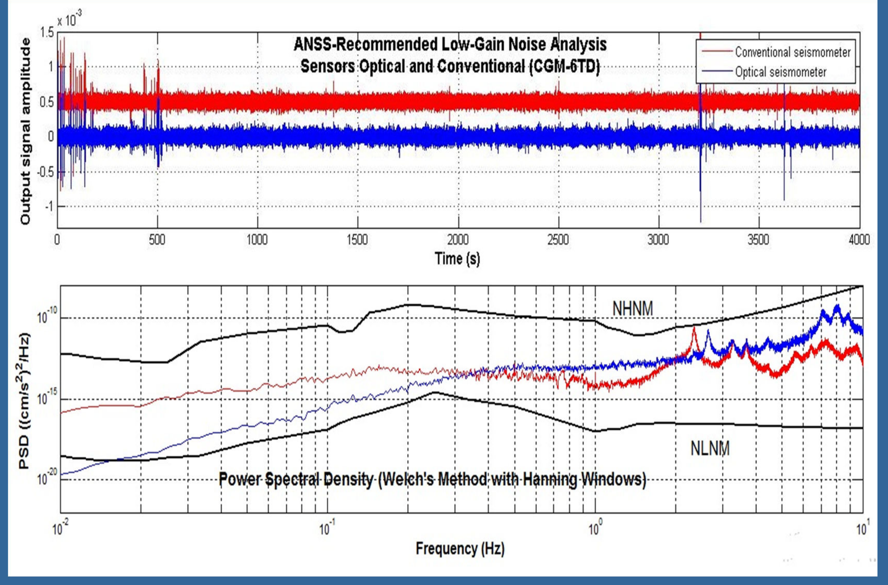
Many experiments have been carried out to investigate the performance of the optical seismometer. The method of test is basically by comparison the waveform of optical sensor with a co-located reference sensor. The reference sensor in this study was Guralp CMG-6TD sensor. The performance of the sensors has been tested by investigation their impulse response. Both sensors were exposed to many impulses and these experiments carried out in a non-isolated environment to have environmental vibrations as well. In this case we were able to study the response of new sensor in real conditions. A 12 bit ADC has been used with sampling rate of 60 Hz. As we can see, there is a good agreement in three-components, between two traces in response to received vibrations. Also, it is observed that, the first motions in optical sensor traces are clearer than those in 6TD output. Also, we have calculated the PSD for the responses of both seismometers. These results well illustrated below.

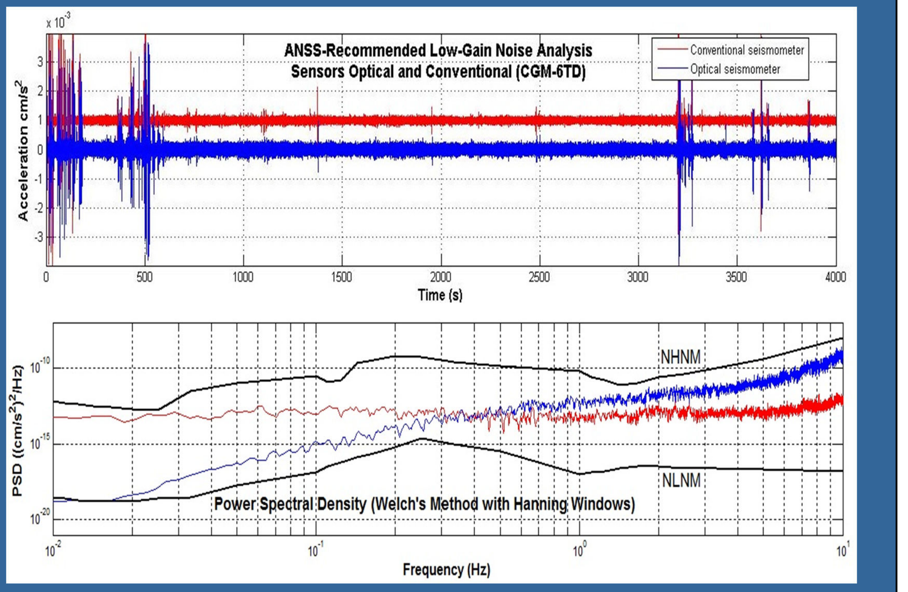


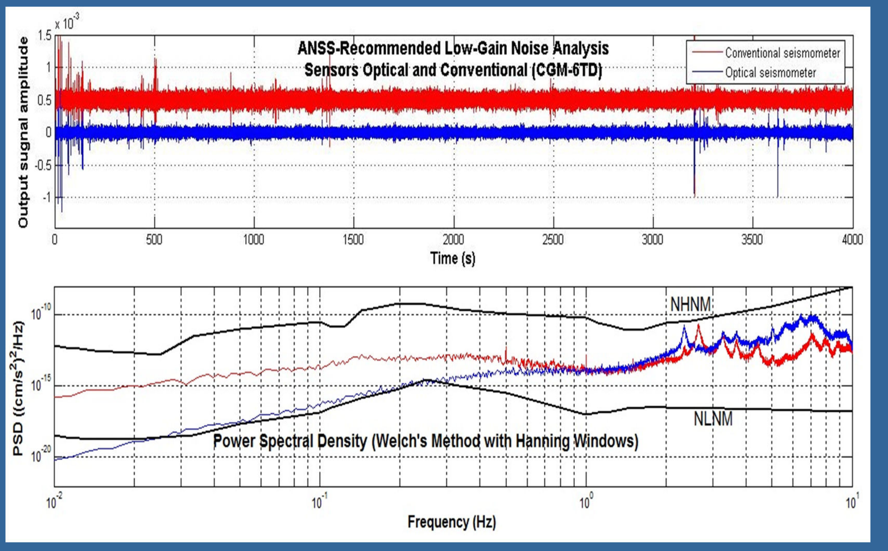




Power Spectral Density (PSD)







CONCLUSIONS

In this work we have described a new optical seismic sensor based on the moiré technique developed for geophysical applications. Adding an optical element to seismometer allowed us to monitor its mass position with high resolution. This sensor is a three-component seismometer with natural frequency of 0.5 Hz. The numerical simulation and quantitative investigation has been carried out on our sensor performance. Preliminary tests, performed on our seismometer and a conventional seismometer, are reported in this work. The results show the good performance of our seismic sensor. Furthermore, our sensor has some advantages. Its output is largely free of EM noise. In our sensor, we can vary the sensitivity by varying the gratings period, and the angle between the ribbons 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.

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