Performance of an interferometric seismometer with a laser diode

Akito Araya[1], Erhard Wielandt[2], Walter Zuern[3]

[1] ERI, Tokyo Univ., [2] Geophys. Inst., Univ. of Stuttgart, [3] Black Forest Obs., Univ. of Karlsruhe

araya@eri.u-tokyo.ac.jp

Since laser interferometers have both high sensitivity and low drift, performance of a seismometer can be improved when applied to a sensor of a pendulum. Self-calibration referred to the well-defined laser wavelength would be another advantage for actual seismic observations. Here we have newly developed a vertical seismometer based on the horizontal laser-seismometer (Araya et al., 1993). A laser diode is applied for compactness and low power consumption. We have evaluated performances both in accuracy of output and in self-noise level, by means of parallel observations with two identical laser seismometers and an STS2 seismometer. As a result, we have obtained an accuracy of 1% in amplitude and a self noise level less than the Low Noise Model from 0.1Hz to its upper limit of 100Hz.

Introduction

Since laser interferometers have both high sensitivity and low drift, performance of a seismometer can be improved when they are applied as a sensor of a reference pendulum. Self-calibration referred to the well-defined wavelength of light would be an advantage for the actual seismic observations. In this research, we have newly developed a vertical seismometer based on the horizontal laser-seismometer (Araya et al., 1993). A laser diode is applied as a light source for compactness and low power consumption.

Instrument description

A hinged horizontal beam is used as a vertical reference pendulum which is suspended by a helical spring. In addition to the suspension spring, two other helical springs serve to apply negative potential to the pendulum, resulting in a low resonance frequency of 0.2Hz; this improves low-frequency sensitivity of the seismometer.

A Michelson-type laser interferometer senses the pendulum motion. A DBR (Distributed Bragg Reflector) laser diode is used to reduce the frequency noise.

Output of the seismometer is obtained from the feedback signal applied to the pendulum; the pendulum is controlled so that it moves together with the ground, and then the feedback force corresponds to acceleration of the ground. Since the feedback gain is very large (4*10^3 at 10Hz and 40 at 100Hz) and its bandwidth is up to 1kHz, contribution of the electronic noise in the feedback circuit is reduced in the feedback bandwidth. The wide bandwidth also provides a flat frequency response and a low phase delay; less than 0.5 degree below 100Hz.

Amplitude accuracy

Because the laser wavelength is known accurately and has very low dependence on time and temperature, it can be used as a reference for calibration. The fixed mirror in the interferometer is moved with a PZT actuator to apply a mimic acceleration to the seismometer, and the output signal is compared with the mirror motion. Calibrated outputs of two identical seimometers as well as that of STS2 seimometer (nominally 1% in accuracy) were compared, resulting in agreement within 1%. Change in effective gravity acceleration by tilting the seismometers caused corresponding output changes which also agreed well with each other within 1%.

Self-noise estimation

We have estimated the self-noise level of the seismometer from differential signals of two identical seismometers which were located on the same pier. For the frequency range between 0.1Hz and 100Hz, the self-noise was measured to be less than the level of Low Noise Model (Peterson, 1993).

Below 0.1Hz, air pressure variation caused a significant noise. We found that the noise was dominated by adiabatic temperature variation due to pressure change which induces spring constant change of the seismometer. We can expect appreciable noise reduction by replacing our springs with elastically stable material such as elinvar. Enclosure of the seismometer into a pressure-proof box will also be effective. In fact, we have observed significant reduction of the low-frequency noise behind the air-lock (two sealed doors) at Black Forest Observatory (Schiltach, Germany).

Conclusions

A laser interferometer was applied to a vertical seismometer, and we have evaluated performances both in accuracy of the self calibration and in self-noise level, by means of parallel observations with two identical laser seismometers and an STS2 seismometer. As a result, we have obtained an accuracy of 1% in amplitude and a self noise level less than the "Low Noise Model" from 0.1Hz to its upper limit of 100Hz. The pressure-dependent noise, observed below 0.1Hz, is expected to be reduced by applying stable springs and pressure shielding.

This seismometer can be made into a borehole seismometer, where laser source can be introduced from outside through optical fibers and most of electronics in the borehole can be removed. Availability of accurate calibration after installation is an advantage for the borehole application.