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Development of a laser strain gradiometer: reduction in thermal noise

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We are developing an instrument to detect slow earthquakes with duration of 200 seconds to 1 day, which are not observed yet. Obstacles for detection include not only an instrumental noise but also background motion. By comparing strain measured at Inuyama Observatory in Aichi prefecture and Kamioka Observatory in Gifu prefecture, and comparing the data of seismometer and that of strainmeter, background motion is estimated to have large sources whose spatial scale is more than hundreds of kilometers. On the other hand, the focal area of a slow earthquake and the distance between hypocenter and an observatory will be several kilometers to tens of kilometers. For these reasons, intensifying small scale phenomena will make detecting slow earthquakes possible.

The instrument will directly measure the second derivative of displacement of the ground. We name it a strain gradiometer. Since spatial derivative intensifies small scale phenomenon, this strain gradiometer will make it possible to detect slow earthquakes. This instrument includes a symmetric laser interferometer. The advantages of using a symmetric laser interferometer are that it directly measures the gradient of strain of the ground, and that it reduces common-mode noise such as the instability of the laser frequency.

The noises of a symmetric interferometer were measured in laboratory. The interferometer was set in a vacuum chamber and adjusted to have its optical path difference below 0.5mm. Noises were caused by thermal expansion or contraction of the optical board and the optical devices. Then the spectrum of thermal fluctuation of the air in an observatory was estimated. Quartz-tube strainmeter in Inuyama observatory was used as a thermometer, assuming that its extension or contraction was caused by variation in temperature. The value of 4.5 x 10^{-4}[K^2/Hz] at f=3.2 x 10^{-5}[Hz] was obtained. Since the value also included the extension of the ground and the noises of sensors, actual temperature fluctuation should be smaller. To detect slow earthquakes with duration of 10,000 seconds (fc=3.2 x 10^{-5}[Hz]) at the distance of 50km, the noise level of 1.4 x 10^{-25} [/m^2Hz] must be achieved. From these figures, temperature fluctuation of an optical board and optical devices must be suppressed to 1/90 of the temperature fluctuation in an observatory. This can be achieved by thermal coupling of a vacuum chamber with the ground, and thermal insulator which covers the chamber. Our previous study assumed that high vacuum, radiation shields, and a ceramic column will reduce heat transfer from the vacuum chamber to the optical board. However, these were not needed, and there was difficulty in preparing an optical board with large heat capacity.

In addition to thermal noises, laser intensity fluctuation, current noise of trimmer resistors, thermal coefficient of them, ADC noise, and axis deviation of laser beam noise were important factors. Except ADC noise, these noises were reduced by introducing a photosensor that monitored the laser intensity, replacing trimmer resister with fixed resistors, using lens that concentrated a beam to photosensors.

As a future plan, we will measure how much the heat transfer from the air to vacuum chamber can be reduced both in the laboratory and in Nokogiriyama Observatory. In Nokogiriyama Observatory, we will also conduct an experiment that what type of noise will arise when the interferometer is set as a strain gradiometer. Then we will construct a strain gradiometer which is 15m long, measuring the noises caused by local inhomogeneity.

Keywords: strain meter, laser interferometer