Statistical analysis of laser-interferometric detector Dylkin-1 data and data on seismic activity

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Abstract. This work presents statistical analysis of data collected from laser interferometric detector "Dylkin-1" and nearby seismic stations. The final goal of Dylkin project consists in creating detector of theoretically predicted gravitational waves produced by binary relativistic astrophysical objects. Currently, works are underway to improve sensitivity of detector by 2-3 orders. The goals of this research were to test isolation of detector from noise caused by seismic waves and to find out whether it is sensitive to variations in the gradient of gravitational potential (acceleration of free fall) caused by free Earth oscillations. Noise isolation has been tested by comparing energy of signals during significant seismic events. Sensitivity to variations in acceleration of free fall has been tested by means of cross-spectral analysis.

Current version of the “Dulkyn-1” detector[1] is a two-resonator laser system generating radiation with a wavelength of 3.39um. Frequency of the reference resonator bound to generation frequency of a He-Ne laser which is stabilized relative to the nonlinear hyper-narrow absorption resonance of a methane molecule (CH4) (relative instability of $10^{-14}$). The signal resonator is working in a free generation mode.

This configuration of the detector has been used to conduct an experiment to test the local position invariance principle, which is component of the Einstein’s equivalence principle. One of its effects is gravitational shift of spectral lines, which is equivalent to dependence of a clock speed on the local gravitational potential $\phi$.

Frequency difference of clocks with different physical nature has been measured in mentioned experiment. The result of experiment was approving of universality of the gravitational red shift with accuracy of 0.9%.

For experiments on the Earth’s surface changes in gravitational potential caused by orbital movement of the Earth and influence of the Moon’s gravitational field. Therefore, gravitational

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Potential can be written in the following way: 
\[ \psi(t, r) = \psi_0 + \Delta \psi(t) + g(t) \cdot r \]
where \( g(t) \) – potential gradient. Changes in frequency of point clock (reference resonator, which is bound to methane molecule resonance frequency) are caused by \( \Delta \psi(t) \). Meanwhile, potential gradient \( g(t) \) also has a significant influence on frequency of signal resonator. If the principle of equivalence is right, changes in frequencies of point and extensive clocks, caused by value of \( \Delta \psi(t) \) will be equal. It means that difference in speed of clocks will be determined only by value of \( g(t) \).

It is well known that earthquakes induce the Earth’s free oscillations[2], which in turn change gravitational potential and its derivatives on the Earth surface. This implies that correlation between a seismic data and readings of the detector could be observed on the free oscillations frequencies.

Magnitude squared coherence value has been calculated to estimate influence of the Earth’s free oscillations on detector readings. This value is being obtained using two datasets and reflects their correlation on various frequencies. It can be written as follows:

\[ C_{XY}(f) = \frac{|P_{XY}(f)|^2}{P_{XX}(f) \cdot P_{YY}(f)} \]

where \( X \) and \( Y \) – some datasets, \( P \) – estimate of power spectral density. \( P_{XY}(f) \) – \( X \) and \( Y \) cross-spectrum. Welch’s average modified periodogramm method has been used to calculate estimate of power spectral density. Signal has been divided into segments with length of about 5 days with 50% overlap. Each segment has been filtered with Hamming window.

Figures 1 and 2 contain magnitude squared coherence functions. Data sources are “Dulkyn-1” detector readings on one hand, and data collected from seismographs, on the other. Peaks connected to the Earth’s spinning (12h and 24h) can be seen on both plots of figure 1. Besides of that, there are few long period components of some different nature that can be seen on plot calculated using the detector data.

Figure 1. Long period components in detector and seismograph signals coherence function.

There are marks on figure 2 that correspond to some of the Earth’s free oscillation modes. Values of the free oscillation mode periods can be found in article[3]. Therefore, in the “Dulkyn-1” data there are several long period components (including 12h and 24h components, induced by spinning of the Earth), and some modes of the Earth’s free oscillations.
Seismic datasets used in this research has been obtained from [http://www.iris.edu](http://www.iris.edu) using BREQ-FAST (Batch REQuest-FAST)[4]. Name of dataset is formed from short name of station and name of seismograph channel. Datasets used for analysis collected from seismic stations of cities Kislovodsk (KIV) and Obninsk (OBN). Seismograph channel (VHZ) used in this work is vertical (Z) low frequency (0.1Hz – V) seismograph channel with high gain (H). Names of stations and channels can be obtained using IRIS DMC Metadata Aggregator service: [http://www.iris.edu/mda](http://www.iris.edu/mda). Abbreviation of channel name can be explained according to the SEED standard[5].

Another mechanism of interaction between “Dylkin-1” detector and seismic events is elastic waves induced by earthquakes, propagating into detector chamber. One of the goals of this research was to check vibration protection of the detector. For this purpose energies of the detector and seismograph signals has been calculated and compared during significant seismic events. On figure 3 there are energies of mentioned signals during the most powerful earthquake with magnitude of 5.8.

![Figure 2. Modes of the Earth’s free oscillations in detector and seismograph signals coherence function.](image1)

![Figure 3. Normed energy of detector and seismograph signals during an earthquake.](image2)
From distance between the detector and seismograph and minimum propagation velocity for seismic wave one can calculate maximum time interval between arrivals on corresponding signals. For station used in this work this interval is about 10 minutes. Therefore, from this fact and figure 3 should be that this earthquake is not seen in detector data. The same result has been obtained for all significant seismic events. It means that for given detector sensitivity vibration protection system is working fine.

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