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A 50-m laser strainmeter system installed in Transbaikalia: testing results

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Abstract

We report testing results for a 50-m laser strainmeter installed 300 m under the ground in a mine of PJSC Priargunsky Industrial Mining and Chemical Union (Krasnokamensk) and demonstrate its ability to record microseisms and waves of infrasonic–sonic bandwidths. Processing and interpretation of the collected data provides information about microseismic to tidal strain changes in the Transbaikalian region.

Keywords: laser strainmeter; regional oscillations and noise; microseisms; earthquakes; bay signal; free oscillations of geoblocks; Earth's background free oscillations; seiche; tides

Introduction

A laser strainmeter system with a 50-m baseline was installed and tested in 2012–2013 in an underground mine *of PJSC Priargunsky Industrial Mining and Chemical Union* (Krasnokamensk), more than 300 m below the surface. Its optical system consists of a modified Michelson interferometer and a *Melles Griot* frequency-stabilized laser. The strainmeter, which can record crustal strain variations within a bandwidth from about 0 to 1000 Hz, to an accuracy of 10^{-10}, makes part of a larger system designed for detection of pending technological disasters in the area of uranium mines under operation or construction (Rasskazov et al., 2012, 2013). In addition to this application, the collected data are of theoretical value for many problems of basic science.

The laser system has to be tested on processes over a large range of frequencies from tidal to acoustic signals from known sources of working machinery in the mine, in order to provide reference for interpretation of new data. Given the high resolving power and other exceptional properties of laser strainmeters, it is expected to reveal more wave characteristics and previously unknown oscillatory processes in the Transbaikal area, especially in the infrasonic bandwidth. These expectations stem from reports of interferometry by systems of this kind installed in different places worldwide to study Earth's geophysical and geodynamic processes (Bagaev et al., 1992; Dolgikh et al., 2002; Garoi et al., 2007; Jahr et al., 2006; Milyukov et al., 2005; Takemoto et al., 2006), as well as extraterrestrial signals (LIGO, 2009). The designed laser strainmeters of single- and double-path modifications (Dolgikh et al., 1998) oriented in vertical and horizontal dimensions (Dolgikh et al., 2002) are used to study earthquake precursors (Dolgikh et al., 2007a), physics of terrestrial ultrasonic processes (Alekseev et al., 2003; Davydov and Dolgikh, 1995; Dolgikh and Privalov, 2009), tsunamigenic earthquake risks (Dolgikh et al., 2007b), hydroacoustic issues (Dolgikh, 1998), and atmospheric and hydrospheric effects on crustal microstrain (Davydov and Dolgikh, 1993; Davydov et al., 1994; Dolgikh et al., 2001, 2015). Due to their frequency range, laser strainmeters are used in short-term earthquake prediction (Dolgikh and Mishakov, 2011). Other applications concern subtle effects such as the state and dynamics of magmatic systems, e.g., Elbrus volcano (Milyukov, 2006), strain variations associated with nonuniform rotation (Milyukov et al., 2011) and background free oscillations (Milyukov, 2005; Milyukov et al., 2015) of the Earth.

The advantages of these laser systems over narrower-bandwidth instruments (Drennov et al., 2013) provide hope for gaining more insights into subtle wave processes in the Transbaikalian region.

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Laser strainmeter

The laser strainmeter is part of a complex geodynamic monitoring system in the Streltsovo mining district (Rasskazov et al., 2013), where three underground mines with depths of 500–900 m are currently in operation. Advanced extraction technologies and mining from ever greater depths triggers geodynamic activity and thus causes hazards of overpressure and induced seismicity.

The Streltsovo ore cluster, which comprises the Antei and Streltsovo deposits, belongs to the Central Asian Orogenic Belt lying between the North-Asian and Sino-Korean cratonic areas, a zone influenced by high seismicity and volcanism of the Sino-Indonesian area. The ore cluster is located in the western part of the Amurian Plate (Southeastern Transbaikalia). Prolonged orogenic activity, with horizontal (strike-slip, thrust, and decollement) and vertical (uplift and subsidence) movements, has produced major structural and compositional heterogeneity in the area standing out against its surroundings.

In the course of the geological history, voluminous Paleozoic igneous complexes of the Shilka–Argun plutonic field, including the Uktui pluton, were drawn to the modern erosion surface over a large part of the territory. The Mesozoic volcanic activity produced the Mongolia-Transbaikalian belt upon this rigid basement, with the Tulukuev caldera as one of its volcanic-tectonic structures.

The location of the laser strainmeter was chosen with regard to natural and technological conditions. Analysis of available data and comparison of several options finally led to a decision to create an observation pavilion in the underground mine No. 1 of the Streltsovo ore field, 1.5 km far from the site of active stoping, in order to reduce the mining effect on the collected data (Fig. 1). Geologically this place corresponds to the base of the eastern Tulukuev caldera block, on the periphery of the Streltsovo mining field (Fig. 1). The strainmeter is oriented at an azimuth of 30°, i.e., facing the current Baikal tectonic flow and orthogonal to the Baikal seismic belt (Rasskazov et al., 2014). It is installed within a volcanic field composed of intermediate and mafic lavas and tuff in a ~10 km^2 tectonic block bounded in the east and west by the N–S Central and Malyi Tulukuev faults, respectively. The NW Tulukuev fault makes the southern block boundary while the northern boundary follows circular faults of the caldera edifice. The position of the strainmeter with respect to the buried basement is above the slope of a local uplift of the basement beneath the caldera.

Viewed on a more detailed basis, the laser strainmeter is located in a horizontal mine within a low-angle lower trachydacite layer, varying in thickness from 60–120 to 450–500 m, which covers an area of about 60 km^2 in the northern half of the caldera (Fig. 1).

The optical system of the strainmeter comprises a modified Michelson interferometer with unequal arms, the measuring arm being 50 m long. It is mounted on two concrete blocks rigidly coupled to the main mined bed: a corner-cube reflector on one block and a *Melles Griot* frequency-stabilized helium–neon laser (providing stable frequency to the tenth decimal) on the other block (Fig. 2), along with a control system (sensors and resonance amplifier) and other constructional and optical elements. The light travels through a sealed waveguide of connected stainless steel pipes with an inner diameter of 9 cm.

A single incoming beam of light (*6*) is collimated (*7*) and then becomes split into two identical beams by a plate beam splitter (*8*). One beam travels along the air-filled sealed pipe to the corner prism and then returns to the mirror. The other beam returns to the mirror having passed through the interference site. The two beams recombine at a partially reflecting (half-silvered) mirror and produce an interference pattern before reaching the photodiode detector. The chosen collimator (*7*) increasing the beam diameter to 8–10 mm is used to reduce the angle between the beams and broadening them to the size convenient for alignment. The optical gate consisting of a diaphragm, a polariser, and a λ/4 plate suppresses parasitic beams and thus improves the operation stability. Low-angle orientation of the laser path with respect to other optical elements likewise attenuates parasitic effects on frequency stability. Furthermore, the rays reflected from the corner prism are shifted 2–3 cm parallel to the incident beam, which prevents reflections from coming back to the laser. The whole light path, except for 30 cm, is within a sealed pipe where the pressure is maintained constant at 1200 GPa. The pipe junctions are kept tight due to high-quality vacuum gum and a U-shaped lock. The pipe has transparent tightly fixed fused quartz windows.

The strainmeter measures relative displacements of blocks. In our case of interference between two beams of the same wavelength, detection is in the homodyne mode. The intensity of the beam arriving at the detector is given by (Dolgikh and Privalov, 2009):

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\left\{\frac{4\pi(L_2 - L_1)}{\lambda}\right\}, \tag{1}$$

where I_1 and I_2 are intensities of recombined beams; L_1 and L_2 are light path lengths of the first and second beams, respectively; λ is the laser wavelength.

The dependence of I on ΔL, $L_2 - L_1$ is periodic, with a period of $\lambda/2$, which allows tying to one intensity peak of the interference pattern to measure the differential arm length ΔL and counting the interference fringes and their shares during automatic tuning of the interferometer to the nearest peak. The data acquisition system provides automatic tuning of the interferometer and emits a signal proportional to the arm length difference in fractions of $\lambda/2$, within $\Delta l = \pm\lambda/2$ at $\Delta l = \Delta L - k\lambda/2$, where k is an integer equal to the integer part of $2\Delta L/\lambda$. The difference ΔL is (Dolgikh and Privalov, 2009):

$$\Delta L = \frac{\lambda}{2}\left[(k_+ - k_-) + \frac{U_2 - U_1}{U_{\lambda/2}}\right], \tag{2}$$

where k_+ and k_- are the numbers of positive and negative resets, respectively, caused by $\pm\lambda/2$ changes of ΔL; $U_{\lambda/2}$ is a normalizing factor in volts; U_1, U_2 are output voltages in the start and end times, respectively.