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МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

A LASER SENSOR OF A SEISMIC SLOPE OF THE EARTH SURFACE

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A principally new method of the measurement of a seismic slope of the Earth surface is suggested. The method makes it possible to stabilize the position of the laser beam as a highly extended coordinate axis in the metrological support of the precision construction of large-scale physical installations. The method has been tested experimentally: for the first time, low-frequency periodic angular oscillations have been registered with an amplitude of $5 \cdot 10^{-7}$ rad and the noise registration value of $2.5 \cdot 10^{-8}$ rad. The measurements were taken at CERN, during the construction of the spectrometric complex ATLAS.

Предложен принципиально новый метод измерения угла сейсмического наклона земной поверхности. Метод открывает возможность on-line стабилизации положения лазерного луча как весьма протяженной координатной оси в метрологическом обеспечении прецизионного сооружения крупномасштабных физических установок. Метод апробирован экспериментально: впервые зарегистрированы низкочастотные периодические угловые колебания земной поверхности с амплитудой $5 \cdot 10^{-7}$ рад и величиной шума регистрации $2{,}5 \cdot 10^{-8}$ рад. Измерения были выполнены в ЦЕРН в период сооружения спектрометрического комплекса ATLAS.

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INTRODUCTION

The construction of modern large-scale research and civil engineering installations needs high-precision geodesic support.

As a rule, a system of reference marks on an all-in-one ground and a system of coordinates related to it (NETWORK) are used for these purposes. The certain location of marks and axes — the metrological components of NETWORK — provides the project precision of the facility under construction. It is clear that uncertainty in the space localization of the reference marks and coordinate axes directly influences the measure of inaccuracy in the controlled dimensions of the facility under construction.

Profound problems occur during the metrological support of the assembling of extra large extended research complexes: the accessible geodesic arsenal (in some cases) is not sufficient and does not meet the strict requirements of the specification permission exactly due to difficulties in the stabilization of the space location of the NETWORK elements. First of all, it relates to the development and stabilization of highly extended coordinate axes (reference lines). The necessity to use extended reference lines occurs during the high-precision assembling of a large number of collider accelerator sections (for example, ILC/CLIC) and the subsequent on-line stabilization of the elements of the assembled construction.

In more approximate plans, our task is to define the position of the tube with interacting proton beams at the LHC in the spectrometric complex ATLAS and the subsequent establishment of its nominal position.

The experience of designing and application of a laser measuring system [1–3] in the development of the hadron calorimeter ATLAS and the related research of the laser beam spread in atmosphere [4–8] showed a promising outlook for the use of the laser beam as a reference line.

In this paper the authors study the stability of such a line, as an important element of NETWORK, in relation to the angle component of seismic noise oscillations.

This type of noise is one of the basic ones that influence the position stability of the extended laser reference line. It leads to an uncontrollable laser source basis inclination and angular displacement of the laser beam. The seismic slope of the Earth surface is determined by the surface sonic waves due to different reasons (lunar and solar tides, seismic oscillations, movement of the terminator along the Earth's surface, industrial noises, etc.). Theoretical evaluations of the seismic noise slope of the Earth's surface are in the range 10^{-7}–10^{-8} rad [9].

Measuring (monitoring) the angle position of the Earth's surface and using this information, it is possible to try to provide on-line stabilization of the laser beam direction. As a reference, the authors suggest that the direction of the gravity vector direction should be used. Its change (up to 10 nrad [9]) is long — 24 h and more. The *liquid's surface* is suggested as the reference: it is perpendicular to the gravity vector.

The reason of gravity vector direction change is the influence of the Sun and the Moon. In other words, the gravity vertical (with the calculable Sun and the Moon influence taken into account) is the high-precision natural fiducial line with $\sim 10^{-9}$ rad day + night stability.

The suggested method has been implemented in the device for the registration of the noise slope of the Earth's surface. This method is a new one and was not mentioned in the review articles on seismic oscillations [10–14].

In the future, we plan to monitor the angle of the slope of the Earth's surface and develop a principally new system NETWORK with the on-line stabilization of the laser beam direction as a quite long-standing reference line with angle stability sufficient for the high-precision construction and control of experimental set-ups of considerable dimensions that consist of a large number of structural elements.

1. THE PRINCIPLE OF CONSTRUCTION OF THE REGISTRATION DEVICE TO MEASURE THE SEISMIC SLOPE OF THE EARTH'S SURFACE

Figure 1 shows a vessel with a liquid positioned on a base stand monolithically connected with the Earth's surface.

The Earth's surface slope changes the angle between the liquid's surface and the base stand. If the laser is positioned on the same base stand, its beam will deviate from the primary direction after the reflection from the liquid's surface, depending on the angle slope ϕ of the Earth's surface.

The slope angle θ of the laser beam reflected from the primary position will be twice as large as the slope angle of the Earth's surface ϕ. Such variations of the laser beam

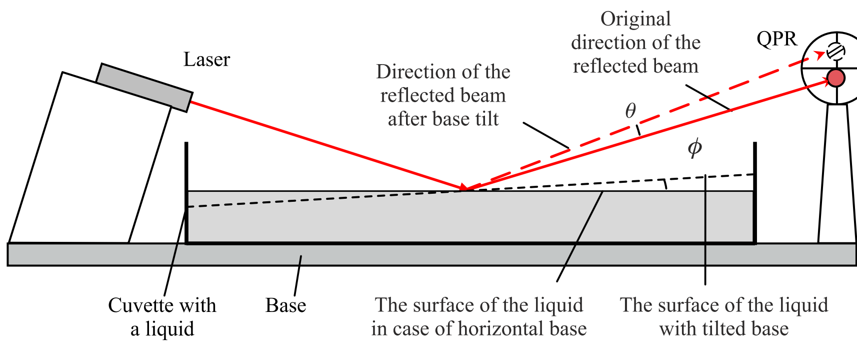

Fig. 1. The principle of the measurement of the angle seismic slope of the Earth's surface using laser beam

directions are fixed with the position-sensitive quadrant photoreceiver (QPR) [15], which is also connected monolithically with the Earth's surface.

2. EXPERIMENTAL SET-UP

In Fig. 2 is given a block diagram of the experimental set-up for the registration of the seismic slope of the Earth's surface, with regard to the horizontal position of the liquid's surface.

The base stand O was made in the form of a massive tube of stainless steel. The upper part of the base stand O_1 to fix the laser L, adjustment elements and QPR was situated on the tube. The cuvette with the liquid was placed in the lower part of the tube.

The bottom part of the tube was fixed on the base stand O_2 which was equipped with a micrometric positioning element K to fix the slope during the calibration of the measurements.

With the semitransparent mirror, the laser beam was directed to the cuvette with a liquid, being perpendicular to its primary position; it was reflected from the liquid's surface and was

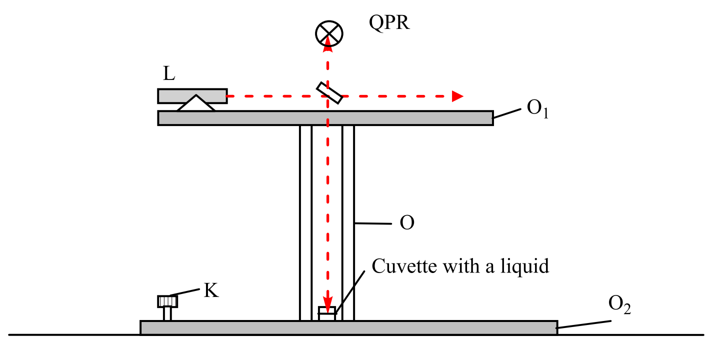

Fig. 2. The diagram of the experimental set-up for measurements of the seismic slope of the Earth's surface

directed to the quadrant photoreceiver QPR. The signal from QPR was detected with the 24-bit ADC and a computer. The duant configuration of QPR was used in the measurement scheme.

To increase the sensitivity of the measurements with the telescopic collimator, installed in front of the laser source, a controllable focusing of the laser beam was done to the surface of the quadrant photoreceiver.

3. THE VALUE OF THE ATTAINABLE SENSITIVITY OF THE SENSOR

The value of the shift of the one-mode laser beam detected by the duant photoreceiver (DPR) that corresponds to the noises of the laser source is determined by the ratio

$$\frac{\Delta P}{P} = \frac{\Delta d}{D}, \tag{1}$$

where $\Delta P/P$ is radiation capacity instability in the laser beam cross section; D is the diameter of the laser beam in the daunt photoreceiver; Δd is a «shift» of the laser beam on the duant photoreceiver caused by the noises $\Delta P/P$ [16].

The beam minimal diameter D is determined by the design specifications of quadrant photoreceivers and cannot be less than 100 μm. For a laser source with radiation power unstability of $\Delta P/P = 10^{-5}$ [17, 18] in the beam cross section from (1), we obtain the value of the angle slope $\Delta d/l$ imitated by noises: with the length of the optical path $l = 1$ m it reaches $\Delta d/l = 10^{-9}$ rad.

4. SOURCES OF DETECTOR NOISES

One of the main noises in long-standing measurements in the suggested detector is the dependence of its value on temperature. The value of the change in the atmospheric temperature in the day–night period reaches $10\,^{\circ}$C. When it changes, the volume of the liquid changes, and, respectively, the level of its horizontal position changes; that, in its turn, leads to a shift of the reflected laser beam at QPR.

To solve this problem, the authors used the co-axis position of the incident and reflected beam (Fig. 2). In this case, changes in the level of the liquid do not affect the results of the measurements.

5. RESULTS OF THE MEASUREMENTS

The sensitivity of the constructed detector of the seismic slope of the Earth's surface has been determined experimentally. Figure 3 shows a diagram of the continuous recording of the measurement of the laser beam position at the duant photoreceiver in the set-up (Fig. 2) with the calibration slope $\phi_c = 2 \cdot 10^{-5}$ rad of the lower part of the O_2 detector's base stand.

Having determined the value of the signal u_c that corresponds to the calibration slope ϕ_c, we obtain the calibration coefficient $K{=}u_c/\phi_c$. In this experiment it was $K{=}(310{\pm}20)$ V/rad.

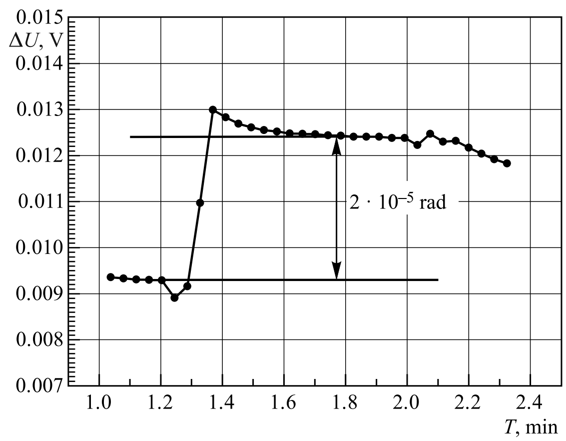

Fig. 3. The DPR signal that occurs in the calibration slope $\phi_c = 2 \cdot 10^{-5}$ rad of the lower part of the O_2 detector's base stand (Fig. 2)

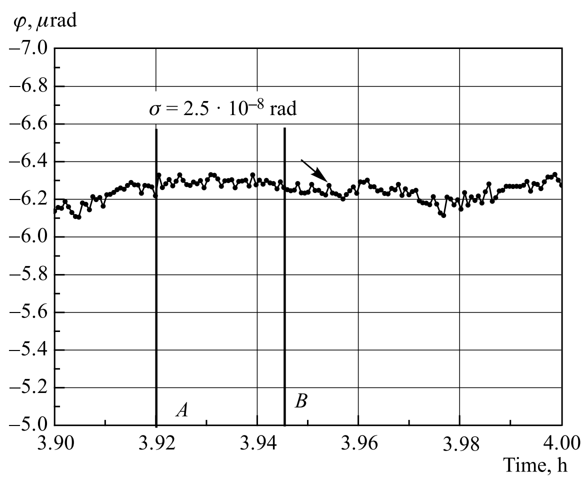

Fig. 4. Determination of the value of the noise slope during a period of 2 min

Figure 4 represents the continuous recording of the change of the slope angle of the Earth's surface during a period of 6 min.

The mean-square deviation of the slope angle of the Earth's surface σ was determined during the period of 2 min (area AB in Fig. 4) and was $\sigma = 2.5 \cdot 10^{-8}$ rad.

A histogram of the area AB data from Fig. 4 is given in Fig. 5.

Figure 6 gives the continuous recording of night measurements during 12 h at CERN. The interval of the slope angle change was $> 20 \cdot 10^{-6}$ rad.

To stabilize the direction of the laser beam (reference line), it is necessary to find and register the angle component of seismic oscillations. The given detector solves this task.

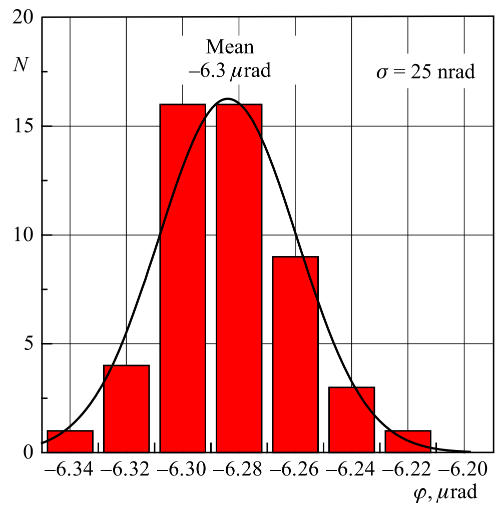

Fig. 5. Histogram of the area AB data from Fig. 4

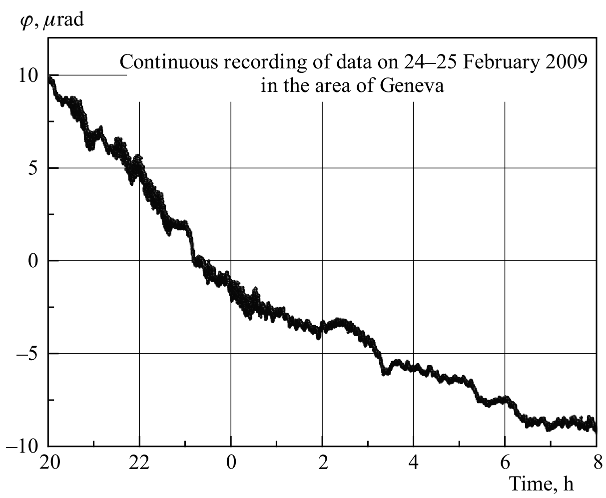

Fig. 6. The slope of the measuring set-up over a 12 h period

During the seismic activity, the sensor registered periodic surface seismic waves. Figure 7 shows the continuous recording of the angle position of the Earth's surface for the period from 24 to 25 February 2009, in the vicinity of Geneva.

Figure 8 shows the results of the Fourier analysis of the data presented in Fig. 7.

Measurements revealed two harmonics with periods $T_C = 250$ s and $T_D = 14$ s, in the relatively intensive angle components of $\sim 5 \cdot 10^{-7}$ rad of periodic seismic oscillations of the Earth's surface in the region of low frequencies 10^{-3}–10^{-1} Hz. Monitoring such oscillations will allow us, as we assume, to provide angle stability of the laser beam direction in reference lines.

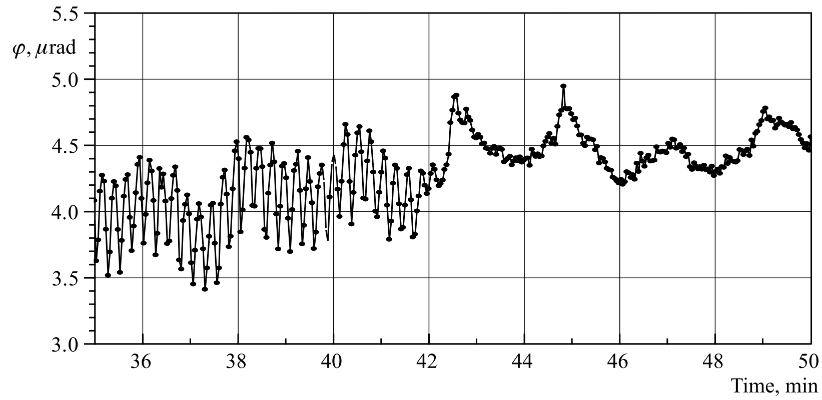

Fig. 7. Periodic slope of the Earth's surface on 24–25 February 2009 in the vicinity of Geneva

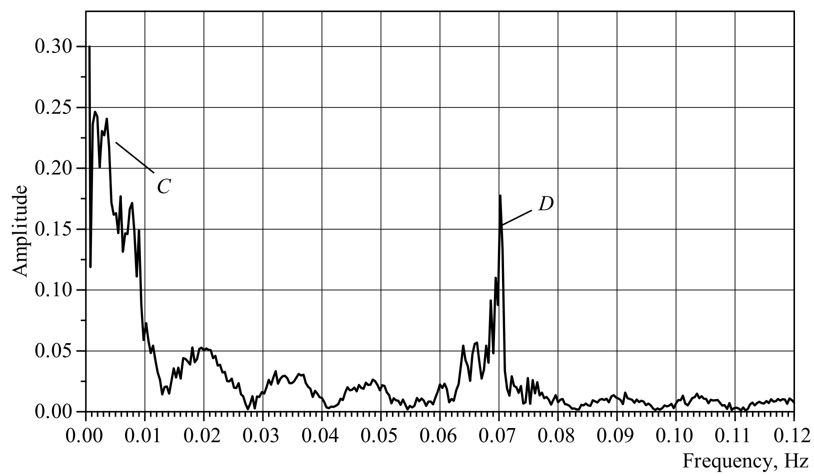

Fig. 8. Fourier analysis of angle oscillations of the Earth's surface on the basis of data from Fig. 7

6. DISCUSSION OF MEASUREMENT RESULTS

The suggested method of registration with the help of the laser beam reflected from the liquid surface, positionally fixed with a sensitive photoreceiver, has been proved experimentally. For the first time, the angle component of the seismic oscillations of the Earth's surface has been experimentally obtained and registered.

The simple optical scheme and a sufficiently large range of the measured slope angles of the Earth's surface $> 2 \cdot 10^{-5}$ rad (see Fig. 6) bring about a possibility to use the device for the observation of quite intensive seismic phenomena and their further monitoring for the compensation in the NETWORK complex with stable laser reference lines.

The measurements revealed the dependence of the results on changes in the outer temperature, which influences the results of the long-standing (day–night) measurements (Fig. 6).

To determine the degree of the influence of the outer temperature on the detector elements, a thermostable volume is developed round the set-up. The material for the thermosensitive elements of the set-up will be changed into thermostable invar and quartz; the geometrical scheme of the set-up will be upgraded to minimize nonlinear deformations in the construction elements.

One should notice that the Earth's surface tilt angle can also be caused by the noises of an industrial and wind origin.

CONCLUSIONS

An experiment on the measurement of the angle component of the seismic noise of the Earth's surface has been suggested and implemented on the basis of the horizontality property of the liquid surface. Monitoring of the angular movements of the Earth's surface has been experimentally carried out.

It gives an opportunity to stabilize the laser reference line with an accuracy of $\sim 10^{-8}$ rad for the metrological maintenance of long-length research facilities and civil sites.

The angular component of the seismic noise is the derivative of surface seismic waves. Therefore, the detector developed according to this scheme is a source of significantly new information on the Earth's tectonics.

The detector allows measurements of the angular component of the surface seismic waves in the frequency range of 10^{-4}–1 Hz and angular measurement interval $\approx 2 \cdot 10^{-5}$ rad.

The device is attractive from the patent and research points of view.

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