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THE PRECISION LASER INCLINOMETER LONG-TERM SENSITIVITY IN THERMO-STABILIZED CONDITIONS

Presented by M. Lyablin at CLIC Workshop 2015
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Азарян Н. и др. Е13-2015-35
Долговременная чувствительность прецизионного лазерного инклинометра в термостабильных условиях

В работе представлены последние результаты тестирования прецизионного лазерного инклинометра в термостабильных условиях транспортного тоннеля № 1 (ЦЕРН). Получены ограничения на чувствительность инклинометра в разных диапазонах частот: 10^{-6} рад при 10^{-6}–10^{-4} Гц; $\sim 10^{-10}$ рад при 0.01–1 Гц. Проведены сравнительные измерения двух независимых инклинометров с практически полным совпадением сейсмограмм. Зарегистрирован сигнал от действия тоннелепроходческой машины.

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The Precision Laser Inclinometer Long-Term Sensitivity in Thermo-Stabilized Conditions

The paper presents the latest results of testing of the Precision Laser Inclinometer in thermostable conditions in Transport Tunnel TT1 at CERN. Restrictions of the inclinometer's sensitivity in different frequency ranges have been obtained: 10^{-6} rad for 10^{-6}–10^{-4} Hz and $\sim 10^{-10}$ rad for 0.01–1 Hz. Comparative measurements with two independent inclinometers have been made and their seismograms almost coincide with each other. The signal of action of tunnel boring machine has been registered.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

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Introduction

The principal significance parameter of any energy collider (CLIC, ILC, LHC, FCC,. . .) is its luminosity.

One of the reasons of the decreasing of the average luminosity is the ground angular motion.

We propose a conceptually new design for the high precision detector of ground angular oscillations — the Precision Laser Inclinometer (PLI).

We think the Precision Laser Inclinometer measurement data can be used for colliding beam space stabilization of beam focus wandering.

The Precision Laser Inclinometer (basic idea)

The main idea is to use the effect of horizontality of surface of the liquid.

Angular displacement of the laser beam reflected from the surface of the liquid is proportional to the inclination of the support with cuvette with liquid.

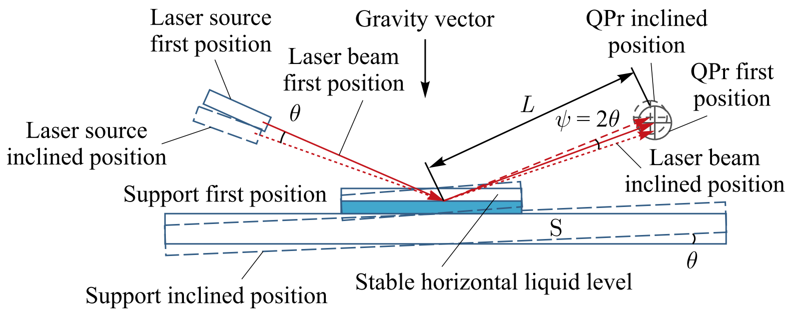

Fig. 1. The angle $\psi = 2\theta$ is the slope of the laser ray in the Precision Laser Inclinometer when its basement S is inclined by the angle θ

The accuracy of the Precision Laser Inclinometer

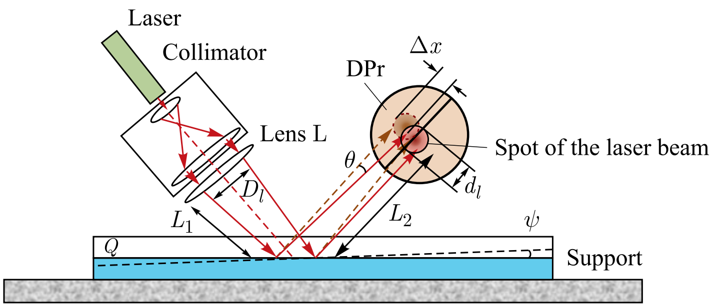

Fig. 2. The measurement of the inclination angle θ of the laser ray reflected from liquid surface

Under the Fig. 2 conditions

$$\psi = \frac{1}{2}\theta, \quad d_l = 1.22\lambda\frac{F}{D_l}, \quad F = L_1 + L_2, \quad L_1 \ll L_2,$$

the minimal measurable value of cuvette base inclination ψ_n limited by the noise of the ADC card in the inclinometer is

$$\psi_n = \frac{\pi}{16} 1.22 \frac{\lambda K_{n.\mathrm{ADC}}}{D_l},$$

where F — lens focus; d_l — diameter of the focus spot; ψ — angular inclination of the support; θ — angular inclination of the laser beam; $K_{n.\mathrm{ADC}}$ — relative resolution of the 24-bit ADC with respect to ADC internal noise.

For the laser wavelength $\lambda = 0.63$ μm, $K_{n.\mathrm{ADC}} = 5.5 \cdot 10^{-7}$ and $D_l =$ 10 mm, we obtain

$$\psi_n = 8.5 \cdot 10^{-12} \text{ rad}.$$

The scheme of the experimental set-up

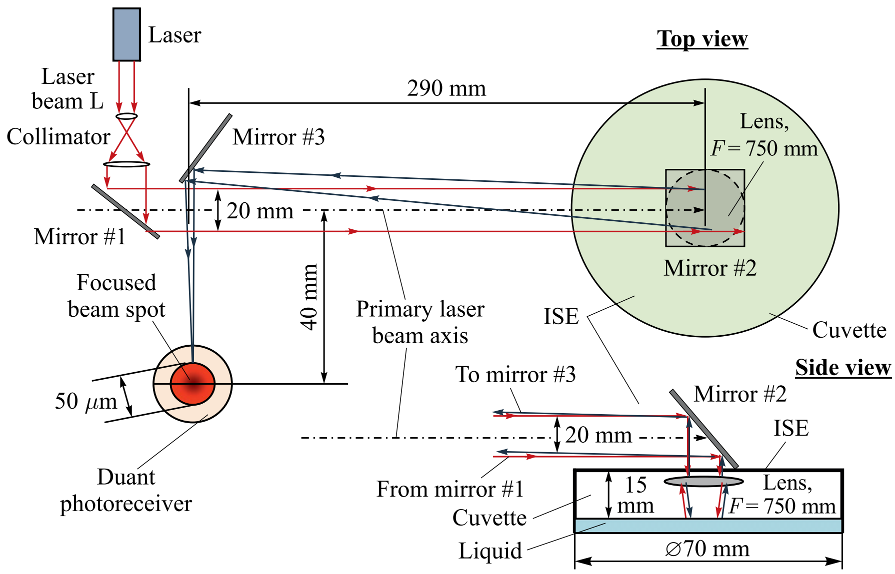

Fig. 3. Experimental set-up of the Precision Laser Inclinometer

The Precision Laser Inclinometer and Transport Tunnel TT1 at CERN

The 140-m-long TT1 is located at 10 m depth underground and has stable daily temperature of 16.4°C ± 0.1°C.

Fig. 4. The Transport Tunnel TT1 (general view), CERN

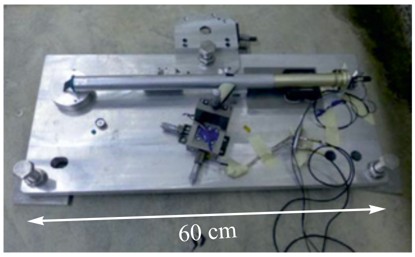

Fig. 5. The Precision Laser Inclinometer (general view) at TT1, CERN

The long-term stability (24 h)

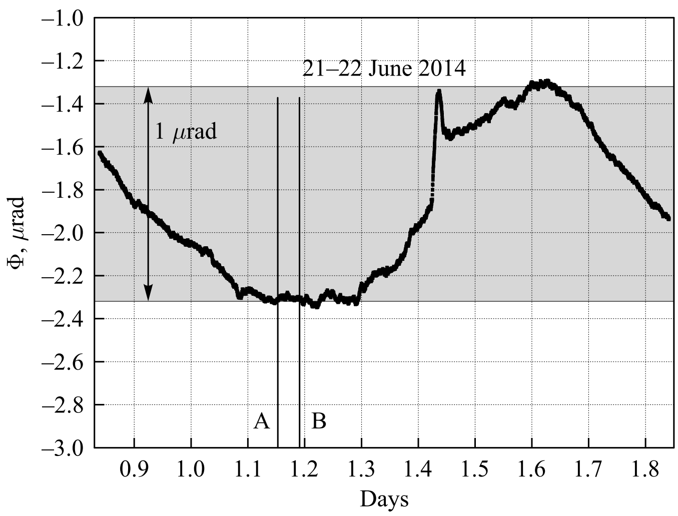

Fig. 6. The long-term variation data (one day) of the Precision Laser Inclinometer (time of one measurement is 50 s)

The angular daily data spread reached with the inclinometer is within the 1 μrad band.

For the single taken short-period (60 min) ”AB” on the inclinometer angular distribution, the sigma is $\sigma_{\rm rms} = 7$ nrad.

One measurement duration is 50 s.

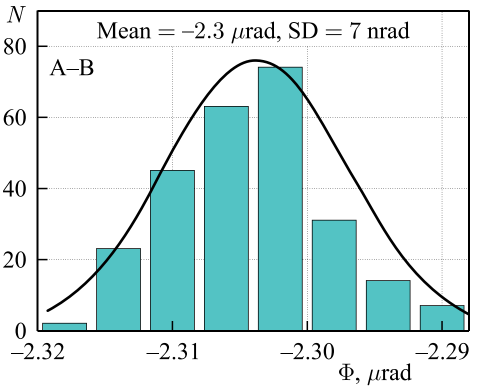

Fig. 7. Distribution of the signal corresponding to the AB interval in Fig. 6

The short-term stability of the PLI

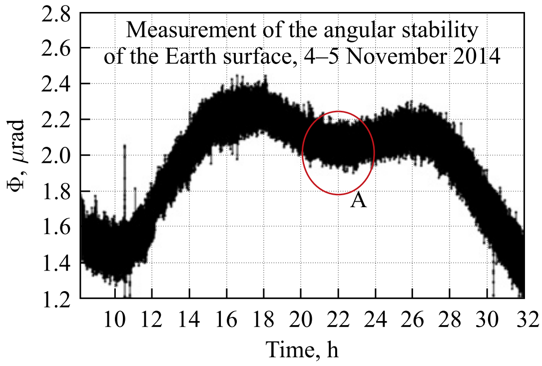

Fig. 8. Long-term variation data (one day) of the Precision Laser Inclinometer (time of one measurement is 0.638 s)

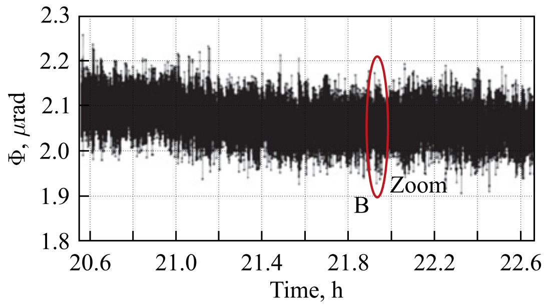

Fig. 9. The part A of the one day data in Fig. 8

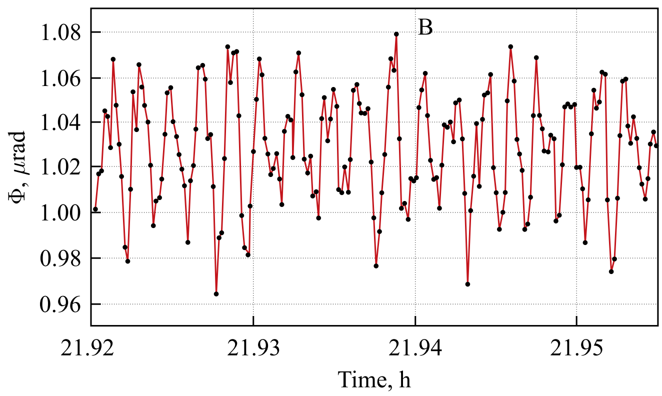

Fig. 10. The periodic process of inclination of the surface of the Earth (microseismic peak) corresponding to the "expanded" B interval (Fig. 9)

There is a periodic process of tilt of the Earth surface with an amplitude of $5 \cdot 10^{-7}$ to -10^{-8} rad in the frequency range of 0.1–1 Hz.

The Fourier analysis of the PLI measurement data

The red line corresponds to the average data.

Noise of the Precision Laser Inclinometer in the frequency range 0.01–0.1 Hz is $\sim 10^{-10}$ rad.

In the 0.1–1 Hz frequency range the "microseismic peak" is observed. The signal at a frequency of 0.0909 Hz (11.001 s) and amplitude of 10^{-9} rad seems to correspond to the tunneling machine working in Europe.

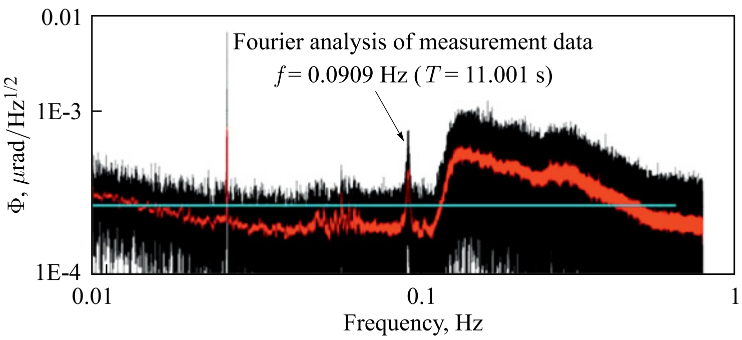

Fig. 11. The Fourier analysis of the Fig. 8 data

The proof of the reality of angular oscillations of the Earth surface at the frequency of the "microseismic peak"

Fig. 12. Two inclinometers which worked in "one direction"

Two independent inclinometers were put into operation having different: lasers, recording ADCs, computers, one measurement duration.

The inclinometers recorded angular oscillations of the Earth surface in one vertical plane.

The comparison of the measurements of two inclinometers

As one may see, for both inclinometers the recorded Φ time dependences are well coinciding.

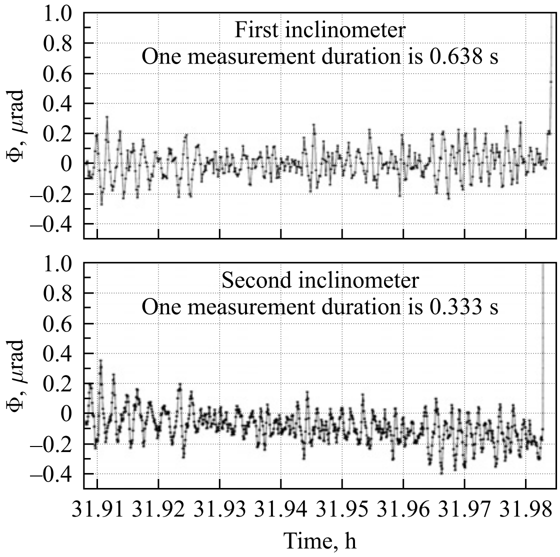

Fig. 13. The first and second inclinometer data

The sources of the long-term noises of the Precision Laser Inclinometer

The noise angular oscillation of a laser beam (non-uniform heating effects of laser active medium).

The instability of the power density distribution in the cross section of the laser beam.

The thermal deformation of structural elements of the Inclinometer.

The laser angular noise compensation for the Inclinometer in the low frequencies

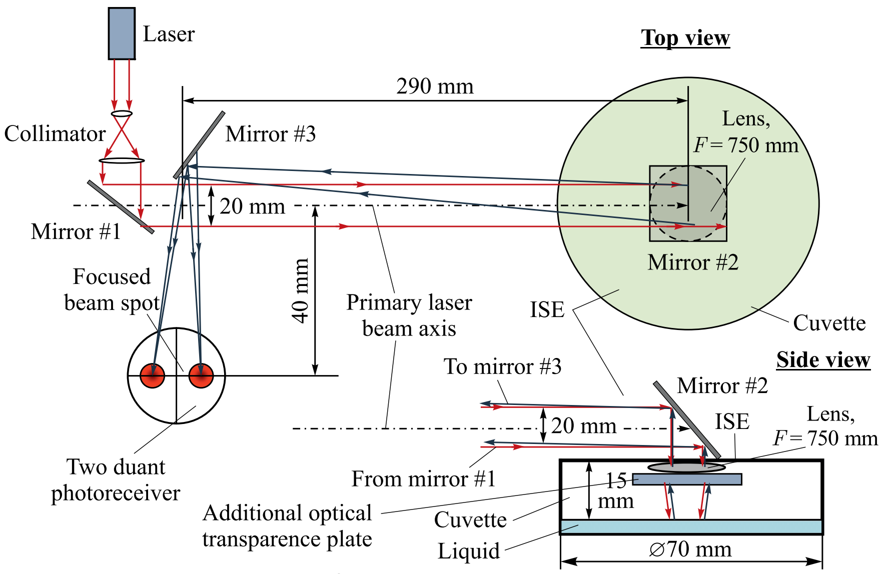

Fig. 14. The method of fixing the angular instability of the laser source

For the reduction of the effect of noise angular deviation of the laser beam, an additional transparent dual flat plate is used. The laser beam reflection from dual flat plate is used as a way of fixing the angular variation of the laser beam and is applied in the further processing of the inclinometer data.

The development of the Precision Laser Inclinometer

The forthcoming R&D steps are:

— the stabilization of the noises of the laser power and of angular movement of the laser beam in the Precision Laser Inclinometer;

— the compact design inclinometer;

— the simultaneous measurements of two angular coordinates.

Conclusions

• The first experiments with the Precision Laser Inclinometer have measured the values of noise of the Earth surface angular motion at different frequencies.

• For one day (10^{-5} Hz) the 1 μrad variation of an amplitude was registered.

• The standard deviation of the Earth angular motion for one-hour period ($3 \cdot 10^{-3}$ Hz) was found to be 7 nrad.

• In the 0.01–0.1 Hz frequency range the Fourier analysis defined the magnitude of the noise to be $\sim 10^{-10}$ rad.

• The PLI sensitivity limited by the ADC registration noise was defined to be $8.5 \cdot 10^{-12}$ rad.

• The proof of the real presence of the angular variation of the Earth surface at a frequency of "microseismicity peak" was given (first observation).

• The oscillation amplitude of the microseismic peak was $5 \cdot 10^{-7}$–10^{-8} rad.

• We plan to further improve the precision of the Laser Inclinometer to reach better than achieved 10^{-6} rad in the frequency interval 10^{-5}–10^{-3} Hz.

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