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МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

AIR TEMPERATURE STABILIZATION IN THE THERMALLY ISOLATED OPTICAL LABORATORY

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For the studies and calibration of optoelectronic components of the high-precision laser-based metrology systems, a large volume (50 m^3) thermoisolated lab based on a seismic isolated concrete block has been created. The inside lab volume temperature stabilization for the daily observation at 16.5°C is $\pm$ 0.05°C with $\pm$ 0.015°C temperature difference between maximal space separated points. This work was initiated by the needs of high-precision alignment of accelerator components of the CLIC, ILC-type colliders.

Для исследования и калибровки оптоэлектронных компонентов высокоточной метрологической лазерной системы создана термоизолированная лаборатория большого объема (50 м^3) на основе сейсмоизолированного бетонного основания. Стабилизация температуры внутри лаборатории для суточного наблюдения при 16,5 °C составляет $\pm$ 0,05 °C с разностью температур $\pm$ 0,015 °C между максимально пространственно разнесенными точками. Работа инициирована задачей высокоточного «выстраивания» ускорительных секций коллайдеров CLIC и ILC.

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INTRODUCTION

For precision investigation of laser ray propagation in an air medium, a special optical laboratory has been created at the JINR, Dubna. This laboratory is based on a 9.5-m-long seismically isolated massive (50 t) basis [1].

To reach precision measurements and their results independence from outside temperature noise factors, the optic lab is equipped with an air media temperature stabilization system. This system includes a thermally isolated 50 m^3 working room on the seismically isolated basement and a conditioner. The article describes the results of investigations of long-term (for a day and more) temperature stability of an air medium inside the lab volume as well as the residual temperature gradients inside it.

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THE THERMOSTABILIZED OPTICAL LABORATORY

The available laboratory space equipped with the seismically isolated basis originally had significant (> 10°C) temperature gradients connected with building local heating system. Additionally, in the summer period due to the specific lab-room design, the day/night temperature variation was high: ∼ 10°C. The seismic protection made possible the fine calibration procedures with the optical-electronic equipment. But long-term precision optics studies of laser ray propagation in air media remained problematic because of temperature «chaos». To realize all available advantages, this lab was to be supplied with temperature stabilization.

To protect the laboratory air media against external temperature variations, a thermally stabilized system was created, supporting stable temperature-dependent optical parameters inside the 50 m^3 lab. The thermally stabilized space (room) is located around the seismically protected basis, and its main features repeat the refrigeration chamber [2] (Fig. 1).

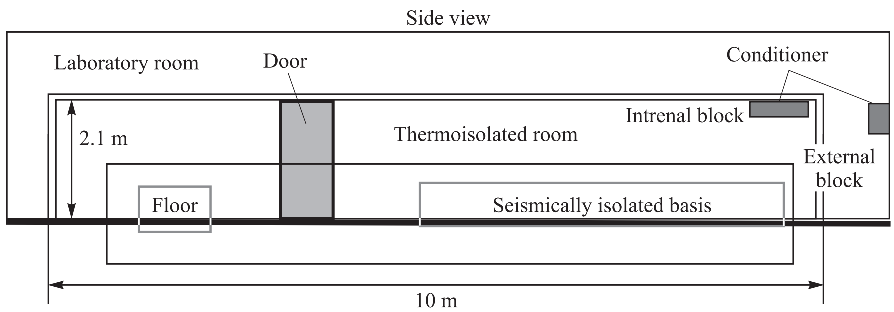

Fig. 1. The principal function scheme of the thermoisolated space (room) around seismically protected basis

The thermoisolated room dimensions are: height 2.1 m, length 10 m, and width 2.5 m. The room's walls are made of polyurethane panels (width 80 mm) with thick metallic cover. The panels are assembled groove-to-groove and the discovered gaps were filled with polyurethane foam. A special thermoisolated door for this room was installed.

To guarantee the long-term stability, the low-pressure channel-type conditioner SUZ-KA25VA2 Mitsubishi Electric was used [3]. This type conditioner was chosen as its internal block is reasonably compact, and the conditioner functional scheme allows one, by means of special collector, to uniformly spread the conditioned air flux inside the thermoisolated room space.

The conditioner internal block on the special support was fixed on the ceiling of the thermoisolated room. The external block was located on the external side of the thermoisolated room — on the main lab wall. The reason for such a block location was to guarantee the conditioner use all the year round (the external conditioner's block working conditions are limited by –15°C).

THE LAB AIR MEDIA TEMPERATURE STABILIZATION

Both active and passive methods of air media thermostabilization inside the lab were used.

The passive methods were:

— thermoisolation by the metalized polyurethane panels which reduced influence of outside temperature gradients,

— seismically isolated basis is very massive (50 t) and is immersed inside the soil at 0.8 m depth. All that makes this basis a slow changing temperature object and that helped to inside-room temperature stability.

The active method is represented by the so-called channel-type conditioner. It is this device that stabilized and equalized the inside room temperature. Two options of the conditioner work were available: COOL and HEAT. In COOL option the conditioner by cooling was able to find the equilibrium inside room temperature and support it. In HEAT option the conditioner supported the inside room temperature set a priori by the transportable sensor of the conditioner's internal block.

THE TEMPERATURE SENSOR

To measure temperature when studying the air temperature stability inside the thermostabilized lab, one used the effect of temperature dependence of the diode reverse current [4, 5] (Fig. 2).

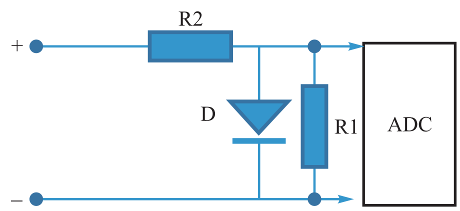

Fig. 2. The temperature sensor using the diode reverse current temperature dependence

In the diode regime with reverse current, a 1.5 V battery was used. The reverse current change was registered as the voltage change on the resistor R_1 by means of 24 bit ADC. In the temperature sensor D, the D213A diode was applied.

To determine the calibration coefficient $K = \Delta T/\Delta U$ with temperature change ΔT and voltage change ΔU, the measurements at $T_1 = 16.5°C$ and $T_2 = 2°C$ were used. The

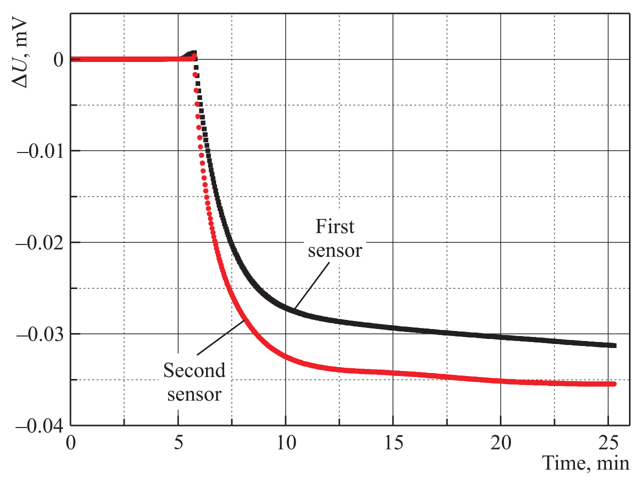

Fig. 3. Calibration of the temperature sensor: change of temperature from 16.5 to 2°C

temperatures T_1, T_2 were controlled by lab measuring thermometer with ± 0.3°C precision. The T_2 measurement was made by immersing the temperature sensor into a container of melting ice. The K-value was obtained for two temperature sensors in assumption of diode reverse current linear T-dependence: $K_{\rm ts1} = (2.2 \pm 0.1)$ mV/deg, $K_{\rm ts2} = (2.5 \pm 0.1)$ mV/deg.

Figure 3 represents the calibration measurements.

The essential result is about 10 min reaction of the temperature sensor used and this is connected with the used diode mass. For our purposes (measurements of diurnal variations of temperature in the laboratory), this factor did not affect the accuracy.

MEASUREMENT SCHEME. RESULTS

In the measurement scheme, two sensors were used with calibration coefficients $K_{\rm ts1}$ and $K_{\rm ts2}$ (Fig. 3).

The used two sensors allowed one to observe the residual temperature gradients inside the optical lab. The residual temperature gradient is a characteristic of temperature uniformity and determines the precision of positional measurements, which is one of the main characteristics of the thermal stability of the lab.

During measurements the sensors were positioned at the maximal distance from each other on the opposite ends of the seismically isolated concrete basis. Measurement duration was 24 h or more in the absence of internal heat sources. Figure 4 gives the air media temperature variation inside the thermoisolated lab with the use of the HEAT option of the conditioner. At this option, the conditioner supports the a priori given temperature within ± 1°C limits.

Figure 5 shows the difference of thermometer data inside the thermally isolated room with the conditioner HEAT option.

As shown, the $T = +22$°C temperature support is achieved with $\delta T_t = \pm 0.7$ spread and relative temperature variation of $\delta T_{t\,\rm var} = \pm 0.5$°C.

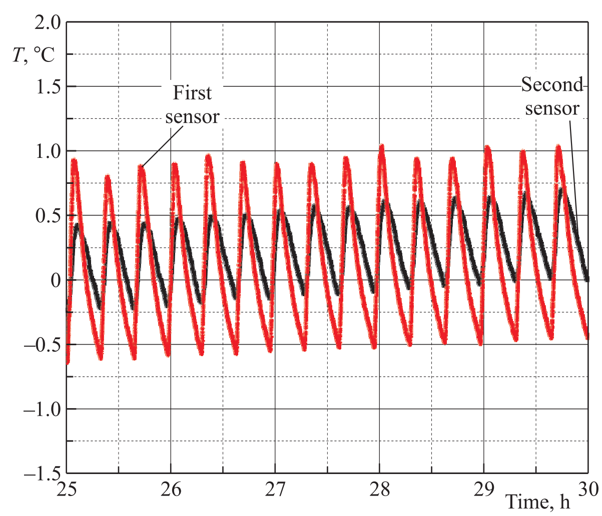

Fig. 4. Time dependence of the stabilized air temperature ΔT inside the thermally isolated room with the conditioner HEAT option

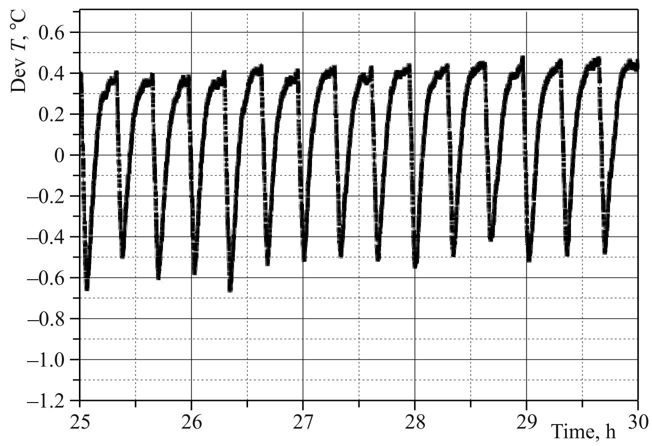

Fig. 5. Two thermometers data difference $\mathrm{Dev}\,T(^\circ\mathrm{C})$ inside the thermally isolated room with the conditioner at HEAT option (the Fig. 4 data are used)

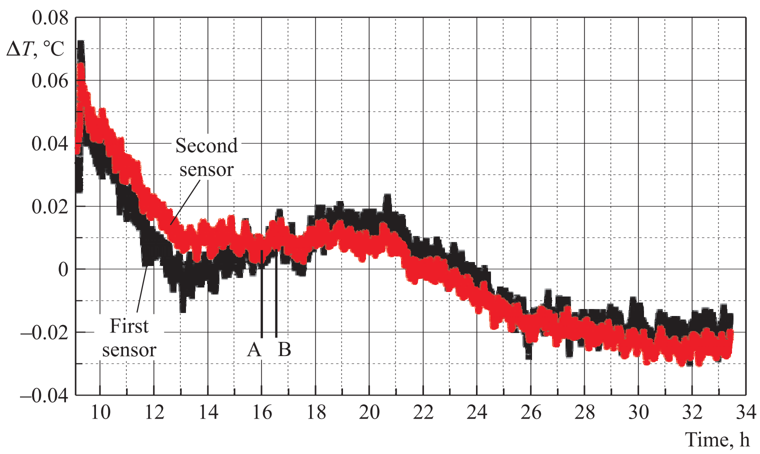

Fig. 6. Time dependence of the stabilized air temperature ΔT inside the thermally isolated room with the conditioner HEAT option

Figure 6 contains the measurement data within about 24 h with the conditioner at COOL option. In this case, inside the thermally isolated room the equilibrium temperature was established to be equal to $T = +16.5°\mathrm{C}$.

One can note the absence of periodic temperature oscillations of a large amplitude ($\sim \pm 1°\mathrm{C}$) as it was in Fig. 4. The temperature measurement precision was $\sigma_{\mathrm{rms}\,t} = 5 \cdot 10^{-3}\,°\mathrm{C}$ for 30 min measurement durations for AB interval (Fig. 6).

Figure 7 shows two thermometers data difference corresponding to temperature gradient value inside the thermally isolated room. The measurements were made on the opposite ends of the optical setup.

The achieved daily temperature variation level was $\delta T_t = \pm 0.05°\mathrm{C}$ (see Fig. 6) with the daily temperature variation $\delta T_{t\,\mathrm{var}} = \pm 0.015°\mathrm{C}$ (see Fig. 7).

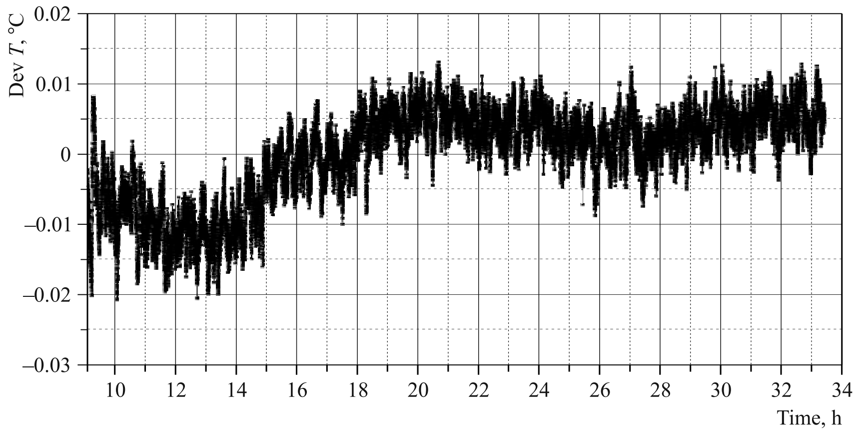

Fig. 7. Two thermometers data difference $\mathrm{Dev}\,T(°\mathrm{C})$ inside the thermally isolated room with the conditioner at COOL option (the Fig. 6 data are used)

The achieved daily air temperature stabilization parameters δT_t, $\delta T_{t\,\mathrm{var}}$ in the optical laboratory are very high and almost an order of magnitude higher than those of the precision climate control system [6]. They are comparable with similar parameters adopted in the clean room for an atomic force microscope [7].

Figure 8 illustrates the temperature $T\,(°\mathrm{C})$ change for both sensors caused by man appearing inside the thermally isolated room for a short time (up to 1 min) close to one of the temperature controlling sensors.

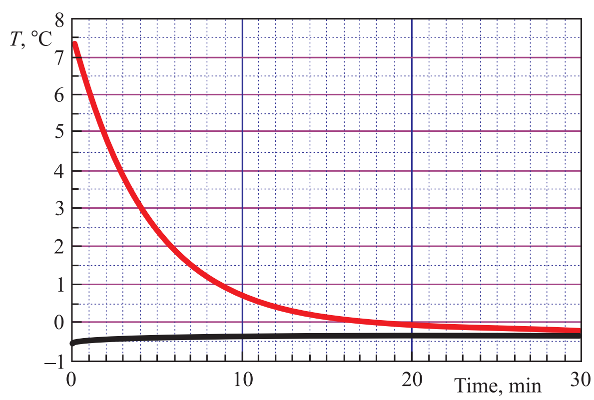

Fig. 8. The temperature change $T\,(°\mathrm{C})$ for both sensors inside the thermoisolated room when man approaches one of the temperature sensors for a short time

The characteristic temperature stabilization time for both sensors is about 20 min. One can mention rather intense temperature gradient caused by air media heating, which indicates the impossibility of man (or other heating surface) presence inside the thermally stabilized lab during measurement.

CONCLUSIONS

For the planned precision studies of the effects of laser ray propagation in an air medium, a large-volume thermally stabilized laboratory room with seismically isolated basis was created. The long-term (a day and more) thermostability parameters inside this volume were measured. The thermostabilization was obtained with channel-type conditioner SUZ-KA25VA2 Mitsubishi Electric inside $10 \times 2.5 \times 2$ m volume around the seismically protected optical table.

At the HEAT option of conditioner operation, to support the given temperature, the following parameters of a *daylong* thermostabilization were reached:

— ± 0.7°C of temperature stability,

— ± 0.5°C of maximal temperature variation between maximally separated points inside the thermostabilization volume.

At the COOL option of conditioner operation, the achieved temperature stabilization parameters were:

— ± 0.05°C of daylong temperature stability,

— ± 0.015°C of a maximal daily temperature variation for the maximally space separated points at $+16.5$°C of working temperature.

The obtained values of the daily air temperature stabilization and daily temperature variation in the optical laboratory are very high and almost an order of magnitude higher than those of the precision climate control system. They are comparable with similar parameters adopted in the clean room for an atomic force microscope.

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