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A STUDY OF AN AIR MEDIUM INFLUENCE ON THE RECTILINEARITY OF LASER RAY PROLIFERATION TOWARDS THE USING FOR LARGE DISTANCES AND HIGH PRECISION METROLOGY

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INTRODUCTION

In physics, technique and industry, numerous examples of the use of instruments with a laser are known. These are in particular the laser levels, laser distance meters, etc. The laser measurement system (LMS) was successfully developed and applied in Dubna during high-precision assembly of the ATLAS Hadron Calorimeter modules [1, 2].

In such instruments the laser ray is used as a reference coordinate axis relative to which the position measurements of objects under study are undertaken.

When proliferating the laser irradiation interacts with a turbulent air medium and with an increase of laser ray passed distance the degree of its distortion (perturbation) grows up and, consequently, the LMS's precision depends on a distance between the laser and a measurement point.

We undertook an experimental determination of a ray position uncertainty as a function of distance from a laser source and indicated possible ways to decrease this uncertainty.

This work may hopefully contribute to the future design of a LMS with higher metrology parameters and an optimal structure. A new generation of long linear collider structure elements with high-precision alignment may possibly be achieved with lasers properly used .

The quantum-mechanic limitations on the laser position precision determination were studied in [3–7] and are not considered in this work.

1. EXPERIMENTAL SETTING-UP

Experimental determinations of a laser ray localization uncertainty as a function of distance were made for two laser sources:

- Helium–neon, one-mode LGN-302 laser (Russian production) and
- Solid state, multimode DS-670 laser (German production).

Both laser beams were proliferating in an air medium. The experimental set-up is shown schematically in Fig. 1.

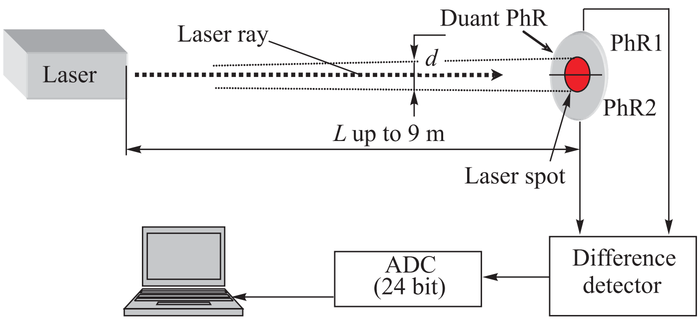

Fig. 1. The block-scheme of the experimental set-up

The duant-type photoreceiver PhR consisting of two photosensors PhR1 and PhR2 was positioned perpendicular to the laser beam. The sensitive base was a quadrant photodiode (see Fig. 2) and its basic parameters are given in [8].

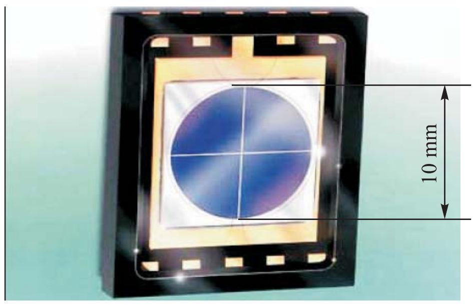

Fig. 2. The view of a quadrant photodiode

Then, the PhR had been adjusted by micrometric screw to the position where signals from both photosensors were about equal. The difference signal $\Delta V = V_{\text{PhR1}} - V_{\text{PhR2}}$ from residual amplifier was sent onto 24 bits ADC and was recorded with 2.7 s interval for 5 min period. The statistic analysis of the data accumulated was made and the RMS-value σ (mV) of signal was determined. The temperature of the room was about 20 °C without special temperature stabilization.

2. MEASUREMENT RESULTS

Figure 3, *a*, *b* represents ΔV signals recorded for DS-670 laser at different experimental conditions (see also Figs. 4, 5) and for the laser-off case (photodiode noise).

To establish the correspondence between the noise origin laser beam displacement (measured in μm) and the PhR signal (measured in mV), the PhR was positioned so that the differed amplifier signal was $\Delta V = 0$. Afterwards,

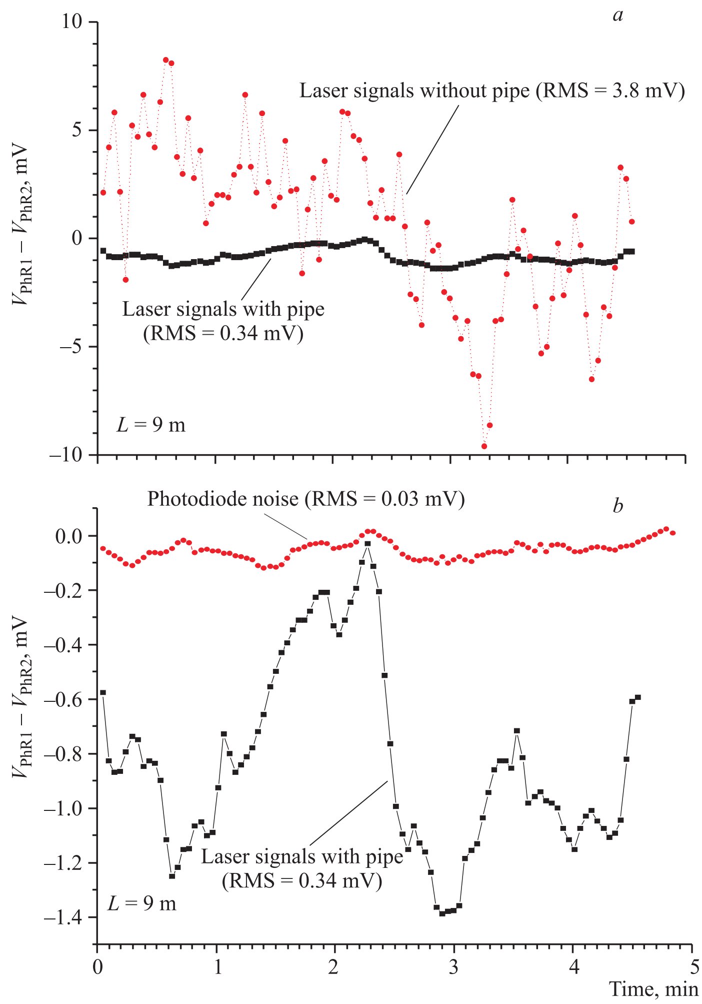

Fig. 3. *a*) ΔV signal direct record for the DS-670 laser. *b*) ΔV signal direct record for the DS-670 laser (bottom line); the photodiode noise with laser-off (top line)

the PhR was displaced by the positioner by $\Delta = 50$ μm (with the accuracy of ± 4 μm) distance in the plane perpendicular to the laser ray direction. And in this position the ΔV signal was measured. The ratio

$$K = \Delta / \Delta V \qquad (1)$$

determines the calibration parameter K.

Such a consideration (linear approximation) is correct on condition that the calibration displacement Δ is much smaller than the laser beam diameter d and, at the same time, is significantly larger than the observed value of the σ ($d \gg \gg \Delta \gg \sigma$). For the lasers used in the experiments, the beam diameter waist d was 0.5 mm for LGN-302 laser and 3 mm for DS-670 laser. The laser beam angular

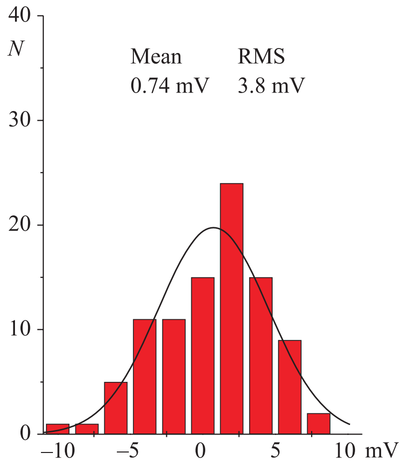

Fig. 4. ΔV distribution for the DS-670 laser (without isolating pipe)

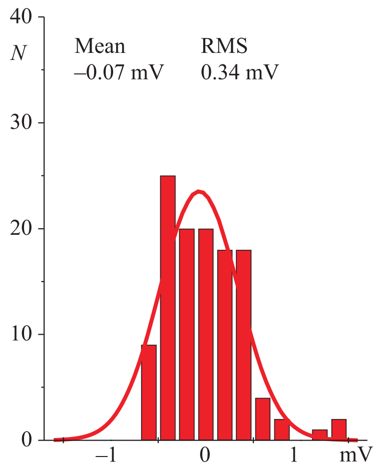

Fig. 5. ΔV distribution for the DS-670 laser (with isolating pipe)

divergence was 10^{-3} rad for LGN-302 laser and $0.5 \cdot 10^{-3}$ rad for DS-670 laser. The laser beams were not collimated.

The ΔV value is proportional to the laser beam power density in the point of calibration. So, the K parameter reflects the laser beam power density variation as a function of distance between the laser and the point of observation.

Figure 6 contains the K parameters for both laser sources.

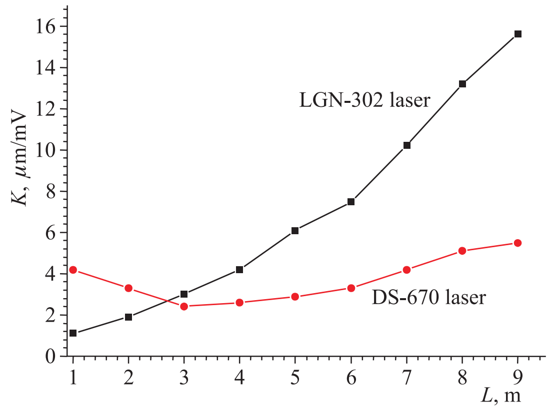

Fig. 6. The calibration parameter K as a function of the L distance between the observation point and a laser source

In accordance with the K parameter value, one determines (using (1)) the values of σ in micrometers.

The measurements described were executed for $L = 1-9$ m interval with a measurement step of 1 m. Figures 7 and 8 contain the σ (L) values of the beam displacement for the helium–neon one-mode laser LGN-302 and for the solid-state multimode one DS-670.

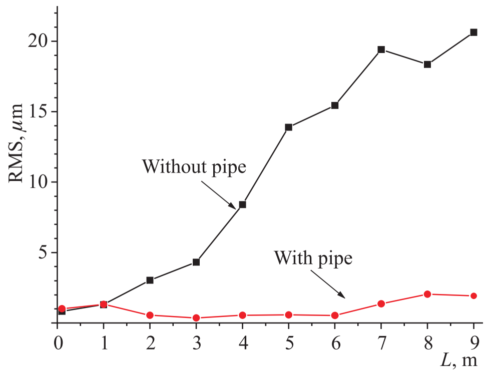

Fig. 7. The DS-670 laser: the σ values as a function of distance L between the laser and the observation point

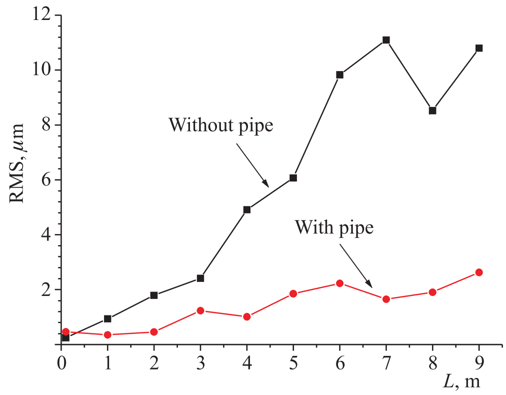

Fig. 8. The LGN-302 laser: the σ values as a function of distance L between the laser and the observation point

3. THE PROTECTION SCREEN EFFECT

As one can see from Figs. 7 and 8, the fast rise of σ (L) is detected, which is a consequence of an air turbulence influence on the laser beam. To reduce such an influence the laser beam was positioned inside the thermoisolation tube. The necessary measurements were performed following the above-described method.

Figures 7 and 8 also represent the σ (L) values depending on the passed way of the laser when proliferating inside a pipe.

Very efficient air turbulence neutralization for $L > 2$ m (both lasers) is observed. It is well manifested by Fig. 3, *a* containing time dependence of signals recorded for the fixed distance $L = 9$ m: records are made when the air turbulence effect is present and when such an effect has been suppressed by the isolating tube.

The least σ value was observed for the DS-670 laser and found to be 0.6 μm in $L = 2{-}6$ m interval of laser–observation point distances (Fig. 7).

The σ (L) decrease for $L = 2{-}5$ m interval with DS-670 laser measurements can be explained by the specificity of laser focusing used in this particular laser: at $L \cong 3.5$ m the laser ray has a beam waist with a diameter $\cong 3$ mm. In this place, the laser power density is increased and it leads to an increase of sensitivity of calibration K parameter and, consequently, to a $\sigma(L)$ decrease.

Figure 3, *b* gives a record of a $\Delta V(t)$ signal at $L = 9$ m for the case when laser beam is proliferating inside a heat-isolating tube. Laser beam position oscillations are possibly due to the slow varying air temperature gradients at different place of an air layer column inside a tube. To equalize the air temperature gradients, one proposes to create and to support the laminar air flux inside a tube. Such a temperature smoothening will lead to a more uniform air index refraction distribution along a tube and, consequently, to a more rectilinear laser ray proliferation in an air medium. Photodiode noise level is negligible and does not affect measurement results (Fig. 3, *b*).

4. ON A LARGE DISTANCE METROLOGY

For the recent period a noticeable interest to the laser beam use as a reference line in large distance metrology has appeared. One means here a possibility of the laser ray use in the theodolites and a level not only for distances but also for angles measurements.

In order to get the necessary arguments for the laser beam use in the above-mentioned directions we plan to execute the whole complex of research described in this work but at the 10–100 m distances.

Another research task will be the study of possibilities to increase the long-term stability against temperature deformations of the optic elements forming the laser ray. This last factor directly affects the long-term angular stability of a laser ray position when the ray is used as a reference line.

In our next publication we will propose the measurement set-up for experimental determination of the laser ray positioning precision for large distances.

CONCLUSION

The isolating tube significantly (by a factor of ≈ 10 for DS-670 laser) decreases the laser beam space localization uncertainty:

- The minimal detected DS-670 laser value of a noise laser displacement is found to be $\sigma = 0.6$ μm for distances from 2 up to 6 m.
- A solid state laser is more preferable for use at distances above 1 m.

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Изучение влияния воздушной среды на прямолинейность распространения лазерного луча при его использовании на больших расстояниях и в высокоточной метрологии

Экспериментально изучено влияние турбулентности воздушной среды на точность локализации лазерного луча в пространстве. Для одномодового гелиево-неонового лазера LGN-302 и для многомодового твердотельного лазера DS-670 были определены неточности измерения координаты лазерного пучка с шагом 1 м на расстоянии до 9 м от лазерного источника. Было найдено значение σ на расстоянии 9 м, равное σ (DS-670) = 21 мкм и σ (LGN-302) = 12 мкм. Для уменьшения влияния турбулентности воздушной среды на точность локализации лазерного луча лазерный пучок был помещен внутрь теплоизолирующей трубы. Существенное уменьшение значения σ было достигнуто на расстоянии 9 м от источника: σ^* (DS-670) = 2 мкм и σ^* (LGN-302) = 2,5 мкм. Работа выполнена в рамках подготовки к созданию высокоточной лазерной методики на больших расстояниях с возможным использованием для юстировки компонентов длинного линейного коллайдера.

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A Study of an Air Medium Influence on the Rectilinearity of Laser Ray Proliferation towards the Using for Large Distances and High-Precision Metrology

The influence of a turbulent air medium on a laser beam space localization precision was studied experimentally. For a helium–neon one-mode laser LGN-302 and for a solid-state multimode laser DS-670 the laser ray coordinate measurement uncertainties were determined with 1 m step for the distances up to 9 m from the laser source. It was found that the σ values at 9 m distance are equal to σ (DS-670) = 21 μm and σ (LGN-302) = 12 μm. To reduce the turbulent air medium influence on the laser ray space localization precision, the laser beam was positioned inside a heat-isolating tube. Very significant decrease of σ values was achieved at 9 m from the source: σ^* (DS-670) = 2 μm and σ^* (LGN-302) = 2.5 μm. The work is made within a framework of a preparation to the creation of a high-precision large-distance laser metrology to be possibly used for long linear collider component alignment.

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

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