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PHOTODETECTOR NOISE LIMITATIONS OF THE LASER RAY SPACE LOCALIZATION PRECISION

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INTRODUCTION

The extended laser ray application as a long coordinate (fiducial) line seems to be an attractive idea in many specific tasks of physics, technique and engineering [1, 2]. As an example one may indicate the necessity of a very high precision alignment of many similar structural units of a long accelerator, say, cryomodules of the ILC.

Therefore, this is of a principal significance to investigate the factors limiting a laser ray space localization precision: the coordinates of the objects under alignment are to be measured relative to the laser fiducial line.

The achievable precision of laser ray space localization is limited by many factors. Some of them are noises of the statistic origin; other ones have the systematic nature.

In this paper we report on the results of the study of the noise introduced by the photoreceiver which we use in our experiments [3–5].

1. EXPERIMENTAL SET-UP

We use the experimental set-up with principal scheme shown in Fig. 1. The duant-type photoreceiver PhR [6, 7] consists of two photosensors PhS1 and PhS2, acting independently. These sensors difference signal is used to measure the laser spot position (coordinate).

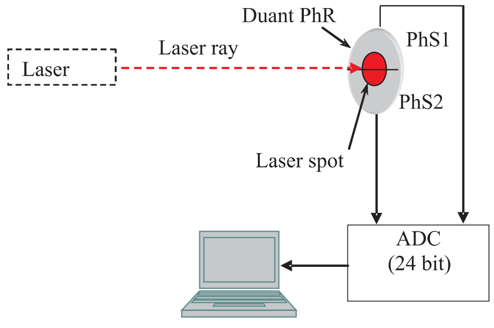

Fig. 1. The block-scheme of an experimental set-up

2. NOISE REGISTRATION WITH THE LASER OFF

In this case no laser light reaches the photosensor which still produces a signal composed of noise of the duant photoreceiver, 50 m long connecting cable noise, ADC card noise, etc.

Four measured «laser off noises» $U_1, U_2, U_1 + U_2$ and $U_1 - U_2$ are written in Fig. 2; the measurement precision was ± 1 μV. Figures 3 and 4 are the same noises but projected on the vertical axis of Fig. 2. The corresponding Gaussian σ's are also indicated in Figs. 3 and 4.

The noise data consideration leads to the following observations:

- The average signal level for each of the four recorded values V_1, V_2, $V_1 \pm V_2$ (20, 30, 50 and 70 μV) is small enough in comparison to about 1 V in case of laser beam registration and therefore for our expectation will not affect the data when laser will be on.
- If signals of Fig. 2 have a statistic origin, their time integrated distributions are expected to be the Gaussian ones. And this is quite the case as follows from the data of Fig. 3.
- If, as we expect, the data from the first and second photosensors are independent, then distributions of the difference and sum of signals are to be Gaussian as it can be seen from Fig. 4. For the same (independence)

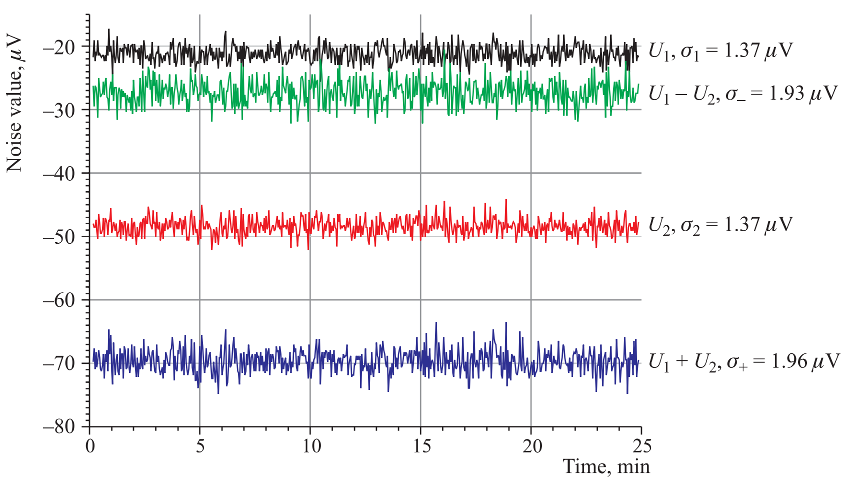

Fig. 2. The noises of the first U_1 and of the second U_2 photosensors; their difference $(U_1 - U_2)$ and sum $(U_1 + U_2)$. The laser beam is switched off. For σ's see Figs. 3 and 4

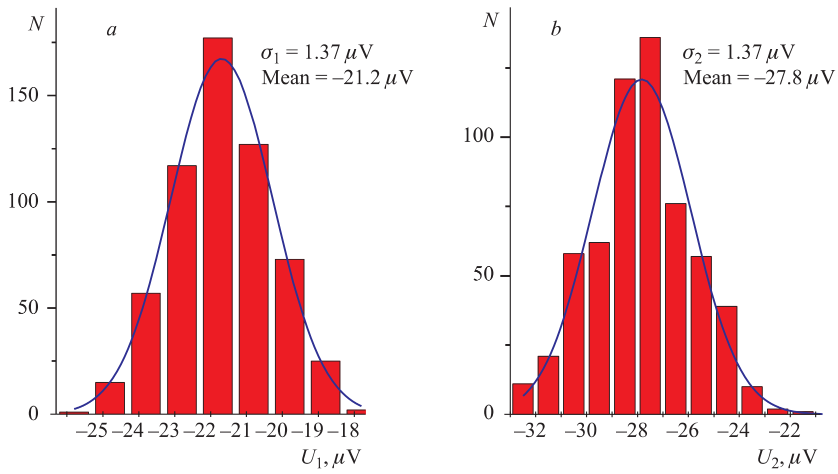

Fig. 3. *a*) Distribution of U_1 — noise of the first photosensor (25 min measurements). *b*) Distribution of U_2 — noise of the second photosensor (25 min measurements)

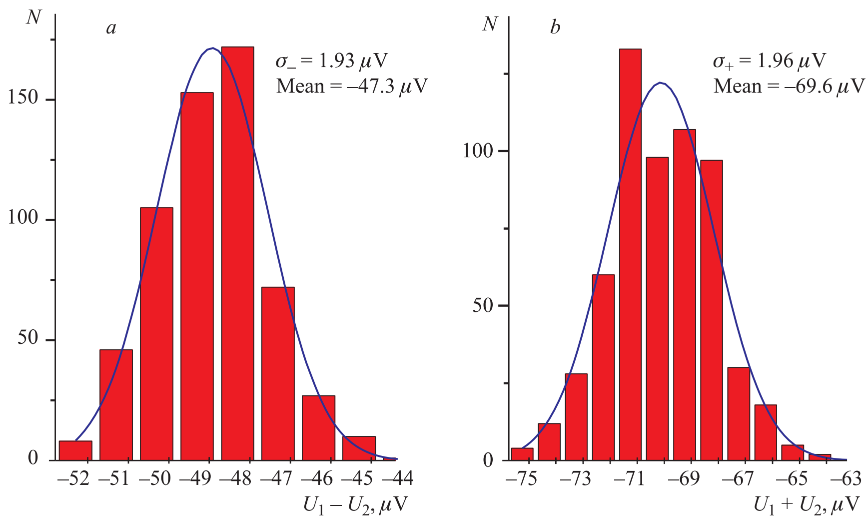

Fig. 4. *a*) Distribution of the difference $U_1 - U_2$ of noises of the first and second photosensors (25 min measurements). *b*) Distribution of the sum $U_1 + U_2$ of noises of the first and second photosensors (25 min measurements)

reason the sigma values in Fig. 4 are the summed quadratically sigmas of Fig. 3 and this is the case: $\sigma_- = 1.93\ \mu$V and $\sigma_+ = 1.96\ \mu$V.

3. THE LASER BEAM SPACE «PSEUDO DISPLACEMENT» DUE TO LIGHT DETECTOR NOISE

The photosensors noises contribute to the laser beam space coordinate uncertainty when laser is on. The sigma of a difference signal for 25 min observation period is $\sigma_- = 1.93\ \mu$V. We are interested to transfer this figure to the uncertainty ΔL_N of the laser beam space position. This transfer depends on conditions of a laser beam registration by the duant photoreceiver: beam spot diameter D_L and summed signal U from both photosensors when irradiated by laser.

Let us consider the virtual experiment: Fig. 5 shows the laser spot position on the duant photoreceiver. By the micrometric screw the spot is biased on the known distance ΔL relative to the AB line separating both halfs of photoreceiver.

As the total signal U from the photoreceiver is proportional to its area lightened by laser and $\Delta L \ll D_L$ we have

$$\frac{\Delta S}{S} \approx \frac{\Delta U}{U}, \tag{1}$$

with $\Delta S = 2D_L \cdot \Delta L$ as a difference in the lightened photoreceiver area when laser axis is biased on a ΔL distance in our virtual experiment. The full area of the lightened photoreceiver is $S = \pi D_L^2/4$, and ΔU is the difference of two photosensors signals when laser displacement. The sum of both sensors sig-

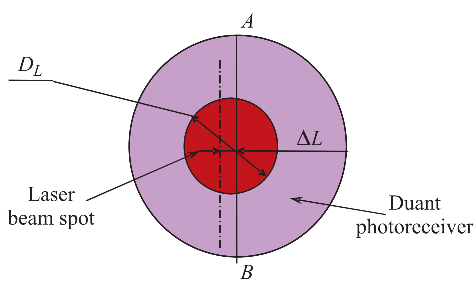

Fig. 5. The laser ray spot position on the duant photoreceiver

nals U corresponds to the laser beam power and does not depend on beam displacement on the photoreceiver surface.

Having measured (with laser off) the noise signal $U_1 - U_2$ with $\sigma_- = 1.93\ \mu$V one may estimate from (1) the expected noise originated uncertainty ΔL_N introduced to the registered (in reality) laser beam displacement on the duant photoreceiver:

$$\Delta L_N \approx \frac{\pi}{8} D_L \frac{\Delta U}{U}. \tag{2}$$

For the typical figures with laser beam diameter $D_L = 1$ cm, summed signal $U = 1$ V from photoreceiver lightened by the laser and taking, say, «3σ level» for the noise signal $\Delta U = 3\sigma_- = 5.79\ \mu$V one gets from (2) the estimate of the ΔL_N value: $\Delta L_N \approx 2.3 \cdot 10^{-8}$ m.

Together with ΔL_N it is also useful to determine a laser direction angular uncertainty $\Delta\alpha_N \cong \Delta L_N / L$; with, say, $L = 100$ m distance between laser source and the photoreceiver one gets $\Delta\alpha_N = 2.3 \cdot 10^{-10}$ rad.

CONCLUSION

The uncertainty introduced in our measurements by the photoreceiver noise to the laser beam position or direction is quite small and expectedly will not affect in practically important situations. Indeed, the $\sim 10^{-10}$ rad level is far lower of the limits one might meet in the majority of real tasks.

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Батусов В. и др. E13-2008-90

Ограничение точности пространственной локализации оси лазерного луча шумом фотодетектора

Исследована неопределенность в пространственной локализации луча лазера, вносимая шумом дуантного фотосенсора; эта величина составляет 10^{-8} м.

Работа выполнена в Лаборатории ядерных проблем им. В. П. Джелепова ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2008

Batusov V. et al. E13-2008-90

Photodetector Noise Limitations of the Laser Ray Space Localization Precision

The laser ray space localization uncertainty introduced by the noise of the laser spot registering duant photoreceiver has been studied and found to be of the order of 10^{-8} m.

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

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