Spatial Stability Investigating and Angular Orientation Ensuring of the Laser Beams of a Dual-channel LMS

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***Abstract* — Laser measuring systems take a significant role in the measurement of large-scaled objects and facilities. In order to evaluate the metrological and operational characteristics of the developed dual-channel laser measurement system, the main influencing factors were investigated. The object of this paper are the results of the study of the spatial stability and ensuring the angular orientation of the laser beams, as well as the stability of the support modules of the optical transducers of the system.**

Keywords: laser measurement system, form deviations, mutual arrangement, angular orientation, spatial stability.

I. Introduction

The deviations of the form, location and orientation of flat surfaces are basic geometric parameters characterizing the quality of a number of mechanical engineering products.

The use of universal measuring tools and coordinate-measuring systems [17, 21] does not always ensure the necessary accuracy and performance of the measurement process, as well as its expediency. This necessitates the search for solutions adequate to these requirements, i.e. the development of relevant methods and systems for their implementation [12, 13, 14, 18, 20].

The financial side is essential, determined by the high price of both the measuring system and the measured object.

The issues of measuring the deviations of the form and mutual location [9] of large-sized objects and facilities are of essential importance for a number of enterprises from the transport and heavy engineering and energy industries. Solving such metrological problems is possible through the use of laser measurement systems (LMS) [1, 15]. The paper presents the results of the study of the spatial stability and ensuring the angular orientation of the laser beams, as well as the stability of the support modules of the optical transducers of the system.

II. Dual-channel Laser Measuring System

The dual-channel LMS developed by the R&D Lab "CMME" of TU-Sofia is a basic element of the metrology assurance of the installation of the distribution modules of the accelerator's waveguide distribution system [2, 4, 15].

The schematic diagram of the system is shown in Fig. 4.

The beam emitted from the laser unit 1 is separated from the polarizing beam splitter (cube prism) into two orthogonal polarized beams, one of which is positioned parallel to the other beam by means of the reflecting prism 4. The parallelism of the two measuring channels (the two beams) is adjusted by the wedge compensator 3. The beams are reflected by retro-reflectors 7 (triple prisms) and after reflection respectively by prism-cube 2 (beam I) and prism 4 (beam II) going over the surface of position sensing detector (PSD) 8.

The polarization compensators 5 and 6 (plates $\lambda/4$) are introduced at the input of the beams to rotate the polarization plane. The switching of the two measuring channels is carried out by means of the polarization filter 9.

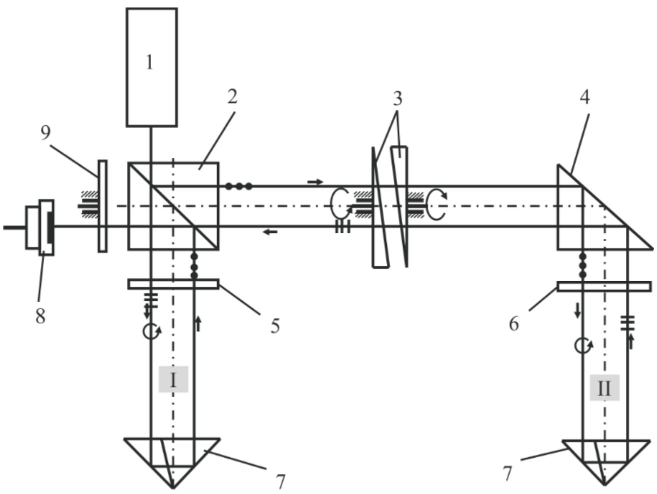

Fig. 1 Dual-channel LMS - schematic diagram: 1 - laser diode with collimating system; 2 - polarizing beam splitter; 3 - wedge compensator; 4 - reflective prism; 5 and 6 $\lambda/4$ plates; 7 - retro-reflector (triple-prism); 8 - PSD; 9 - polarizing filter

III. Investigation of the Spatial Stability of the Energy Axis of Laser Beams

The process of measuring large-scaled objects and facilities with the dual-channel laser measurement system is lengthy. At the same time, the influence of temperature change, etc. environmental factors lead to shifts, mostly angular (drift), of the position of the reference energy axis, which in some cases lead to significant errors in the measurement result.

One of the main sources of errors [7] when measuring with systems based on the energy axis of the laser beam is the spatial instability of the axis.

When using a laser diode and an electronic block for processing the signals from the PSD with the corresponding filtering, the influence of the high-frequency instability (spatial and power) of the laser radiation is eliminated.

During long-term measurements, the measurement results will be affected by the slow change in the position of the beam axis due mainly to temperature deformations of the mechanical components of the system.

The spatial instability of the axis of the laser beam emitted by the developed LMS is investigated according to the scheme of Fig. 2.

The optical transducers (triple-prisms) are established in the two measurement channels in point A and point B, respectively, located at distances Y_A and Y_B, respectively, from the output window of the first channel of the light-splitting unit.

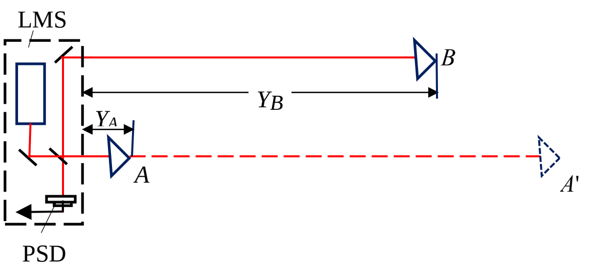

Fig. 2 Schematic of the study of the spatial instability of the laser beam

An implementation of the study of the spatial instability of the laser beam is presented in Fig. 3.

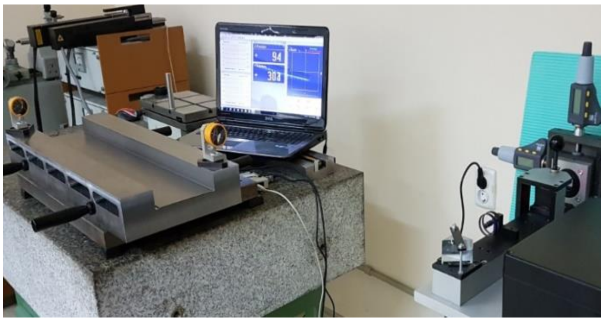

Fig. 3 Realization of laser beam spatial instability study

The research was conducted by measuring the *X* and *Z* coordinates of point *A* and point *B*, at equal time intervals (15 min), for 3 hours from the moment the laser was turned on. The measurement results are presented in Fig. 4.

Based on the obtained results for the displacement of the center of the laser beam in the plane of the characteristic point of each of the transdusers, the transverse displacements δ*X*, and δ*Z* of the center of the beam in the output window of the first channel and the angular displacements α_X, α_Z of the beam in *XOY* planes were determined and *ZOY* by the formulas:

$$\left.\begin{aligned} \alpha_Z &= \frac{X_B - X_A}{Y_B - Y_A} \\ \alpha_X &= \frac{Z_B - Z_A}{Y_B - Y_A} \end{aligned}\right\} \qquad (1)$$

$$\left.\begin{aligned} \delta X &= X_A - \alpha_X Y_A \\ \delta Z &= Z_A - \alpha_Z Y_A \end{aligned}\right\} \qquad (2)$$

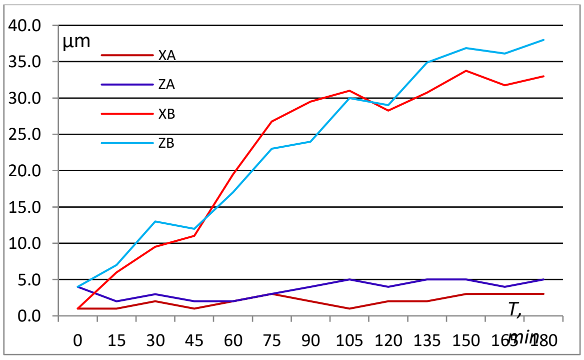

Fig. 4 Measured coordinates of point A and point B in the study of the spatial instability of the laser beam for 3 hours

Based on the measurements made and the results obtained, the translational and angular displacements of the energy axis of the laser beam were determined when placing the two retroreflectors respectively at a distance of 500 mm for item *A* of the first measurement channel and 2500 mm for item *B* - for the second measurement channel. The results are presented in Fig. 5.

Fig. 5 Spatial instability of the laser beam axis

The analysis of the results shows that when measuring large objects, the influence of angular displacements is significant.

The influence of reference energy axis drift can be minimized by tracking the position of the beam axis using additional (corrective) retro-reflectors

IV. Providing the Spatial Position of LMS Laser Beams

A basic requirement for the spatial position of the laser beams in the two measurement channels is the requirement for parallelism of their energy axes.

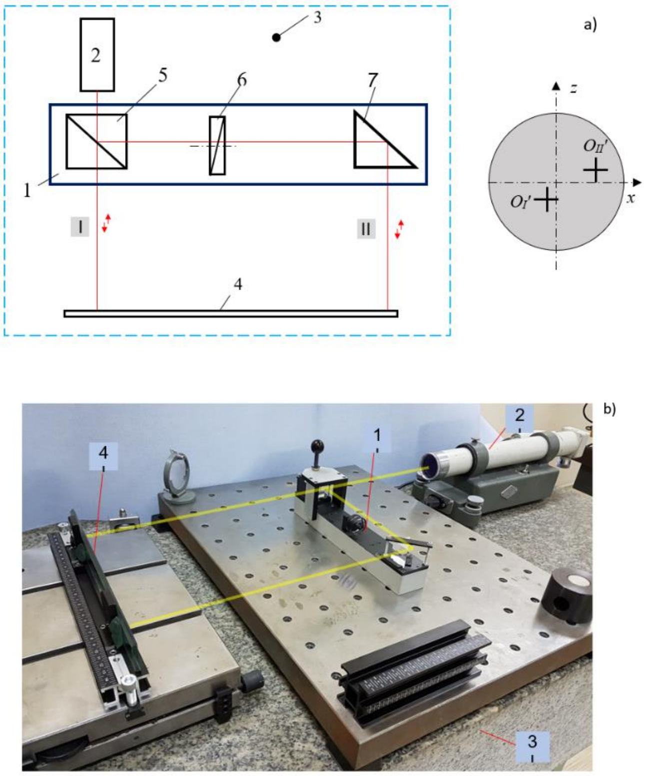

Fig. 6 Autocollimation system for adjusting the beam splitter and checking the parallelism of the laser beams: a) schematic diagram; b) experimental setup

The common plane defined by the two energy axes should nominally lie in the *XOY* coordinate plane of the LMS.

To satisfy these requirements, two schemes have been developed for the adjustment of the measuring channels of the system.

When implementing the first scheme, the adjustment and control of the parallelism of the channels is carried out using the principle of autocollimation (Fig. 6) [1, 21].

The parallelism of the axes of the two laser beams is achieved with the help of the wedge compensator 6 introduced in the direction of beam II. The beam-splitting block 1 and the autocollimator 2 are based on the granite table 3. The flat mirror 4 is established nominally perpendicular to the main plane of the beam-splitting system.

The beam emitted by the autocollimator 2 is split by the beamsplitter 5 into two beams. One beam (beam II) passes through the two-wedge compensator 6, is reflected by the prism 7 and is turned directly to the mirror 4, while beam I is going directly to it. After reflection from the mirror 4, the beams form two autocollimation images O_I' and O_{II}' in the focal plane of the lens of the autocollimator 2. The deviation from parallelism of the channels is determined by the displacement of one image relative to the other in two mutually perpendicular directions - horizontal (*OX*) and vertical (*OZ*) direction (Fig. 6a). By rotating one wedge relative to the other and rotating them around the axis of the compensator, the two autocollimation images O_I' and O_{II}' are aligned, thereby achieving parallelism of the laser beams coming out of the beam splitting unit. The accuracy of the beam splitter adjustment is determined by the resolution ψ of the autocollimator used.

When implementing the second scheme, the parallelism of the axes of the two channels is checked by the autoreflection method [1, 21] according to the scheme presented in Fig. 7.

In this case, the LMS and the flat mirror 4 are based on the granite table 3. The mirror 4 is located from the beam-splitting block 2 at a distance *L*, significantly greater than the distance *b* between the two channels (*L* >> *b*), and is oriented nominally perpendicular to laser beams I and II.

Channel I is switched on and the coordinates x_I, z_I of the center of the laser spot of beam I reflected by the mirror (beam I′) are measured. Channel II is switched and the coordinates x_{II}, z_{II} of the center of the laser spot of the reflected beam II (beam II′) are measured. By the differences $\Delta x = x_{II} - x_I$ and $\Delta z = z_{II} - z_I$, the deviations from parallelism of the channels β_x in the common plane *XOY* and β_z in the plane *ZOY* are determined:

$$\left.\begin{array}{l} \beta_x = \dfrac{\Delta x}{2L_R} \\[2ex] \beta_z = \dfrac{\Delta z}{2L_R} \end{array}\right\}, \qquad \text{(IV.1)}$$

where L_R is the distance from the mirror to the PSD.

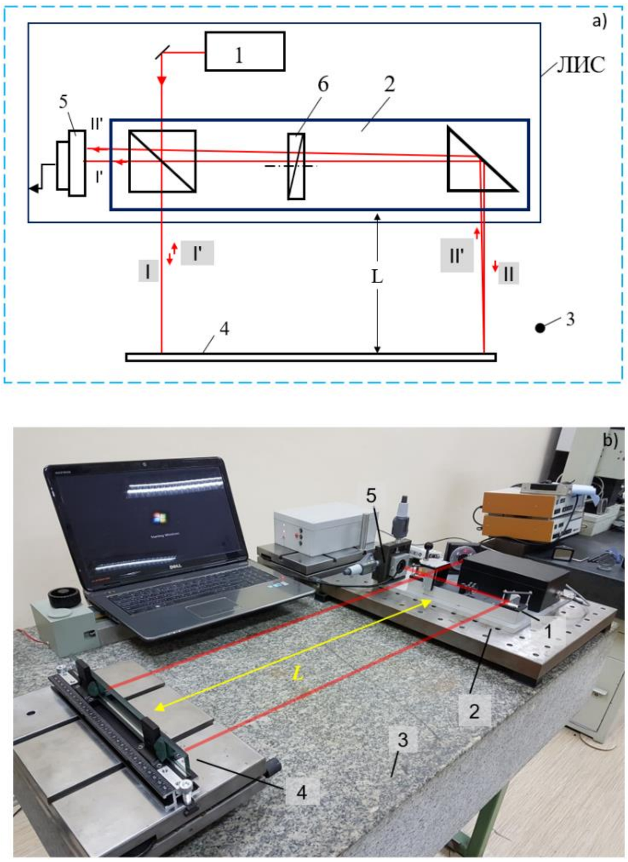

Fig. 7 System for adjusting the light-splitting block and checking the parallelism of the laser beams using the autoreflection method: a) principle scheme; b) experimental setup

With the help of the wedge compensator, matching of the centers of the two reflected beams is achieved, corresponding to the parallelism of the channels.

V. Investigation of the Stability of the Based Modules of the Optical Transducers

When measuring with the developed LMS, the accuracy of basing the optical transducers (OT) in the measurement position is of essential importance for the accuracy of measuring the form and arrangement of the surfaces. As a criterion for evaluating the accuracy of basing, the repeatability of the results during repeated positioning [6, 8, 19] of the optical transducer in a measurement position, evaluated by the root mean square deviation, was used. The developed modules for basing the optical converters of the systems have been studied [3, 5].

Research based on the optical transducer of LMS for measurement of form deviations

The optical transducer supporting system for measuring the form deviations of planar surfaces is investigated. The base module (Fig. 8 a) with the optical transducer (triple-prism) is positioned *n* times at the same point of the investigated surface ($n \geq 20$). Coordinates in vertical direction Z_i ($i = 1...n$) are measured and their average value and root mean square deviation σ_z are calculated. The obtained repeatability results (rms deviation $\sigma_z = 1.25$ µm) confirm the capabilities of the system to meet the accuracy requirements arising from the measurement objects [10].

Research based on OP to measure the location of planar surfaces

The sphere-based V-channel optical transducer basing system (Fig. 8) designed to measure displacement on planar surfaces is investigated. The support module with the optical transducer (PSD/triple-prism) is positioned *n* ($n \geq 20$) times on the three spheres embedded in the plate, implementing the kinematically defined connection. The coordinates X_i, Z_i ($i = 1...n$) of the characteristic point of the optical transducers (triple-prism) are measured and the average values and the root mean square deviations σ_Z and σ_X are calculated.

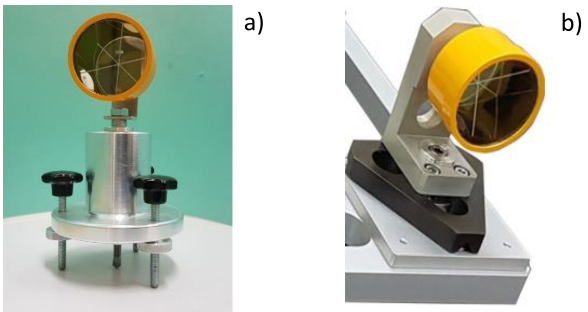

Fig. 8 Supporting modules of the optical converters: a) to measure deviation from flatness; b) to measure the arrangement of surfaces

The obtained results for the mean square deviations in both directions ($\sigma_x = 0.97$ µm and $\sigma_z = 1.38$ µm) confirm the system's ability to meet the accuracy requirements arising from the measurement objects [11, 16].

VI. Conclusion

The developed dual-channel laser measurement system for assessing the form, location and orientation of large-sized objects or details with flat surfaces was investigated.

The spatial stability of the laser beam was evaluated in order to evaluate the translational and angular displacements of the beams.

The stability of the support modules of the optical transducers was investigated. The obtained results confirm the capabilities of the system to meet the accuracy requirements for the form, location and orientation deviations arising from the measurement objects.

Two schemes are proposed to ensure the spatial position and, more specifically, the parallelism of the energy axes of the LMS's laser beams in the two measurement channels - based on the principle of autocollimation and based on the autoreflection method.

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