Dual-channel Laser Measuring system Study

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Abstract* — *The assessment of metrological and operational characteristics of measuring systems are of the main importance. The subject of this paper are the results of the accuracy characteristics study of the developed dual-channel laser measuring system for measuring the centering and angular orientation of flat surfaces.

Key words:* *laser measurement system, accuracy assesment, mutual location, angular position.

INTRODUCTION

In mechanical engineering practice, the installation of new equipment, as well as the operation of a number of facilities, often requires centering and adjustment of objects or parts with flat surfaces. These processes are invariably related to the measurement and control of the relative position of these surfaces. Such measurements become especially important in heavy engineering and energy, where it is necessary to control the centering and angular orientation of individual components. In the most cases, they are required to be parallel to their axes and their centers to lie on one line, i.e. the flat surfaces must be in one plane. This is essentially a serious metrological problem. The application of universal measuring instruments is not always possible and economically unjustified.

Solving such metrological problems is possible through the use of laser measuring systems (LMS). Of particular importance is the assessment of the metrological and operational characteristics of these systems. The paper presents the results of the study of the accuracy characteristics of the dual-channel laser measuring system developed in R&DLab "CMME" at TU-Sofia [2] for measuring the centering and angular position of flat surfaces.

DUAL-CHANNEL LASER MEASUREMENT SYSTEM

The schematic diagram of the dual-channel laser measuring system is shown in Fig.1. The system contains the following main modules: laser diode emitting unit *1*, reflector *10*, light dividing unit *2*, wedge compensator *3*, reflector *4*, polarizing compensators *5* and *6*, measuring retro-reflectors *7* and *11*, PSD *8*, and polarizing filter *9*.

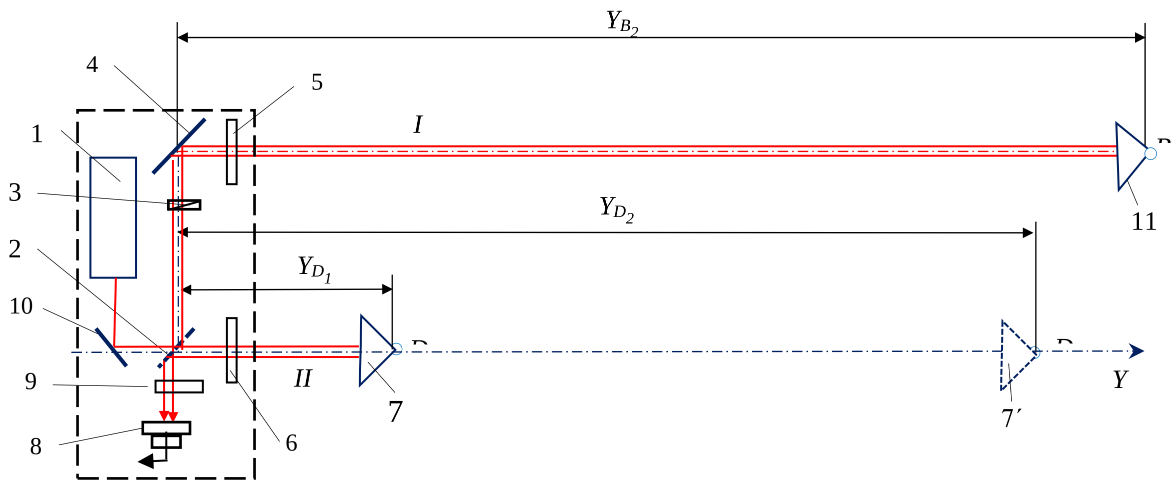

Fig. *1* Dual-channel laser measurement system for mutual position ot flat surfaces control

The beam emitted by the laser unit *1*, reflected by the reflector *10*, is divided by the beam splitter *2* into two orthogonally polarized beams, one of which oriented parallel to the other beam by means of the reflecting prism *4*. The parallelism of the two measuring channels (*I* and *II*) is adjusted with the wedge compensator *3*. The beams are reflected by the retroreflectors *7* and *11* (triple prisms) and after reflection by the beamsplitter 2 (beam I) and the reflector *4* (beam *II*) respectively point to the photodetector module with PSD *8*. In the beams directions the polarization compensators *5* and *6* (plates λ / 4) are introduced for rotation of the plane of polarization.

The switching between the two measuring channels is performed by means of the polarizing filter *9*.

EXPERIMENTAL STUDY OF THE LMS

The experimental study of the dual-channel LMS was performed by repeated measurement of attested surfaces of a specially developed experimental construction (Fig. 2).

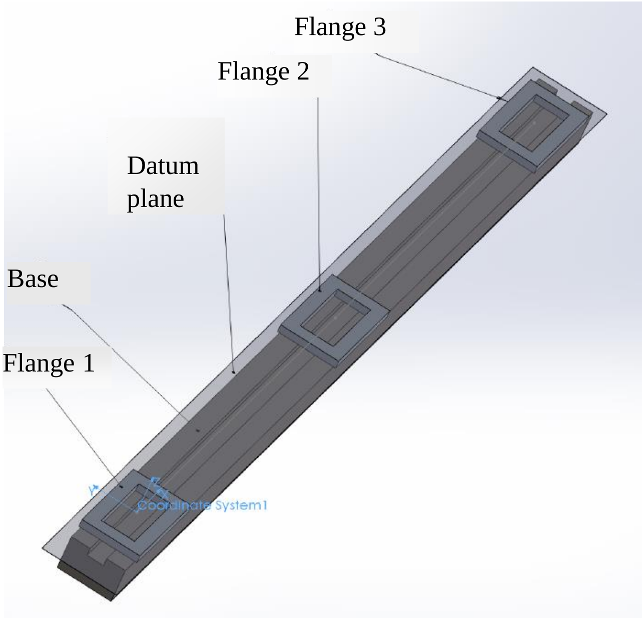

Fig. 2 Basic elements of the experimental construction

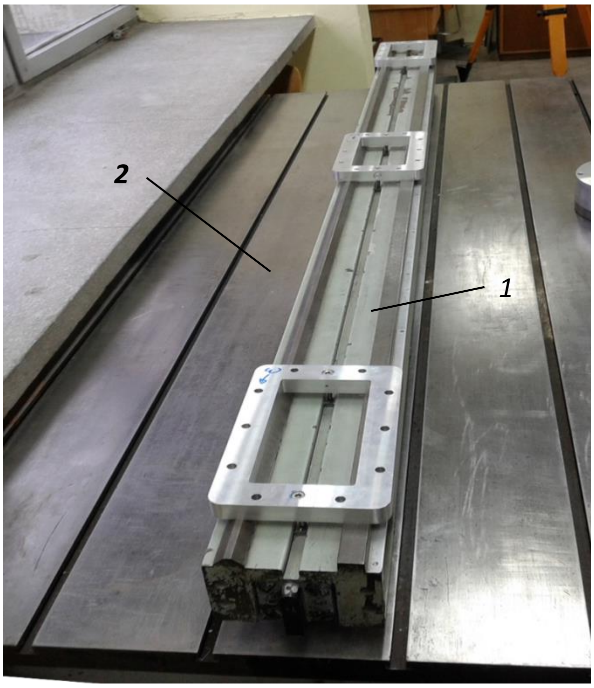

Fig. 3 Experimental construction realization

The experimental construction was designed to study the method for measuring the mutual position of flat surfaces which nominally lie in one plane and their centers lies on one line. The aim is to provide positioning of a number of identical parts in a way that allows the measurement of the mutual position and angular orientation of their flat surfaces (nominally lying in one plane) with respect to a given basic coordinate system.

The experimental construction, consisting of three flanges mounted on a common base, is realized on the support beam *1* with a linear guide with dimensions 2000x130 mm (Fig. 3) and is mounted on a massive measuring table 2 with dimensions 2000x1000 mm.

The experimental details and constructions are attested with coordinate measuring machines. This allows their use as working standards in the assesment and calibration of measuring systems.

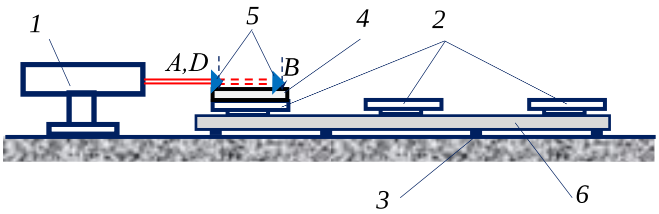

Fig. 4 Measurement scheme

A measurement scheme is shown in Fig.4. For conducting research on laser measuring technology was developed system based on experimental design, enabling the realization of different mutual positions of the flanges *2* by deformation of the supporting beam *6* by means of set screws *3*

Fig. 5 Experimental setting

A tripod with LMS position *1* is mounted on the massive measuring table.

By means of the adjusting mechanisms of the LMS tripod, the laser beams are oriented nominally parallel to the flat surfaces and symmetrically to the line of the centers (common axis) of the flanges *2*.

On the measured flange j (j = 1… 3) the datum element 4 is established and the retroreflector *5* is positioned sequentially in p. A_j, p. B_j and p. D_j, identically located with respect to the centers C_j and the axes of symmetry - the coordinate axes ξ_j and η_j on the surfaces so that the three points to lie down on two mutually perpendicular lines ($A_jB_j \perp A_jD_j$), and the point C_j is the middle point for the hypotenuse A_jD_j (Fig. 6). The points A_j and D_j are located symmetrically with respect to the axis η_j and at a distance M from each other, coordinated with the distance between the LMS channels, and the p. B_j and p. A_j are symmetrical with respect to the axis ξ_j and at a distance L / 2 from it. The centers C_j of the measured surfaces lie nominally on a straight line and at a distance T_j from the center of the first surface C_1.

The coordinates X_{Aj}, Z_{Aj}; X_{Bj}, Z_{Bj}; X_{Dj}, Z_{Dj} are measured at points A_j, B_j and D_j relative to the *XYZ* coordinate system of the LMS, determined by the energy axes of the laser beams of the two measuring channels of the system.

The results of the measurement of the coordinates X_{Aj}, Z_{Aj}; X_{Bj}, Z_{Bj}; X_{Dj}, Z_{Dj} of the points on the surfaces of the flanges of the experimental construction are given in Table I, indicating the average results of 10 consecutive measurements of the coordinates of the points

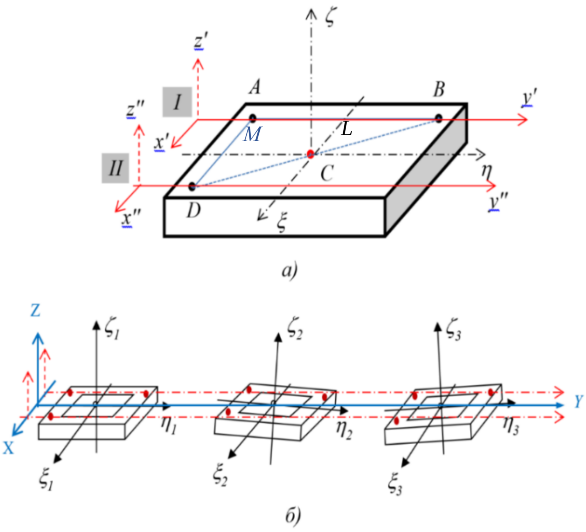

Fig. 6 Elements of the measured surfaces

TABLE I MEASUREMENTS OF THE COORDINATES OF P. *A*, P. *B* AND P. *D*

Flange №	X_A	Z_A	X_B	Z_B	X_D	Z_D	X_C	Y_C
1	110,127	0,099	110,607	0,086	-109,873	0,001	0,127	0,093
2	110,588	0,948	110,779	0,912	-109,412	0,928	0,588	0,930
3	110,626	0,583	111,400	0,500	-109,374	1,054	0,626	0,542

The coordinates of the center of the j^{th} flange in the *XYZ* system are determined by the formulas:

$$\begin{cases} X_{C_j} = \frac{X_{A_j}+X_{D_j}}{2} \\ Z_{C_j} = \frac{Z_{A_j}+Z_{D_j}}{2} \end{cases} . \qquad (1)$$

To determine the angular displacements α_{Xj} (rotation about the *OX* axis), α_{Yj} (rotation about the *OY* axis) and α_{Zj} (rotation about the *OZ* axis) the dependences are used:

$$\begin{cases} \alpha_{X_j} = \frac{Z_{B_j}-Z_{A_j}}{L} \\ \alpha_{Y_j} = \frac{Z_{A_j}-Z_{D_j}}{M} \\ \alpha_{Z_j} = \frac{X_{B_j}-X_{A_j}}{L} \end{cases} , \qquad (2)$$

where L is the distance between point A and point B, and M is the distance between point A and point D. For the developed support element L = 220 mm; M = 220 mm.

The research was carried out by comparing the results obtained during the processing of the primary measurement information and the results of the performed attestation of the examined surfaces.

The comparison was made in the implementation of three different datum lines used in the creation of the coordinate system used to assess the mutual position of the individual components:

- mean line of the three centers, determined by the least squares method;
- a straight line joining the centers of the two end flanges of the structure;
- line determined by the position of one of the flanges.

The choice of datum line is determined by the specifics of the measured object and the specifics of the operational requirements imposed on it.

Table II shows the results of the processing of the primary measurement information for the coordinates X_{Aj}, Z_{Aj}; X_{Bj}, Z_{Bj}; X_{Dj}, Z_{Dj} of the points and the estimation of the position of the surfaces of the flanges in the coordinate system *XYZ*, as well as the displacement of the location of their centers (decentralization) in planes *XOY* and *ZOY* relative to their common axis, respectively deviations from straightness EFL_X and EFL_Z. The common axis is defined as the mean line by the least squares method. The centering of the surfaces is estimated by the deviation from the straightness of the centers relative to the datum line (axis) and the angular displacements (rotation) of the surfaces around the axes of the coordinate system, the axis *OY*, which coincides with the datum axis, and the axis *OX* lies in the plane Σ_o.

The obtained results show that the maximum differences between the deviations from straightness when measured with LMS and when attesting the experimental construction are ΔEFL_X = 0,004 mm in the *XOY* plane and ΔEFL_Z = 0.006 mm in the *ZOY* plane, and the maximum differences in the rotations around the respective axes are - $\Delta\alpha_X = 4''$, $\Delta\alpha_Y = 6''$ и $\Delta\alpha_Z = 5''$.

TABLE II POSITION OF FLANGE SURFACES IN THE *XYZ* COORDINATE SYSTEM WHEN THE DATUM LINE IS MEAN LINE DETERMINED BY THE LEAST SQUARES METHOD

Flange №	Measured by LMS					Attestation				
	EFL_X, mm	EFL_Z, mm	α_X	α_Y	α_Z	EFL_X, mm	EFL_Z, mm	α_X	α_Y	α_Z
1	-0,073	-0,201	1′13″	1′31″	6′29	-0,067	-0,205	1′17″	1′35″	6′26″
2	0,138	0,398	1′34″	4′11″	1′52″	0,134	0,403	1′35″	4′5″	1′57″
3	-0,074	-0,218	-2′18″	27″	10′56″	-0,070	-0,224	-2′15″	23″	10′59″

TABLE III POSITION OF THE FLANGE S SURFACES IN *XYZ* SYSTEM WHEN THE DATUM LINE JOINING THE CENTERS OF TWO END FLANGES

Flange №	Measured by LMS					Attestation				
	EFL_X, mm	EFL_Z, mm	α_X	α_Y	α_Z	EFL_X, mm	EFL_Z, mm	α_X	α_Y	α_Z
1	0	0	1′25″	1′45″	6′37″	0	0	1′ 29″	1′ 43″	6′ 39″
2	0,212	0,598	1′46″	4′24″	2′1″	0,205	0,607	1′ 48″	4′ 17″	2′ 7″
3	0	0	-2′31″	41″	2′14″	0	0	-2′23″	36″	2′17″

The values of angular deviations and decentering given in Table III are defined in the *XYZ* system, the *OY* axis of which is set by the line joining the centers of the two end flanges.

In this case, the results show that the differences between the deviations from straightness (in Flange 2) when measured with LMS and when attesting the experimental construction are ΔEFL_X = 0,007 mm in the *XOY* plane and ΔEFL_Z = 0,009 mm in the *ZOY* plane, and the maximum differences in rotations around the corresponding axes are - $\Delta\alpha_X$ = 8″, $\Delta\alpha_Y$ = 7″ and $\Delta\alpha_Z$ = 6″.

Table IV shows the values for the linear and angular displacements of Flanges 2 and 3 relative to the axis of the assumed datum Flange 1, determined by the formulas:

$$\begin{cases} \overline{X}_{C_j} = X_{C_j} - \left[X_{C_1} + \alpha_{Z_1}.\left(Y_{C_j} - Y_{C_1}\right)\right] = \overline{EFL}_X \\ \overline{Z}_{C_j} = Z_{C_j} - \left[Z_{C_1} + \alpha_{X_1}.\left(Y_{C_j} - Y_{C_1}\right)\right] = \overline{EFL}_Z \end{cases} \quad (3)$$

$$\begin{cases} \overline{\alpha}_{X_j} = \alpha_{X_j} - \alpha_{X_1} \\ \overline{\alpha}_{Y_j} = \alpha_{Y_j} - \alpha_{Y_1} \\ \overline{\alpha}_{Z_j} = \alpha_{Z_j} - \alpha_{Z_1} \end{cases} \quad (4)$$

The results obtained when estimating the deviations from one datum flange (Flange 1) show that the maximum differences between the deviations from straightness when measured with LMS and when attesting the experimental construction are ΔEFL_X = 0,008 mm in the *XOY* plane and ΔEFL_Z = 0,012 mm in the plane *ZOY*, and the maximum differences in the rotations around the respective axes are - $\Delta\alpha_X$ = 6″, $\Delta\alpha_Y$ = 9″ and $\Delta\alpha_Z$ = 7″.

TABLE IV LOCATION OF FLANGES ACCORDING TO FLANGE 1 AS A DATUM ELEMENT

Flange №	Measurement with LMS					Attestation				
	EFL_X, mm	EFL_Z, mm	α_X	α_Y	α_Z	EFL_X, mm	EFL_Z, mm	α_X	α_Y	α_Z
2	-1,804	0,947	2′ 17″	2′35″	7′16″	-1,796	0,939	2′12″	2′ 30″	7′ 23″
3	-3,193	0,751	1′53″	1′21″	3′31″	-3,187	0,739	1′59″	1′ 12″	3′24″

Based on the results obtained for the mutual arrangement of the flanges in the considered three variants for assessment of the respective datum line, it can be seen that the largest difference in deviations when using one of the flanges as datum, and the smallest when using median line joining the centers and defined by the least squares method.

CONCLUSION

A dual-channel laser measuring system has been developed to assess the mutual position during the alignment and adjustment in the process of operation of objects or parts with nominally lying in one plane flat surfaces.

The realized laboratory model of dual-channel LMS is studied by comparing the results of measuring the mutual arrangement of the flanges (deviation from straightness and angular orientation of the functional surfaces) of the developed experimental construction with the results obtained during its attestation.

In the considered three variants for evaluation in relation to the respective datum line, it is seen that the largest difference in the deviations when using one of the flanges as a datum, and the smallest when using median line joining the centers defined by the least squares method.

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