THE ACCURACY OF LASER BEAM DETECTION IN THE ALIGNMENT METHOD

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1. INTRODUCTION

The alignment method is used in surveying as setting out of machines’ axes or liner engineering constructions. It is applied in surveys of geometry or displacements of elongated structures or others as bridges, cranes, rotated furnaces, crest of dams, embankments of reservoirs. The application of the method involves a realization of a reference line (a surveying one) during surveys located in the object axis (or parallel to it). Such a line can be determined by a line of sight of geodetic instruments, thin steel wire or laser beam. Distances to marks or to certain construction elements of surveyed structures as measured perpendicularly from such a line. The distances are measured directly on linear scales or indirectly with the use of opt electronics sensors. There are laser interferometers are used in precise measurements. Currently, the alignment method is used rarely. It was replaced by methods utilizing electronic tachimeters or GPS techniques. So, it is applied in cases, when the use of mentioned methods is impossible, they are carried out with insufficient accuracy or widen range of information about object as its displacement kinetics is needed. The paper presents examples of this method applications and a survey system carrying out the measurements.

2. THE ALIGNMENT METHOD WITH COMPUTER SYSTEM OF LASER BEAM DETECTION

In the discussed method a survey line is determined by laser beam and a distance (d) from the mark to laser beam is determined by computer with the use of detector with CCD matrix [Jóźwik 2008a]. The scheme of performance of measurements is presented on Fig. 1.

![Fig. 1. The Scheme alignment method with laser application.](image-url)
The distance \( d \) between mark and laser beam is determined from a difference of coordinates on CCD matrix – the center of laser beam and the center of detector axis. The coordinates of detectors axis on the matrix are an constant of its construction. It is determined during test surveys in laboratory. The coordinates of the center of laser beam is automatically determined on the base of computer analysis of the laser spot falling on CCD matrix. They are calculated in the used technique as coordinates of the center of area contoured by laser spot. The components of a distance (\( d \)) in the coordinate system of CCD matrix are calculated according to formulas:

\[
\begin{align*}
X_i &= X_i - X_0, \\
Y_i &= Y_i - Y_0,
\end{align*}
\]

where:

- \( X_i, Y_i \) - coordinates of the center of laser beam on CCD matrix,
- \( X_0, Y_0 \) - coordinates of the center of detector on CCD matrix (a constant of construction).

The average error of determination of mentioned above parameters with a presumption of error-free constants will equal the error of the center or laser beam on CCD matrix. The detection system was involved to determine this accuracy (Fig. 2.).

![Fig. 2. The Scheme of laser beam detector.](image)

The frequency of determination and recordings of coordinates (\( X, Y \)) of laser beam center from the CCD matrix on the computer disc was in the used detector 12 Hz. The laboratory determined resolution of the device corresponding to 1 pixel was 0.06 mm. During measurements the values of the laser beam center coordinates are recorded. The description and results of the study with accuracy of the laser beam detection with several examples of application of the detector are presented further on.

3. THE ACCURACY OF LASER BEAM DETECTION WITH EQUIPMENT OF CCD MATRIX

The accuracy of laser beam detection was determined on the base of the field surveys. The relied on several minutes recordings of coordinates of the laser beam center on a disk of portable computer.

The measurements were carried out at various atmospheric conditions and at various distances between the detector and laser. In day time conditions the maximum range of surveys with the use of semiconductor laser with the power of 1mW was 180 m. The
surveys were carried out at distances: 50, 100, 150 and 180 m. The results are presented further on. The exemplary distributions of a laser beam locations in vertical direction, on stationary detector in 5 minutes time interval are presented on Fig. 3. For the 12 Hz frequency recordings a collection of 3600 coordinates (x,y) of the laser beam center was obtained. The analysis of the results confirmed to phenomenon known in physics of atmosphere escalation of amplitudes of fluctuation of laser beam location on detector according to increase of the distance.

Fig. 3. The displacements of laser beam In vertical direction in 5 minutes observations. a) on a distance of 50m, b) on a distance of 180m.
The differences of the amplitudes are clearly visible on the Fig. 3 – they are lower on the distance of 50 m (Fig. 3a) than those on the distance of 180 m (Fig. 3b). The calculated values of standard deviation for the results presented on Fig. 3 are 1.2 mm (for 50 m distance) and 2.3 mm (for 180 m distance). But errors of the average coordinates from all 5 minutes surveys are subsequently: 0.02 mm and 0.06 mm. They are lower than the resolution of photo detector used in surveys (0.06). The average values of errors of location the laser beam center for one minute observations were 0.05 mm for the 50 m distance and 0.13 mm for the 180 m distance.

The errors determined in such a way don’t contain a refraction influence. To determine them there were observations carried at certain distances, where detector was displaced in intervals from laser perpendicularly to laser beam.

The intervals were determined from differences of coordinates of laser beam center. From the comparison of known values of intervals and calculated values average errors were calculated. They were 0.21 mm for 50 m distance and 0.44 mm for 180 m distance. The values of the average errors for all distances with corresponding linear trends are presented on Fig. 4. The determined trends have linear characteristics.

The charts presented on Fig. 4. show linear increase of terror values accordingly to the distance between detector and laser. They show as well that the accuracy of detection in vertical is lower than accuracy of detection in horizontal direction.

\[
y = 0.0025x - 0.0288 \quad R^2 = 0.976
\]

\[
y = 0.0019x - 0.0163 \quad R^2 = 0.9857
\]

**Fig. 4.** The average errors of detection of laser beam.

The values of average errors of detection of laser beam for the tested detector in field conditions are lower than values of errors obtained in other techniques (tachimeters, GPS).

High frequency recordings of coordinates (in new detector prototype was 100 Hz) enables application a laser method in kinematic measurements, what was up now hard to obtain. Examples of these applications are presented in the charter.
4. THE EXAMPLES OF THE METHOD APPLICATION WITH LASER BEAM DETECTOR IN GEODETIC SURVEYS AND STUDIES

The first example of application of proposed detection system is a survey of bridge arches during test loads and utilization of bridge structures. The detector in surveys was located in the middle of bridge arch and a laser was on portal frame. Deflections and side displacements of the bridge were derived from differences of laser beam coordinates on CCD detector, which was displacing in reference to laser beam with a construction of the bridge [Jaśkowski 2003]. The system of detection used in surveys was placed on the bridge as it was shown on Fig. 5.

Fig. 5. The system of detection placed on the bridge.

On of exemplary chart of bridge deflections is demonstrated on Fig. 6. Two phases of slight uplifts (about 1 mm) are visible; they occurred when bus was moving on or out the bridge or just on area of the bridge deflection.

Fig. 6. The bridge deflection during bus movement.
During test loads with the registered deflections their analysis were determined with Fourier transformation (STTF) of frequency of bridge vibrations and determination of dumping coefficient [Jóźwik 2004].

The second example of the system application are surveys of refraction of laser beam. The part of the results of the surveys are presented on charts on Fig. 7. The first (Fig.7a) show the changes of laser beam location in vertical direction in detector within 8 hours. The second chart (Fig.7b) show changes of temperature gradient changes in the same time. The displacements of laser beam between its extreme positions was 5,5 mm on the distance of 50 m. The maximum change of temperature gradient change was in that time 1,8 C/m. The comparison of the both charts suggests a correlation between displacements of laser beam and temperature gradient (with the respect of slight shift in phase between them).

![Fig. 7. The displacement of laser beam a) the displacement caused by temperature gradient b)](image-url)
The third example of application of the presented method is monitoring of deflection of shaft tower top stage (Fig. 8). The deflection of the tower were caused by mining. There is an example of chart with deflections observed during one week. They demonstrate a deflection tower to southern direction caused by mining. They are violated by thermal deformations of the construction caused by isolation. A day period cycle of deflections is visible.

Fig. 8. The view of monitored shaft tower.

![Fig. 8. The view of monitored shaft tower.](image)

![Fig. 9. The displacements of the tower top in N-S and E-W directions.](image)

The presented examples show that application of the system of laser beam detection makes more possibilities in the alignment method extending its applications to measurements of kinematic displacement and it improves accuracy of the surveys [Jóźwik 2008].
5. FINAL CONCLUSIONS

The presented in the paper the system of laser beam detection that applies a computer analysis of laser spot on CCD matrix opens new possibilities of the alignment method applications in geodetic surveys. The frequency of recordings of the coordinate of laser beam center (even to 100Hz) and appropriately matched to atmospheric condition time of observations enable acquisition of high accuracy data. They provide as well results of dynamic parameters of surveyed structures as dominating frequencies, amplitudes of displacements or dumping coefficients. On this base it is achievable to control conditions of the structure with the use of geodetic observations. It was not possible up to now. Presented examples of applications don’t illustrate all potential opportunities. They are extended on new areas related to kinetic surveys of engineering structures.

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REFERENCES