THE USE OF THE COMPUTER SYSTEM OF DETECTION OF THE LASER BEAM IN THE MEASUREMENTS OF GEOMETRY OF MINE SHAFTS

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1. INTRODUCTION

A huge progress in the laser technology, in particular the creation of the semiconductor laser, allows to see the method of laser plumbing as a method of the future which can replace mechanical plumbing.
Therefore, the issues connected with the method of plumbing become more and more popular.
The most important ones are:
- directing the laser beam,
- determining the center of the laser beam at the point of target (detection of the laser beam).
The issue of the focus of the laser beam, thanks to the researches made in 1970 and 1980 and aimed to the use of the laser light in the measurements of the shafts, is practically resolved (Jóźwik 1994). The construction of many types of laser plummets (based on different operating principles), as well as the possibility of adapting the optical plummets to cooperate with the laser diode , enables to focus the laser beam with high precision.
The second issue concerning the detection of the laser bean, limited so far the possibilities of applicability of this method. Currently, the most common method of detection is a visual method (used by PMG Katowice, ZG Rudna, ZG Polkowice) aimed to specify the center of the laser beam on the observation wheel with an accuracy of 3mm. There is also applied the photogrammetric method based on the digital photography used by DARTECH company from Ruda Śląska. These methods are either not very accurate (the visual method) or allowing to perform measurements only at selected levels of measurement (the photogrammetric method).

2. THE MEASURING HEADS USED FOR MEASURING VERTICALITY AND STRAIGHTNESS OF SHAFT GUIDES

The Department of Mining Surveying AGH together with the ARCO company, has developed the new method for detection of the laser beam using a computer analysis, performed in real time, of an image captured by the CCD matrix. The applying of this new method allows to improve the accuracy of the positioning of the laser beam. The

accuracy of detection, obtained by testing, ranges from 0,1-0,3mm. Such a high detection accuracy, as well as the ability to perform continuous detection of location of the laser 'spot' on the observation screen, encouraged the authors to construct the instrument which could use, to determine the deviation of the guide from the laser beam, the laser beam computer detection system (Jaśkowski et al. 2009). Built by the author, the prototype of the device to measure the verticality and straightness of the shaft guides using a computer system for the detection of the laser beam is shown in Figure 1.
A key part of the device is the measuring head in which the detector is the digital camera connected to the card of an image analysis. The camera is placed in a sealed enclosure in the front part of which there is a focusing screen. Power supply and controlling of the camera as well as sending information to the industrial computer are provided by the control and transmission device, connected with the camera and the computer by use of cables. The functioning of the entire system provides the determination of the coordinates (X,Y) of the center of the image of the laser beam falling on the screen of the detector device.

The measuring head is designer to determine surtaxes from the guide shaft to the laser beam emitted by the laser plummet. The surtaxes are automatically recorded on a computer-controlled frequency (up to 56 Hz) The time of the recording is determined by the user.
The device consists of two measuring heads (CCD detectors) and the device which controls the parameters of CCD detectors and records the values of the surtaxes. The measuring heads and the controlling and recording device are placed in the separate housings. They are combined with each other, during the measurements, by use of the power supply and control cables with a length of 3m or 6m.
There can be one or two measuring heads connected to the controlling device. The diagram of the device is shown in Figure 2. The controlling and recording device is placed in the housing together with the three battery powers connected to the power block which contains switches of selection of the battery powers, LEDs, fuses, battery charging slots and amplification signaling system of currently used battery discharge.

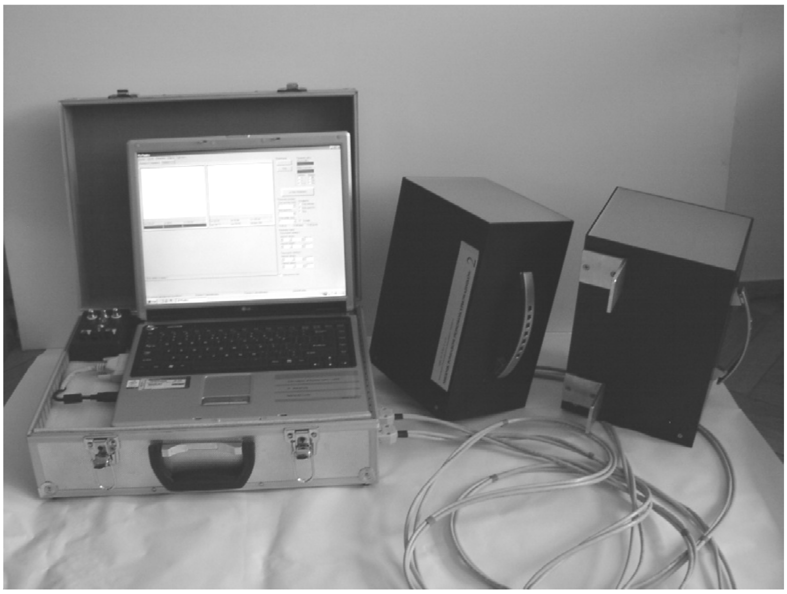


Fig. 1. The device for measuring verticality and straightness of the shaft guides.

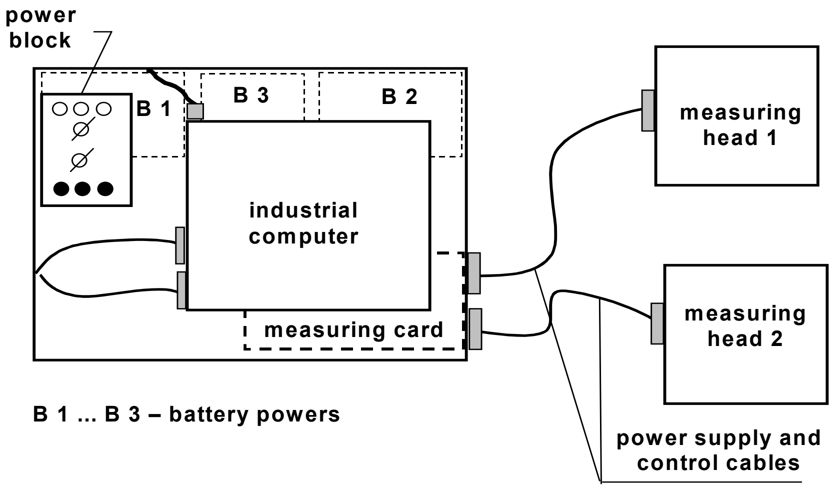


Fig. 2. Schematic diagram of the device for measuring perpendicularity and straightness of the guides.

The displacement measurement range for each of the heads is – 200mm(X axis) and 150mm (Y axis). The measurement resolution, the corresponding value of a pixel, is 0,3mm.

The task of the measuring card is the transmission of the control data to the CCD detectors and the measurement data from the CCD detectors to the computer.

The software, controlling the operations of the heads, called 'the Spot' was installed on the industrial computer (Fig. 3). The program allows

- **to visualize the image of the spot from the two measuring heads**
- **to determine the detection parameters for each of the heads separately**
- **to determine the time for the detection**
- **to attribute the place of the measurements to the results obtained**

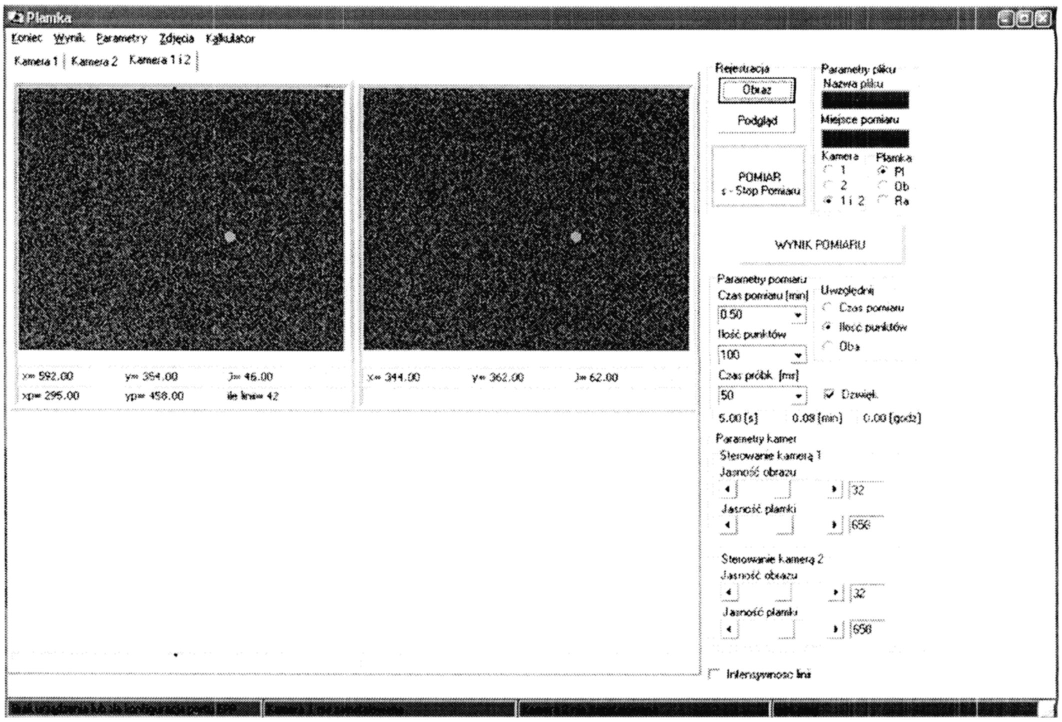


Fig. 3. The dialog window of 'the spot' program.

The measurements results are saved in two output files. The first file contains the results of the multiple detection of the position of the laser beams on the screens of the measuring heads /values in pixels/ at a certain level of measurement (The sample file for the measurement level of 140 is given below)

140 Date/time of measurement: 07-06-10 08:44:24

1	0.003	408	287	14	192	111	23
2	50.010	410	286	15	192	114	23
....							
13	600.084	409	286	18	193	113	24
14	650.090	410	286	19	192	117	27
15	700.096	410	291	13	193	115	18

The second output file is a file that contains the averaged results of the position of the laser beams on the screens of the measurement heads at various levels of observation /values in mm/.

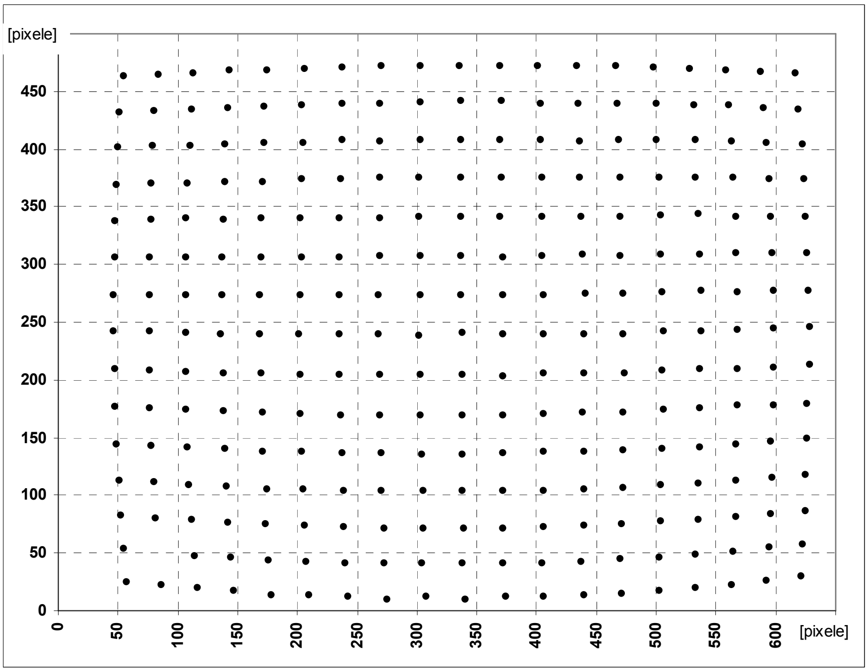
Results 0527_I.dan [mm]

level	gauge1		gauge2	
	Xav	Yav	Xav	Yav
136	74.7	62.9	56.1	77.2
137	69.9	71.1	55.7	81.2
138	75.6	73.3	52.2	83.7
139	75.2	73.7	54.6	84.2
140	76.7	69.5	56.6	83.3
141	72.9	73.2	56.6	82.7
142	75.1	75.3	53.6	83.9

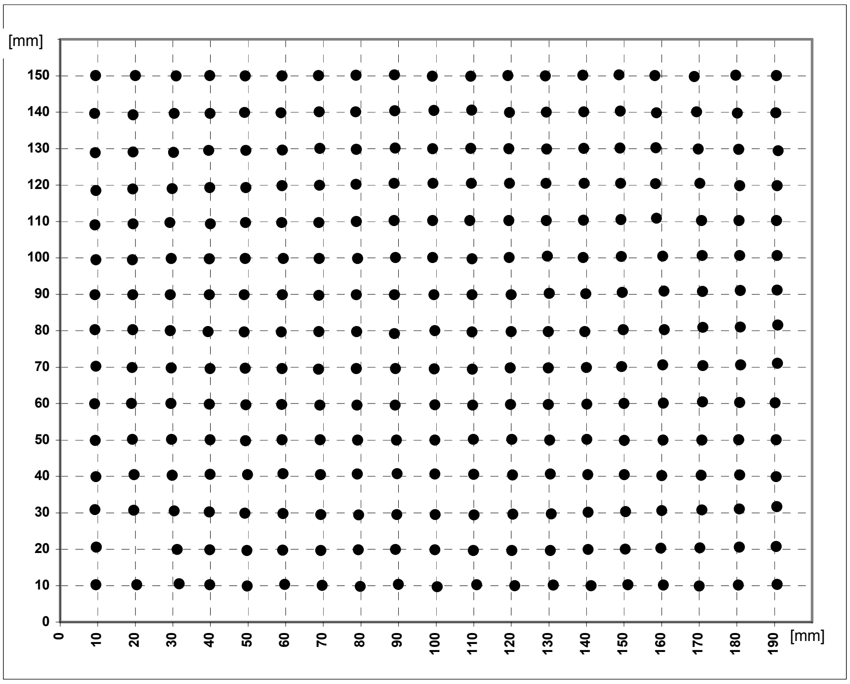
3. THE CALIBRATION OF THE MEASURING HEADS OF THE DEVICE FOR MEASURING VERTICALITY AND STRAIGHTNESS OF THE GUIDES

The accuracy of the determination of the displacement of the detection device with respect to the laser beam depends on many factors, both external (laser propagation) and internal (construction of the device). One of them is a digital camera parameters, i.e. the camera lens and sensor.

Figure 4 shows a picture of the test field of a grid of squares with sides of 10mm and size 150 X200mm recorded by the camera of the prototype detector. There are clear distortions visible on it, caused by the lens distortion, the banks of which reach a height of 5mm. Figure 4a shows the image of the same field after the correction of the distortion, which the authors carried out using the polynomial approximation. Obtaining such a good fit required to separate several imaging zones, throughout the whole field, for which, for the line along the X and Y axes, the approximate polynomials were determined. After substituting for them the value of X or Y coordinates in pixels, the corresponding coordinates in millimeters are obtained.



a)



b)

Fig. 4. The picture of the test field registered by the system
a) before correction (X,Y in pixels)
b) after correction (X,Y w millimeters)

The conversion formulas of the coordinates for both measuring heads are provided in Table 1. The best results were obtained using the polynomials of the second or fourth degree. The maximum differences at the edges of the test field (150X200mm) do not exceed 1mm, and in the middle of the field are 0,1-0,2 mm.
The designated polynomials were included in the system software, which automatically converts the recorded in pixels values of the coordinates of the center of the laser beam to the corrected ones in millimeters.

Table 1 Conversion formulas for the X and Y coordinates

Head 1		
From	**To**	**Conversion formulas for the Y coordinate of**
0	265	$Y_m = 80-(0{,}3265386637 - 0{,}0001709783431 * X + 0{,}0000004371541949 * X^2 - 0{,}0000000005137677451 * X^3 + 4{,}005452708E\text{-}13 * X^4)*(265-Y)$
265	520	$Y_m = 80-(0{,}3284613387 - 0{,}0001566557671 * X + 0{,}0000003559982418 * X^2 - 0{,}0000000003714926621 * X^3 + 2{,}915190792E\text{-}13 * X^4)*(265-Y)$
Conversion formulas for the coordinate X of		
0	152	$X_m = 50-(0{,}3533942609 - 0{,}0001455012927 * Y - 0{,}0000001142524127 * Y^2 + 0{,}000000001163821866 * Y^3 - 6{,}992481085E\text{-}13 * Y^4)*(152-X)$
152	320	$X_m = 100-(0{,}3037538716 + 0{,}00003454663438 * Y - 0{,}0000005683499929 * Y^2 + 0{,}000000001659874837 * Y^3 - 1{,}260494423E\text{-}12 * Y^4)*(320-X)$
320	520	$X_m = 100-(0{,}3184747542 - 0{,}0001837424624 * Y + 0{,}0000006610778474 * Y^2 - 0{,}000000001082418754 * Y^3 + 9{,}591603194E\text{-}13 * Y^4)*(320-X)$
520	640	$X_m = 150-(0{,}3756113169 - 0{,}0005070078598 * Y + 0{,}000001991374685 * Y^2 - 0{,}000000003815975885 * Y^3 + 3{,}619626937E\text{-}12 * Y^4)*(520-X)$

X Y in pixels; X_m Y_m in millimeters

4. THE MEASUREMENTS OF VERTICALITY AND STRAIGHTNESS OF THE SHAFT GUIDES USING THE STRAIGHT LASER REFERENCE

In determining the geometry of the guiding strings the straight laser reference is used. Its position, in relation to the guides, is determined by the measuring heads at various levels of measurement.

The measuring heads are used in the method of the laser plumbing, where the read-out discs, attached to the guide, are replaced by the measuring heads. After applying the heads to the guide, the operator of the controlling and recording device determines the parameters of detection and records the laser beam position on the screen. In practice, the measuring heads are applied to the guides at the time of free movement of the cage (about 0.2-0.5 m/s) and, at the same time, the registration of the position of the laser beam is made. This time allows to implement 15-16 designations of the position. This method significantly reduces the time of measurement in the shaft.

Figure 5 shown below presents the graphs of verticality of the guides (in the parallel and perpendicular directions to the stretch of the shaft girders) obtained from measurements using the measuring heads in one of the mining shafts LGOM. (Jaśkowski 2010).

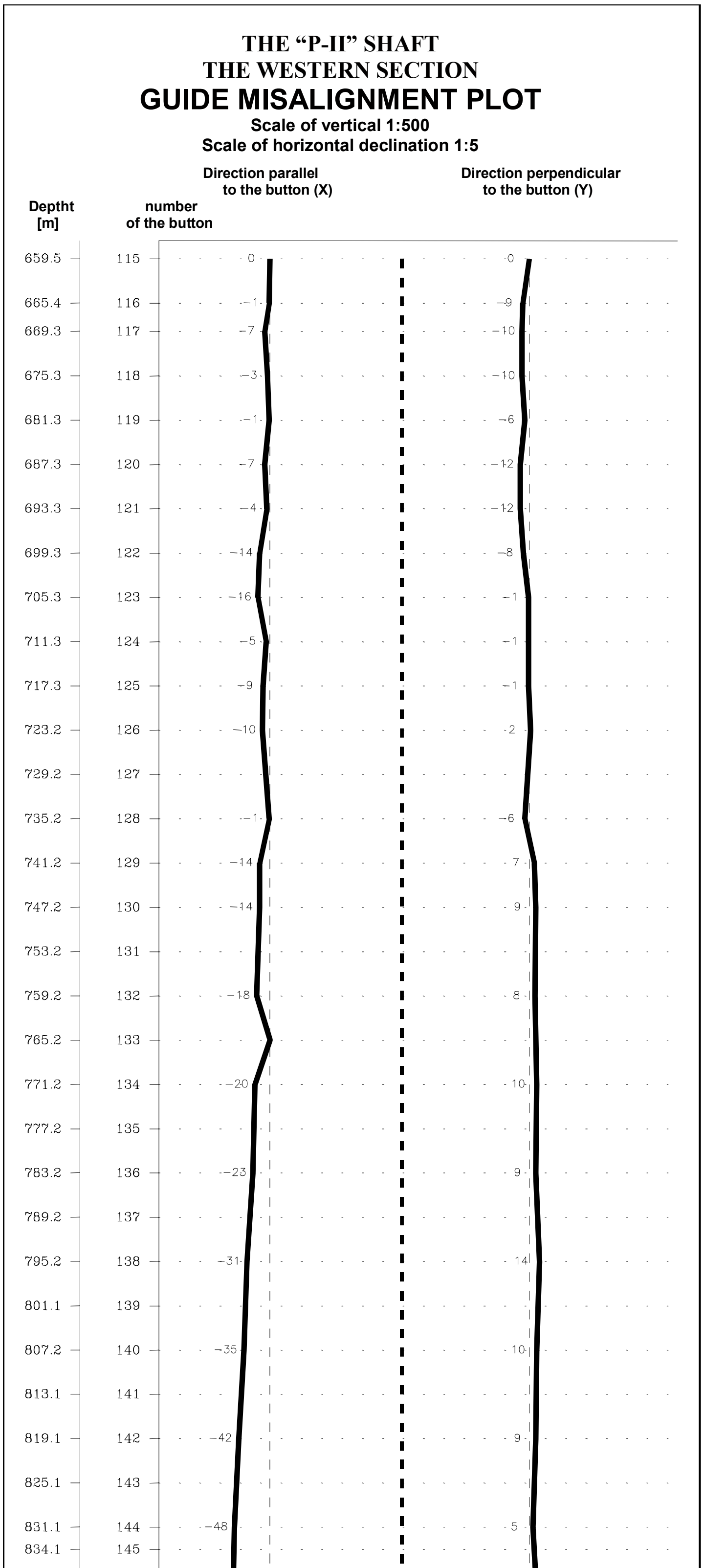


Fig. 5. The graph of verticality of the shaft guides.

5. CONCLUSIONS

The use of the measuring heads allows you to increase three times the accuracy of designation of the coordinates of the laser beam in relation to the visual method and eliminates errors of the read-observer (the thick errors). This method also allows for automatic determination of the average position of the laser spot vibrating under the influence of the turbulent air flow, the operation of equipment, the weather impacts on the construction of the tower which are carried by the elements of the arms of the shaft to which there are attached the laser plummets.

In the visual method, with large movements of the scintillating spot, this is another source of errors.

The use of the set of two measuring heads and two plummets allows, during a single pass through the shaft, to determine the profile of the two opposite guides and the front spacing between them. It is also advisable, in these measurements, to perform control measurements of the frontal and lateral spacings in selected levels of observation (they can also be performer by use of the rangefinders). These figures, at the stage of the calculation, allow to eliminate largely the influence of refraction on the laser beam.

The measuring heads can also be successfully applied to all other geodetic measurements performed by the use of the fixed laser reference line method (the measurements of displacement, the inventory of cranes, etc.)

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