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THE USE OF OPTOELECTRONIC TECHNIQUES IN STUDIES OF RELATIVE DISPLACEMENTS OF ROCK MASS

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ABSTRACT
This paper describes a prototype of the authors own design used to measure the relative inclinations of engineering objects and inanimate nature phenomena. A set of measurements can be used to determine ground surface deformation caused by mining activities or due to influences of hydro-geological, geotechnical or construction. The instrument was built with elements of the optoelectronic technique. Fiber optic, CCD camera and semiconductor laser are the basic building blocks of the device. The elaborated device runs on a Central Registration and Data Processing (CRPD) System. The deflection of freely suspended fiber are recorded by a CCD camera and next are transmitted to an external recorder (eg. notebook). Natural light or laser light was introduced into the fiber. The length of the fiber and the optical construction affects the measuring range of the device. The accuracy of instruments depends on: method of fiber suspension, method of fiber attenuation fluctuations, resolution CCD camera and identification method of the image laser spot recorded. Experiments have shown that the built prototype device is able to obtain a submillimetre accuracy.

KEYWORDS: optoelectronic techniques, studies of relative displacements

1. INTRODUCTION

Changes occurring in an environment, in mountain areas reveal many natural derivative phenomena like: landslides, ground erosion, rock falls.

Human activity - anthropogenic processes cause also rock mass and surface deformation (Cheung, 1996; Kavvadas, 2003; Mulder and Smith, 1996).

As a result of this activity there occur mainly mining damage.

Geodetic surveys conducted on the inanimate nature and engineering objects have different precision. Such an example are observation segments of the control-measurement system

- segment I – satellite GPS observations and precise levelling (accuracy deformation measurements is ±0.5 ÷ 10 mm);
- segment II – observations as above mentioned and total stations (accuracy deformation measurements is ±0.5 ÷ 2 mm);
- segment III – relative measurements performed with extensometer, inclinometer (accuracy deformation measurements is ±0.01 ÷ 0.1 mm).

When conducting relative measurements, particularly changes of:

- distances of points,
- heights of points,
- deviations of vertical line,

there are used specialised instruments (crack gauges, inclinometers, pendulums, extensometers, distansometers), which allow to obtain accuracies up to a few millimetres (Chrzanowski et al., 1972; Ćmielewski, 2007; Jamroz et al., 2006; Jaśkowski, 2010).

In scientific publications, you can find different types of inclinometers. The described devices performing angular measurements in the majority were patented (Ćmielewski, 2003; Jaśkowski and Jóźwik, 2007; Nakao, 1988). These devices have components performing the vertical line and the receiver recording the location of this line. With the use of these devices were performed measurements in scientific laboratories or on real engineering objects.

An example is the patent Nakao Kiyoharu (Nakao, 1988) in which the displacement of a pendulum indicating a tilt angle into an electric signal (the photoelectric system). The pendulum is suspended by an elastic wire clamped by a clamper. At the end of the elastic wire has a light-emitting diode which emits light to the two-dimensional optical position detector. The LED diode is placed in the center of the lower end of the pendulum. The light emitted by the LED is received by a two-dimensional optical position detector that determines the location of the center of the spot light.

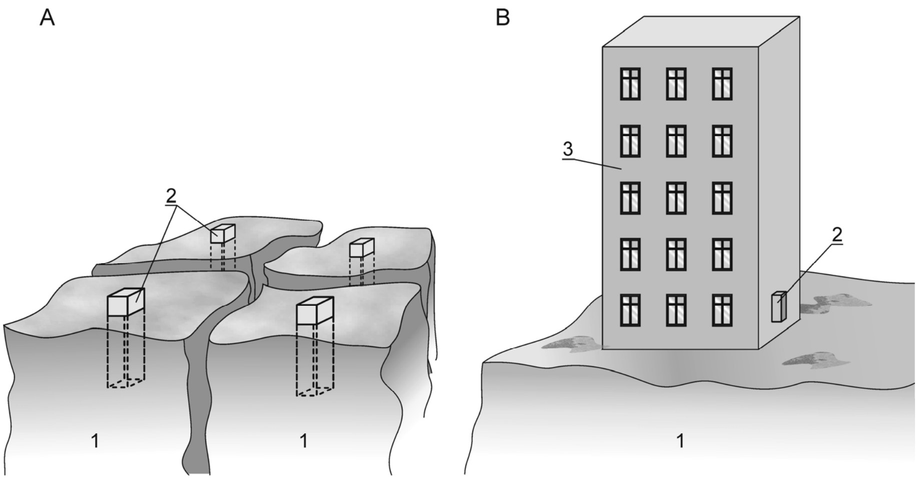

Fig. 1 The examples of the arrangement of optoelectronic plummets on the measurement objects:
A. blocks of rocks: 1 - blocks of rocks, 2 - optoelectronic plummet;
B. building: 1 - block of rock, 2 - optoelectronic plummet, 3 – building.

Another example is a device patented in 2003 (Ćmielewski, 2003). The device has a light source which is connected to the fiber bundle and a weight located in the hole of a board equipped with floats. The floats are placed in a fluid reservoir which is mounted inside the chamber. At the bottom of the chamber is fixed a photoelectric transducer connected by transmission from the central registration system and data processing.

Another solution is the shaft inclinometer patented in 2007 (Jaśkowski and Jóźwik, 2007). This inclinometer consists of a suspended pendulum, while the bottom of the pendulum has LED lights powered by battery. The pendulum is mounted in a tubular cover, in its bottom and top section are two pairs of profiling rolling wheels set on bearings. It is a system for measuring the length of route. In the lower part of the tube is mounted a detection system, which records the geometric center LED light beam. Laser beam detection system uses CCD matrices as photo-detecting receptors. The paper (Jaśkowski, 2010) included the results of studies of practical application of the system for mine shaft inventory.

In this paper the authors presented a measurement set for the implementation of the vertical line by using the optical fiber and the photoelectric system is replaced by a CCD/CMOS matrix. The light beam can be directed either directly or after reflection from the surface of the mirror (or the prism) on the CCD/CMOS matrix. Optical fiber acts as a pendulum and simultaneously leads a highly focused light wave. With this solution there is no need collimation light beam. The misalignment error of pendulum axis and beams of light emitted are eliminated. Our device also reduces the environmental impact of the propagation of laser light. For example, if the lift shaft on the emitted laser beam is affected by temperature, dust, etc. This limits the range of measurement, turbulence and refraction, which is reduced by positioning accuracy of the laser spot on the photodetector.

Optic fibres and CCD matrix's could be used in relative measurement surveys (Ćmielewski et al., 2011). Optic fibres are characterized by small diameter of core, low weight, high disruption of resistance, long term constancy of own parameters, usage in difficult accessible places and different configuration. CCD matrix for digital image registration is characterized by small size and weight, low voltage, cooperation with computer and possibility to detect laser beam.

By creating innovative systems and measurement instruments with the use of optoelectronic technique it is possible to improve acquisition of measurement information for engineering objects with respect to reliability, functionality, extension of geodetic service range and improvement for industrial safety (Bryś et al., 2011).

2. CONCEPTION OF THE OPTOELECTRONIC PLUMMET

In this article there is presented the prototype of the device, designed and constructed in the Institute of Geodesy and Geoinformatics. It is used for relative inclination measurements of the engineering and inanimate nature objects. The created measurement set can be applicable for surface deformation measurements as a result of mining exploitation or caused by hydrogeologic, geotechnical or constructional influences. In Figure 1 there are presented selected applications of the optoelectronic plummets.

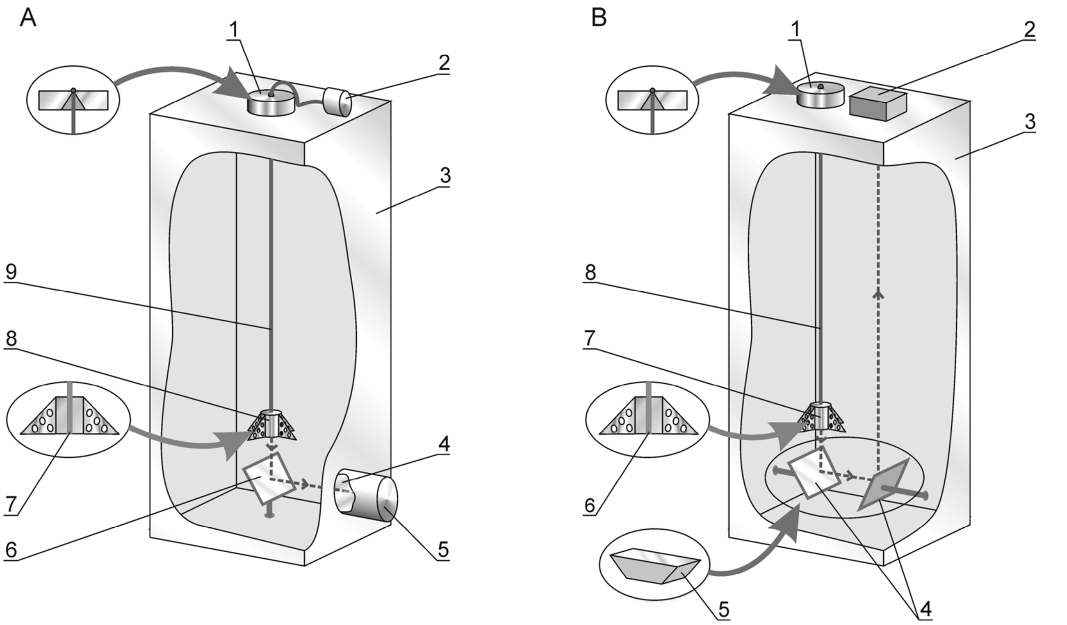

Fig. 2 The constructional-functional idea of the optoelectronic plummet:

A. One reflective surface (refraction of 90^0): 1 - suspension, 2 - light source, 3 - body, 4 - window with glass, 5 - CCD camera, 6 - mirror, 7 - core of optic fiber, 8 – weight, 9 – optic fiber;

B. Two reflective surfaces (refraction of 180^0): 1 - stand, 2 – CCD camera, 3 - body, 4 - mirrors, 5 - prism, 6 – core of optic fiber, 7 - weight, 8 - optic fiber.

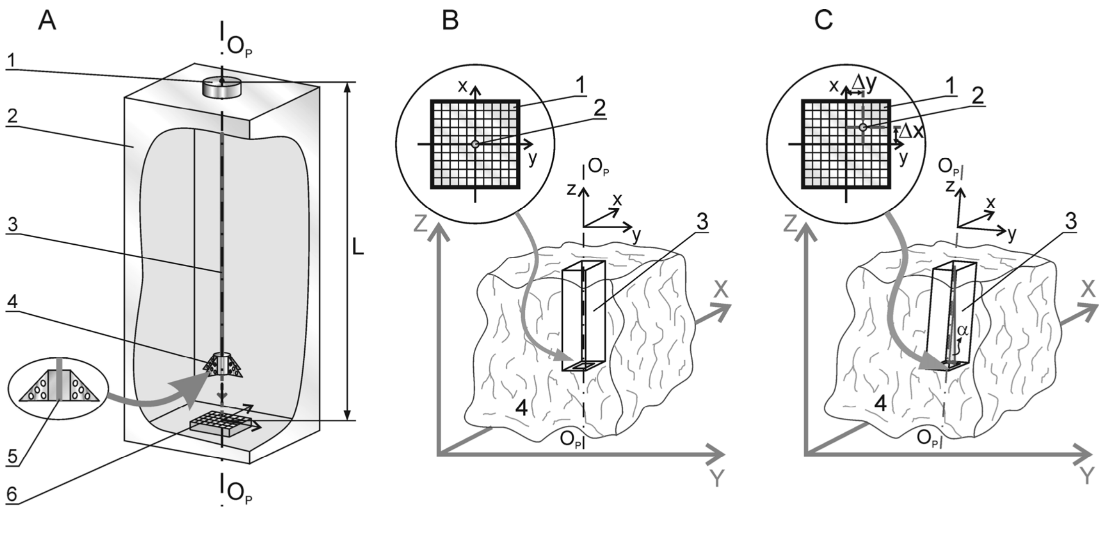

Fig. 3 The observation method of the shining optic fiber core by the CCD camera:

A. The idea of the optoelectronic plummet: 1 - hanger, 2 - body, 3 - optic fiber, 4 - weight, 5 - optic fiber core, 6 - CCD camera, O_p-O_p - plummet axis, L - plummet length;

B. The observation and measurement of the plummet setting + time t_0:
1 - CCD camera matrix, 2 - image of the optic fiber core, 3 - optoelectronic plummet, 4 - rock block, O_p - plummet axis;

C. The observation and measurement of the plummet setting + time t_i:
1 - CCD camera matrix, 2 - image of the optic fiber core, 3 - optoelectronic plummet, 4 - rock block, O_p - plummet axis, α – inclination angle of the plummet embedded in a block of mass rock.

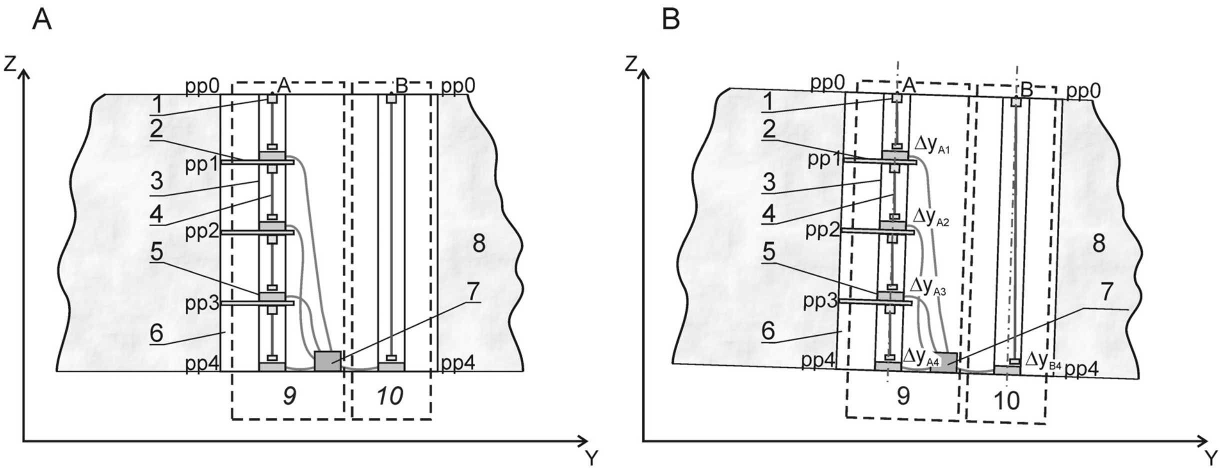

Fig. 4 The disposition of the construction sets of the optoelectronic plummets on the investigated object:
A. Observation and measurement of the setting of plummet sets + time t_0: 1 - source of light, 2 - clasp, 3 - optoelectronic plummet, 4 - optic fiber, 5 - CCD camera, 6 - vertical measurement shaft, 7 - computer, 8 - mass rock, 9 - basic set, 10 - control set;
B. Observation and measurement of the setting of plummet sets + time t_i: 1 - source of light, 2 - clasp, 3 - optoelectronic plummet, 4 - optic fiber, 5 - CCD camera, 6 - vertical measurement shaft, 7 - computer, 8 - mass rock, 9 - basic set, 10 - control set, Δy-linear increment of the angular inclination of the individual plummet.

In Figure 2 there are presented versions of constructional-functional outcomes for the opto-electronic plummets.

In each version in the body of a cuboid shape there are (Fig. 2A): mounted optic fibre (9) tipped with the weight (8) with supressive elements with an optical element (6) used to direct the image of the optic fibre core (7) into tube, where the CCD camera (5) is located.

It is possible to increase reflections of the optic fibre core image by the system of optic elements (2 mirrors) and camera, putting them in the upper part of the body as in Figure 2B. The designed devices work in the Central Registration and Data Processing (CRDP) system. The inclinations of the freely mounted optic fibre (8) are registered by the CCD camera (2) and are sent to the external recorder (f.eg. notebook).

In Figure 3 there is presented the simplest case of the direct image observation of the shining optic fibre core (5) by the CCD camera (6). The change of the vertically mounted optic fibre inclination (3) is registered in the fixed periods of time t_i.

The measurement range of the device results from the used optic fibre length and optic construction, copying the optic fibre length. The accuracy of the device depends on: the method mounting of the optic fibre, the suppression of the optic fibre fluctuation, the CCD camera resolution and the used identification method of the registered laser spot image.

After setting (mounting) the plummet in a rock block (Figures 3B and 3C) there is registered the position of the shining optic fibre core at the time t_0, and then after a lapse of time - t_i the next registration is taken (Fig. 3C). The differences of the registered images are considered as Δx and Δy increments and the plummet length, taken into consideration, allow to calculate angles of the plummet inclination (α).

Figure 4A and Figure 4B shows the location of measurement systems: a basic measuring set (9) and control set (10). The closed construction of the plummets is the basic measurement set (a few plummets mutually connected) and control set (a single plummet mounted on the whole length). These systems can be embedded in the observed subsurface or on engineering structures such as the measuring shaft of the dam.

Based on observations conducted on the successive levels of the basic set (9) it is possible to determine changes in the position of measurement shaft in the observation periods. The control set (10) is a separate plummet, which allows to perform control of inclinations of the particular plummets of the basic set (9) according to the formula 1:

$$\sum_{i=1}^{n} \Delta y_{Ai} = \Delta y_B \tag{1}$$

where: sum of inclinations of the particular plummets Δy_{Ai} is equal to the inclination of the control plummet Δy_B .

3. OPTOELECTRONIC PLUMMET

On the basis of the project assumption there is created the prototype of the optoelectronic plummet,

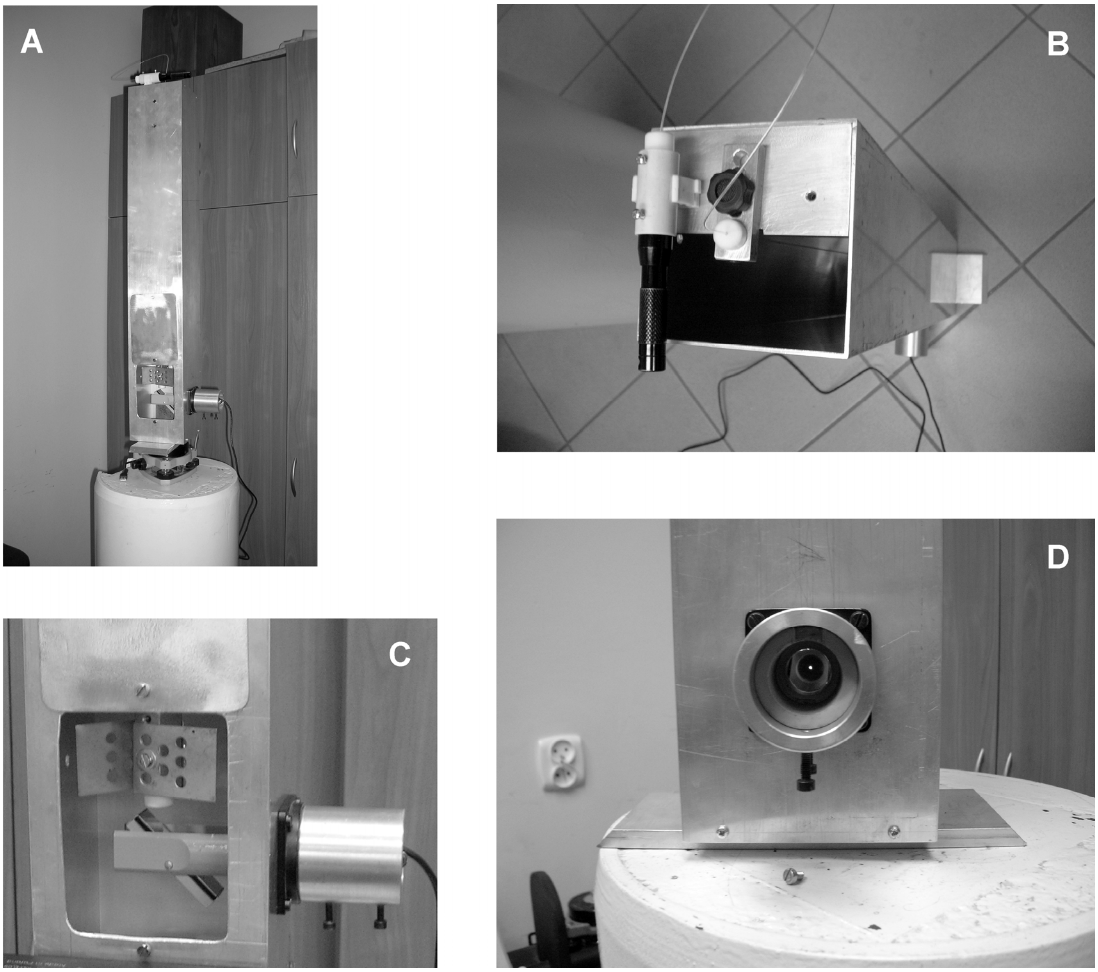

Fig. 5 The prototype of the optoelectronic plummet:
A. The general view of the plummet;
B. The mounting way of the optic fiber in the casing;
C. The view of the optic fiber weight and the mirror surface;
D. The shinning front of the optic fiber reflected from the mirror.

which is presented in Figure 5. In the prototype there is used the polymeric optic fibre of the core of 1mm diameter and 700 mm length.

The source light is a LED, white diode; whereas for observation of the shinning core image there is used a standard CCD camera (1.3 mln px). The core image is observed by the flat mirror inclined at 45 degrees.

With the use of the created prototype there are conducted experimental works. In Figure 5 there is presented a view of the plummet mounted by the tribrach to the observation pillar. In the upper part of the plummet there is presented the mounting way of the plummet and the light source illuminating the plummet core. In the lower part of the device the weight of the plummet with the suppressive element can be noticed through the window. Under the end of the plummet there is mounted the mirror controlling the reflected shinning core image to the tube, in which there is the CCD camera.

4. EXPERIMENTAL WORKS

To perform experimental works there are used two different measurement sets allowing for the inclination of the optoelectronic plummet at a given angle value.

The first of them is the tabular crack gauge (the set of model plates) (Fig. 6), for which there are performed 6 observation cycles in the range of 0÷3mm. The second device is the machine spirit level (Fig. 7) with a sensitivity of 0.05mm/1m, for which there are performed 10 observation cycles.

The measurements are conducted in the Laboratory on the observation pillar equipped with the tribrach. By inserting the next plates under the base of the plummet the location of the optic fibre is inclined. The series of images (272 images at the time of 15 seconds) of the glowing fiber core is registered for each position of the optoelectronic plummet. The influence of the light intensity change in the optic fibre on the identification accuracy of the geometric

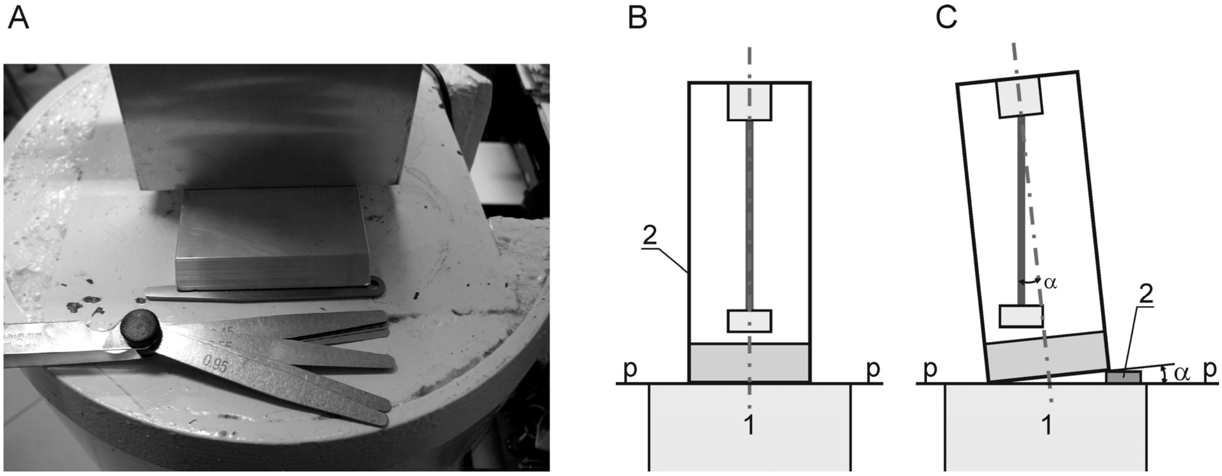

Fig. 6 The measurement setting of the optoelectronic plummet tested by the model plates:
A. The optoelectronic plummet with model plates;
B. The initial position of the plummet during the experiment: 1 - observation pillar, 2 - optoelectronic plummet, 3 - pp-horizontal axis of the observation pillar;
C. The measurement position during experiments: 1 - observation pillar, 2 - model plate, pp - horizontal axis of the observation pillar, α - inclination angle of the plummet given by the model plate.

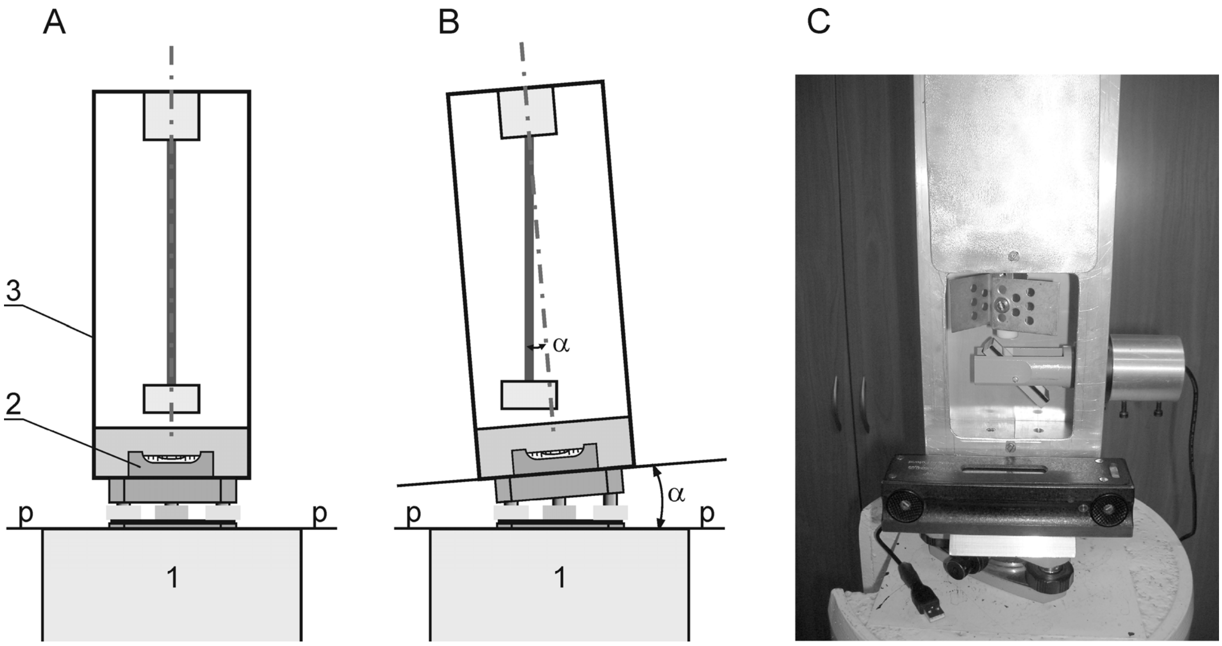

Fig. 7 The experimental setting of the optoelectronic plummet:
A. 1 - observation pillar, 2 - level, 3 - optoelectronic plummet, p-p - horizontal axis of the observation pillar;
B. 1 - observation pillar, α - the inclination angle of the optoelectronic plummet determined by the level, p-p - horizontal axis of the observation pillar;
C. The view of the optoelectronic plummet with the level on the observation pillar.

centre of the fibre core registered by the CCD camera is checked during experimental works. The different subject of the experimental works is to check how the amplitude value of the plummet swings influences the accuracy calculation of the middle position. For the analysis films are registered by the CCD camera at 5 frames/second and 20 frames/second. In Figures 6B and 6C there are presented the change of the optoelectronic plummet position with the use of the model plates.

In Figures 7A and 7B there are presented the change of the optoelectronic plummet position with the use of the machine spirit level- the plummet inclination at the alfa angle.

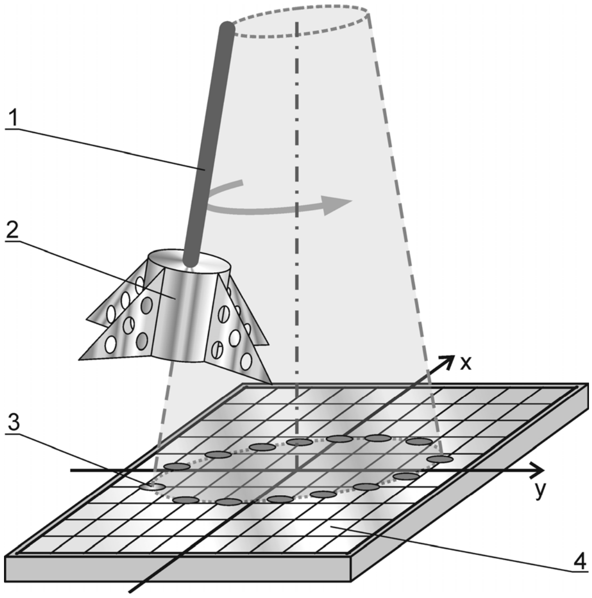

Fig. 8 The bearing of the optic fibre plummet during measurements:
1 - optic fiber, 2 - weight, 3 - optic fiber core image, 4 - CCD matrix.

Table 1 The combination of the measurement series for a given plummet position.

Measuring	x [mm]	y [mm]
1 series	2.30	-13.07
2 series	2.30	-13.11
3 series	2.30	-13.10
	m_0	**±0.018 mm (0.2 pix)**

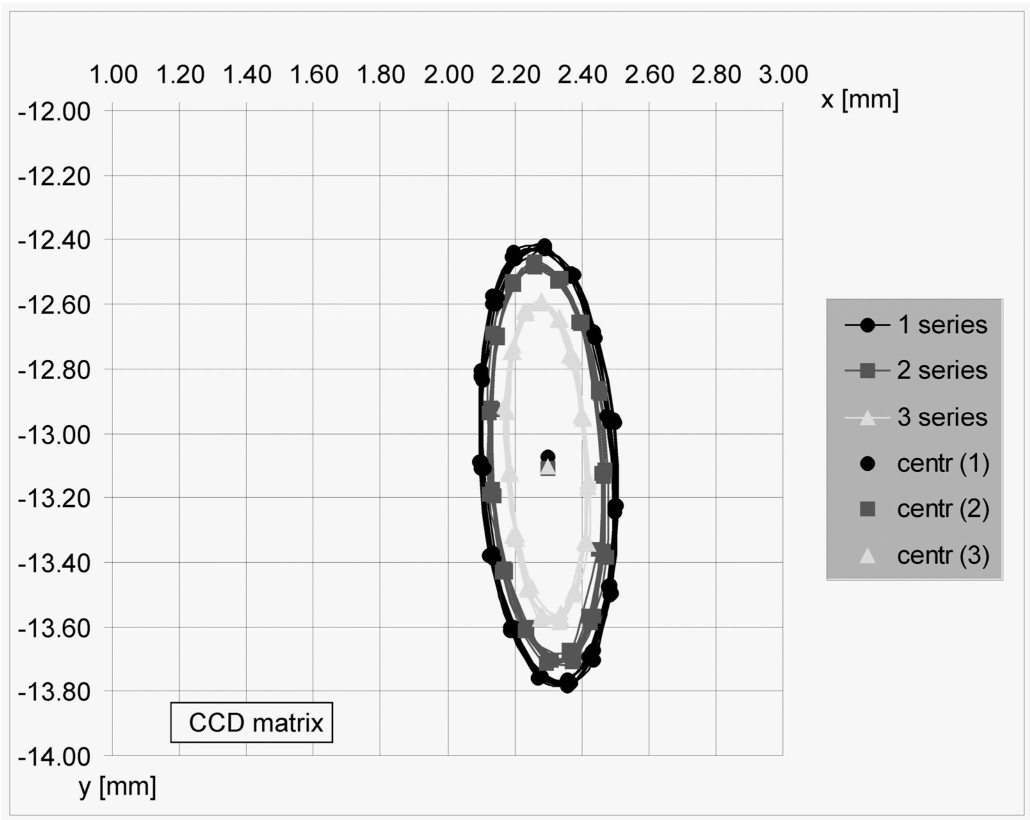

Fig. 9 The chart of the registered positions of the optic fibre core images for the three series (for model plate equal 2.5 mm).

For experimental works a machine spirit level of the sensitivity of 0.05mm/1m is used. The use of the spirit level allow to determine the initial accuracy of the inclination measurement.

Taking the indication of the spirit level into account and using the screws of the tribach there is carried out the 10-times deviation of the optic fibre-increasing with the stroke of 10” (0.05mm/1m). For

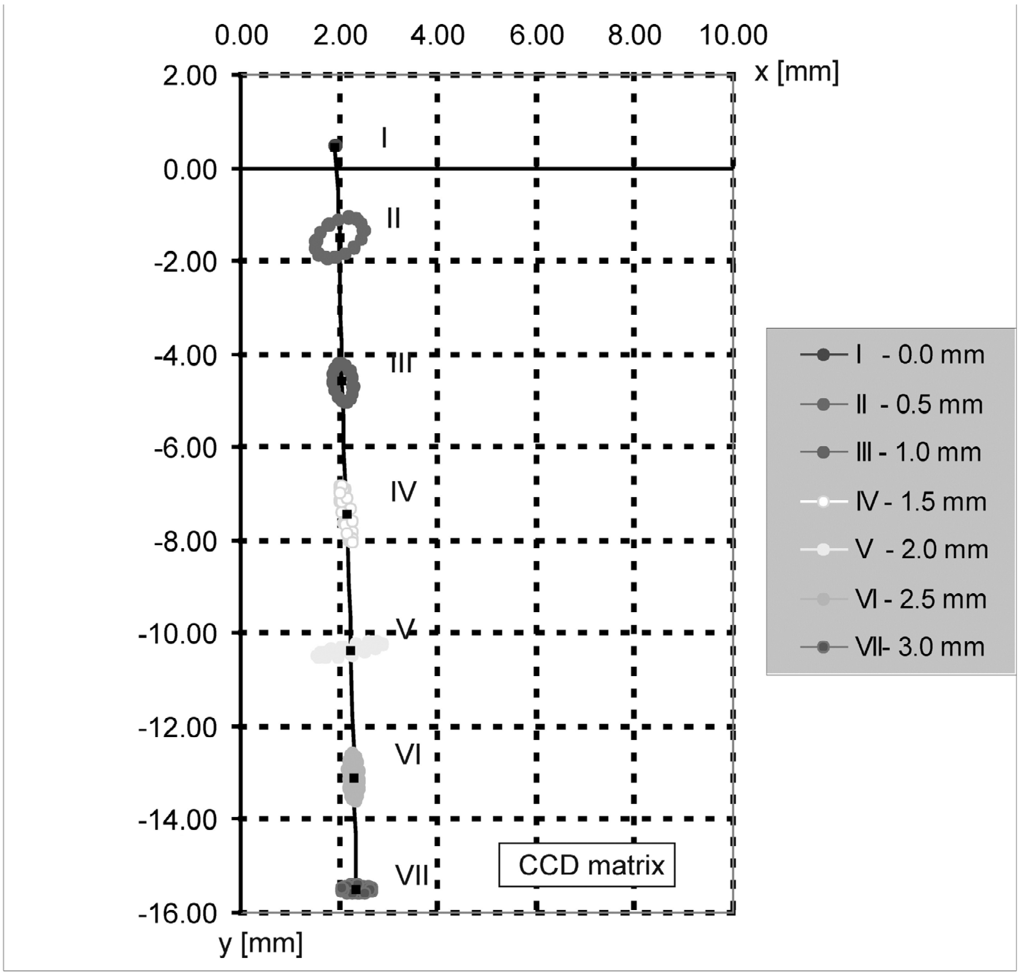

Fig. 10 The chart of the simulated optic fibre plummet inclinations for six measurement positions.

Table 2 The combination of the measurement outcomes for the given plummet inclinations of 10” interval.

L.p.	x [mm]	y [mm]	differences mm/1m
1	4.367	-6.425	-
2	4.372	-6.385	0.010
3	4.361	-6.361	-0.004
4	4.368	-6.325	-0.001
5	4.358	-6.302	-0.015
6	4.361	-6.267	-0.012
7	4.349	-6.232	-0.010
8	4.351	-6.203	-0.016
9	4.350	-6.174	-0.023
10	4.346	-6.144	-0.027
		m_0 =	**±0.010**

particular inclinations there are registered a series of the images of the shinning core position.

In Figure 8 there is presented the registration idea of the sequence of the optic fibre core images on the matrix of the CCD camera. The movements of the pendulum around the vertical axis determine an elliptical shape.

In Table 1 and in Figure 9 there are presented the average results of the 3 measurement series for the fixed plummet position (for model plate equal 2.5 mm). On the basis of the conducted analysis there is stated the recurrence of determination of the geometrical centre of an ellipse of ±0.018 mm. The plummet naturally moved undergoes the movement on the generator reminiscent of a cone shape.

Figure 10 presents the outcomes of the 6 plummet inclinations observed during simulated angular adjustments by the model plates (6 model plates of the thickness of 0.2 mm/1m). On the basis of a couple of observations (level adjustment and reading of the core position) there is stated, that the average error of a single measurement comes to 0.01 mm/1m.

On the measurement stand (Fig. 7) there are precisely set 10 plummet inclinations increasing of

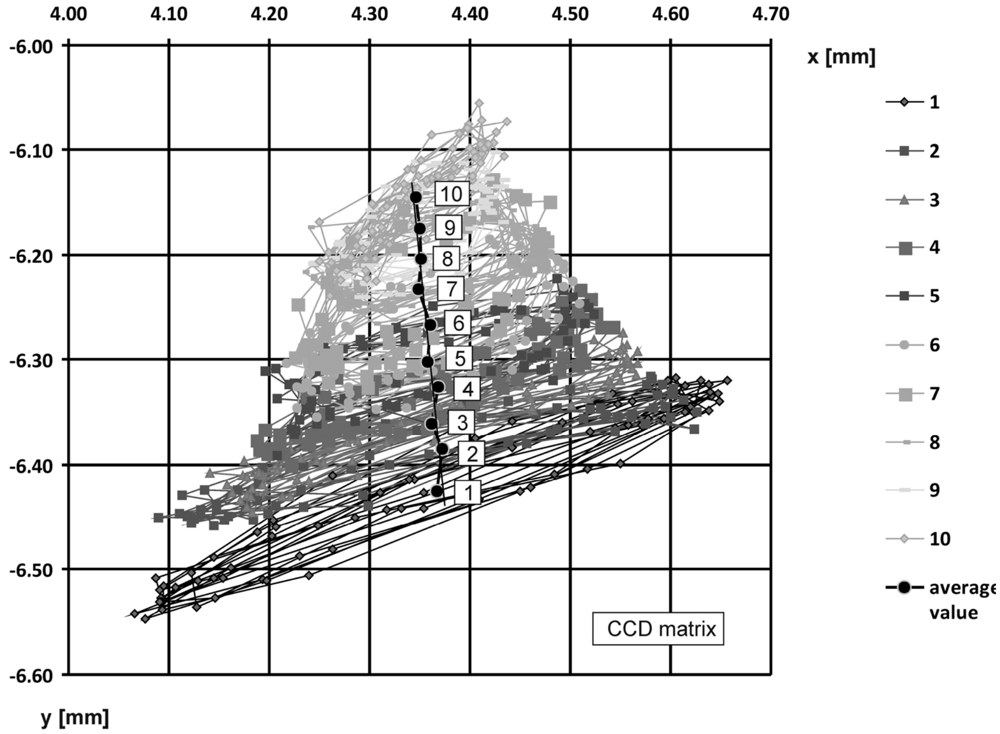

Fig. 11 The chart of the positions of the geometric centres of the shinning optoelectronic front for ten simulated inclinations.

10” with the use of the machine spirit level. In Figure 11 and in Table 2 there are put the averaged outcomes of the experiments. In Table 2 there are given average measurement values of the geometric centre based on the observed series of images (272 frames during 15 seconds, that is 20 frames per second).

The decreasing lengths of halfaxises of the ellipses (Fig. 11) result from the stabilization of the plummet inclinations. The maximum inclination lengths for the first measurement position (halfaxis) come to 0.3 mm, in the final position the length of the halfaxis is about 0.1mm.

The comparison of the inclinations fixed by the examiner with the inclinations of the investigated plummet allows to determine the average value of the single angle measurement with the use of the plummet. The accuracy of the given inclination by the machine spirit level with the use of the optoelectronic plummet does not exceed the value of 0.01mm/1m. It is about ± 2”. This is a very high accuracy. It is satisfying for authors.

5. CONCLUSION

The main expected effects of the usage of the proposed solution for the optoelectronic plummet could be referred to:

1. The reliability increase of outcomes of the measurements (telemetric and automatic measurements);
2. The possibility to connect the observations realized on a few measurement levels in difficult to access places;
3. The range extension of the object accessibility;
4. The higher reliability of measurements through the automatisation;
5. The improvement of the functionality and industrial safety.

During experiments there are noticed as following:

- The use of the optic fibre improves the identification of the geometric centre of the optic fibre core image in the ratio of the laser spot. The use as a plummet the weight of the optic fibre eliminates; the influence of the environment in the ratio of the laser beam light used as a plummet.
- Our device there is no need collimation light beam. The misalignment error of pendulum axis and beams of light emitted are eliminated.
- The accuracy determination of the geometrical centre image of the optic fibre core comes to ±0.018 mm (five-times measurements).
- The proposed solution for the plummet unable to obtain the frequency of image core registration to 20 frames/second.
- The determined accuracy of the given inclination by the machine spirit level with the use of the

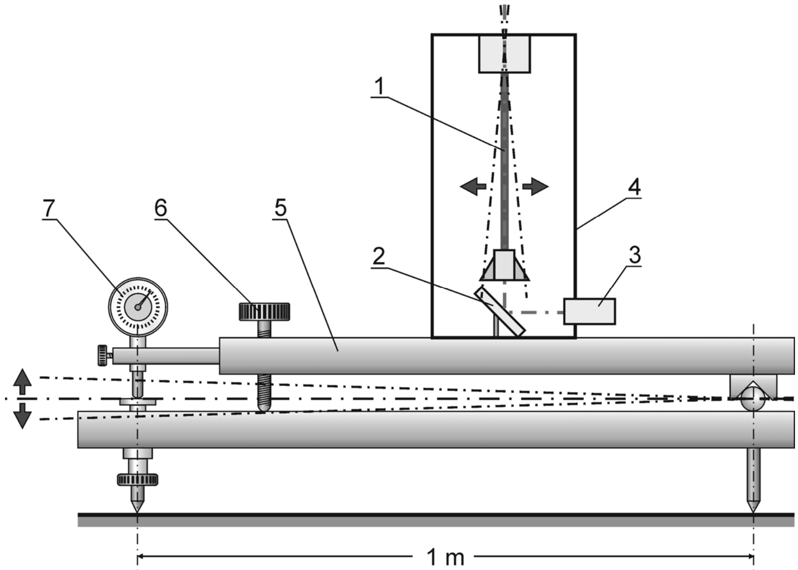

Fig. 12 The view of the examiner during plummet investigations : 1 - optic fibre, 2 - mirror, 3 - CCD camera, 4 - optoelectronic plummet, 5 - examiner of the levels, 6 - adjusting screw, 7 - clock sensor.

optoelectronic plummet does not exceed the value of 0.01 mm/1m. It is about ± 2”.

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