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The Concept of Applying the Shaft Inclinometer in Verticality and Rectilinearity Measurements of Shaft Guides**

1. Introduction

Data referring to the geometry of guides, including their rectilinearity and measuring the inclination of guides from the vertical line provide necessary information for the assessment of the safety in the functioning of a mining shaft. Changes in the geometry of these elements occur due to the rock mass movements in the vicinity of the shaft. The observations of rectilinearity and verticality of the guides in the mining shaft are basic in making the rectification of the work of pulleys, which is necessary for the safety of the cage in the shaft.

According to the Enactment of the Minister of Economy of 28th June 2002 on the safety and hygiene of work, movement and specialist anti-fire security in the underground mines (Dz. U. No. 139 position 1169) [5] it was stated that: in the time established by the director of the movement in the mining enterprise, depending on local conditions and work of the pulley systems, but not rarer than every 5 years – the control measurements should be carried out checking the geometry of shaft lining and the elements of shaft reinforcement, rectilinearity of the rails and the value of the telemetere between the guides and the working areas of glide rails (p. 5.13.9.6). Thus a periodic check-ups (inventory) of the rectilinearity of the rails guiding the cage in mining shafts is necessary.

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2. Classical Measurement Method

So far in practice, as measurement control lines for the measurements of the details in mining shafts two reference systems have been used so far. It is reference to the main shaft axes, in which the situation of four freely hanging verticals is determined or four steel wires inclined from the direction of the gravitation, fixed in the places of the places of the refraction of vertical shaft profile and/or in the bottom of the shaft. A basic inventory measurement means taking situation details in the profiles of the shaft on the height of the shaft girder. These details are connected with shaft guides (their dimensions and sizes), girders, at least every 3 points of the shaft lining (for the cross section) and other elements of the shaft reinforcement to define so called movement spaces The method of x and y axes supplemented with the measurement of front parts is applied in this case [4]. These measurements, because of their character are very time and work consuming and require switching off the shaft during the measurements.

3. The Structure of the Shaft Inclinometer

Problems with making classical measurements generating the need of making the prototype of an instrument allowing the measurement of rectilinearity and verticality of shaft guides, called shaft inclinometer (patent claim no. P.381 685) [1]. The main advantages of the new instrument should be the safety of making measurements, short time of making measurements, their automatization and comparability of the obtained results with classical methods.

The scheme of the structure of the shaft inclinometer was presented in figure 1.

The shaft inclinometer is based on the solution requiring continuous measurement of the inclinations from vertical of the pendulum of 1-m length immersed in damping liquid. This is carried out by a computer system of laser beam detection, where CCD was applied as a photodetection receiver measuring the movement of the pendulum, with the source of the light. The inclinometer consists of the lining, the top and bottom part of which (in the telemeter of 1 m) two pairs of wheels were placed in the bearings During the measurements they are touching the front part and sides of the guide. To stabilize the movement of the inclinometer on the guide, on its lining two clamp wheels were placed. One of them is measuring the route of the inclinometer during the measurements In the middle of the lining on the level of the upper profiling wheels the pendulum was placed on the Cardan gear. The pendulum can tilt in two directions (perpendicular and parallel to the front plane of the guide).

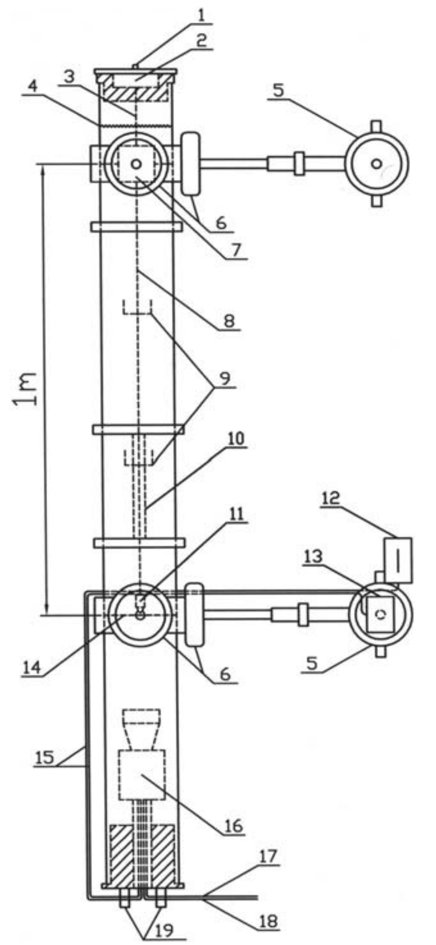

Fig. 1. The scheme of the structure of the shaft inclinometer: 1 – the switch for the LED diode, 2 – power for LED the diode (2 × 1,5 V), 3 – the cable for the diode power, 4 – the level of the damping liquid, 5 – clamp wheels, 6 – profiling wheels, 7 – Cardan gear on bearings, 8 – shifting cable, 9 – elements of damping, 10 – clamp handle, 11 – the LED diode, 12 – girder sensor, 13 – the meter of depth (impulse every ~10 cm), 14 – screen, 15 – connection cables, 16 – CCD camera with the image processing card, 17 – the cable connecting with the computer, 18 – the cable for the power to the camera (12 V), 19 – legs (to fix on the floor)

4. The Technology of Measurements with the Application of the Prototype

The measurement of the shaft inclinometer means touching the instrument to the examined guide (with the use of portable slings) from the compartment of the shaft cage. Then the tilts of the pendulum are registered on-line (with the frequency of about 60 Hz) during the run of the cage (with the revision speed) over the length of the studied rail guide (bottom-up). The inclination of the guide from the vertical, when the shaft inclinometer is touching the guide causes relative changes of the situation of the CCD and LED diode centres, registered by the computer [2]. During the measurement, the presence of two persons is sufficient. One of them is controlling the data recording process on a portable computer and the other is checking the clamp of the profiling wheels to the main surfaces of the guide (with a special handle). The technology of the measurement allows preserving proper security, guaranteeing the absence of physical threat to the personnel.

During the measurements, apart from the determination of X and Y coordinates of the situation of LED (in the CCD form) and the time unit, also the telemeter is due to the applied "telemeter". The principle of the work of the meter is clamping to the side surface of the guide a bottom clamp wheel of the 20-cm perimeter that, due to the applied electronic system, during the run, generates a signal after each 10 cm made by the device. Additionally, the signal from the "girder marker" is recorded, which, due to the application of the electronic system recording the inclination of the sensor, allows catching the moment when the upper pair of profiling wheels passes near the girder. Both elements are installed on the bottom clamp handle of the inclinometer. The telemeter meter and girder sensor was presented in figure 2.

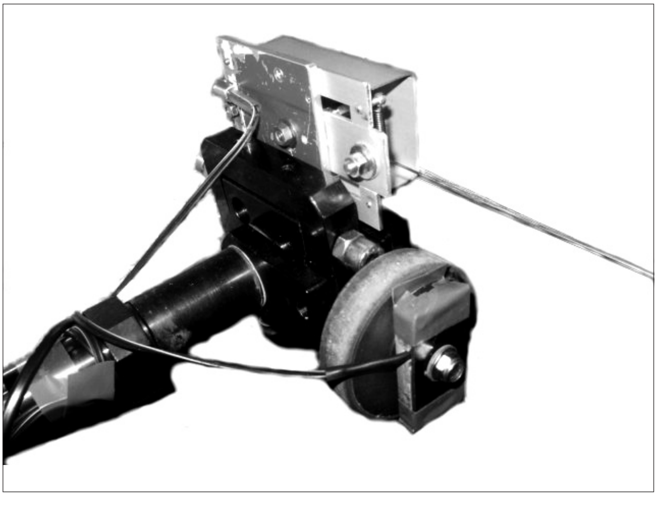

Fig. 2. The telemeter and girder sensor

The measurements are recorded on the computer by a special program, in the form of text files, their format was presented in table 1.

Table 1. The format of the recorded result file

X [pixel]	Y [pixel]	Number of lines	Observation no.	System time	Identification code
317	218	24	1	394677738	0
317	218	24	2	394699515	1
316	217	24	3	394721292	2
315	215	24	4	394743070	3

The number of lines corresponds to the intensity of the LED diode signal on the CCD
The constant used to calculate system time into seconds: 1 s = 1 193 180
Identification codes:
0 – no signals, 1 – girder sensor, 2 – depth meter, 3 – girder sensor + depth meter

5. The Results of Testing the Shaft Inclinometer

To test the prototype a special measurement stand (experimental guide) was put in the experimental shaft. Test measurements were to define the measurement range of the instrument and determine metrical values corresponding pixel units on the CCD. Based on the studies the image of the measurement range obtained in CCD units (pixel) was presented in figure 3. The obtained measurement range of the inclinometer comes into the shape of a circle of the mean radius of 180 pixel.

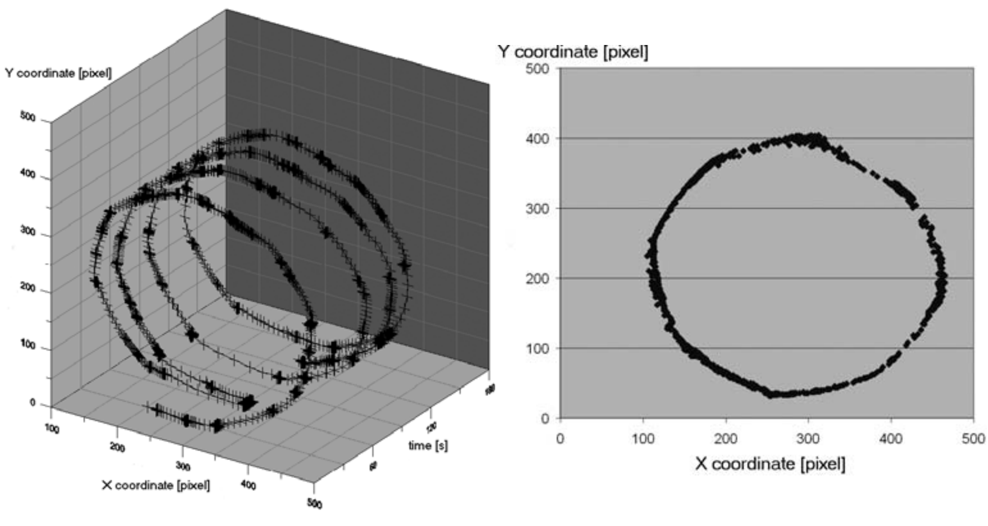

Fig. 3. 3D and 2D images of the measurement scope of the inclinometer

On the further stage of the tests the metric values corresponding to the pixel units on the CCD were determined. For this purpose, the observation of the pendulum relative position on the CCD was made for the cases of the instrument tilts in four main directions, by the constant provided value (1 cm). These directions were compliant with the clamp surfaces of the profiling wheels of the front and side surfaces of the guide. During these studies the prototype was placed on a specially constructed experimental guide.

The graphs of the tilts of pendulums in the main directions were presented in figure 4. The obtained values of the tilts in pixels were calculated into metric units, getting the relationship

$$1 \text{ pixel} = 0.12 \text{ mm}.$$

It can be accepted that the measurement range from the central situation of CCD is 21.6 mm in every main direction.

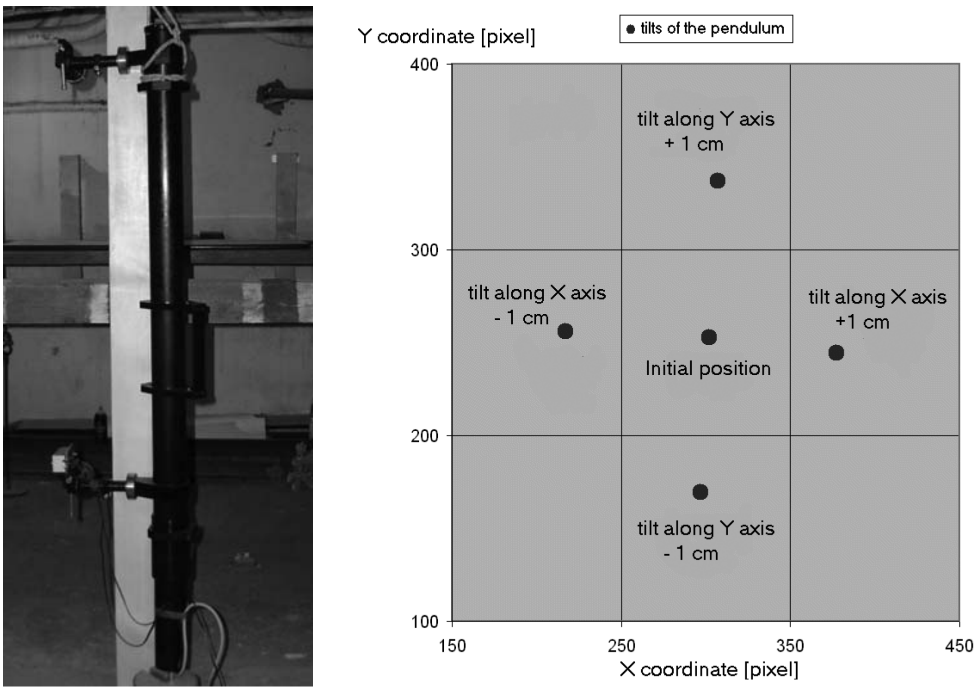

Fig. 4. The observation stand and determined pendulum tilts in the main directions

6. The Results of the Guide Verticality Measurements in the Shaft

In checking the correctness of the work of the shaft inclinometer, the measurement of the guide in the "Eastern" Shaft KWK "Halemba-Wirek" was carried out. The measurement was made twice on the length of 480 m (from the level of the girder no. 121), following the technology described in chapter 4. The definition of metre long sections on the guide corresponding the length of the inclinometer, was made based on the identified situations of the girders in the base of the registered data (signals from the girder sensor).

The inclination of the guide from the vertical reference line was determined with the formula

$$W_i = \sum_{i-1}^{i=K} p_i = s \sum_{i=0}^{i=K} \alpha_i ,$$

where:

- p – linear inclination of the shaft inclinometer (the section of the guide) from the vertialc,
- s – length of the inclinometer (1 m),
- α – the angle of the inclination of the guide from the vertical [2].

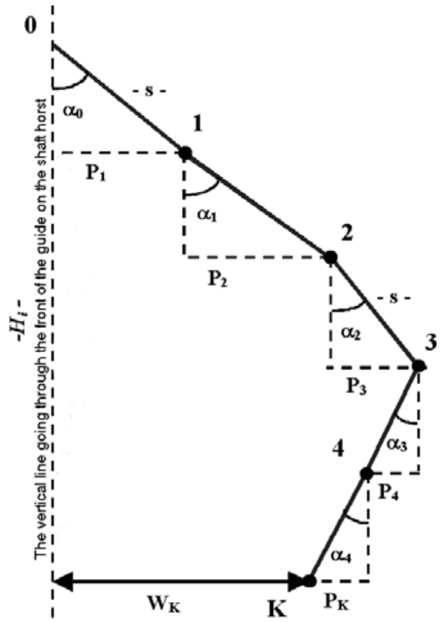

Fig. 5. The scheme of the idea of the measurements of the guide verticality with the shaft inclinometer with description from formula

As a result of the calculations of the guide profile was defined as the sum of the individual tilts of the guide from the level of the shaft horst (Fig. 5). The values calculated in such a way represent only the profile of the guide in two areas, without its reference from the vertical. According to the regulations (given in chapter 1), the obtained in such a way profile can be regarded sufficient in the documentation of a so called rectilinearity of the routes of cage running.

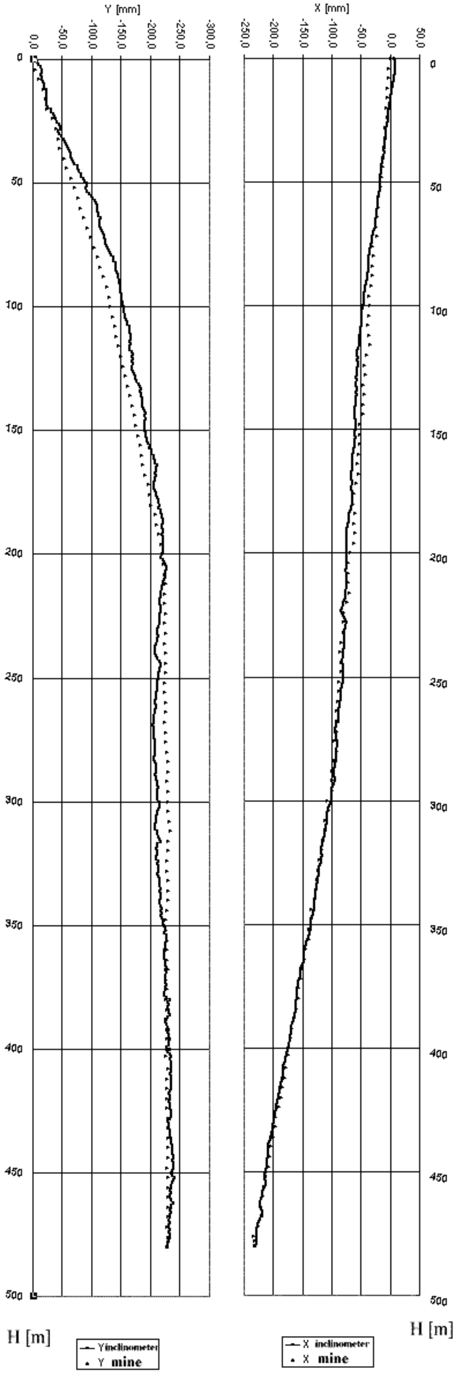

Fig. 6. The guide verticality in the Eastern Shaft

The definition of the orientation of the guide rectilinearity in the space requires adding the values of the constant of shaft inclinometer to the measured inclinations of section values The constant can be calculated from the difference between two corners of the guide obtained from the inclinometer measurement and the measurement of their verticality of any geodetic method. For this purpose the results of the measurements in the described shaft by the Enterprise of Mine Surveying Przedsiębiorstwo Miernictwa Górniczego (PMG).

The accuracy parameters, calculated from the differences of coordinates between the runs of the shaft inclinometer and a classical measurement (by PMG) were put in table 2.

Table 2. Parameters characterising the accuracy of the method

Coordinate	*X* (Front surface of the guide)			*Y* (Side surface of the guide)		
Runs	K-I	K-II	K-M	K-I	K-II	K-M
Average value of the difference [mm]	6.3	7.3	**5.4**	12.7	11.6	**12.0**
Mean error of the difference [mm]	5.1	6.5	**5.1**	10.5	10.1	**10.1**

The course of the guide verticality in the Eastern Shaft obtained by the inclinometer was presented in figure 6. A high compliance with classical measurements for coordinate *X* (characterising the front surface of the guide). The discrepancies for coordinate *Y* (side surface) result form the specifics of the technology of measurements, unfavourably influenced by the irregularities of the side surface of the guide.

7. Closing Remarks

Carried out laboratory studies and measurements made with the help of a prototype instrument called shaft inclinometer allow the conclusion that this instrument can effectively be used in the inventory of shaft guides.

These studies are still continued by the author to fully document the efficiency of inclinometer measurements As far as the course of the rectilinearity of the guides at the inclinometer measurement are obtained from the measurement, to define the verticality of the guide it is necessary to supplement this method with a geodetic reference measurement that will allow to orient the profile (this measurement can be implemented with the application of a single laser plumb, materializing the vertical line near the examined guide, based on them additional measurement orienting the course of the profile).

Thus the reference of profile is not very difficult. The most significant fact is the consciousness that the measurements are made with the use of shaft inclinometer are comparable in terms of their accuracy, but much less time and work consuming and safer compared to classical measurements This makes a good alternative to methods applied at present.

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