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Original Research Article

TESTS RESULT OF THE PROTOTYPE MONITORING SYSTEM FOR THE OPERATING PARAMETERS OF THE POWERED ROOF SUPPORT IN REAL CONDITIONS

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A b s t r a c t

Monitoring of operating parameters of machines and devices is recently used more often in hard coal mining. This solution is one of the elements of the intelligent mine concept. This concept means that the enterprise uses innovative technologies while considering economic and social factors. The aim of applying practical solutions under the guiding idea is to increase the efficiency of the production line and the safety of the crew's work. The authors propose introducing a system monitoring the geometrical parameters of the powered roof support. The proposed system fits the requirements of creating an intelligent mine, a plant that meets the global safety and efficiency requirements. The article depicts studies of the underground working conditions of the section geometry monitoring system. The tests contributed to determining sensor installation locations and clarifying the geometric parameters of the measurement and recording system. The system is a solution so far not used in Polish hard coal mining at such a highly advanced level. Based on the measurements, the tested system determined the transverse and longitudinal inclinations of the essential elements of the section. In addition, through the designated angles, the working height of the section in the wall excavation was determined.

Keywords: geometry, pressure measurement, monitoring of powered roof support, work safety, work efficiency

1. INTRODUCTION

Several threats characterise the mining industry [1-3]. The hazards are natural and technical [4-6]. Natural hazards result from the prevailing mining and geological conditions, and technical ones result from the improper use of machinery and equipment [7-9]. In order to improve working conditions, innovative system solutions are used [10-12] to monitor the operation of machines and devices [13-15]

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and the environment [16-18]. Monitoring systems are used in a significant number of areas of the mining industry [19-21]. They concern ventilation, tremor and energy and mechanical areas, monitoring gas concentrations, phenomena occurring in the rock mass [22-24] and the proper functioning of machines and devices [25-27].

The specificity of a mining plant's work poses many challenges and barriers to the monitoring systems, such as constraints arising from geology alone, equipment mobility, telecommunications and financial constraints [28-30]. The acquisition in real-time of data from systems, their joint processing, interpretation and control of the entire process are necessary, even critical, conditions for ensuring the crew's safety and the optimal use of assets, energy and other means of production [31-33]. The authors propose to present a monitoring system solution, which is a measuring and recording system of the works of the powered roof support section in the wall excavation [34-36].

The Polish mining industry only monitored the sections of powered roof support, compared to other devices of the wall complex in 2000 [37-39]. The powered roof support's basic task is cooperation with rock mass [40-42]. Properly selected powered roof support affects the proper maintenance of the roof [43-45], which significantly impacts the efficiency and safety of people working in the wall [46-48]. This, in turn, translates into the safety of operating on the wall and the financial results of coal companies [49-51].

A wireless measuring and recording system installed on the basic elements of the powered roof support section was used for the conducted tests of the system operation in underground conditions. The research has yet to include such an innovative approach to monitoring the operation of powered roof supports. The conducted study included preliminary analyses based on the prototypes of sensors monitoring the geometry of the sections on the test stand and tests in real conditions. The research thoroughly monitored the powered roof support section provided on the market [52-54]. Taking into account geometric parameters and changes in the pressure values in the props gave the authors a broader look at the phenomenon of the powered roof support's cooperation with rock mass.

The presented research is the result of many years of analysis and research related to the creation of a measurement and recording system of geometric parameters of the powered roof support. The activities preceding the application of the system in the underground conditions included bench tests, FEM analysis, measurement error levelling, software development and correct interpretation of measurement data [55-57]. After completing these steps, the measurement system was approved for scientific measurements in the extraction wall.

The research in the underground conditions was aimed at reflecting the actual conditions of the system's operation. The main objective was to determine the significance of work monitoring and guidelines for the cooperation of the system with the section of the powered roof support. In this respect, the conducted research provided important information for authors, constructors and users in terms of the location and operation of the monitoring system. The results are a valuable source of data for the implementation of the system to work in real conditions.

2. MATERIALS AND METHODS

In the wall excavation, the installed recording and measurement system consisted of four sensors and one additional sensor equipped with a memory card. The system measured the slopes values based on which the working height of the section in the wall was determined. The sensors were located on the basic elements of the section, i.e. the roof, the floor base, the front lemniscate, the shield (Fig.1). The additional sensor with the memory card was located on the shield. The sensor system communicated wirelessly, using accelerometers in MEMS technology built into the sensors to measure angles. A specially manufactured battery powered the entire system. Battery life was two years.

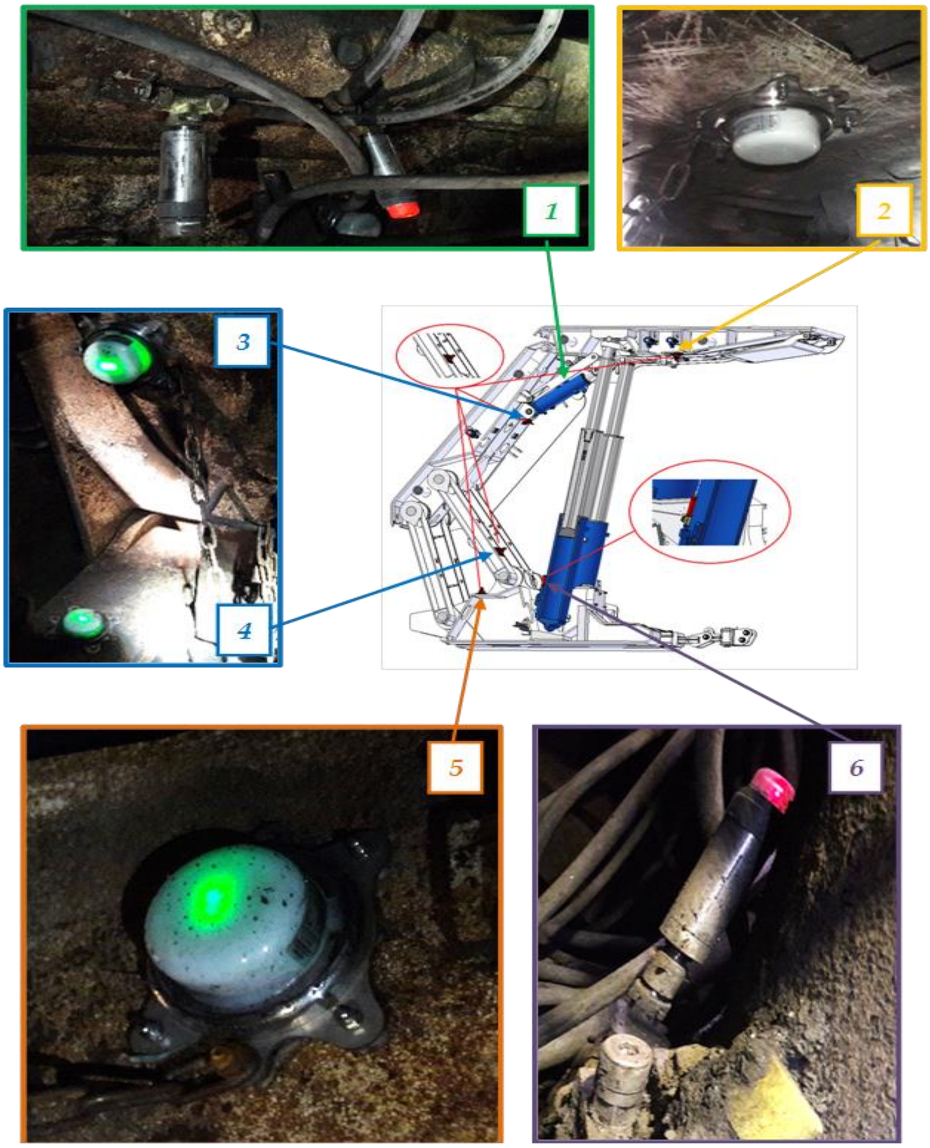

Fig. 1. Underground research stand, where: 1 - hydraulic props sensor, 2 - roof sensor, 3 - shield sensor, 4 - lemniscate sensor, 5 - floor base sensor, 6 - hydraulic leg sensor

The sum of the transverse and longitudinal inclinations was determined using the formula:

$$\sum \lambda = (R_\alpha - HL_\alpha) + (HP_\alpha - SH_\alpha) + (L_\alpha - F_\alpha) \cdot \frac{C}{2} \tag{2.1}$$

where:
$\sum\lambda$– the sum of the inclination, [°]

Rα – roof inclination, [°]
HLα – hydraulic leg inclination, [°]
HPα – hydraulic props inclination, [°]
SHα – shield inclination, [°]
Lα – lemniscate inclination, [°]
Fα – floor base inclination, [°]
c – calculation factor constant.

The height was determined based on the measurement of the angles formed between the work of individual elements of the powered roof support in relation to the selected level. We define the level in the software as the point "0" of the initial measurement, i.e. machine levelling. This operation is performed at the beginning of the implementation of the machine with the software. This action lets us obtain a reliable measurement at a moment of machine operation.

The specified angles form the sum of the slope of the powered roof support's components during operation. Using these data, we determine the sum of the transverse and longitudinal slope and the height of the powered roof support in the wall excavation. In the presented (Fig. 2) longwall excavation, a system monitoring the geometric parameters of the powered roof support was installed. Measurements in real conditions allowed us to analyse the variable phases of operation of the powered roof support section and the system's efficiency. The system sensors were located on the essential elements of the powered roof support section, which were determined based on the analysis of strength, geometry and bench tests. The bench analysis allowed us to perform tests using the system prototype in the technological hall to determine individual sensors' communication efficiency. Successful research made it possible to install the system in the mining wall.

Fig. 2. Longwall excavation of the Coal Mine, where: 1 - power roof support, 2 - conveyor, 3 - shearer

Measurement works were carried out in underground conditions, which are classified as complicated in terms of many threats and factors affecting the damage to the measurement system and its communication. The coal bed, in which the wall was located, reached a thickness of 2.55 - 4 m. The inclination of the bed for the analysed wall is from 15° to 20°. The direct footwall and roof of the coal bed 408 consisted of shale. The wall length was ~ 111-242 m, and the depth was ~ 1195 m. The coal bed was classified as the fourth methane category, the second-degree tremor hazard, the B-class of coal dust explosion hazard and the third category of the gas and rock discharge.

3. RESULTS

In the wall excavation, the installed recording and measurement system consisted of four sensors and one additional sensor equipped with a memory card. The system monitored the work of three selected sections subjected to research. The test stand in the first phase measured for six days. The results of the measurements in Figure 3 show the changes in the height of the total work of the monitored sections.

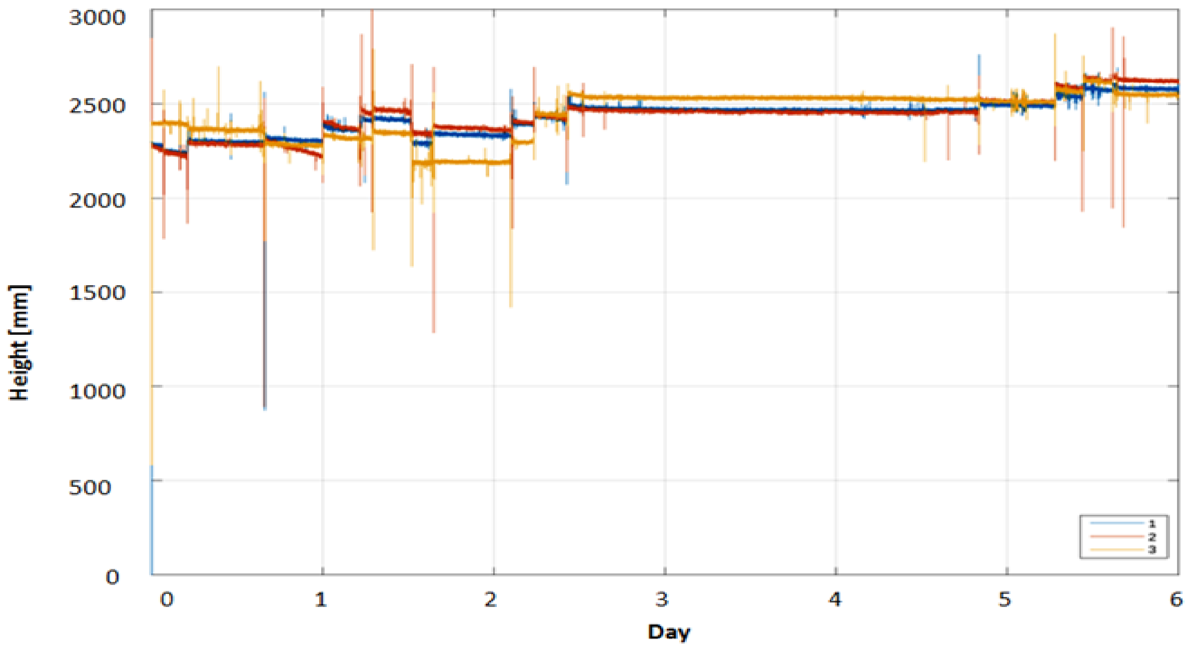

Fig. 3. The height of the three sections tested

In Figure 3, the characteristic changes in height are caused by the given phase of operation of the powered roof support. The powered support performs a movement consisting in lowering the working range, then moving towards the coal bed and moving again lifting, A characteristic feature of this diagram is the similar working height of each support, which proves that the longwall excavation is carried out correctly.

Figures 4 - 7 show the transverse and longitudinal inclinations of the tested elements of the section.

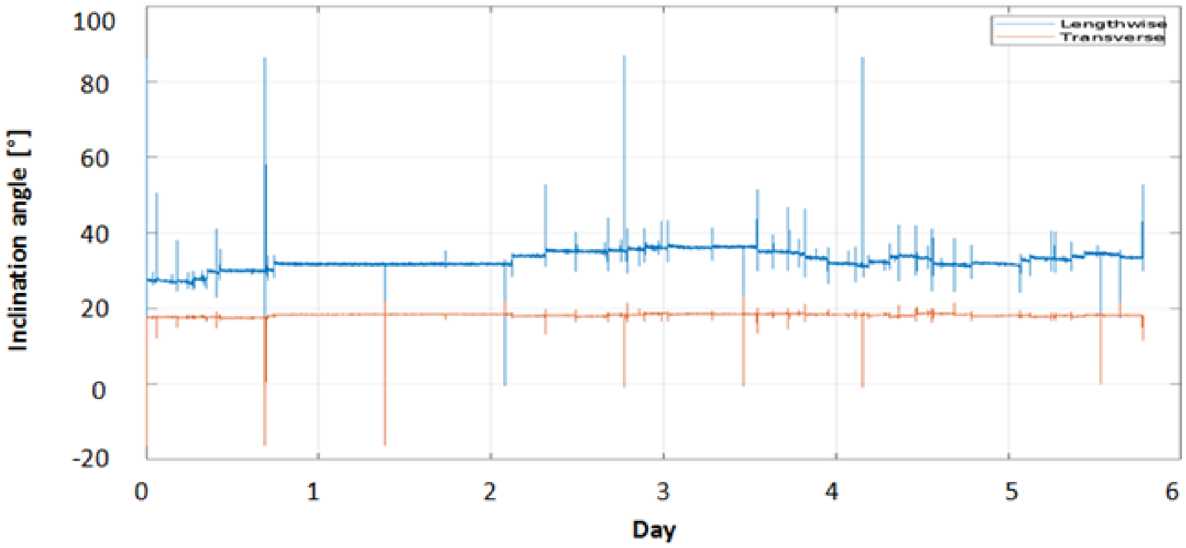

Fig. 4. The transverse and longitudinal inclination of the shield of the tested section

Figure 4 presents the inclination of the infarction shield, which is characterized by a constant value for day 2. This is due to the lack of movement by the example section of the powered roof support. The values of the transverse inclination are approximately 19º, the longitudinal inclination ranges from 29 -38º. The highest value of 38º is on the 3rd day of the research.

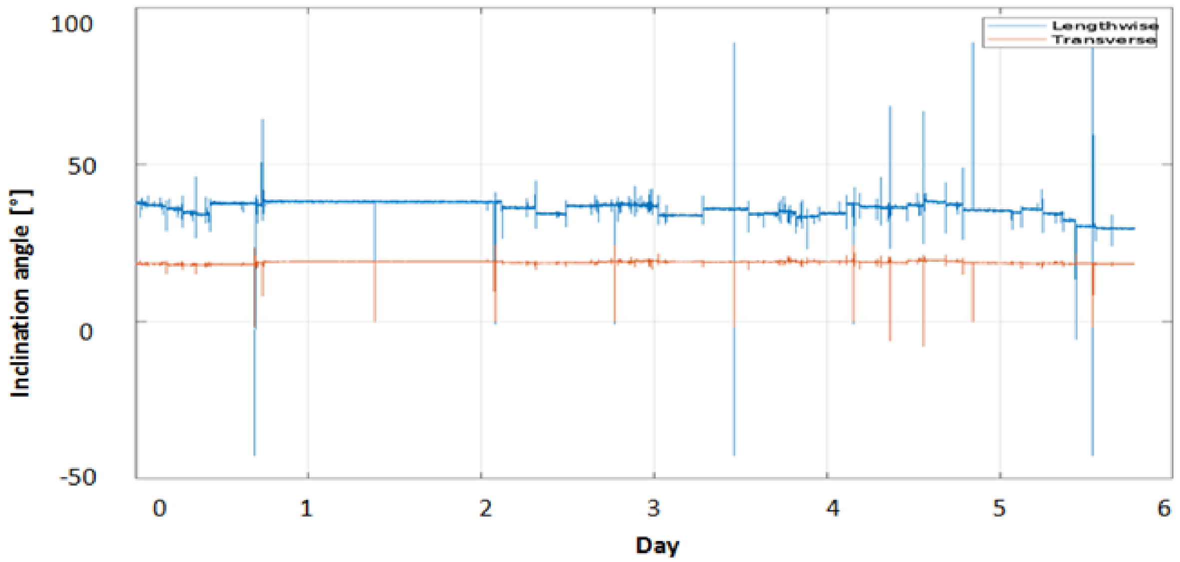

Fig. 5. The transverse and longitudinal inclination of the lemniscate of the tested section

Figure 5 presents the inclination of the lemiscate, which is characterized by a decrease in the longitudinal inclination angle for day 3.This is due to the movement of the casing during the mining process. The lowering of the casing and the shift towards the coal bed generates a greater angle of longitudinal inclination for the caving shield, and a lower angle of longitudinal inclination for the lemniscates.The values of the transverse inclination are approximately 20º, the longitudinal inclination ranges from 30 - 45º.

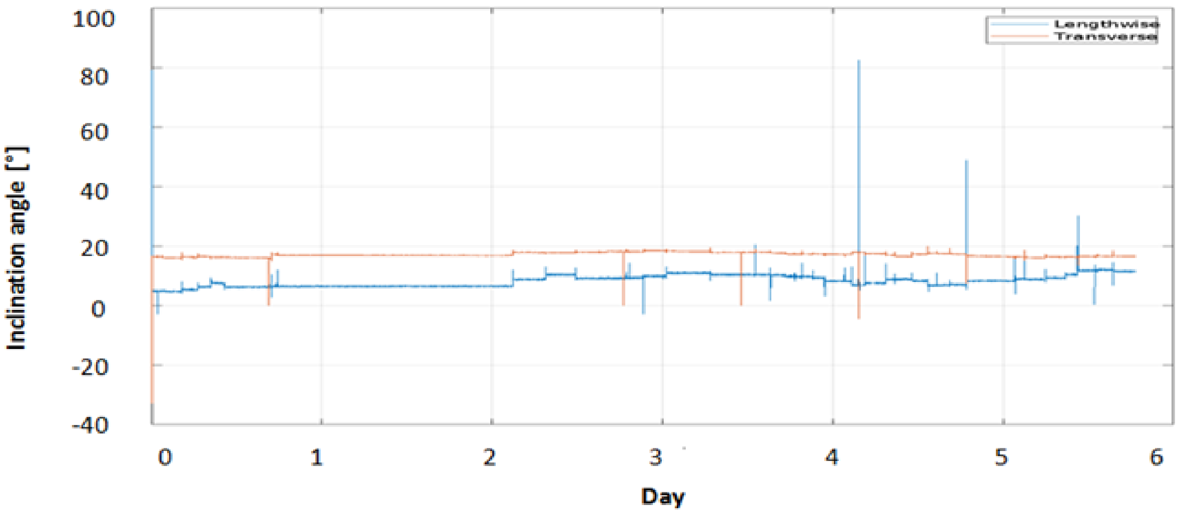

Figure 6. The transverse and longitudinal inclination of the floor base of the tested section

Figure 6 presents the slopes of the floor base, which are characterized by a low variable longitudinal and transverse inclination angle. The operation of the floor base in the longwall working should constitute the 0 support point for the lining in the longwall working.The values of the transverse inclination are approximately 19º, the longitudinal inclination ranges from 8 - 15º.

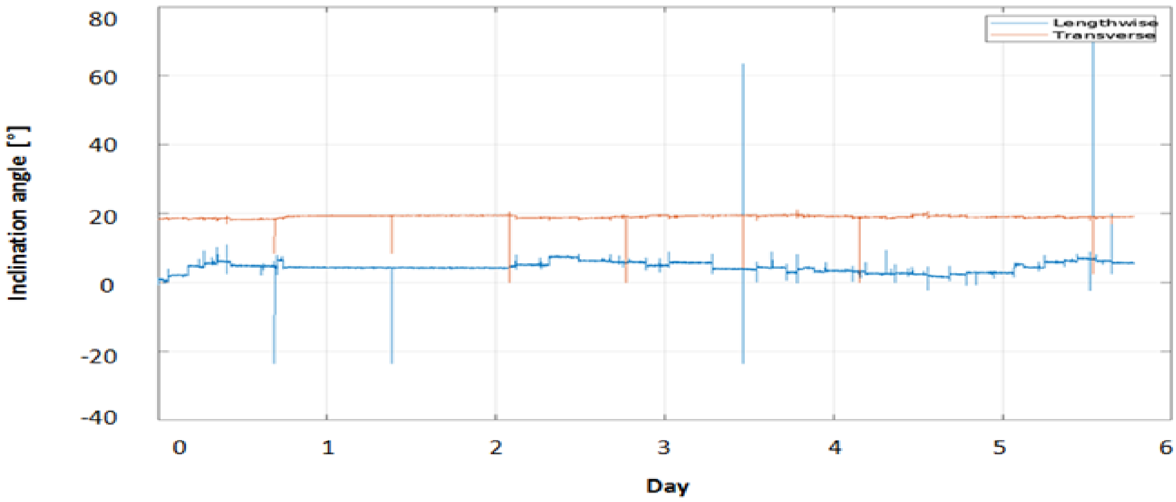

Figure 7. The transverse and longitudinal inclination of the roof of the tested section

Figure 7 presents the slopes of the roof, which are characterized by a low variable longitudinal and transverse inclination angle. The operation of the roof in the longwall working should constitute the 0 support point for the lining in the longwall working. The values of the transverse inclination are approximately 19º, the longitudinal inclination ranges from 8 - 15º.

The drawings characterize the slopes of individual housing elements. A feature that characterizes these drawings is the reflection of the actual operation of the powered support in real conditions. The element that constitutes the basis for the proper conduct of longwall excavations is maintaining the parallelism of the roof beam in relation to the floor base.

This leads to even coverage of the roof of the excavation and, as a result, reduces the risk of roof rocks falling. A characteristic feature is the cooperation of each element of the casing, which can only be noticed during the installation of the casing and the lemnisact.

Data from measurements are presented in Tables 1 and 2.

Table 1. Longitudinal slope values

Longitudinal						
Floor base [Fαº]	Roof [Rαº]	Lemniscate [Lαº]	Shield [SHαº]	Hydraulic leg [HLαº]	Hydraulic props [HPαº]	The sum of the inclination [∑λº]
4,81	1,25	37,7	27,84	8,6	6,5	12,37
5,06	1,15	38,3	30,2	5,9	5,2	11,66
4,70	0,95	34,27	31,36	5,5	8,3	8,06
5,24	1,3	37,10	33,89	4,6	8,2	8,95
4,95	4,70	35,78	34,79	7,6	10,5	2,69
4,75	1,08	34,80	35,75	7,8	7,3	2,47
4,83	5,13	37,62	34,74	6,4	8,5	3,63
5,03	6,01	36,80	33,22	4,2	10,1	5,55
10,45	3,85	36,07	31,82	10,4	11,6	11,45
9,34	4,27	35,78	32,94	12,9	15,6	9,26
11,74	3,16	30,49	33,35	4,7	8,4	7,57
12,09	6,26	29,42	33,32	13,6	10,6	0,43

Table 2. Transverse slope values

Transverse						
Floor base [Fαº]	Roof [Rαº]	Lemniscate [Lαº]	Shield [SHαº]	Hydraulic leg [HLαº]	Hydraulic props [HPαº]	The sum of the inclination [∑λº]
16,55	18,32	18,48	17,50	81,8	22,7	28,76
16,07	19,37	18,12	17,46	79,0	24,7	24,51
17,23	18,77	18,33	17,64	76,4	24,6	25,05
16,85	18,69	19,12	17,39	76,5	22,2	27,04
16,78	19,06	18,66	18,33	77,8	25,6	24,15
16,77	19,24	19,03	18,08	79,0	27,0	24,48
18,09	19,22	18,97	18,09	73.0	31.0	20,75
18,15	18,83	19,16	18,49	72,1	36,3	17,89
17,32	19,36	19,57	18,31	62,4	32,4	14,22
17,43	19,21	18,69	17,85	64,6	23,2	19,76
16,66	19,11	18,72	16,60	62,6	24,6	18,67
16,61	19,14	18,46	18,17	66,1	36,7	12,46

The basic inclinations of the powered roof support's elements, which are illustrated by the data from Tables 1 and 2, are obtained directly from the measurement-recording system installed on the test stand. The measurements are the basis for determining the working height of the powered roof support and determining the sum of the slope. Figure 8 shows the sums of the transverse and longitudinal inclinations of the examined section.

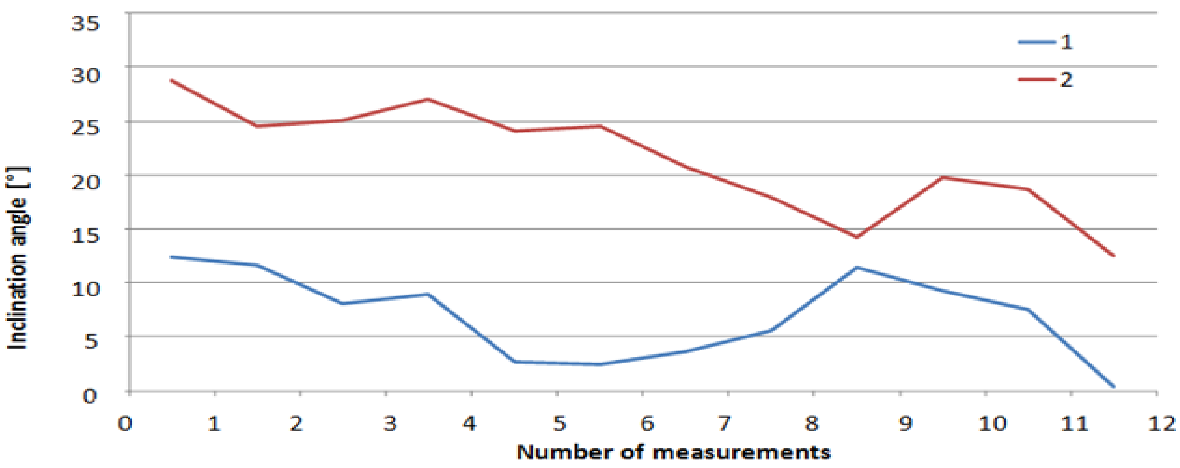

Fig. 8. Graph of the sum of the transverse and longitudinal inclinations of the tested sections, where: 1- sum of the longitudinal slope, 2- sum of the transverse slope

The sum of the transverse and longitudinal inclinations constitutes a reference to the increasing height of the support work in the longwall excavation. The method of controlling the casing to obtain height generates a decrease in transverse and longitudinal inclinations for the operation of the casing elements. It determines the phase of the powered roof support's operation in the space. The inclinations and the designated height of the powered roof support operation show the critical parameters of its operation. Such information constitutes the necessary database for the visualization of the actual operation of the powered roof support in the wall excavation. The operator and the person supervising the work of the powered roof support can use this information to diagnose the correctness of the powered roof support's operation and react to changing mining and geological conditions during the excavation of the wall. This system can also be a supporting tool for departments dealing with the observation of changes occurring in the rock mass and measuring departments of the mine.

4. DISCUSSION

The measurements carried out are a source of information that refers to the prevailing mining and geological conditions in the mining excavation and the efficiency of the powered roof support and the crew. Using the proposed system of monitoring the operation of the powered roof support, it is possible to verify in real time the changes in the conduct of the wall excavation.

During of the powered roof support operation in real conditions, they were not significantly exposed to difficult mining and geological conditions. The system correctly performed measurements of the transverse and longitudinal inclination of the tested elements (Fig. 4-7) and the height of the powered roof support (Fig. 3). Manual measurements were performed at random to confirm the correct operation of the system. In order to enrich the presented research, the system was equipped with pressure The authors used pressure monitoring and powered roof support geometry during the analysis. The data made it possible to take a broader look at the phenomenon of powered roof support cooperation with rock mass. Figures 9 and 10 show the variable values of the pressure in the props and the hydraulic leg.

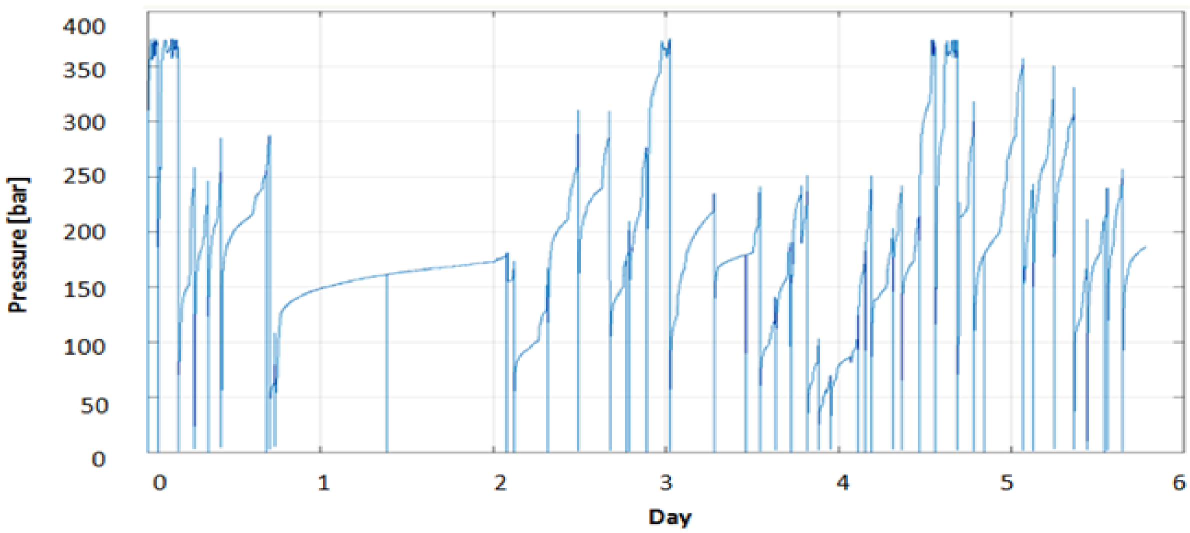

Fig. 9. Pressure value for powered roof support's hydraulic leg

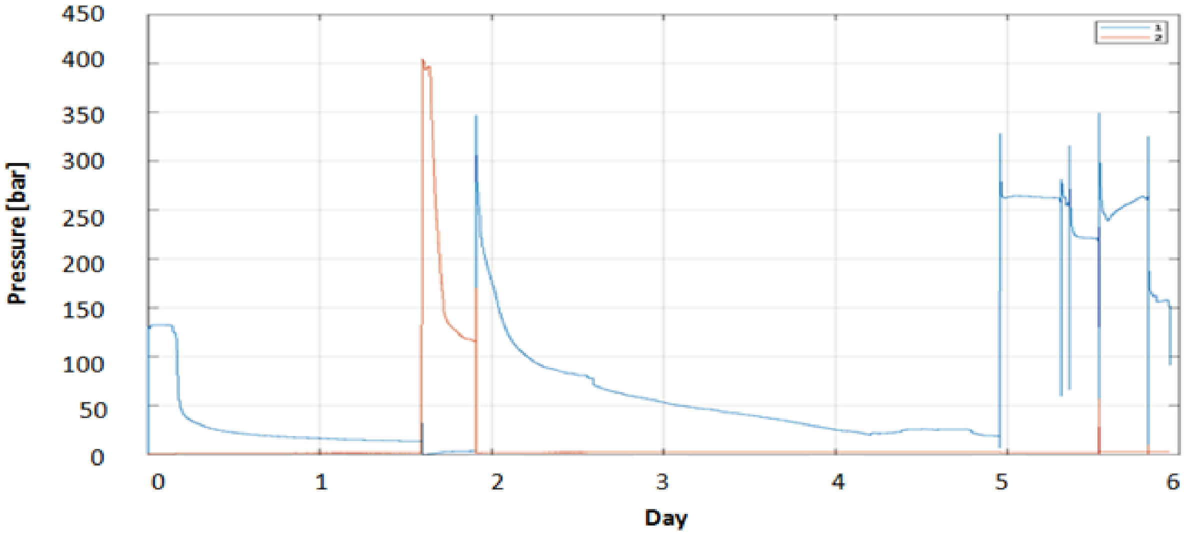

Fig. 10. Pressure value for powered roof support's hydraulic props, where: 1- sub-piston pressure, 2 – over-piston pressure

The value of the pressures in the powered roof support's operation is referred to in the measurements of the powered roof support's operation height. The observation shows that the pressure value variable coincides with the height variable of the powered roof support. This phenomenon depends on the control of the section by the operator, giving the authors values confirming the correct operation of the system. The irregular state of mining and geological conditions, which have a crucial impact on the recorded measurements, is discussed. They are the direction of occurring phenomena in the operation of powered roof support. The human factor, the manner and experience in conducting the wall excavation and section control are worth considering in the measurements made. These factors have a significant impact on the quality of measurements, efficiency, work safety and the economic factor associated with the stops of the wall complex. The stops result from roof rocks collapsing. After determining the height of the powered roof support, the system enabled determining the transverse (Fig. 11) and longitudinal inclinations (Fig.12) of each of the elements on which the sensors were installed.

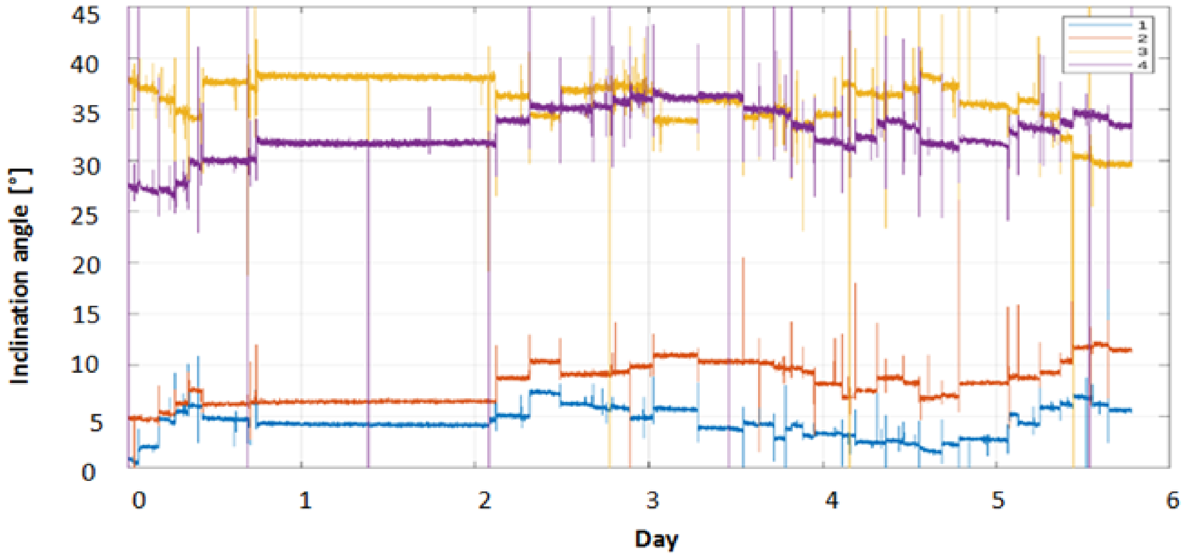

Fig. 11. Transverse inclinations of the basic elements of the powered roof supports, where 1 – roof, 2 – floor base, 3 –lemniscate, 4 – shield

Monitoring the geometric parameters of the section is vital to ensure the stability of the wall excavation and the correct conditions of the powered roof support's cooperation with the rock mass. Under challenging conditions, it may affect the reduction of damage in the elements of the section of the powered roof support. Significant features of the tested system are the possibility of continuous measurement, data transfer to any place and wireless communication between the sensors collecting measurements from individual elements of the section.

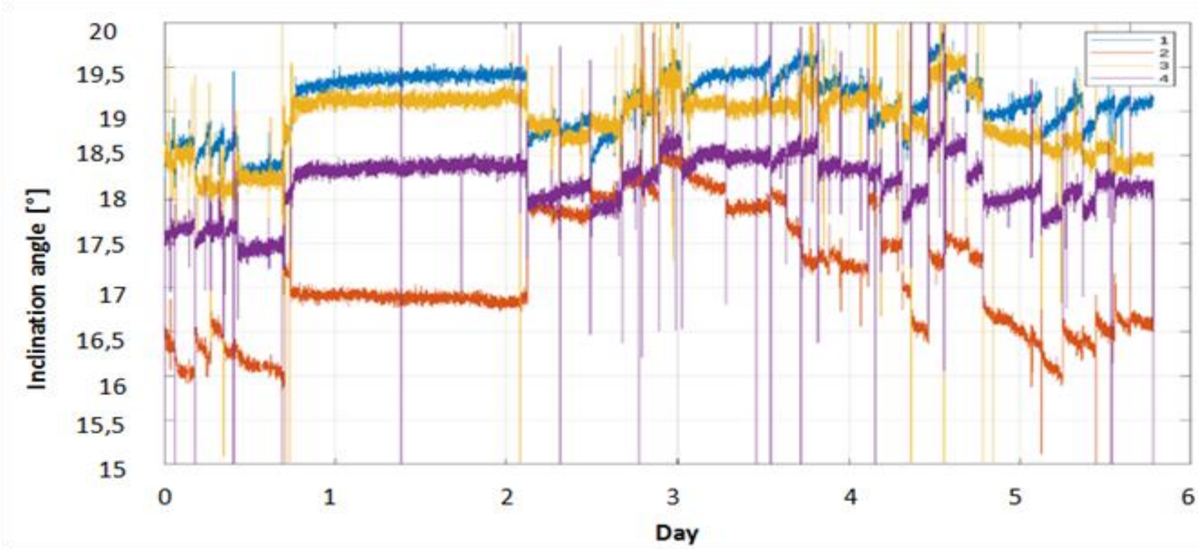

Fig. 12. Longitudinal inclinations of the basic elements of the powered roof supports, where 1 – roof, 2 – floor base, 3 –lemniscate, 4 – shield

Figure 12 shows the variable slopes of the powered roof support section elements in underground conditions during its operation. In order to determine the sum of transverse and longitudinal inclinations, the authors used the proposed formula and data obtained from the measurement and recording system.

The presented drawings reflect the working height of the powered roof support. The values of the slopes are subject to discussion. Does their degree of lowering have a significant impact on the operating height of the housing? After determining the sum of the transverse and longitudinal inclinations, it follows that they have an influence. An additional feature that, according to the authors, should be taken into account in relation to determining the working height of the support is the monitoring of pressure drops for the hydraulic leg and hydraulic props.

5. CONCLUSION

Systems analysing production processes are an indispensable element for maintaining the continuity of hard coal production. Thanks to the introduced optimization packages, monitoring phenomena occurring in mining excavations and monitoring machine parameters in real-time, there is a chance to reduce the accident rate and increase personal safety while improving production processes. The construction of new and updated existing systems for monitoring the production process gives opportunities to compete with other companies related to the mining industry.

The practical application of the system assumed the installation of sensors in the sections of the powered roof support in the wall excavation. The conducted research confirmed the correctness of the designated mounting places for the sensors. sensors, the measurements of which are shown in Figures. The results of the tests are graphs of measurements of the current height of the section (Fig. 3) and a diagram of the sum of the transverse and longitudinal inclination of the powered roof support's elements (Fig. 8).

The tests determined the geometric parameters for the three tested sections, constituting the test stand in underground conditions. The presented graph from the article is a fragment of measurements that, based on correct interpretation, diagnostics and experience, can be used as a tool to predict mechanical phenomena in the operation of the powered roof support and mining and geological phenomena in the excavation of the wall. Ongoing monitoring of the presented parameters will contribute to increasing the efficiency and safety of workers in the mining walls.

The conducted research provided the authors with practical knowledge of the mounting locations of sensors in sections intended for high, medium and low walls. The applied section geometry system is a tool that improves the efficiency and safety of the conducted extraction walls and the operation of the powered roof support. Current monitoring of the geometric parameters of the powered roof support provides users with key information for conducting a wall excavation at a much higher level of advancement. The analysed geometry system is an element that supports broader perspectives for the use of automatic wall complexes.

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