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Application of a measuring and recording system with MEMS technology for a powered roof support

Innovative technologies in hard coal production are indispensable for building a modern business enterprise. The pace of environmental and social changes inspires the need for continuous improvement of the coal mining process. The domain of machinery and equipment is the most important element of the entire production process. Machines and equipment require the constant monitoring of their operating parameters to ensure production continuity and safety. A solution addressing those needs is a measuring system that records the parameters of the powered roof support. The constructed measuring system uses MEMS technologies to measure changes in the transverse and longitudinal inclination of the elements and the height of the powered roof support. The measuring system allows for determining the parameters of the powered roof support's operation in the mining wall. The following paper presents an example of the use of MEMS technology in the measuring system sensors, as well as the stages of real-life research on adapting the powered roof support to the measuring system.

Key words: *powered roof support, efficiency, safety, FEM, MEMS, underground mining*

1. INTRODUCTION

The development of innovative solutions provokes the need for research on their adaptation to the difficult conditions of the mining industry [1, 2]. Implementing research in this domain requires several analyses of large data sets and real-life tests [3]. Difficult geological and mining conditions pose major challenges to the engineering environment [4–6]. The machine park is an area that needs continuous improvement [7]. The wall complex is the key element for coal processing and consists of a mining machine, a powered roof support, and a scraper conveyor [7].

The powered roof support is the part of the mechanized wall complex that excavates the rock mass and transports it from the forehead zone. The powered roof support is tasked with securing the working space in which the operation is carried out and supporting the operation of the entire mechanized complex, the elements of which are largely important for the entire system [8].

The risks in the mining production process, especially the natural ones, place very high demands on the powered roof support and its sections [8]. The cooperation of the powered roof support and the rock massaffects the efficiency of other machines, including primarily the mining machine [8].

The primary elements of the powered roof support include all parts that transfer loads caused by the pressure of the roof rocks. Additional elements are the parts that do not carry loads coming from the pressure of the roof rocks, but that are necessary for the functioning of the powered roof support [9]. The primary elements are shown in Figure 1.

Continuous monitoring of the powered roof support's operating parameters is required to improve work safety and efficiency. The author proposes adapting the measuring system, which would allow for constant measurement of geometric parameters and pressure [9].

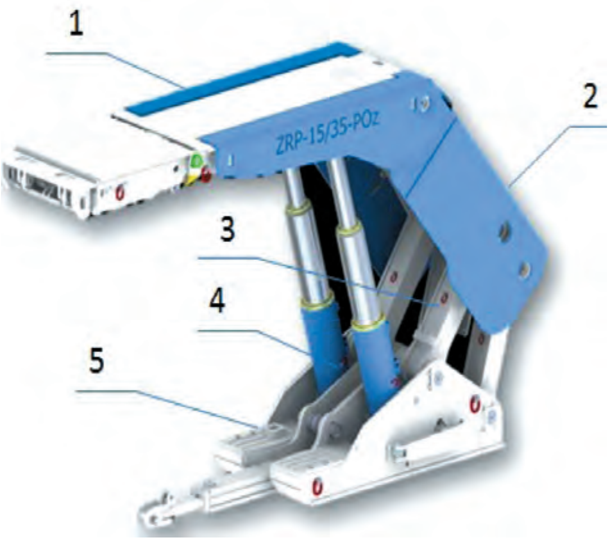

Fig. 1. Structural elements of powered roof support 1 – cap piece, 2 – shield support, 3 – lemniscates, 4 – hydraulic props, 5 – foot piece

The measurement system is based on miniaturized electro-mechanical devices operating using MEMS technology [9–11]. The technology facilitates the development of advanced machines and devices [10, 11]. MEMS technology is interdisciplinary. It combines engineering, design, and manufacturing areas [10, 11]. It is used in mechanical engineering, chemistry, materials engineering, electrical engineering, fluid engineering, optics, medicine, communication systems, and space science [10, 11]. Using the technology in various types of sensors allows for measuring vibration, impact, inclination, displacement, and rotation (Fig. 2) [10–12]. The measurement is made with the component force of gravity (g), which affects the object on the surface. MEMS is resistant to vibration and is highly reliable. Furthermore, it has low energy consumption, microscopic construction, and low production costs [10–12].

The paper presents the results of the model, bench, and real-life tests, the purpose of which was to determine the installation location of sensors and the correct operation of the measuring system. The measuring and recording system consisted of a computer with specialized software and four sensors. The applied solution made it possible to measure the inclination angles of the powered roof support elements and the height of the machine at a given stage of its operation.

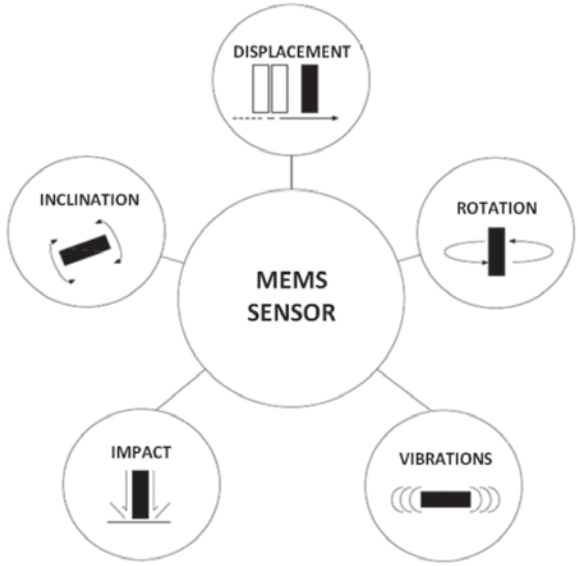

Fig. 2. Measuring capacity of MEMS sensors [11]

It was possible to visualize the operating cycle of the powered roof support thanks to the measurements obtained, and the collected data.

2. THE RESEARCH PROCESS OF THE POWERED ROOF SUPPORT'S DEVELOPMENT

Monitoring the parameters of the operation of a powered roof support is a challenge for engineers due to the difficult working conditions of the entire measuring system and the powered roof support cycle resulting from the coal mining process. Ameliorating the measuring system requires long-term research and analysis of the data obtained at each research stage. To refine the measuring system, we focused on each of its elements, carrying out model, bench, and experimental real-life tests, and finally attempting to implement them into the production cycle.

2.1. Model tests

The model tests were the first part of the analysis, which was supposed to determine the mounting locations of the measuring system designed for constant monitoringof the powered roof support parameters [15]. The research was based on the finite element method (FEM), which included performing real stress simulations on the structural elements of the powered roof support. The first stage consisted of determining the geometric parameters of the designed section of the powered roof support. Then, the limits of elasticity and plasticity of the structure were determined with the view to the boundary conditions. The next step included determining the calculation area in the form of a computational grid, as well as performing a simulation of reduced stresses. Figure 3 presents an example of the simulation on a powered roof support section.

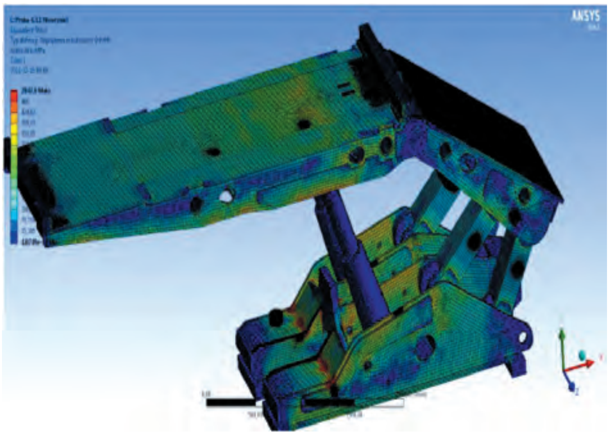

Fig. 3. Example of simulation of model tests on powered roof support – FEM method

The simulation facilitated identifying the areas which are most vulnerable to breakage or plasticization by external forces in real-life conditions, thus excluding these areas as a potential mounting location for the measuring system. The model tests carried out at the design stage made it possible to exclude collisions of the basic elements of the powered roof support with the measuring and recording system and to determine the initial locations of its installation.

2.2. Bench testing

Bench tests were carried out on the measuring system designed for this purpose and the powered roof support sections, which during real-life tests were installed in a wall excavation. The sensors constituting the measuring system were installed following the guidelines established at the stage of computer simulations. The sensors were installed on the primary elements of the powered roof support section, i.e. cap piece, foot piece, shield and lemniscate. The tests aimed to obtain data pertinent to the height of the powered roof support (Fig. 4) in the alternating phases of its operation and to confirm whether the measuring system works correctly.

Measurements were continuously verified manually (Fig. 5).

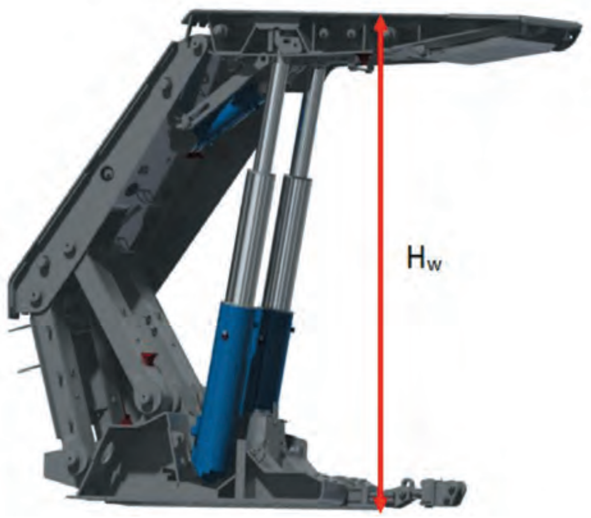

Fig. 4. Measuring the powered roof support working height

Fig. 5. Manual measurement of the powered roof support working height

The Figure 6 and Table 1 present changes in the working height of the powered roof support, resulting from the way it is controlled during bench tests. This data is used to pre-determine the measurement error. The measurement error was calculated by comparing the manual measurements with the data obtained from the measuring system. The scope of error at the time of testing was within 4–10 cm. In addition, no collision was detected with the primary powered roof support and additional structural elements while operating it in real-life conditions with the installed measuring system. Thus, the analyses from computer simulations were correct [15].

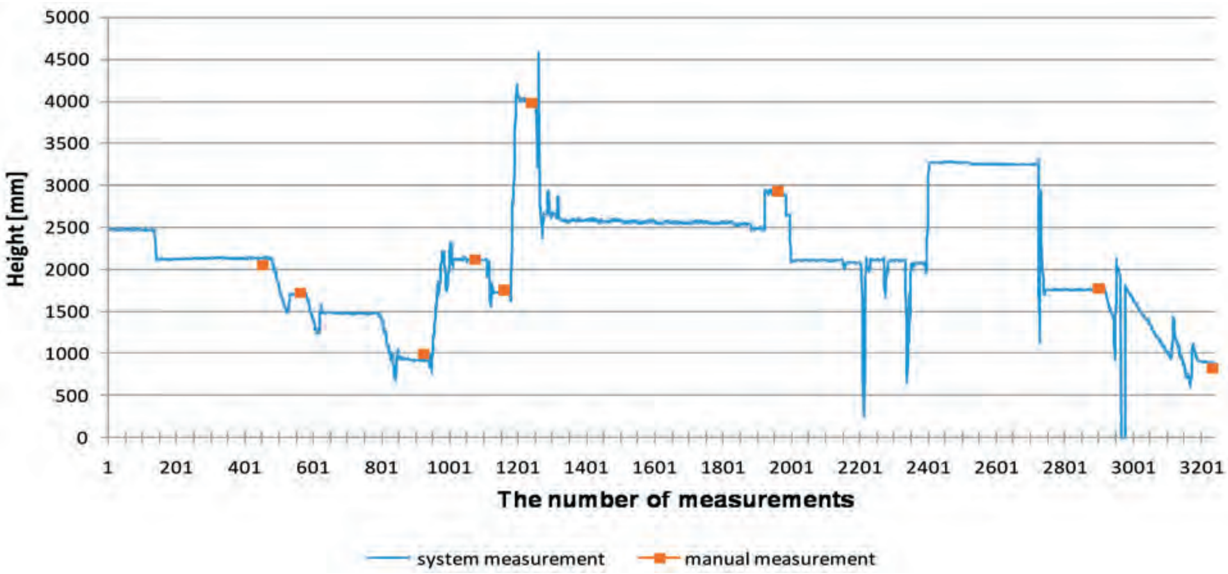

Fig. 6. View of the distribution of the system's measurements and manual height of the powered roof support section at the test station

Table 1

Comparison of measurements from bench tests

Type of measurement	1	2	3	4	5	6	7	8	9
System [mm]	2137.89	1715.61	927.29	2131.12	1722.03	3987.04	2906.37	1768.74	883.83
Manual [mm]	2235.89	1761.61	1004.29	2193.12	1780.03	4039.04	2973.37	1811.74	967.83
Difference [mm]	98	46	77	62	58	52	67	43	84

2.3. Experimental tests

Model tests performed with the finite element method (FEM) and bench tests allowed to exclude collisions of individual elements of the powered roof support with built-in sensors at the initial stage. They also identified and excluded the sensor mounting locations that were most exposed to external forces. The developed guidelines helped to create a research station and enabled the practical use of the entire system under real-life conditions. The placement of sensors in real-life conditions is presented in Figure 7.

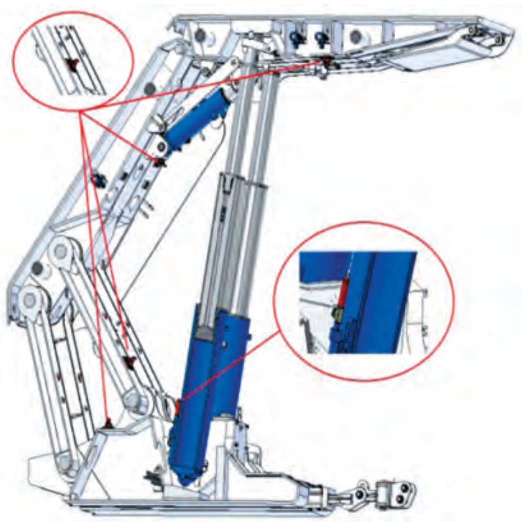

Fig. 7. Placement of sensors on the test station under real-life conditions

The measuring system was equipped with a hydraulic prop operating pressure sensor to obtain additional parameters of the section in the wall excavation. This measurement additionally provided the load-carrying capacity of the powered roof support that can affect its working height. The location and installation method had a key influence on the calibration of the measuring and recording system. The correct orientation of the sensor is dependent on the mounting brackets. The innovative mounting brackets are installed so that the orientation of the sensor's lens is as per the guidelines established at the stage of bench testing. An example of a sensor installed with a mounting bracket is presented in Figure 8.

Fig. 8. Sensor installation in real-life conditions using mounting brackets

Conducting tests in real-life conditions provided large data sets, which served to determine the guidelines for the monitoring system. At the stage of experimental tests, the parameters of the operation of three sections of the powered roof support were determined based on the height of their operation (Fig. 9). The obtained data confirmed the correct operation of the measuring system. The next stage involved the use of a measuring system for continuous monitoring of the parameters of the powered roof support. The system enables data to be transmitted to the visualization stand located in the sub-wall excavation and to the surface [9].

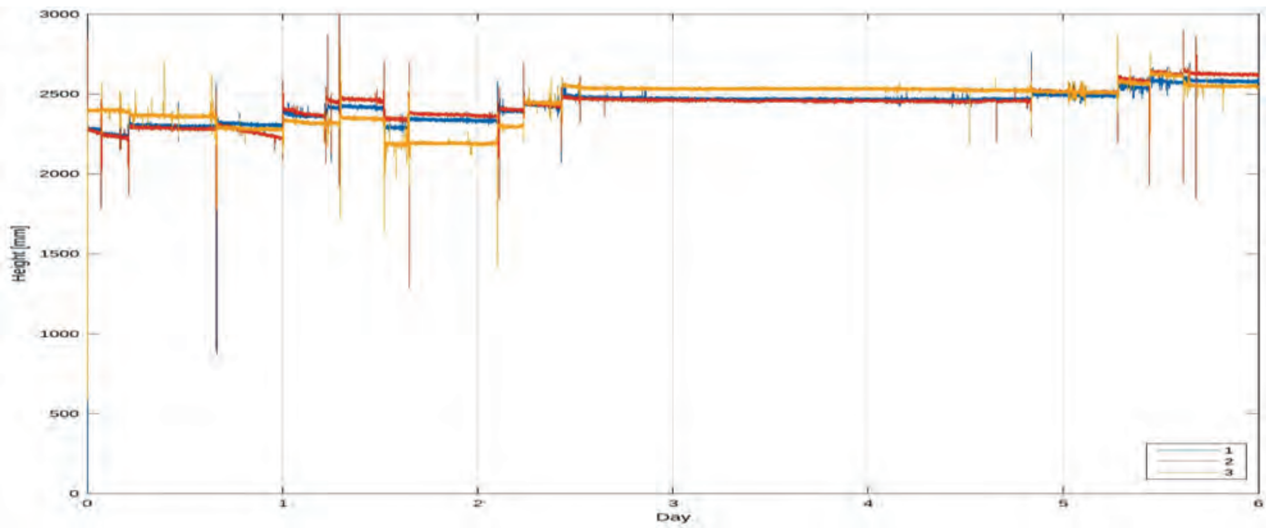

Fig. 9. View of height distribution in powered roof support sections

3. EXAMPLE OF USE

Measuring system has been installed in underground conditions in the mining wall in deck 510 with a mass from 8.8 m to 10.8 m. The layers there collapse at an angle of approx. 6° southwest. Five sections in the wall excavation were monitored. Three of them were equipped with a set of sensors installed side by side. The others were installed at a distance of 25 and 35 sections in the direction of the reverse drive of the scraper conveyor.

The bottom computer for the current data visualization from the section was located in the sub-wall excavation. The geometric parameters of the section i.e. the transverse and longitudinal inclination of the primary elements of the powered roof support, height, and pressure were all monitored. Figure 10 presents the visualization of the operation parameters of one of the monitored sections. Connection and mutual communication of sensors in the sections was wireless. Data was transmitted to the server room on the surface from an underground station located in the excavation. Wireless communication between 5 sections and the cooperation of the underground station with the server room on the surface was used in the measuring system's tests for the first time.

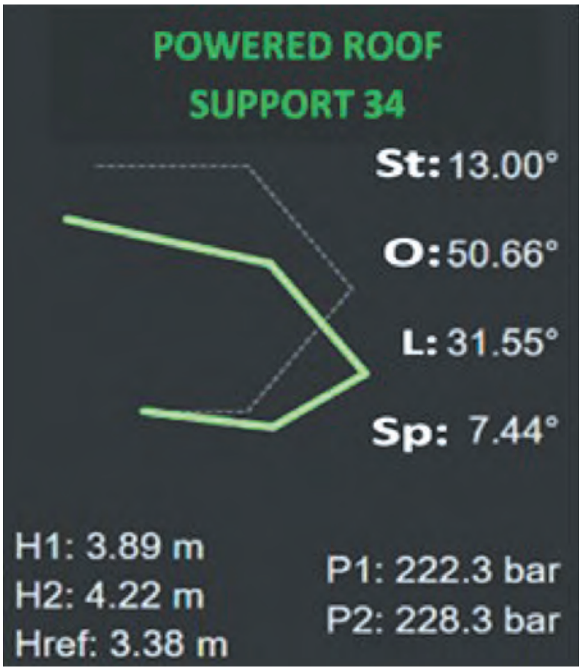

Fig. 10. Visualization of powered roof support operational parameters under real-life conditions

4. SUMMARY

Thanks to the measurements of the powered roof support geometry (transverse and longitudinal inclination, height), we can determine changes occurring in the height of the wall and the inclination of the powered roof support's primary elements. The difficult conditions forced us to use additional equipment in the powered roof support sections in order to increase the safety and efficiency of work in the wall excavation. Mining in a pit with variable inclination significantly affects the efficiency of the coal loading process and increases the power consumption of the electric and feed motor. The increasing inclination degree in the wall excavation changes the way machines are operated and managed. Improving working conditions and constant monitoring of these factors is possible with the help of continuous measurement of changes in the inclination of the machines and devices. Using powered roof support geometry monitoring systems, we have a chance to reduce the number of malfunctions of the entire wall complex, reduce the effects of uncontrolled falling of roof rocks, preserve the geometric parameters of the excavation, and constantly monitor the powered roof support operation from any place. Ongoing monitoring of geometric changes in the powered roof support, occurring during the mining process, will allow for:

- ensuring the stability of the roof;
- maintaining the expected geometric parameters of the excavations;
- increasing competitiveness in the mining market;
- increasing security;
- reducing the risk of adverse events associated with falling roof rocks;
- improving the quality of big data storage and analysis;
- increasing the effectiveness of control and supervision of employees;
- early detection and prevention of malfunctions;
- determining the inclination and height of the section at a given working stage;
- increasing the efficiency of the entire wall complex.

The measuring and recording system is one with the tools for improving autonomous wall complexes. The data made available by the measuring sensors can be used by the control systems of the powered roof support to visualize the wall, in advanced automatic wall complexes. They will allow for automatic control of the powered roof support progress following the recognition and assumed shape of the wall excavation. The applied measuring system allows continuous access to the operating parameters of the powered roof support without the need for intervention of employees and adaptation of these parameters to external conditions.

The paper presents the stages of the tests, the purpose of which was to adapt the measuring system and the design of the powered roof support to cooperate, thereby obtaining the compatibility of the structure with the measuring system. Without long-term research on the location and method of mounting the sensors of the measuring system, the quality of the measurement data obtained would be fraught with a high error possibility.

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