Analysis of the impact of mining and geological conditions in longwalls on the introduction of pressure monitoring for powered roof supports

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Abstract. Polska Grupa Górnicza has analysed the longwalls in its mines where powered roof supports should be subject to pressure monitoring. The main goal was to increase the safety of people working in the longwall. The scope also included the economic improvement of active longwalls in terms of stoppages caused by roof fall or possible tremors. The analysis, carried out in this regard, allowed strategic longwalls to be selected from the individual mines of Polska Grupa Górnicza. The paper describes mining and geological conditions in the longwalls, where monitoring is carried out, with particular attention paid to potential tremors. The paper discusses the scope and use of powered roof supports in longwalls. The research team selected the pressure monitoring system as the most important parameter of work of the powered roof support. The paper also presents the results of an analysis carried out on the implementation of the system. A survey was conducted among the employees regarding the relevance of the monitoring system. The analyses results were used to recommend the directions of further actions related to a development of the system for monitoring the supporting parameters of the powered roof support systems.

1. Introduction

In Poland, hard coal is the basic raw material used to generate electricity and heat, thus guaranteeing energy security. Despite numerous changes in the structure of the functioning mining plants, restructuring of the mining industry, automation of exploitation processes, underground mining is an area of economy ranked among the most dangerous in terms of accidents and occurrence of natural hazards [1]. An accumulation of negative factors, such as methane, rock bursts, ejecting rocks, and so on, calls for actions to improve working conditions and comfort [2]. Therefore, it is very important to invest in innovative machinery and equipment to ensure safety, comfort and operating efficiency [3,4,5,6].

Polish hard coal mining is characterised by an occurrence of several natural hazards that necessitate taking preventive measures to improve occupational safety. The application of the proposed solutions largely influences the mining method, efficiency and mining costs [7]. It is accepted that the safety factor is primary and forms several challenges for companies competing in the mining machinery and equipment market. All the activities, especially an implementation of new technical solutions for
mining already at the design stage, force companies to take into account geological conditions and natural hazards occurring in mining [8,9].

The article discusses the operation of the pressure monitoring system of a powered roof support unit in selected longwalls of the Polska Grupa Górnicza. In addition, it proposes measures that can be taken to improve occupational safety in mining and, based on surveys, discusses the reaction of employees to the application of innovative solutions in mining using a system for monitoring the units of powered roof supports. The paper aims to analyse the pressure monitoring system against natural hazards and the way the employees perceive it in practice.

2. Characteristics of natural hazards for selected longwalls in Polska Grupa Górnicza covered by pressure monitoring

In the Polish coal mining, practically all the natural hazards typical of underground mining occur, especially the so-called catastrophic hazards. Natural hazards generate several incidents and accidents. The degree of natural hazards present can lead to a reduction in mining efficiency [10]. This phenomenon may even result in the shutdown of a mining plant. Natural hazards are an integral part of the mining operation, but modern machinery, equipment and technologies for mining in difficult conditions make it possible to avoid them [11]. The characteristics of natural hazards in coal mining are presented below [12].

Methane is an odourless, colourless, flammable mine gas and, when combined with air, forms an explosive mixture [13]. The presence of methane in the mine air can displace oxygen, creating an unbreathable atmosphere and an explosion. At concentrations up to 5.0%, methane burns off steadily in contact with a thermal source, in the range 5.0-15% an explosion may occur, and above 15% the mixture is flammable. The strongest explosion occurs at the 9% methane concentration.

Rock bursts are phenomena during which the structure of rocks surrounding workings is violently destroyed as a result of exceeding their strength. It manifests itself in a dynamic movement of rock rubble into the excavation followed by a loud noise with gusts of air and a tremor.

A coal dust explosion is classified as Class A and B. Several factors must be fulfilled for a coal dust/air mixture to explode:
– the coal dust must contain more than 10% volatile matter calculated on the anhydrous and ash-free basis,
– must be fine, its grains not passing through a sieve with a mesh size of 1.0 × 1.0 mm,
– coal dust must be mixed with air within a range of 50 to 1 000 g/m³.

Water hazards are divided into three degrees and are influenced by the degree of hydrogeological conditions, the depth of mining carried out and surface conditions. Aquifers, watercourses on the surface of the ground, provide the potential for direct increase, uncontrolled inflow or water intrusion into the excavation.

The climatic hazard is described by determining the so-called substitute climate temperature in the manner specified in the Polish Standard or by determining the microclimate parameters of the mine air. Using the climate proxy temperature, the working time of the mining personnel in the excavation is determined.

Here, the rocks or coal are rapidly moved/ejected by means of energy that have accumulated in the rock mass. Gas and rock blast hazards fall into three categories.

Fire hazards in underground mining are endogenous and exogenous. Endogenous hazards are caused by spontaneous heating of coal which is a natural phenomenon. Endogenous hazards are caused by human factors [14]. Table 1 presents the characteristics of the longwalls in terms of the analysis of mining and geological conditions in which the pressure monitoring system of the powered roof support units was used. Table 2 shows the list and data of the coal walls included in the pressure monitoring.
Table 1. Characteristics of natural hazards in longwalls subject to pressure monitoring.

| longwall | methane [category] | rock bursts [degree] | coal dust explosion | water [degree] | atmospheric | gas or rock outbursts | fire |
|----------|-------------------|----------------------|--------------------|----------------|-------------|---------------------|------|
| 393a     | -                 | I                    | A                  | I-II           | -           | -                   | V    |
| C-3      | III               | I                    | B                  | I              | -           | -                   | I, II, III |
| C-1      | III               | I                    | B                  | I              | -           | -                   | II, III |
| W-7      | III               | I                    | B                  | I              | -           | -                   | II   |
| 3b-S     | IV                | II                   | B                  | I              | I           | -                   | III  |
| TB103    | IV                | I                    | B                  | I              | -           | -                   | II   |
| 7a       | IV                | -                    | B                  | I              | -           | -                   | II   |

The compilation of data makes it possible, in the first stage of selection of the support system, to analyse prevailing conditions in selected longwalls before introducing the pressure monitoring system. The data collected on mining and geological conditions are used to select the type and scope of roof support operation and pressure monitoring system that will be used in the longwall units.

Table 2. List of analysed pressure monitoring at individual longwalls and data of coal faces subject to pressure monitoring.

| Mine       | Longwall | Seam  | Panel length [m] | Length [m] | Type of roof support | No. of units in the longwall [pcs.] |
|------------|----------|-------|------------------|------------|----------------------|-------------------------------------|
| Piast      | 393a     | 209   | 440              | 165        | Glinik-21/46-POz     | 109                                 |
| Marcel     | C-3      | 507   | 448              | 180        | Hydromel 16/41 POz   | 118                                 |
| Marcel     | C-1      | 505wg | 1,056            | 119-128    | Glinik 14/34         | 89                                  |
| Marcel     | W-7      | 505   | 839              | 180-190    | Hydromel 16/41 POz   | 113                                 |
| Murcki-Staszic | 3b-S  | 510   | 921              | 155        | KW-17/43 POzW1/ZRP   | 103                                 |
| Sośnica    | TB103    | 414/2 | 895              | 233        | POzW1/BSN/ZRP        | 130                                 |
| Halemba    | 7a       | 402/K | 730              | 230        | ZRP-15/35-POz        | 8                                   |

3. Mode of operation of the pressure monitoring system for powered roof support units

The system works in a form of wireless communication among pressure sensors located in units of the powered roof supports. Interruptions of selected sensors do not affect the continuity of data transmission. The sensors are equipped with a replaceable energy source in the form of a battery, whose average operating time is about 2 years. The battery is approved for replacement in underground conditions with regard to hazards without the need to dismantle the sensor. The data acquired by the sensors are sent to a station located in the main workings. This station is equipped with a radio system, a cable interface for communication with a computer. The main station can be used for 3D visualisation of pressure distribution in powered roof support units.

They can be used to determine the working load bearing capacity of the support unit. They also include the pressure values in the legs of the powered roof support, on the supply or supply bus, as well as the supply voltage values of the sensors, so that links replacements can be planned in advance.
The system is equipped with a signalling system mounted on the canopy of the powered roof support unit. The signalling allows, through three colours (red, green, orange), to determine the pressure state during the working phase of the unit. This feature makes it easier for employees to work. In addition, it increases efficiency, improves safety for workers and powered roof support sections.

The underground station uses optical fibre or a teletechnical network to transmit data to the surface. There is a control station on the surface where it is possible, via the website, keep of archives, view in 3D and analyse the data sent by the sensors operating in the longwall workings. The web access facility has the additional feature of allowing general access to the data of several users and viewing the operation of powered roof support units in several longwall workings. The 3D visualisation and data analysis enables an earlier detection of casing unit failures and the efficiency of units and workers.

The wireless pressure monitoring system, whose sensors are built into hydraulic jacks and the floor support cylinder, makes it possible, based on the data collected, to visualise the work cycle of a powered roof support unit, and to analyse the occurrence of leaks in the hydraulic systems and power hydraulics. The data extracted from the monitoring system forms an algorithm to represent the pressure state for the mechanised shoring unit, as shown in Figure 1.

![Figure 1. Example of a course of recorded pressures for a selected section of the powered roof support, where; the blue line represents the right leg, and the red line represents the left leg.](image)

The devices included in wireless pressure monitoring are; a wireless pressure transmitter, whose task is to measure pressure every second when connected to the hydraulic system. Its task is to measure the pressure in the leg of the support unit. The sensors are also located in the supply and discharge bus, as standard at three spots in the longwall. In addition, sensors are placed in the floor base support actuator. The device, providing the connection between the system elements in the wireless network and the device communicating by wire, is an intrinsically safe radio converter. Its operation is characterised by the conversion of a wireless signal into a wired one. The current distribution of pressure in the longwall for the hydraulic legs, the supply and return lines and the floor base support actuator are displayed at the underground visualisation station. This is a computer in a flameproof case, which can also generate pressure distribution graphs for the entire longwall, as shown in Figure 2, and displays archives of the data.
Figure 2. Pressure distribution for powered roof support in a longwall, where: red represents insufficient spragging of the roof support, and green represents proper spragging of the roof support.

The transmission of the collected data between the excavation and the surface server is carried out using the optical fibre. The data, collected by the surface server, are made available to the dispatching station.

4. Surveys
Due to several activities, related to an improvement of occupational safety in hard coal mining, a preliminary survey was conducted among mine employees regarding the use of the pressure monitoring system for powered roof support units and an implementation of modern technologies in mining. The introduction of pressure monitoring systems in the mining sector received negative feedback from employees because of fear of the unknown and the cost of implementation. Given the vital importance of hard coal mining in the Polish economy and the need to improve efficiency, a preliminary survey of employees was carried out to address the technical barrier.

The survey has been designed for a group of 70 employees, working in the departments where investments are planned. This group consisted of physical workers and supervisors of an underground hard coal mining plant. The average age was 37 years and the average period of service was 13 years. Respondents were asked to answer the questions by marking an "X" in the appropriate box. The results are shown in Table 3 and in the graph (Figure 3).

Table 3. The survey designed to determine an impact of modern technology on the manner of performing tasks.

| Item | Questions | Responses |
|------|-----------|-----------|
| 1 | Is the applied control system of the powered roof support unit easy to use? | 62 yes, 3 no, 5 no opinion, 89% yes, 4% no, 7% no opinion |
| 2 | Is it reasonable to introduce a system for a visualisation of emergency states of operation of units (including assessment of supply pressure drop)? | 68 yes, 1 no, 1 no opinion, 97% yes, 1% no, 1% no opinion |
| 3 | Should the control system have a warning signalling system during the switching off units (including a signalling system prohibiting entry under the unit being modified)? | 58 yes, 7 no, 5 no opinion, 83% yes, 10% no, 7% no opinion |
4 Is the message of the warning signal unambiguous/readable?  
5 Are you in favour of introducing new technologies for controlling powered roof support units?  
6 Have you received training on the correct use of a powered roof support unit equipped with the pressure monitoring system?  
7 Are you satisfied with the current control technology of the powered roof support unit?  
8 Is direct control of the support unit a good solution?  
9 Have you had the opportunity to work with an autonomous longwall unit?  
10 Would an autonomous longwall complex improve safety during the ongoing work?  
11 Have you got any experience with electro-hydraulic control?  
12 Are you in favour of introducing electro-hydraulic control of powered roof supports?  
13 Are you in favour of introducing a single pressure monitoring system for powered roof support units across the entire company?  
14 Do you think that powered roof support is a complex machine?  
15 Are current IT systems made in an employee-friendly way?  
16 Are the currently available operational manuals for machinery and equipment in the mine written in a clear and comprehensive manner?  
17 Is it necessary to know the construction and principle of operation of powered roof support to operate it?  
18 Is training provided in the mine on the construction, operation and principle of operation of powered roof support units?  
19 If the answer to question 18 is YES, is the level of this training sufficient?  
20 If the answer to question 18 is NO, do you think such training should be provided?  
21 Does the pressure monitoring system improve occupational safety?  
22 Can you keep up with mastering the use of increasingly modern technical devices in everyday life?

The preliminary analysis shows that the majority of employees support an implementation of modern technology and use of the pressure monitoring system for powered roof support units. The employees agree that innovative solutions improve safety and comfort at work. However, it is worth noting that as a result of reduced knowledge and a presentation of these solutions in an incomprehensive way, the employees feel anxious, mainly due to previous habits and traditions of their work.
The process of implementing modern solutions has increased dramatically, but there is still a long-term process before mining gets fully automated. If it does happen, it will take time for employees to change their attitudes, so more intensive trainings will enable to increase their awareness and reduce their fears. At present of technological development, it is essential to directionally improve the quality and frequency of courses and trainings provided. The development programmes for employees will enable them to expand their knowledge and experience in the safe use of modern solutions. Such activities are aimed at preparing employees and managers for market changes and a technical implementation of modern solutions following the ideas of Industry 4.0.

5. Conclusions

The Polish mining industry is characterised by the presence of many natural hazards. Therefore, it is important to evaluate occupational risks and identify preventive actions. The documents prepared before and during an exploitation of the deposit, should describe the procedure to be followed to ensure a safe operation of the mine, the occupational safety of employees, and a control of emergencies. Creating diagrams, technologies, a protection of buildings or environmental elements, makes it possible to visualise working conditions and a selection of machinery and equipment.

Each mining facility has individual mining and geological conditions. Therefore, with the worsening conditions in mining, it is inevitable to use the technologies proposed by the ideas of the fourth industrial revolution. One of the proposals of the fourth industrial revolution is flexible automation, which allows an introduction of programmable controllers and computers into industrial equipment. An example is the use of a monitoring system for powered roof support units in the mining industry. The monitoring system will make a significant contribution to improving workplace safety. Increased investments in machinery and equipment supplied with modern safety features and the quality of trainings, will enable employees to develop and feel comfortable at work. Aware and well-trained employees are the basis for limiting dangerous incidents and minimising their negative effects.

The presented scope of use of the pressure monitoring system of powered roof support units will provide an opportunity in the mining industry to:
- increase competitiveness in the mining market,
- increase safety,
- reduce the risk of losing sufficient unit support,
- prevent the occurrence of undesirable events,
- increase the efficiency of mining operations,
- increase productivity,
- store and analyse data,
- increase the effectiveness of the control and supervision of employees,
- detect and prevent failures earlier,
- indicate the differences in pressure values in a particular unit.
In addition, the paper presents a survey conducted among employees working in the mining industry. Its results provided an insight into the employees’ approach to a realisation of their tasks using modern technologies. The data indicate that they have never had such opportunities before. They expressed a sincere desire to learn more about the machines and equipment that are being developed to improve their work comfort. Incomplete knowledge that they receive makes them anxious and afraid of the unknown. To change their attitude towards modern technologies, it is necessary to provide them with appropriate trainings aimed at presenting the scope of work and the techniques of using modern machinery and equipment in a simple and understandable way. It seems reasonable that the possibility of a dangerous incident, involving the human factor, can be significantly reduced through appropriate investments and use of modern technologies.

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