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A wireless pressure parameters visualization system of a powered roof support on the example of Polish mines

The introduction of pressure monitoring for powered roof support in recent years by coal companies has been one of the main objectives of the Industry 4.0 programme. The development of the monitoring of operating parameters of powered roof supports in a longwall complex was aimed at increasing the safety of workers and improving the economic result associated with longwall downtime. One of the main objectives of monitoring is to observe the correct spreading of the sections in the excavation and to diagnose damage in the hydraulic systems and the occurrence of internal leakage in the hydraulic cylinders. A system for monitoring the operating parameters of powered roof support has been developed for this purpose. This article describes the advantages of DOH-DROPSY monitoring and its implementation based on the experience of the authors on the example of a production longwall.

Key words: *pressure monitoring, powered roof supports, load-bearing capacity, improved occupational safety*

1. INTRODUCTION

Powered roof support sections in the Polish mining sector, as compared to other longwall system equipment, were not covered by pressure monitoring until 2000. The first reports on their implementation can be found in the literature [1]. The main task of a powered roof support is its interaction with the rock mass [2–4]. This requires the proper selection of the powered roof support [5–7] according to mining and geological conditions prior to the launch of mining operations. Properly selected powered roof supports adequately maintain the roof, which has a significant impact on the efficiency and safety of people working in the longwall [8, 9]. This, in turn, affects the safety of longwall operation and the economic performance of the coal companies. In order to ensure safety and comfort at work, reduce the negative impact of mining on the environment and maintain operational efficiency, increasingly modern technologies and reliable technical means are being implemented, in particular advanced machinery and equipment. An example of this approach is the implementation of the solutions proposed in the concept of the fourth industrial revolution [10–12].

A noticeable development of pressure monitoring for powered roof support can be seen in Polish coal companies [13–15]. The works [16–18] present problems related to the supportability of powered roof support and the possibilities offered by monitoring. The use of monitoring for the analysis of operational parameters of longwall support has a significant impact on the earlier detection of leaks and of a drop in the required pressure and a sudden increase in pressure in the spaces under the hydraulic legs caused by sudden overloading of the rock mass [9, 19].

The development of the monitoring system for powered roof supports and its application in a longwall complex has a significant impact on the safety of other machinery and equipment [20, 21]. The purpose of this publication is to present the development of the DOH-DROPSY monitoring system and its implementation at longwalls in Polish coal mines. Figure 1 shows the design of a wireless pressure monitoring system.

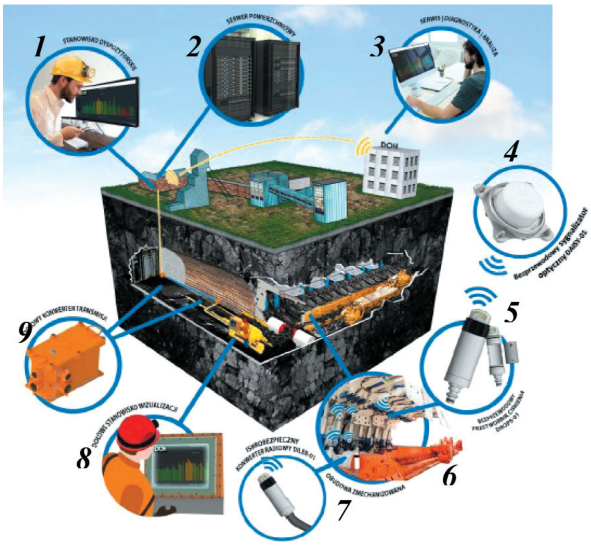

Fig. 1. The solution of a monitoring system for powered roof support: 1 – control stand, 2 – surface server, 3 – diagnostic and analysis server, 4 – wireless signaller DAISY-01, 5 – wireless pressure sensor DROPS-01, 6 – powered roof support, 7 – intrinsically safe radio converter DILER-01, 8 – underground visualisation station, 9 – underground transmission converter

2. DESIGN OF THE MONITORING SYSTEM

In its basic version, the system consists of pressure sensors that take measurements with a high degree of accuracy and transmit them between each other by radio. The lack of a neighbouring sensor does not cause a break in communication, as is the case with the wired transmission. The transmission continuity is ensured within the range of the radio signal and can reach up to two break sections between successive sensors. The sensors, as autonomous modules, have high-efficiency interchangeable power sources, ensuring trouble-free operation of the system for approximately one year depending on the configuration parameters. The wireless signal finally reaches the converter, which provides a local database for the system. It is equipped with radio systems and a cable interface for communication with a face-to-face computer, on which the visualization and configuration application provides a constant view of the pressure values measured in the longwall. These 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. This is carried out under underground conditions without the need to dismantle the sensor itself and transport it away from the hazardous area. This system is an open system, which makes it possible to monitor other parameters, such as the position of section elements from inclinometric sensors. Configuration of the system takes place at the customer's location, making the system user-friendly and non-hermetic. The sensors are suitable for warehouse storage without the need for cell disassembly and initial configuration/reconfiguration.

An additional feature of the system is the DAISY-01 signalling device. It is a wireless device for emitting light signals. It can be mounted anywhere and allows more convenient control of the correct spreading of the sections through visual indication of the level of the measured pressure in relation to the set threshold values.

Located in the main gate, the computer is the local data server (Fig. 2). Using specialised software, it continuously visualises and analyses the transmitted data. It enables network diagnostics, reporting and viewing of measurement history by authorised users. All the data collected by the system in the longwall is transferred to a server on the surface, whose application provides an on-line view of the data, its archiving with the possibility of generating reports and carrying out analyses. It is presented in Figure 3.

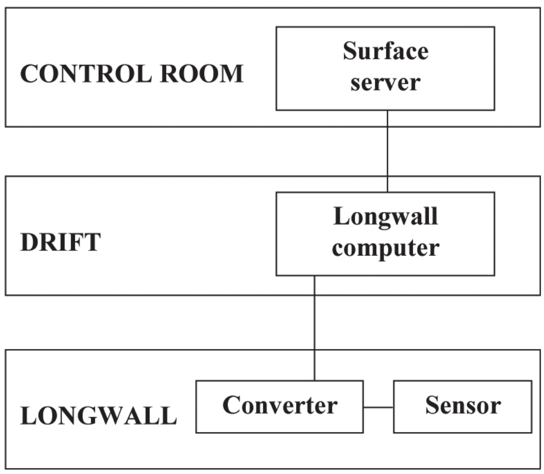

Fig. 2. System components

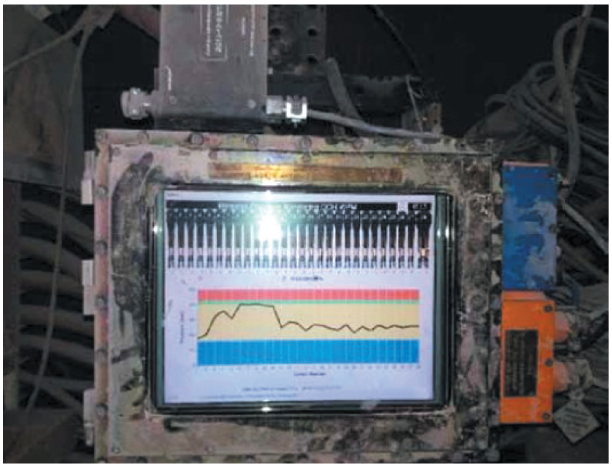

Fig. 3. Overview of pressure monitoring of powered roof supports from a computer located in the main gate

The wireless pressure monitoring system consists of sensors that are built directly into the hydraulic leg block and the canopy support cylinder. On the basis of the measurements obtained and the data collected, it is possible to visualise the working cycle of a powered roof support, and it is possible to analyse the emergence of leaks in the hydraulic systems and the power hydraulics. The data obtained from the monitoring system is compiled as a map with the pressure distribution of each support section. One of the objectives of this system is to improve safety and comfort at work.

2.1. Wireless pressure transmitter type DOH DROPSY-01

The purpose of the wireless pressure transmitter (Fig. 4) is to measure pressure every 1 second when connected to the hydraulic system. The transmitter is an intrinsically safe device. The measuring element of the transmitter is a piezoresistive pressure sensor. The sensor uses a piezoresistive process, whereby the resistance of the measuring bridge changes in proportion to the pressure being measured. Tasks (Fig. 5) that the wireless pressure transmitter performs include:

– measure pressure in section legs, as standard for all sections in the longwall,
– measure pressure in the supply and discharge mains, typically at three points in the longwall,
– measure pressure in the canopy support, by default, both pistons of the support are monitored on selected sections in the longwall, for example, every 10 sections.

Fig. 4. Wireless pressure transmitter type DOH DROPSY-01

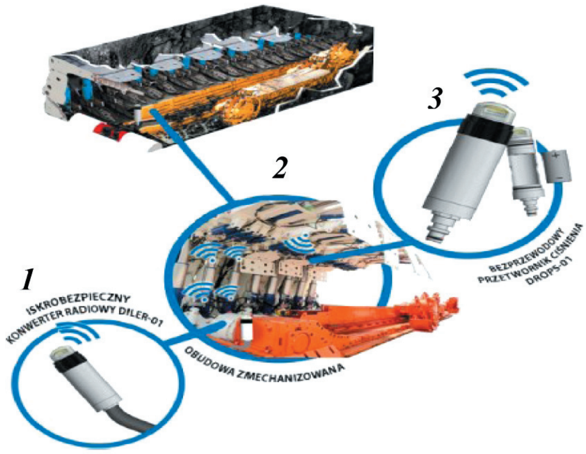

Fig. 5. A method of measuring pressure: 1 – intrinsically safe radio converter DILER-01, 2 – powered roof support, 3 – wireless pressure sensor DROPS-01

2.2. Intrinsically safe radio converter DILER-01

This is a device (Fig. 6) that provides a connection between devices on a wireless network and wired communicating devices. It has the following functions:

– converts a wireless signal into a wired one,
– visual indicator: status of wireless communication with DROPS-01 transmitters, the status of wired communication with the underground computer,
– assembly within 1 to 5 sections of a powered roof support.

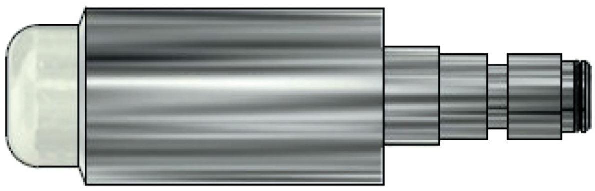

Fig. 6. The intrinsically safe radio converter DILER-01

2.3. Underground visualisation station

The underground visualisation station (Fig. 7) is located in the main gate; it is a computer in an Exd flameproof case (Fig. 6).

Its tasks include:

- preview of the current pressure distribution in the longwall for the legs, the supply and drainage lines and the floor support actuator,
- review of archive data,
- generating a map of pressure distribution in the longwall.

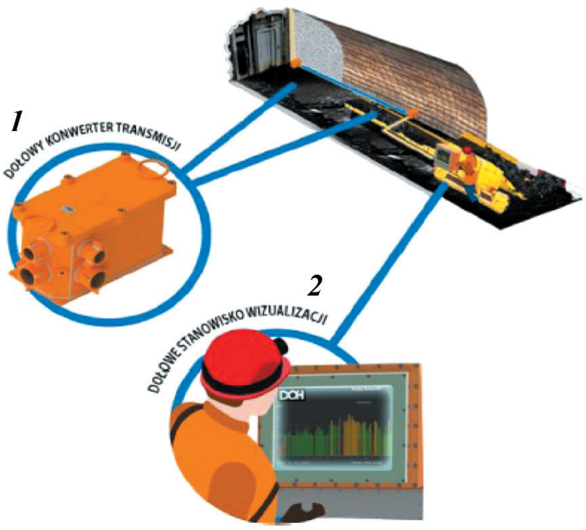

Fig. 7. Method of communication within the longwall: 1 – underground transmission converter, 2 – underground visualisation station

2.4. Data transmission between the excavation site and the surface server

The transmission of data obtained from pressure measurements is carried out via:

- fibre optic cable directly to the surface or,
- twisted pair, using DSL-OPTO signal media converters.

2.5. Surface server with the control station

The task of the surface server (Fig. 8) is to:

- provide measurement data via a website,
- preview the current pressure distribution in the legs of the powered roof support in the longwall,
- review of archive data,
- generate a map of pressure distribution in the longwall,
- visualise the operation of the system on any number of computer stations in the mine.

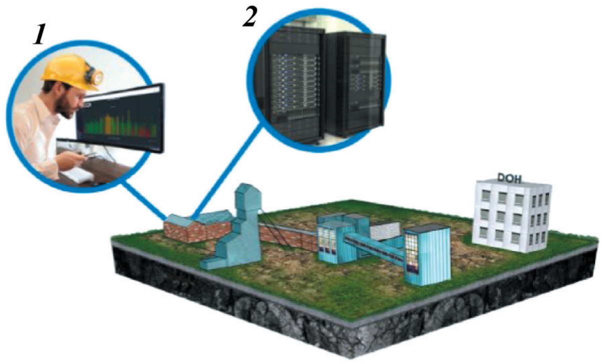

Fig. 8. A means of communication on the surface: 1 – control station, 2 – surface server

3. EXAMPLE OF USE

Longwall 7a, exploited in seam 402/K at depths of 913 m to 952 m, is characterised by a thickness of approximately 2.1 m to 3.1 m, with a transverse slope of 2° and a longitudinal slope of approximately 3°. The seam is overgrown by coal shale with a thickness ranging from about 0.45 m to about 0.9 m. The longwall was mined to the full thickness of the seam without leaving a layer of coal in the roof or floor. There are no discontinuous geological disturbances in the preparatory excavations for longwall 7a in the form of slip faults, etc.

The average compressive strengths are:

- for rocks of the direct roof:
  - shale – 16.7–32.2 MPa,
  - sandy shale – 20.7–94.9 MPa,
  - sandstone – 40.2–79.1 MPa;
- for rocks of the direct floor:
  - shale – 25.0–44.96 MPa;
- for coal bed 402 – 7.9–20.2 MPa.

The above results make it possible to classify the roof rocks in classes from A(II), which defines weak roof falling after a certain delay, to E(VI), which defines very strong and durable roofs. The floors are classified as highly compact [22].

The longwall 7a was carried out in a longitudinal system with roof rock caving with panel lengths of approximately 750 m. The length of the longwall was up to 235 m.

In longwall 7a, the mine used type KW-16/32-POz/ZRP powered roof support sections with a working height of up to 3.1 m and DOH-DROPSY pressure monitoring system. The roof support was a support and shield structure based on an articulated quadrilateral with a lemniscate stabilisation system for the canopy. The selection of the powered roof support and its yielding was carried out by the Central Mining Institute, which determined the roof maintenance index g (0.8, correct roof maintenance conditions) and the ability to absorb loads as a result of a rockburst (according to the loading factor) n_{tz} = 1.4 [23].

The measuring system allowed pressure measurements to be taken with an accuracy of 0.1 MPa at a frequency of 1 second in each leg of all sections of the powered roof support.

The parameters of the system therefore allowed the pressure in the piston cavities of the legs to be measured under basically static conditions only. The pressure measurements covered 152 sections during 350 days of measurement. The measured pressure values in the spaces under the piston of the legs were compared with the area of the longwall, as shown in the following figures.

Pressure monitoring is fundamental to the operation of a longwall complex to ensure that the powered roof support operates at the correct parameters. Based on the monitoring, it is possible to control the working cycle of the powered roof support, such as withdrawing, sliding, and spreading.

This pressure monitoring registers values mainly in the piston spaces of the hydraulic legs and in the supports of the canopy. The DOH-DROPSY wireless monitoring system enables pressure measurements with an accuracy of 0.1 MPa and a frequency of 1 second to be taken. The pressure values for maintaining the required maximum pressure of a given section for proper operation are marked in green. The red colour marks the pressure values indicating that the required pressure has not been reached, which may be the cause of, among other things, insufficient spreading of the sections, the occurrence of external or internal leakage in the piston space of the legs. Figure 9 shows the pressure distribution for the powered roof support section and Figure 10 shows a map of the pressure distribution in the longwall field.

As literature [5, 24, 25] indicates, a powered roof support is characterised by three support capacities. The initial support obtained at the moment of expansion resulting from the supply pressure in the mains. The nominal bearing capacity is the maximum that a powered support section can achieve at static load and depends on the opening pressure of the safety valve. The support that the section reaches at a given moment under the influence of the pressure of the rock mass is the working support; its value is between the working support and the nominal support. Ensuring the required support that a powered roof support set develops is shown in Figure 11, which also interprets the work cycle of a powered roof support section. The location of the pressure sensors in the powered roof support section is shown in Figure 12, where a pressure signaller is placed on the canopy to provide light information on the pressure status. The list of applications of working monitoring in Polish mines is summarised in Table 1.

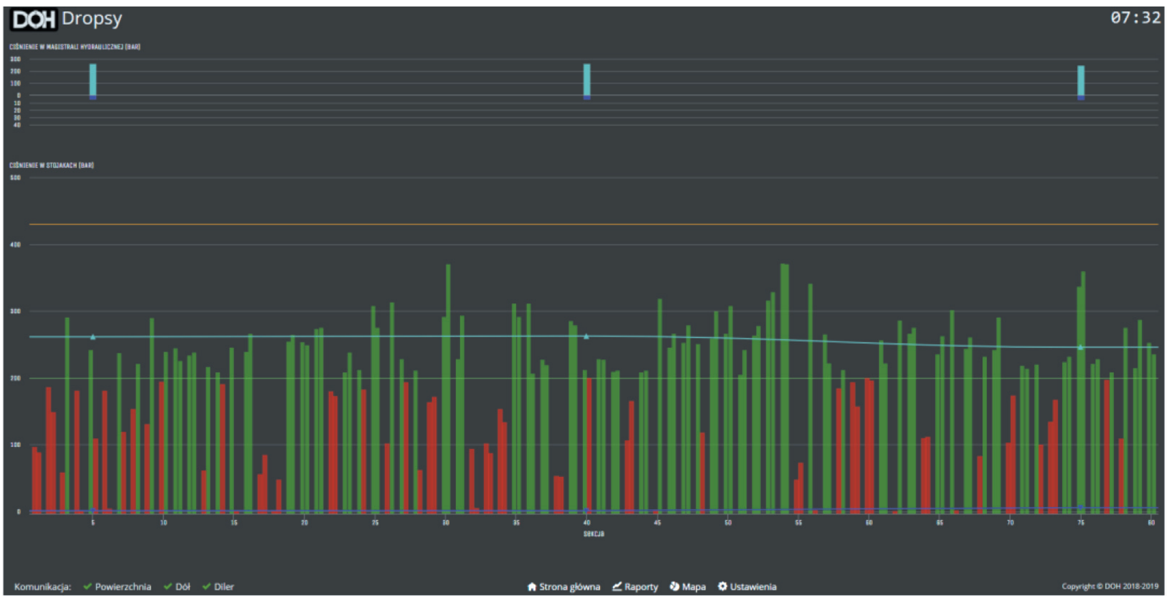

Fig. 9. Pressure distribution in a powered roof support section

Fig. 10. Map of pressure distribution in powered roof support sections

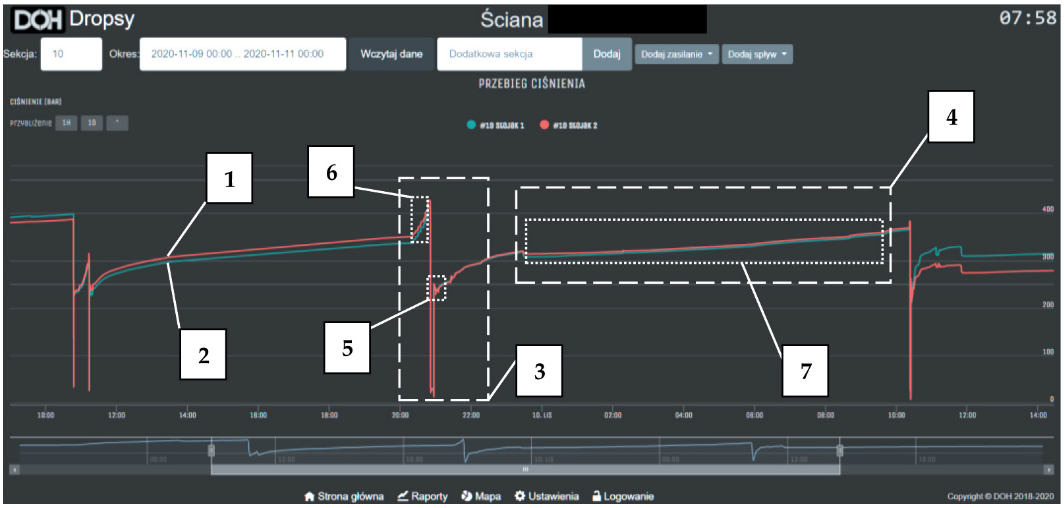

Fig. 11. The workflow of a powered roof support section: 1 – left leg, 2 – right leg, 3 – a time associated with the withdrawal, rearrangement and spragging, 4 – monitoring of section spreading in the longwall, 5 – initial support, 6 – nominal bearing capacity, 7 – working bearing capacity

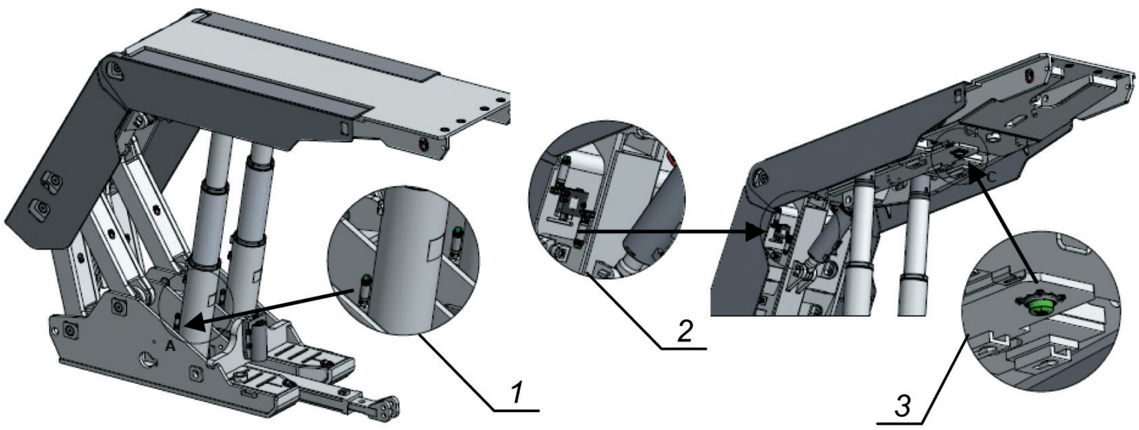

Fig. 12. Arrangement of sensors monitoring pressure parameters for powered roof supports: 1 – pressure monitoring sensor for the hydraulic leg, 2 – pressure monitoring sensor for the floor support cylinder, 3 – pressure sig nalling device located in the canopy

Table 1

List of applications of DOH-DROPSY type wireless pressure monitoring in coal mine longwalls

Mine	Long-wall	Seam	Panel length [m]	Length [m]	Roof support type	No. of longwall sections [pcs.]
PGG S.A. KWK ROW Ruch Marcel I	C-3	507	448	180	Hydromel-16/41-POz Glinik-14/34-POz	118 3
PGG S.A. KWK ROW Ruch Marcel I	W-7	505	1 430	190	Hydromel-16/41-POz Glinik-14/34-POz	113 26
PGG S.A. KWK ROW Ruch Marcel I	C-4	507	620	180	Hydromel-16/41-POz	125
PGG S.A. KWK ROW Ruch Marcel II	C-3	505	1 056	128	Glinik-14/34-POz	89
PGG S.A. KWK ROW Ruch Marcel II	Z-2	502/1	650	160	Glinik-14/34-POz	109
PGG S.A. KWK Ruda Ruch Halemba	7a	402/K	730	230	KW-16/32-Poz/ZRP	152
PGG S.A. KWK Sośnica	tb103	414/2	860	235	ZRP-15/35-POz	156
PGG S.A. KWK Piast-Ziemowit Ruch Piast	393a	209	440	165	Glinik-21/46-POz	109
JSW S.A. KWK Knurów-Szczygłowice Ruch Szczygłowice	XXI	405/1	825	210	FRS-19/45-POz	138
PGG S.A. KWK Mysłowice-Wesoła	411	416	980	142	ZRP-15/35-POz	95
PGG S.A. KWK Murcki-Staszic	3b-S	510/III	921	155	KW-17/43-POzW1/ZRP	103
JSW S.A. KWK Budryk	Bw-1	402	1 100	150	BW JZR-13/37-POz	98
JSW S.A. KWK Knurów-Szczygłowice Ruch Knurów	14	355	1 400	250	Glinik-08/25-POz	158

4. CONCLUSION

Pressure monitoring of powered roof support sections is one of the key elements of Industry 4.0. The changes taking place in the energy sector are forcing companies to act to ensure profitability, increase efficiency and improve safety. The only solution is to invest in innovative solutions and modern machinery and devices.

The mining industry, characterised by a high accident rate and several natural hazards, is a testing ground for investment opportunities in innovative solutions. An additional element that will allow energy companies to secure their future in the market is increased control and supervision of the works carried out through monitoring systems. In the course of mining work, it is necessary to continuously monitor the changes taking place in the excavation. This guarantees that the continuity of the excavation roof and the proper level of stress in the coal seam and roof rock are maintained. Monitoring will enable unprecedented operational efficiency and increased safety. Valuable information can be obtained in the course of mining operations using the pressure monitoring system in the powered roof support sections.

This article describes the DOH-DROPSY monitoring system and the process of its implementation based on own experience of the authors in longwalls. The main objective of the monitoring is to detect the abnormal expansion of the sections in the excavation and to diagnose failures in hydraulic systems.

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