sciendo

Management Systems in Production Engineering

2024, Volume 32, Issue 4, pp. 474-483

Date of submission of the article to the Editor: 05/2024
Date of acceptance of the article by the Editor: 10/2024

DOI 10.2478/mspe-2024-0044

APPLICATION OF MODERN MACHINE DIAGNOSTIC SYSTEMS TO IMPROVE SAFETY IN THE UNDERGROUND MINING PROCESS

Konrad Trzop
Polish Mining Group S.A

Ivan Kuric
University of Žilina

Jarosław Brodny, Magdalena Tutak
Silesian University of Technology

Abstract:
Currently used machine diagnostic systems are based on very modern solutions based on the acquisition and recording of their operating parameters in real time. Increasingly available and high-tech sensor systems mean that the number of recorded parameters is increasing and their quality is improving. These data are mainly used to assess the technical condition of machines and the processes they perform. In mining, these data can also be used to assess and, at a later stage, improve the safety of the underground mining process. Referring to this issue, the paper presents examples of the use of diagnostic systems for powered roof supports and longwall shearers to assess the safety status of the underground hard coal mining process. In the case of the wall support, the focus was on measuring the pressures in the stands of its individual sections. Temporary changes in the values of these pressures constitute a valuable source of information regarding the interaction of the support with the rock mass. In particular, this concerns the identification of the effects of the informational impact of the rock mass on the longwall excavation protected by the support. The research results presented in the paper, especially in the case of very dangerous dynamic impacts, indicate the possibility of both diagnosing the operating condition of the section and identifying symptoms of exposure to such events. This undoubtedly significantly expands the possibilities of using the measured pressures. Diagnostic signals from a longwall shearer are also widely used. The current intensities drawn by its motors while cutting the rock mass, as well as the advance speed and its position in the wall make it possible to analyze these parameters and their changes before, during and after the occurrence of various types of events. These data enable the assessment of the effects of the rock mass on its operational efficiency and safety status. It also enables the identification of symptoms that precede the occurrence of such events. The presented examples indicate the need for a broader and more holistic approach to the use of diagnostic parameters of mining machines. In particular, this concerns the study of the cooperation between the support and the rock mass and its influence on the efficiency and safety of the rock mass mining process. The subject matter addressed relates to very important and current issues, and the developed methodology and obtained results should be applied in practice as soon as possible.

Key words: machine diagnostics, underground mining, process safety, production engineering, mining machines

INTRODUCTION

Despite many changes taking place in the global power industry, hard bituminous coal remains to be one of the world's main energy resources. This also applies to Poland, where, despite the changes associated with the implementation of the sustainable development economy and new climate concepts, coal is the basis of the energy mix [1, 2]. It should also be emphasized that in addition to the great importance of coal for the domestic power industry, it is a fundamental raw material used in the production of coke necessary for steelmaking. Also in other economic sectors, the use of coal is notable and important for the economic development of the country and the world. Its new applications continue to emerge (e.g.

© 2024 Author(s). This is an open access article licensed under the Creative Commons BY 4.0 (https://creativecommons.org/licenses/by/4.0/)

graphene production), confirming its importance and enormous potential.

The coal production process itself is very complex and dangerous [3, 4, 5, 6]. This is primarily due to the environmental conditions in which it is mined. The unpredictability of these conditions makes the rock mass extraction process and the transportation of mined material to the surface dangerous and subject to a high risk of adverse random events. Therefore, more and more modern and reliable equipment including mining machinery is being used in the process of mining the rock mass and transporting the mined material.

This particularly applies to the most dangerous part of the process: the rock mass (coal) extraction and its transportation from the face of the mining wall.

In order to achieve appropriate efficiency and ensure safety of the rock extraction process, powered longwall systems are used. Such a system consists of a mining machine (shearer or planer), powered roof support, scraper conveyors (longwall and subwall), and crushers. Despite being interconnected, each of these machines has its own role and tasks in the entire extraction process. Their functionalities are interrelated, and from a reliability point of view, they constitute a serial structure system.

The powered roof support plays a crucial role in the entire underground mining process and its safety. Its primary task is to secure the working environment (the face area) during the excavation process, as well as to assist with additional tasks. It also supports the process of moving other machines of the system during an operation. A well-matched powered roof support should also guarantee proper interaction with the rock mass. This applies to both the roof and the floor of the longwall excavation [7, 8]. Consequently, it can be concluded that the powered longwall support is the basis for the process of mining the rock mass and hauling the mining material from the face area. The entire support is made of individual sections, which are now highly sophisticated machines that have the ability to adapt to changing geological and mining conditions in which mining is carried out.

Similarly, the other machines of the powered longwall system feature a high degree of modernity and reliability, mainly due to very challenging environmental conditions in which these machines are operated.

Along with the development of modern technologies [9, 10] as well as the energy and climate changes [11, 12] that have been taking place in the domestic and global economies in recent years, mining machines now feature increasingly advanced diagnostic systems [13]. Their main purpose is to diagnose their condition and monitor the operating parameters of these machines and the entire mining process [14, 15, 16, 17]. The diagnostic systems used in mining machinery are characterized by their enormous potential for data recording and acquisition, often in real time [18, 19, 20, 21, 22, 23].

The frequencies of data recording are also increasing, allowing for the analysis of gradually more dynamic changes in these parameters.

In the case of mining machines, this is particularly advantageous because processes such as the deformational impact of the rock mass on the roof support [24, 25] or ventilation hazards [26, 27, 28] are dynamic in nature.

Thus, diagnostic systems, and in particular the data they record, may find much broader applications in mining than initially anticipated. In many cases, this data provides an additional source of information about external conditions that determine the operating parameters of mining machines.

Critical to the correct way of functioning of such a system is its ability to acquire, collect and process this data and analyze the obtained results appropriately [29, 30]. In this part, it is crucial to correctly interpret the results obtained and look for patterns, regularities, symptoms and rules that provide the basis for drawing conclusions and generalizing the findings. This process is highly complex and, in addition to having access to large diagnostic datasets, also requires the expertise of researchers who specialize in data analysis. The effectiveness and quality of the results obtained are significantly influenced by the issues related to analyzing large datasets and the entire inference process. [31, 32, 33, 34].

Thus, despite the many problems associated with the analysis and inference process – which should also include elements of forecasting – the use of diagnostic data, especially in the mining industry, should be more widely adopted. This is also due to the fact that it is very challenging and expensive to install additional sensory systems (such as those for monitoring changes in rock stress) under very dynamically changing conditions of mining operations. Such systems would further disrupt the entire exploitation process, requiring additional systems for transmission, archiving, etc.

Therefore, it is entirely reasonable to use diagnostic signals from machines that are most often already equipped with sensory and archiving systems or signal transmission features. From both a cost and organizational perspective, such a solution seems to be very advantageous.

Addressing this extremely important and current issue of the lack of dedicated systems for diagnosing work processes and monitoring the working environment of mining machinery, a methodology has been developed for using diagnostic signals from these machines to also study operational processes.

This paper proposes, particularly for the mining industry, to integrate the technical diagnostics of machines with the diagnostics of the extraction processes in which these machines are used. This approach is highly advantageous as it allows for the additional use of diagnostic signals to assess the process itself and/or the environment in which the process is carried out. This approach thus provides significant opportunities to enhance the utility of diagnostic data by using it in the management of operational processes, including workplace safety [35, 36].

The paper focuses on diagnostic signals from a powered roof support and a longwall shearer, the basic machines that make up a powered longwall system.

In the case of powered roof support, the analysis was based on temporal pressure changes in the props section of the roof support. In the case of longwall excavations, the powered roof support consists of several dozen to over a hundred of these sections, depending on the length of the excavation. Since each section typically has two hydraulic props, this can result in a total of over two hundred pressure sensors along the entire longwall. This provides an opportunity to monitor changes in the pressure values across individual props and to track the deformational impact of the rock mass on the roof support. The sections represent independent parts of the entire roof support, allowing us to evaluate the pressure exerted by the rock mass on the roof support at each prop mounting point independently.

The main objective of this part of the research is to assess the uniformity of the load distribution across the individual sections of the roof support and the effects of dynamic interactions with the rock mass. Strong anisotropy of the rock mass causes stress distributions and deformations to often deviate significantly from those observed in an isotropic medium. Therefore, the large number of sensors allows for the identification of locations where the effects of such events are accumulated.

A very important aspect of this part of the research is also the analysis of these pressure changes prior to the occurrence of shocks. In this case, it becomes crucial to look for signals from the rock mass regarding the possibility of such dynamic events occurring.

The study also proposes the use of diagnostic signals coming from a longwall shearer. This highly modern machine has dozens of different types of sensors, enabling the monitoring of its operational parameters and diagnosing the condition of the entire machine as well as its individual components. From the perspective of the rock extraction process, it is crucial to determine the power consumption of individual motors of the shearer and its advance speed in relation to factors such as mining tremors or the increased deformational impact of the rock mass.

Thus, analyzing the impact of these factors (identified based on the analysis of pressures in the roof support props) on the shearer's operating parameters provides an opportunity to assess their effects. Additionally, by being able to locate the shearer, it is also possible to estimate how these influences are distributed.

The analysis of the shearer's performance parameters also enables the assessment of its availability and the degree of loading on individual motors. The analysis of this data provides information on the utilization of the machine's potential, which is closely related to the economic aspects and the efficiency of the entire mining production process.

In summary, it can be stated that the aim of the conducted research is to utilize diagnostic signals from mining machines (including the powered roof support and longwall shearer) to assess their operational conditions as well as safety and efficiency of underground mining processes.

The results obtained should serve as an inspiration for conducting similar research and applying it in mining practice. Modern mining should unquestionably make greater use of diagnostic signals from machines and new technologies to support the management processes [37, 38, 39].

MATERIALS AND METHOD

The chapter presents two examples of the use of advanced diagnostic systems to monitor the operating parameters of mining machines. The recorded diagnostic signals also create enormous opportunities for their use in examining the safety status in the environment in which the underground mining process is carried out. The first case concerns the measurement of pressure values in the props of the powered roof supports, and the second case concerns the measurement of diagnostic signals of the longwall shearer.

PRESSURE MEASUREMENT IN HYDRAULIC PROPS OF POWERED ROOF SUPPORTS

As previously mentioned, the powered roof support is one of the fundamental machines that make up the powered longwall system, whose primary purpose is the direct extraction of the rock mass. The functions performed by the powered roof support are more complex. On the one hand, it must secure the working environment for the crew and machines in the face of the mining wall. On the other, it supports the operation of other machines in the system, including the mining machine (shearer or planer), the scraper conveyor, crushers, and other equipment. Ensuring the safety of the crew and machinery in the longwall excavation area is unquestionably the top priority in this case. The roof support, as an active component, must interact with the rock mass to maintain the proper cross-section of the longwall excavation, which is essential for the movement of the crew and the flow of ventilation air. At the same time, it should interact with the rock mass (the roof and the floor) to ensure stable and safe operation of the entire powered system. In this case, the focus is mainly on its interaction with the roof and floor of the longwall excavation so as not to disrupt the continuity of the mass rock layers in these areas. It is also very important that its operating parameters, as much as possible, support the rock mass extraction process and ensure the proper formation of the collapse zone (when extracting with roof caving). In this regard, maintaining the roof of the longwall excavation is of crucial importance.

The criterion for maintaining the roof, designed to eliminate the possibility of collapse and developed based on a series of studies in real conditions, is as follows [40]:

$$g = \frac{1}{\frac{z_{L1}}{z_g} - 0{,}3} \tag{1}$$

where:

g – floor load-bearing capacity index,

z_{L1} – roof slope on the first meter of the excavation span, mm/m,

z_g – ceiling slope limit value, mm/m.

From the perspective of the powered roof support, it is critical to determine the roof inclination over the first

meter of the excavation span. This inclination is dependent on the support capacity of the roof support [41].

It is then evident that the operating parameters of the roof support significantly impact the continuity and efficiency of the extraction process. To fulfill the tasks required of the roof support, it is essential to appropriately select it based on the mining and geological conditions and technical requirements of the operation, as well as to ensure proper control and monitoring of its operating parameters throughout the extraction process.

Therefore, selecting a powered roof support for operation in such complex and not entirely predictable environmental conditions requires adequate knowledge as well as a range of environmental and technical data. This data should also include information on potential random events that may occur during the operation of the roof support. This particularly applies to the deformational impact of the rock mass on mining excavations, which translates directly to the impact of the rock mass on the roof support. In this case, various types of rock mass tremors and stress relieves are particularly dangerous and difficult to predict in terms of timing, location, and intensity.

Even a properly selected roof support, according to specified procedures, does not provide a complete guarantee of successfully performing its tasks. In this case, it is necessary to monitor the operating parameters used in the selection process to ensure its effective operation.

The operation of the powered roof support involves four basic phases: relieving, moving, spreading, and main operation. An exemplary segment of the actual work cycle of a roof support section, showing the temporal pressure changes in both of its props, is illustrated in Figure 1b. Meanwhile, Figure 1a shows a view of this section with the props indicated.

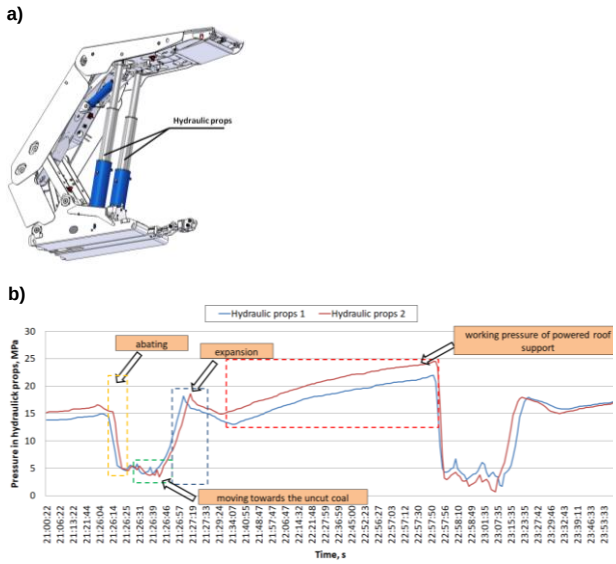


Fig. 1 View of the powered roof support a) and the basic phases of its work b)

For the efficiency of the roof support's functioning, the main operation phase is crucial (see Fig. 1b), during which the support bears the deformational load of the rock mass. The interaction between the roof support and the rock mass must proceed in a manner that ensures safe and efficient rock mass extraction.

The main source of load on the powered roof support is the deformational impact of the rock mass, which can be either static and/or dynamic. The source of this load is primarily the rock mass disturbed by mining operations. The load on the roof support section is also influenced by operational factors, including initial support conditions, stability, and the interaction between individual sections. Estimating the load on the roof support is a complex process that requires various information, primarily concerning the geological structure of the exploited area and the strength parameters of the rocks.

Due to the difficult-to-predict working conditions of the roof support, both types of load (static and dynamic) are of a random nature. This makes it difficult to predict both the timing and location of their occurrence, as well as the magnitude of the loads acting on individual sections of the roof support.

These loads, when the roof support is properly selected and operated, are primarily carried by the support's structure and, most importantly, by the hydraulic props. The measure of the intensity of the load carried by the section is the average rate of force increase in these hydraulic props, determined by the equation (2) [8]:

$$w_{F,n} = \frac{0{,}8\ (F_m - F_{st,p})}{t_n} \tag{2}$$

where:

F_m – maximum value of the force in the props during the tested time course,

$F_{st,p}$ – initial static force value in the props,

t_n – load rise time.

As a result of the deformational impact of the rock mass on the roof support, the forces in the section's props are generated. In this paper, these forces are measured by the pressure values in the hydraulic props of the powered roof support's sections.

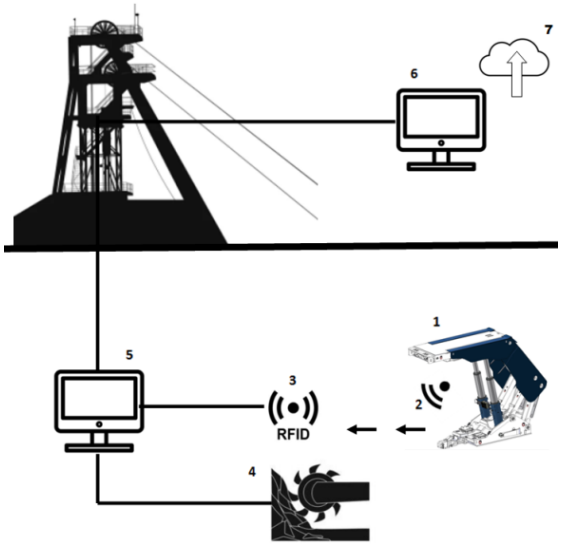
During the mining operation process, stress and load measurements within the rock mass are practically not conducted. This means that the occurrence of various types of loads is essentially assessed based on their effects, most commonly through the deformation of the rock mass. In the case of powered roof support, the possibility to measure the pressure values in the hydraulic props of the roof support is crucial for assessing the magnitude of these loads. This diagnostic signal not only provides information about the impact of the rock mass on the roof support and its sections but also allows for assessing the load level on the section itself during operation.

In the phases of the powered roof support section's operation shown in Figure 1b, it is evident that during the main operation phase, the roof support actually interacts with the rock mass, and it bears the deformational impact of the rock mass.

It can therefore be assumed that measuring the pressure values in the hydraulic props of the powered roof support's sections offers significant potential for monitoring the section's performance and assessing its interaction

with the rock mass. This is particularly relevant for hazardous conditions resulting from increased static or dynamic pressure exerted by the rock mass.

The study of temporal pressure changes in the hydraulic props of the powered roof support is conducted using a recording system, whose main components are pressure sensors installed in each prop of the support's section. The working height of the section was up to 3.6 meters. The measurement system recorded pressure in the subcylinder space of the props with an accuracy of ±0.1 MPa and a frequency of 1 Hz. The studies were conducted for a longwall excavation in which 162 sections of powered roof support were operating. The scheme of the pressure measurement system in the props of the section is shown in Figure 2.



1 – Powered roof support, 2 – wireless pressure sensor, 3 – radio converter, 4 – shearer, 5 – pit computer, 6 – dispatcher's station, 7 – data cloud and diagnostic parameters of the shearer

Fig. 2 Schematic diagram of the pressure recording system in the powered roof support stands

In this process, the transmission of measurement data between the excavation zone and the surface server, which was carried out using optical fiber, was crucial.

Figure 3 shows the map of the longwall mining area where the pressure measurements in the hydraulic props of the powered roof support were conducted. The map also indicates the quantity, location, and intensity of recorded tremors during the mining operation.

The examined longwall was located in a seam classified as category II seismic hazard zone. The seismic and tremor hazards were primarily influenced by factors such as:

- the depth of the exploited seam, reaching up to 890 meters,
- the geomechanical properties of the coal from the seam and the overlying rocks, as well as their natural tendency to induce tremors,
- past mining history, namely mining edges formed in the overlying seams.

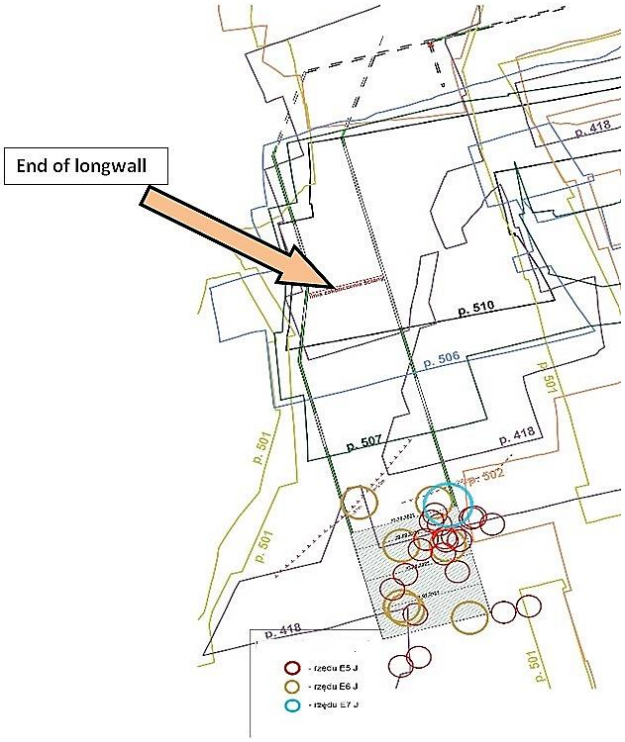


Fig. 3 Map of the mining area of the tested wall, including recorded rock mass tremors

The longwall was mined using a transverse longwall system with roof caving up to a height of 3.00 meters. The dip of the strata in the area ranged from 0º to 15º. The immediate roof of the seam consisted of clay shales and sandy shale with interlayers of sandstone. The floor of the seam consisted of shale with coal interlayers and partially sandy clay shale, under which there was a layer of fine-grained sandstone followed by a coal layer approximately 0.80 meters thick. The average compression strength (R_C) of the mined coal ranged between 7.9 and 14.4 MPa.

The recorded pressure values in the props of individual roof support's sections allowed for the analysis of their temporal patterns during the operation of the sections. Figure 4 presents the general pressure variation patterns in selected props of seven roof support's sections on a workday when one of the tremors occurred. On that day, at 7:36 AM, a high-intensity tremor with an energy of 2E5 J occurred in the longwall.

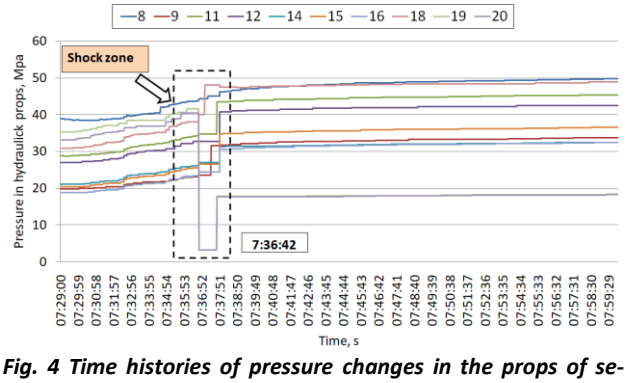


Fig. 4 Time histories of pressure changes in the props of selected sections of powered support on the day of the high–energy 2E5 J shock

It is clearly evident that pressure changes in the presented section's actuators are quite varied. To analyze the pressure changes more precisely before and after the tremor. Figure 5 presents the time series of pressure variations in the studied props over 8 hours of their operation. Figure 6 shows the pressure changes in the immediate time vicinity of the tremor.

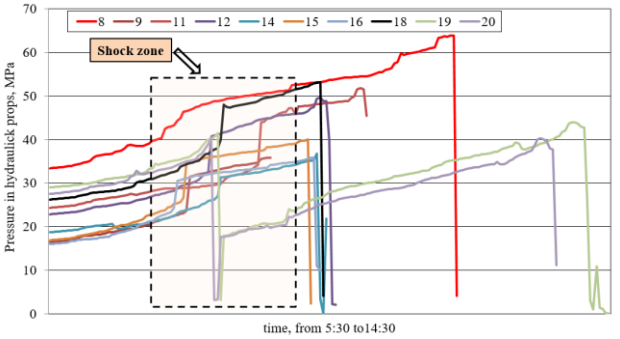


Fig. 5 Time histories of pressure changes in the props of selected sections of powered support during a high-energy 2E5 J shock

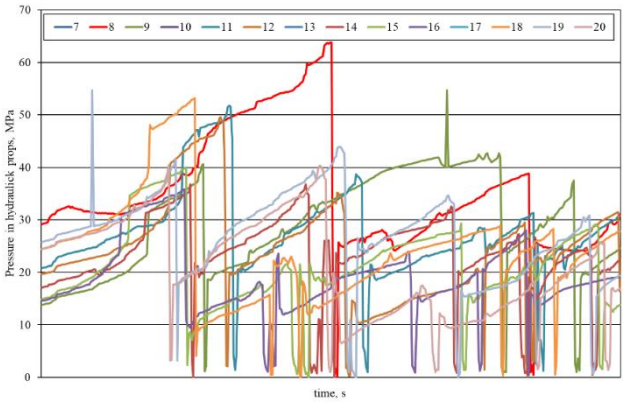


Fig. 6 Time histories of pressure changes in the props of selected sections of powered support directly during the occurrence of a high-energy 2E5 J shock

The obtained time series clearly indicate a significant increase in pressure within the roof support section's props before the tremor occurred. This is likely the result of an increase in the deformational impact of the rock mass. The tremor itself also caused an increase in these pressures, which continued to rise even after the event. These increases and the entire event did not cause any damage to the longwall excavation or disrupt the mining process. Nevertheless, the analysis of the recorded pressure changes in the props, especially before the event, indicated changes in the impact of the rock mass on the roof support.

Similar patterns were recorded for this longwall during another tremor with an energy of 4E5 J at 2:59 (Fig. 7).

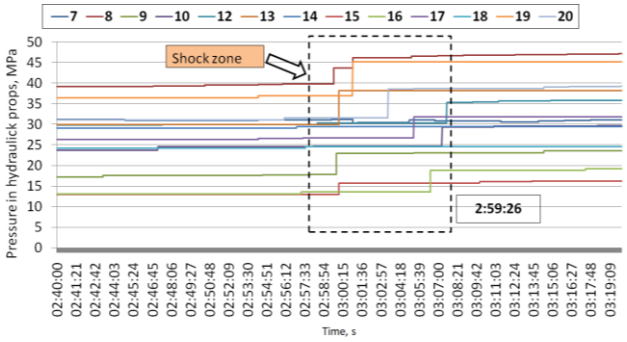


Fig. 7 Time histories of pressure changes in the props of selected sections of powered support directly during a high-energy tremor in the longwall with energy of 4E5 J

In this case, there were also pressure increases in the props before, during, and after the tremor. In this instance as well, the roof support ensured the safety of the longwall excavation. However, the recorded tremors caused pressure increases in the roof support's props, with an increase of about 8 MPa in the first case and about 4 MPa in the second.

Measurement of diagnostic parameters of shearer operations

The machines that are part of the longwall complex cooperate closely with each other during the process of mining and transporting mined material from the face zone. In particular, this applies to the already powered roof support, which protects the longwall excavation, stabilizes and supports the entire process of mining the rock mass. The key to this process is the mining machine, which directly separates the mineral used from the rock mass. Currently, this task is most often performed by shearers.

Modern shearers, as well as other machines in the complex (scraper conveyors, crushers) are equipped with a number of sensors enabling monitoring of their operating parameters. This data provides enormous opportunities for diagnosing their technical condition and the process being implemented. In the case of a shearer, the parameters of its operation, such as the current drawn by individual motors, the feed speed or those determining its location in the operating wall, are of particular importance. They make it possible to assess the power consumed by its engines and, consequently, its load and the availability of this machine.

In the case of the tested wall, the basic diagnostic parameters of the shearers were recorded thanks to the industrial automation system.

Of particular interest are their changes at the time of the occurrence of the tremors already discussed in the rock mass. In the case of the first of the presented events (shock with energy of 2E5 J), the combine was located near section 20 (Fig. 8).

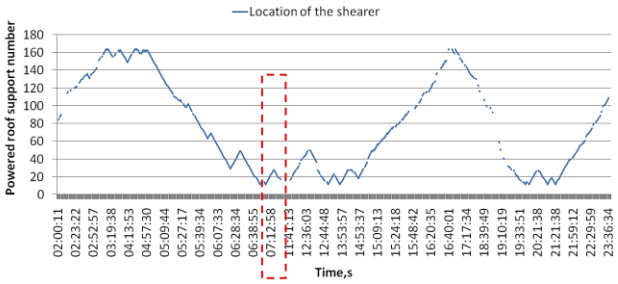


Fig. 8 Temporal changes in the shearer's position in the exploitation wall during the shift in which a 2E5 J shock occurred

The changes in current intensity in the left and right feed motors of this combine during this time are shown in Figures 9 (left motor) and 10 (right motor).

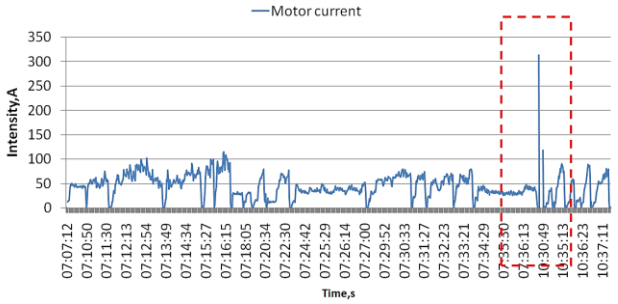


Fig. 9 Time histories of current intensity changes in the left combine feed motor during the shift in which the 2E5 J shock occurred

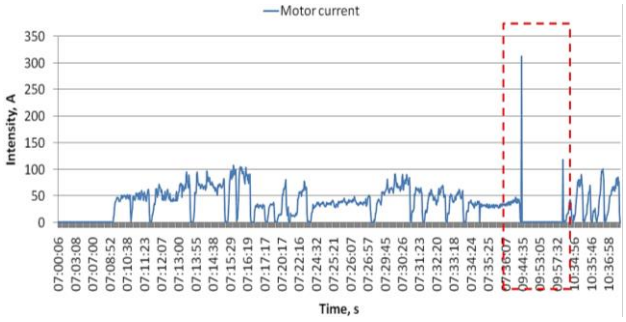


Fig. 10 Time histories of current intensity changes in the right combine feed motor during the shift in which the 2E5 J shock occurred

Also interesting is the course of changes in the shearer speed during this work shift (Fig. 11), as well as the distributions of currents drawn by the shearer head motors (Fig. 12 and Fig. 13).

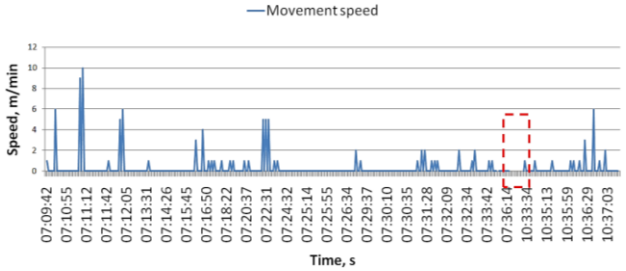


Fig. 11 Time histories of changes in the combine feed rate during the exchange in which a shock with energy of 2E5 J occurred

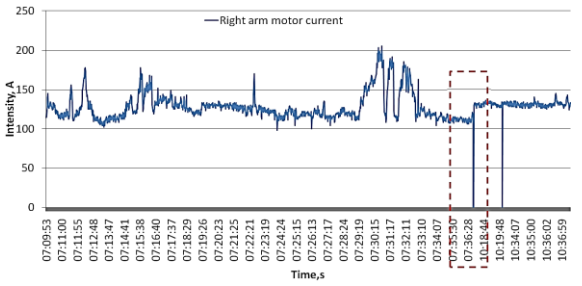


Fig. 12 Time histories of current intensity changes in the right arm motor of the shearer's cutting head during the shift in which the 2E5 J shock occurred

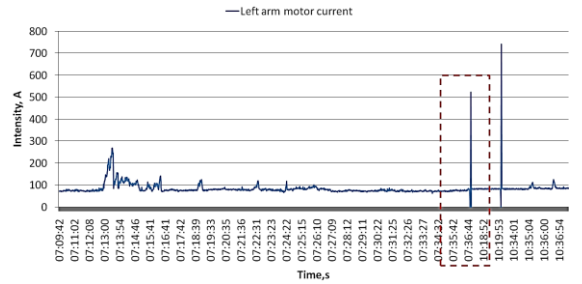


Fig. 13 Time histories of current intensity changes in the left arm motor of the shearer's cutting head during the shift in which a 2E5 J shock occurred

The waveforms obtained from the industrial automation system provide enormous opportunities for examining the operating states of the entire shearer and its individual components, also in terms of the impact of the increase in the stress state in the rock mass, e.g. on the current intensity drawn by its individual motors. In this case, the analyses of changes in the current intensity drawn by the cutting head motors are particularly interesting (Fig. 12 and 13). It is clearly visible that these intensities increased significantly before the shock occurred. A lot of information can also be provided by analyses of the shearer's position in the wall (Fig. 8) and its advance speed (Fig. 11). Based on them, it is possible to determine the shearer availability time, i.e. its actual working time. It can be seen that in the presented period this indicator reaches low values (there are quite many interruptions in the combine's work). In the case of the second discussed shock (energy 4E5 J), the indicated shearer operating parameters were also recorded. For this event, it is worth monitoring the position of the shearer in the wall (Fig. 14) and the changes in the current drawn by the feed motors (Fig. 15 and 16) and the cutting head motors (Fig. 17 and 18).

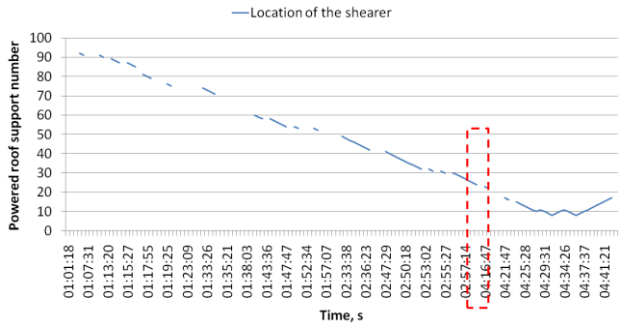


Fig. 14 Temporal changes in the shearer's position in the exploitation wall during the 4E5 J shock

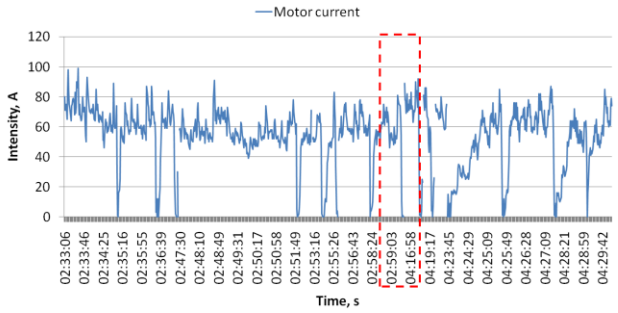


Fig. 15 Time histories of current intensity changes in the left combine feed motor during the shift in which the 4E5 J shock occurred

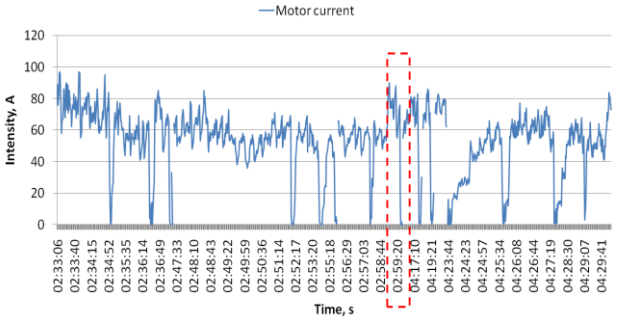


Fig. 16 Time histories of current intensity changes in the right combine feed motor during the shift in which the 4E5 J shock occurred

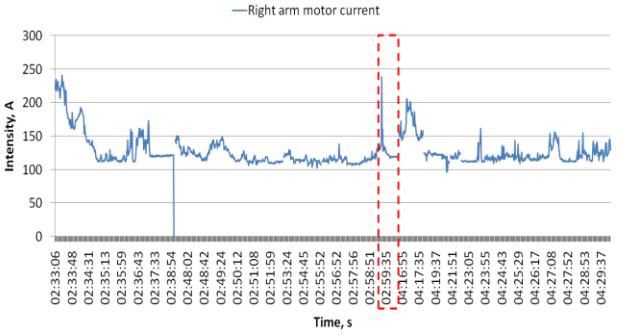


Fig. 17 Time histories of current intensity changes in the right arm motor of the shearer's cutting head during the shift in which the 4E5 J shock occurred

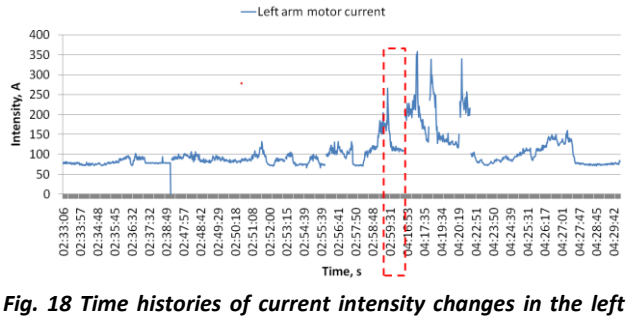


Fig. 18 Time histories of current intensity changes in the left arm motor of the shearer's cutting head during the shift in which a shock with energy of 4E5 J occurred

The presented time histories of parameters recorded by industrial automation systems provide great possibilities for interpretation and conclusions. Their analysis indicates increased values of current intensity drawn by the feed motors and cutting drums. It can therefore be concluded that this was the result of an increase in the stress state in the rock mass due to the occurrence of a high-energy shock.

SUMMARY AND CONCLUSIONS

The issues addressed in this paper concern a current and extremely important topic for the mining industry. This industry, often seen as very conservative, should indeed approach new solutions more extensively and openly, as these offer opportunities to improve safety and the efficiency of ongoing processes.

The extensive use of diagnostic parameters for mining machines proposed in the paper should be considered a new approach to diagnosing and monitoring the technical condition of machines and the operational processes being carried out. From both a scientific and practical perspective, it is a new approach based on data that is already largely recorded in most mines by industrial automation systems or internal systems of individual machines. Therefore, from an economical standpoint, implementing such comprehensive analyses of these parameters should not pose a significant problem.

The results of such analyses should significantly enhance knowledge regarding the interaction between the roof support and the rock mass, as well as the impact of the roof support's load-bearing capacity on the mining process. These issues are crucial for the energy consumption of the entire process and its overall efficiency. Another very important issue is safety. The analysis of the temporal pressure patterns in the support section's props clearly indicates the appearance of symptoms of potential dynamic events.

Generalizing these observations at the current level may still be premature, but further research in this area should identify directions for action to recognize such early symptoms and, based on them, implement appropriate preventive measures.

The conducted research and obtained results confirm the immense capabilities and potential of diagnostic data collected from mining machines. Especially considering that most of this data is currently underutilized. On the other hand, it becomes fully justified to utilize and analyze data from multiple machines. It is possible to correlate the impact of the rock mass on the roof support with the quality of roof and floor, as well as with the effectiveness of the mining process. In the future, it would also be advisable to consider incorporating results from automatic methane monitoring systems. Undoubtedly, stress increases in the rock mass, changes in the geometry of the longwall excavation, and mining efficiency influence methane emissions as well as ventilation parameters. This broad, holistic approach – integrating diagnostic parameters recorded by various systems with ventilation data – should facilitate and support the management of the entire production process, particularly in terms of safety.

In summary, given the current state of the industry, it is advisable to make fuller use of all data recorded by various systems in mines to improve the efficiency and safety of the processes. In particular, it concerns accessing recorded diagnostic parameters of machines and allowing to

analyze them in terms of the interaction between the powered longwall system and the rock mass, as well as its impact on ventilation parameters.

Based on these analyses, it will be possible to establish evaluation criteria and threshold values, and to adopt standards that can be used for making management decisions.

It is evident that the results of the presented and future research should serve as a crucial source of knowledge to support the management of various departments within the mine.

ACKNOWLEDGEMENT

This work was supported by the project VEGA 1/0470/23 – "Research into methods and means of implementing artificial intelligence in automated quality control systems for products with volatile quality parameters".

REFERENCES

[1] Brodny J., Tutak M., Applying computational fluid dynamics in research on ventilation safety during underground hard coal mining: A systematic literature review. *Process Safety and Environmental Protection* 151, 2021, pp. 373-400.

[2] Brodny J., Tutak M., Challenges of the polish coal mining industry on its way to innovative and sustainable development *J. Clean. Prod*. 2022, vol. 375, Article 134061

[3] Brady B.H., Brown E.T.: Rock mechanics for underround mining. 3rd ed., Springer, 2006.

[4] Abramov, I.; Bozek, P.; Nikitin, Y.; Abhramov, A.; Sosnovich, E.; Stollmann, V. Diagnostics of electrical drives. In The *18th International Conference on Electrical Drives and Power Electronics. EDPE 2015*. The High Tatras, Slovakia, pp. 364-367.

[5] Galvin J.M.: Ground Engineering. Principles and Practices of Underground Coal Mining. Springer International Publishing 2016.

[6] Peng S.S., Longwall Mining, 3rd edition, Taylor & Francis Group, London, UK, 2020.

[7] Harron P. E., Heshmat M., Imbaby S., Ibrahim A.: Current Theories and Concepts for the Determination of Roof Loading over the Hydraulic Supports in Longwall Faces. *Journal of Petroleum and Mining Engineering* 2022.

[8] Witek M., Influence of strength parameters of floor rocks on the work charateristic of the powered roof support in the longwall. PhD Thesis, 2014 Katowice.

[9] Litvinenko, V.S. Digital Economy as a Factor in the Technological Development of the Mineral Sector. *Nat. Resour. Res.* 2020, vol. 29, pp. 1521-1541. https://doi.org/10.1007/s11053-019-09568-4.

[10] Sánchez, F., Hartlieb, P. Innovation in the Mining Industry: Technological Trends and a Case Study of the Challenges of Disruptive Innovation. *Mining, Metallurgy & Exploration* 2020, vol. 37, pp. 1385-1399. https://doi.org/10.1007/s42461-020-00262-1.

[11] Brodny, J.; Tutak, M. Analysis of the diversity in emissions of selected gaseous and particulate pollutants in the European Union countries. *Journal of Environmental Management* 2019, vol. 231, pp. 582-5951.

[12] Brodny, J.; Tutak, M., The analysis of similarities between the European Union countries in terms of the level and structure of the emissions of selected gases and air pollutants into the atmosphere*. Journal of Cleaner Production* 2021, vol. 279, 123641.

[13] Singh, V., Gangsar, P., Porwal, R. et al. Artificial intelligence application in fault diagnostics of rotating industrial machines: a state-of-the-art review. *J Intell Manuf* 2023, vol. 34, pp. 931-960. https://doi.org/10.1007/s10845-021-01861-5.

[14] Atul, K., Dheeraj, K., Singh, U.P., Gupta, P.S., Development of an Automated System for Continuous Monitoring of Powered Roof Support in Longwall Panel. *Journal of Coal Science and Engineering*, 2010, 16(4), pp. 337-340.

[15] Bartelmus W., Condition Monitoring of Open Cast Mining Machinery. 2006, Wroclaw: Wroclaw University of Technology Press.

[16] Brodny, J., Tutak, M., Michalak, M., A Data Warehouse as an Indispensable Tool to Determine the Effectiveness of the Use of the Longwall Shearer. In: Kozielski, S., Mrozek, D., Kasprowski, P., Małysiak-Mrozek, B., Kostrzewa, D. (eds) Beyond Databases, Architectures and Structures. Towards Efficient Solutions for Data Analysis and Knowledge Representation. BDAS 2017. Communications in Computer and Information Science, vol 716. Springer, Cham. https://doi.org/10.1007/978-3-319-58274-0_36.

[17] Surucu O., Gadsden S.A., Yawney J., Condition monitoring using machine learning: A review of theory, applications, and recent advances. Expert Systems with Applications, 2023, No 221.

[18] Angeles, E.; Kumral, M. Optimal Inspection and Preventive Maintenance Scheduling of Mining Equipment. *J. Fail. Anal. Prev*. 2020, vol. 20, pp. 1408-1416.

[19] Bołoz, Ł.; Biały, W. Automation and Robotization of Underground Mining in Poland. *Appl. Sci*. 2020, vol. 10, 7221. https://doi.org/10.3390/app10207221

[20] Fernandez, O.; Labib, A.W.; Walmsley, R.; Petty, D.J. A Decision Support Maintenance Management System: Development and Implementation. *Int. J. Qual. Reliab. Manag*. 2003, vol. 20, pp. 965-979.

[21] Peng B., Wan S., Bi Y., Xue B., Zhang M., Automatic Feature Extraction and Construction Using Genetic Programming for Rotating Machinery Fault Diagnosis. *IEEE Transactions on Cybernetics*, vol. 51, vol. 10, pp. 4909-4923, Oct. 2021, doi: 10.1109/TCYB.2020.3032945.

[22] Biały W., Prostański D., Korbiel T., Kuric I. „Weibull distribution as a criterion of emergency levels". *Acta Montanistica Slovaca*, (2024) Volume 29 (1), pp. 216-226.

[23] Biały, W., Prostański, D. & Bołoz, Ł. Selection of longwall shearers based on the results of research on the mechanical properties of coal. *Sci Rep* 14, 18606 (2024). https://doi.org/10.1038/s41598-024-69178-w pp. 1-11

[24] Brodny J., Analysis of operation of new construction of the frictional joint with the resistance wedge. *Archives of Mining Sciences* 2012, No 57, pp. 209-227.

[25] Brodny J., Determining the working characteristic of a friction joint in a yielding support. *Archives of Mining Sciences*, 2010, No 55, pp. 733-7462010.

[26] Brodny, J.; Tutak, M.; John A., Analysis of influence of types of rocks forming the goaf with caving on the physical parameters of air stream flowing through these gob and adjacent headings. *Mechanika* 2017, vol. 24, pp. 43-49.

[27] Brodny J., Tutak M., Assessing the energy security of European Union countries from two perspectives – A new integrated approach based on MCDM methods. *Appl. Energy* 2023, vol. 347, 121443

[28] Brodny J., Alszer S., Krystek J., Tutak M., Availability analysis of selected mining machinery. *Arch. Control Sci*. 2017, vol. 27, pp. 197-209.

[29] Demirkan, D.C.; Duzgun, H.S.; Juganda, A.; Brune, J.; Bogin, G. Real-Time Methane Prediction in Underground Longwall Coal Mining Using AI. *Energies* 2022, No 15, 6486.
[30] Brodny J., Tests of friction joints in mining yielding supports under dynamic load. *Archives of Mining Sciences*, 2011, No 6, pp. 303-318.
[31] Cao, X.G.; Zhang, M.Y.; Gong, Y.R.; Jia, X.L.; Zhang, R.Y., Maintenance Decision Method Considering Inspection of Mining Equipment. *Int. J. Metrol. Qual. Eng*. 2021, No 12, 21.
[32] Chimunhu P., Topal E., Ajak A. D., Asad W., A review of machine learning applications for underground mine planning and scheduling. *Resour. Pol*., 2022, vol. 77, Article 102693.
[33] Tretten, P.; Karim, R. Enhancing the Usability of Maintenance Data Management Systems. *J. Qual. Maint. Eng*. 2014,20, pp. 290-303.
[34] Hashmi A. S., Ahmad T., Big Data Mining: Tools & Algorithms. *Int. J. Recent Contrib*. from Eng. Sci. IT, 2016, vol. 4, no. 1, pp. 36-40.
[35] Kosinar, M., Kuric, I. Monitoring possibilites of CNC machine tools accuracy.*1st International Conference on Quality and Innovation in Engineering and Management (QIEM)*, Cluj Napoca, ROMANIA, pp. 115-118.
[36] Szweda S., Identyfikacja parametrów charakteryzujących obciążenie sekcji obudowy zmechanizowanej spowodowane dynamicznych oddziaływaniem górotworu. *Zeszyty Naukowe Politechniki Śląskiej*, 2004.
[37] Angeles Pasco, E. Equipment Management towards Sustainable Mining. Masters Thesis, McGill University, Montreal, QC, Canada, 2020.
[38] Hamid, T. Moving Predictive Maintenance in Mining from Theory to Practice. Aust. Min. 2020.
[39] Gericke B.L., Sushko A.E., Gericke P.B., Efremenkov A.B., Digital technologies used in technical diagnostics assessment of technical condition maintenance and repair of mining machines and equipment. *Journal of Physics*: Conference Series, 2021, vol. 2052, no. 1, pp. 012016.
[40] Biliński A.: Metoda doboru obudowy ścianowych wyrobisk wybierkowych i chodnikowych do warunków pola eksploatacyjnego. Prace naukowe – Monografie CMG KOMAG z.11, Gliwice 2005
[41] Szweda S., Szyguła M., Mazurek K., Czynniki wpływające na postać konstrukcyjną i parametry techniczne sekcji ścianowej obudowy zmechanizowanej, cz. 1. Wydawnictwo Instytutu Techniki Górniczej KOMAG, 2016.

Konrad Trzop (corresponding author)
ORCID ID: 0000-0001-8077-3430
Polish Mining Group S.A
KWK Ruda, Ruch Bielszowice
ul. Halembska 160, 41-711 Ruda Śląska, Poland
e-mail: Konrad.trzop.kt@gmail.com

Ivan Kuric
ORCID ID: 0000-0003-2386-9211
University of Zilina
Univerzitná 8215/1, 010 26 Žilina, Slovakia
e-mail: Ivan.Kuric@fstroj.uniza.sk

Jarosław Brodny
ORCID ID: 0000-0002-6807-4431
Silesian University of Technology
Faculty of Organization and Management
Rossevelta 26, 41-800 Zabrze, Poland
e-mail: jaroslaw.brodny@polsl.pl

Magdalena Tutak
ORCID ID: 0000-0003-4781-8697
Silesian University of Technology
Faculty of Mining, Safety Engineering
and Industrial Automation
Akademicka 2, 44-100 Gliwice, Poland
e-mail: magdalena.tutak@polsl.pl