Robotic walking module as underground mining safety device

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Abstract. The authors studied the acting loads on the powered walking roof support in the preparatory mine and numerical modeling of stresses and deformations in the coal seam and host rocks in the preparatory face. The patterns of intensification of roof rocks displacements and the normative load on the workings support with increasing distance from the face are revealed. For additional safety maintenance authors designed remote control system allowing to control walking module from safe place. The purpose of the article is to develop a methodological approach to substantiate the technical parameters of a powered walking roof support to create temporary support for roof rocks near the preparatory face, preventing the risk of collapse.

1 Introduction

In modern conditions it is impossible to ensure efficient and safe coal mining without comprehensive consideration of specific mining and geological terms and naturally changes in the course of mining operations. One of the main technological processes in coal mines is conducting underground preparatory mining operations.

World experience confirms that mining operations are accompanied by high risks of incidents and accidents, which requires the search for means of reliable temporary advance fastening of the mining face.

In terms of mining underground workings in coal mines, mining and geological risks leading to accidents and incidents should be prevented, primarily related to the characteristics determining the collapse of roof rocks, the danger of rock impacts, the danger of sudden emissions and formation disturbance. To assess the risk of the technological process of underground mining stopping using a tunneling combine, technological risks that may lead to accidents or incidents related to technical parameters and a design feature of a technical device that provides temporary safety fastening of the mine face should be taken into account.

The process of underground mining is associated with spatial and temporal changes in the stress-strain rock mass and support elements state. In the mining face, zones of increased rock pressure arise, the destruction of the sections of the coal seam and the collapse of roof rocks occur [1]. One of the ways to prevent these dangerous events in the

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underground personnel work areas and the location of mining machinery and equipment is to create a safety fastener.

2 Powered walking roof support for underground mining

The authors believe that one of the promising solutions to improve the efficiency and safety of tunneling operations is a powered walking roof support, which allows to create a temporary secure fastening of the mining face space above the tunneling combine and allows to anchor the mines without stopping the combine and outside its working area [2].

Thus, the powered walking roof support provides mechanized support for the roof of the mine and reduces the number of the tunneling combine forced stops for the roof fastening device.

The powered walking roof support (Figure 1) in the mining creates an advanced temporary support of the roof rocks due to the alternating cyclic walking of the two-section support structure and the alternate perception of rock pressure from the roof rock mass by its sections, which provides protection of the workspace from roof rock collapses.

The walking support moves after the combine, the excavation of the rock mass is carried out under the protection of the support, which ensures guaranteed safety of tunneling and increases the speed of excavation. Figure 2 shows the scheme of operation of a tunneling combine under the protection of a walking support in the bottom of a preparatory mine.

According to the proposed scheme, the tunneling combine 1 destroys the seam protected with the walking support 2. The bottom-hole part of the workings is supported by protecting sections of the walking support 2, creating a temporary safety fastening and forming a safe working space, while the anchor installer 3 is also placed under the overlap of the walking support 2 in the side of the passed workings, which allows simultaneously with the excavation of the rock mass to permanently fix the roof and sides of the workings. Transportation of the recaptured rock mass is carried out by vehicle 4 in the mining area with a permanent anchorage.

![Fig. 1. Powered walking roof support type design: 1 – top beam; 2 – hydraulic rack; 3 – side guard; 4 – heading section; 5 – lagging section; 6 - bridge.](image)

One of the urgent scientific tasks in creating a walking temporary support is to determine its optimal technical parameters that support the roof in the tunneling face and
are sufficient to perceive the emerging loads from the roof rocks. The experience of operating underground equipment requires to reduce the metal and energy consumption of the structure and support elements. At the same time, the technical solutions of the powered walking roof support structure directly depend on the values of the normative load acting on the support in the preparatory face. Therefore, the study of the acting loads on the powered walking roof support in the preparatory work is an important scientific task.

3 A methodical approach to determining the parameters of a walking temporary support near the preparatory face

Using the software package [3-4], by solving the 3D numerical modeling task, the authors calculated the stresses and deformations of the coal seam and host rocks in the preparatory face according to the given initial data.

Based on the simulation results, it was found that the displacement of roof rocks at a given point near the face gradually increases as it moves. The dependence of the values of subsidence of roof rocks on the distance to the face obtained from the research results clearly reveals the pattern of displacement growth with increasing distance from the preparatory face towards the mine, along with this, the displacement of roof rocks at a distance of 0.5 m from the preparatory face increases most intensively.

To generalize the revealed pattern of changes in displacements of roof rocks near the preparatory face, the ratio of the values of roof subsidence in the face to the maximum subsidence of the roof in an extended mine, that is, at a distance of more than the reference pressure zone, approximately 0.2 of the depth of working, was used.
The dependence of changes in the subsidence of roof rocks on the distance to the face was determined:

\[ q_y = \frac{w_y}{w_{y,\text{max}}} \]  \hspace{1cm} (1)

\[ q_{yn} = \frac{w_{yn}}{w_{yn,\text{max}}} \]  \hspace{1cm} (2)

Where \( w_y \) - calculated resilient subsidence of roof rocks in the preparatory face of the mine, m; \( w_{y,\text{max}} \) - maximum resilient subsidence of roof rocks in mine, m; \( q_y \) - proportion of resilient subsidence of roof rocks in the preparatory face to maximum resilient subsidence of roof rocks in mine; \( w_{yn} \) - calculated resilient plastic subsidence of roof rocks in the vicinity of the preparatory face of the mine, m; \( w_{yn,\text{max}} \) - maximum resilient plastic subsidence of roof rocks in mine, m; \( q_{yn} \) - proportion of calculated resilient plastic subsidence of roof rocks in the vicinity of the preparatory face of the mine to maximum resilient plastic subsidence of roof rocks in mine.

As a result, it was revealed that at a high rate of movement of the preparatory face, when mainly only resilient deformations are realized, the displacements of the roof rocks near the face are 2.0–2.5 times less than the displacements at the stopped face, when the rocks containing the production pass into the stage of nonlinear deformation.

Based on the results of a computational experiment, the authors justified a methodological approach to determine the parameters of the support near the preparatory face. For the specified geological and mining engineering conditions, according to the current methodological documents, the forecast of maximum displacements of \( U_{\text{max}} \) roof rocks for extended workings with a service life of less than one year is carried out. At a certain distance from the face, the ratios of \( q_y \) and \( q_{yn} \) roof rock subsidence near the preparatory face and maximum subsidence are determined. Finally, the displacement of the roof rocks at a distance \( X \) from the face is determined by the formulas:

At high-speed mining:

\[ U_x = U_{\text{max}} q_y \]  \hspace{1cm} (3)

At mining stopping:

\[ U_x = U_{\text{max}} q_{yn} \]  \hspace{1cm} (4)

According to the values of the \( U_x \) displacements, the normative load on the support is determined, the value of which is distributed over points near the face in proportion to the ratios \( q_y \) and \( q_{yn} \).

Thus, during high-speed mining, the normative load on the temporary walking support near the face can be reduced by 1.5-3 times compared with the load during periodic stopping of the preparatory face.
The dependence of changes in the subsidence of roof rocks on the distance to the face was determined:

1. Calculated resilient subsidence of roof rocks in the preparatory face of the mine, m;
2. Maximum resilient subsidence of roof rocks in mine, m;
3. Proportion of resilient subsidence of roof rocks in the preparatory face to maximum resilient subsidence of roof rocks in mine;
4. Calculated resilient plastic subsidence of roof rocks in the vicinity of the preparatory face of the mine, m;
5. Maximum resilient plastic subsidence of roof rocks in mine, m;
6. Proportion of calculated resilient plastic subsidence of roof rocks in the vicinity of the preparatory face of the mine to maximum resilient plastic subsidence of roof rocks in mine.

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4. Powered walking roof support remote control

Opportunities of robotics infusion in mining are presented in many articles. [5-8].

Powered walking roof support is designed as a highly automated unit of mining equipment capable of performing a number of tasks without human intervention. At the same time, movement behind the combine in the tunnelling face may be accompanied by a number of abnormal situations that are difficult to automate, or their automation requires significant time costs. In such situations, it is appropriate to transfer control of the support from the automatic system to a human operator. It is quite obvious that the operator should spend most of the time outside the area where the combine is working (Figure 2), but at the same time have good situational awareness, if necessary, take control. These two conditions require the support to be equipped with a control panel. The control panel must provide two modes of operation: automatic control correction (can be performed from a remote control permanently mounted on the support) and manual control in an emergency situation (a mobile remote control is required).

The industry produces a fairly large range of control panels, both stationary and remote, which are used to control various mining machines with a high degree of automation. Stationary control panels that allow remote control of mining equipment include consoles manufactured by various companies [9, 10, 12].

EEP Elektro-Elektronik Pranjic company is one of the leading in automation technologies in mining. The main intellectual and innovative product and application of EEP is PRA_matic® - complex underground mining control system. Spark proof PRA_matic® control blocks designed by EEP provide accurate electric hydraulic control and can execute up to 24 functions (Figure 3).

![Fig. 3. PRA_matic control panel (Elektro-Elektronik Pranjic).](image-url)

EEP Elektro-Elektronik Pranjic set on operation more than 60 sets of modern automatic control for underground mining. In this case, as a rule, underground personnel is necessary only for technological process control and maintenance. Automation allowed to upgrade safety and economic conditions.

In some countries full automation of technological processes in mining face is provided with "Robotic Mining" complex control system designed by "marco System Analysis and Development GmbH" [10]. This system provides with process and mechanisms computer control in mining face in full automated mode with one panel. Going processes, mechanisms location and mining face capacity are presented visually in real time. Gain results were determined as steps to realize stated issues for full automation and robotics of
coal face work [11]. For remote control “marco” developed compact ergonomic remote control panel (174×86×30.2 mm) with RFID module allowing to control all processes in mining face from coal heading (Figure 4).

![pm32 control panel](image)

**Fig. 4.** pm32 control panel (marco System Analysis and Development GmbH).

GHH Group [12] and specialists from Nerospec SK develops technologies for full automation and remote control. With radio control panel T-RX100J designed by GHH Group operator can control mining devices from safe distance. The main advantage of this technology is universality of usage with other vendors technics.

![T-RX100J control panel](image)

**Fig. 5.** T-RX100J control panel (GHH Group).

Powered walking roof support contains remote control system allowing operator to remove from mining face and control roof support from safe place (Figure 1). Universal remote control panel for mining devices is presented for working with underground mining and long-wall top coal caving modelling work bench.

Remote control panel for moving mining devices has size 300 x 100 x 50 mm. Front panel contains two displays for technological parameters indication and buttons functions demonstration. It has no less than 20 programmable buttons. Back and side panels contains pins for connection to commutation devices. The panel provided with programmable hardware module for experimental mining devices control (Figure 6).
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Fig. 6. Universal remote control panel (FRC CCC SBRAS).

The panel construction is protected with two patents and one ECM program.

5 Conclusion

Based on the above material, the following conclusion can be drawn: the use of a walking temporary support in the preparatory face due to the alternating cyclic walking of the two-section support structure and the alternate perception of rock pressure by its overlap, an advanced temporary support is created, which reduces the risk of roof collapse.

The methodological approach proposed by the authors, based on numerical modeling of stresses and deformations of the coal seam and host rocks in the preparatory face and the revealed pattern of reducing displacements of roof rocks and the normative load on the support near the face, allows to substantiate the technical parameters of the walking support to create temporary support for roof rocks in the form of a recommendation: during high-speed mining, the normative load on the temporary support near the face, it can be reduced by 1.5–3 times compared to the load during periodic stops of the preparatory face. However, in order to confirm the results of modeling, taking into account the influence of the time factor on the stability of the roof rocks of the mine, additional research is necessary to identify patterns of displacement of roof rocks with variability of the physics and mechanical properties of the carboniferous massive in specific mining and geological conditions and different modes of the hydraulic struts of the walking support.

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References

1. N. Bulychev, N. Fotieva, E. Streltsov, Design and calculation of capital workings supports (Nedra, Moscow, 1986)
3. A.B. Tsvetkov, L.D. Pavlova, V.N. Fryanov, Program for the numerical study of a nonlinear mathematical model of geomass deformation taking into account the heterogeneity of rocks, 2020618419 (2020)
4. V.N. Fryanov, L.D. Pavlova, A.B. Tsvetkov, A software package for modeling
gomechanical processes in a structurally inhomogeneous geomass under the mutual
fluence of an underground mining system, 2020618595 (2020)
5. J.A. Marshall, A. Bonchis, E. Nebot, S. Scheding, Springer Handbook of Robotics, 2,
1549-1576 (2016)
science issues, 4, 2, 263-269 (2017)
12. Full cycle agency "Marketing from Timchenko", https://stimchenko.ru/coffee-
break/robotic-and-remote-controlled/