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Abstract. The article presents the design of the heading set of equipment for drivage of development galleries in rocks prone to gas-dynamic phenomena. This equipment can carry out the full technological cycle of rock excavation. The use of the P-110 roadheader of Ukrainian PJSC "Novokramatorskyi Machine Building Plant" with an operating device on a telescopic boom is offered for the aggregation of the heading set of equipment for underground development galleries drivage in emission-hazardous rocks. The device for mechanized boreholes drilling in an emission-hazardous coal seam has been devised based on the EBGP-1 M drilling machine of the Ukrainian SPA "Chervonyi Metalist Co Ltd". This device is placed on the telescopic boom of the roadheader. For mechanized drilling of explosive, degassing, unloading and injection boreholes, a rock-breaking tool has been proposed that can perform an effective vibratory and rotary loading method of drilling in medium-hard and hard rocks. Safe methods for underground development galleries drivage in gas-bearing emission-hazardous rocks have been worked out. The effectiveness of these methods was determined in industrial conditions. It is possible to conclude that this new heading set of equipment and technology can be recommended for implementation in the mining coal industry.

1. Introduction

Gas-dynamic phenomena (GDPh) can occur in emission-hazardous coal seams when performing mining works with the use of roadheaders which threaten the safe operation of miners mainly during the following conditions: coal extraction; simultaneous excavation of rock and coal; mine face clearance; mechanical shock after an explosion, as well as even after the mine face has stood for a short time. In mine conditions, GDPh are caused by a set of factors, the most important of which are the following: the stress state of rocks in the mine face zone of working, the presence of stress concentrations, gas-bearing state, physical and mechanical properties. Conditions of coal seams in the Donetsk basin are more difficult in comparison with other regions. The average depth of field development exceeds 700 m, and 30% of mines operate at a depth of 1000 - 1400 m. Approximately 80% are gas mines, 60% are dangerous due to coal dust explosions, and 50% are dangerous due to sudden emissions and rock strikes [1, 2]. So in-seam drivage with a roadheader in emission-hazardous coal seams and rocks, as well as in zones of mining and geological disturbances, development of emission-hazardous formations by workings in mines of Ukraine refer to mining operations in extremely difficult conditions. Therefore, ensuring labor protection and industrial safety and at the same time maintaining high rates of production during the development of technological schemes of the in-seam drivage with roadheaders in emission-hazardous coal seams and rocks are important tasks. One of the best solutions to these problems is to create an aggregate heading set of equipment, consisting of a roadheader equipped with devices and mechanisms (corresponding to the inventive novelty for Ukraine), to perform one complete technological cycle of rock excavation. Its anti-ejection means are able not to increase labor intensity and heading duration and to fit organically into drift cycle operations. Safety measures are necessary during the roadheader underground development galleries drivage in emission-hazardous coal seams and rocks. Therefore the technological cycle can consist of preliminary drilling of explosive boreholes at a drilling and explosive way of underground development galleries drivage in a concussion mode; preliminary drilling of advanced holes, set of unloading, degassing and injection holes; carrying out the process of hydro-loosening of the mine face zone of the emission-hazardous rock mass to safe rates of unloading and degassing and subsequent purely mechanical destruction of rocks at the working face by the operating device of roadheader.

It is necessary to recognize the difficulties in drilling boreholes and wells in any coal seams and rocks, especially when forming workings with a cross-sectional area of more than 20 m^2. To make such workings, it is necessary to drill at least 65 - 70 holes to a depth of 2.5 m [2]. This problem can be solved only by using a device for mechanized drilling of boreholes or wells (drilling machine) in the emission-hazardous coal seam during underground development galleries drivage with a roadheader with an operation device on a telescopic boom, which can drill in any location of the mine face surface of the working and any direction relative to its axis. Another difficulty is the lack of an effective domestic rock-breaking tool (crown) for the drilling machine in medium-hard and hard rocks.

Therefore, the purpose of this work is to develop a set of equipment and technology for the implementation of the necessary safety measures for underground development galleries drivage in areas of rocks with clear demonstrations of GDPh.

2. Methods

Inspection and evaluation of the operational equipment of technological sets during the underground development galleries drivage with a roadheader in the zones of rocks with clear demonstration of GDPh have revealed a problem – the lack of a set of equipment and technology for the necessary safety measures. To choose a way to solve this problem, the requirements have been formulated to determine the components of the set, taking into account the minimum negative losses for the enterprise.

It is known that machine-building plants of Ukraine OJSC "Yasynovatskyi Machine Building Plant", CJSC "Horlivskyi Machine Building Plant", Technological Park "Vuhlemash" and PJSC "Novokramatorskyi Machine Building Plant" today have developed efficient roadheaders and are mass-producing them, such as KSP-32M, KPD, and P-110. The authors of the article have conducted a comparative analysis of their technical and mechanical characteristics, which was used for the new heading set of equipment. The roadheader P-110 of domestic production brand PJSC "Novokramatorskyi Machine Building Plant" has been selected.

The conducted engineering and analytical studies have helped to make technical decisions on the components of the new heading set of equipment for underground development galleries drivage in rocks prone to GDPh. To solve the current problem of drilling holes and wells in any coal seams and rocks in workings with a cross-sectional area of more than 20 m^2, there has been devised a device based on the drilling machine EBGP– 1M, which was placed on the telescopic boom of the roadheader. An effective rock-breaking tool (crown) of the drilling machine has been developed for drilling holes and wells in medium-hard and hard rocks.

To calculate the number of degassing, unloading and injection wells, the dependencies have been established by mathematical modeling, which were confirmed by the results of mining experimental studies conducted in mine conditions. These dependencies can be used when developing an effective method for drivage of development galleries on gas-bearing emission-hazardous coal seam by the aggregate heading set of equipment.

3. Results and discussion

3.1. Development of the device for mechanized drilling of boreholes for the heading set of equipment

Important requirements for the development of a device for mechanized drilling of boreholes or wells in the emission-hazardous coal seam during drivage of development galleries are the minimum physical costs for its installation in the mine face and the ability to drill anywhere on a face with a cross-section of at least 20 m^2 for rocks with Protodyakonov hardness f = 6-8.

Such requirements are met by a device that is placed on the telescopic boom of the roadheader with the ability to move together with the boom on the axis of the working and rotate 360º around the perpendicular and parallel axes of the roadheader telescopic boom.

The authors of the article have developed the design of the device based on the drilling machine EBGP–1M design of SPA "Chervonyi Metalist Co Ltd", in which, due to the equipment of the drill with a clamp, a riser and a two-forked bracket, it is possible to provide the drilling process in any place of the mine face and any direction, relative to its axis. This solution allows the rock-breaking tool (crown), which is fixed on the drill rod, to move on six degrees of freedom: to move relatively to the axis of working (forward-backward, right-left and up-down), rotate around the axis of the telescopic boom and operating device of roadheader, rotate around the axis of the riser and the axis of the bracket forks in the plane of the drill rod.

Figure 1 shows a device for mechanized drilling of boreholes or wells in the emission-hazardous coal seam, which is placed on the telescopic boom of the roadheader.

The device consists of a clamp 1, a riser 2, rigidly fixed on a clamp 1, a two-forked bracket 3, fixed to a rider 2 with the possibility of swing around its axis, a drilling machine 4 with a drilling rod 5 and a rock-breaking tool 6, fixed to a two-forked bracket 3, with the possibility of swing around the axis of bracket forks. Tool 6 is fixed with clamp 1 on the telescope part of boom 7 of roadheader 8 behind its operating device 9.

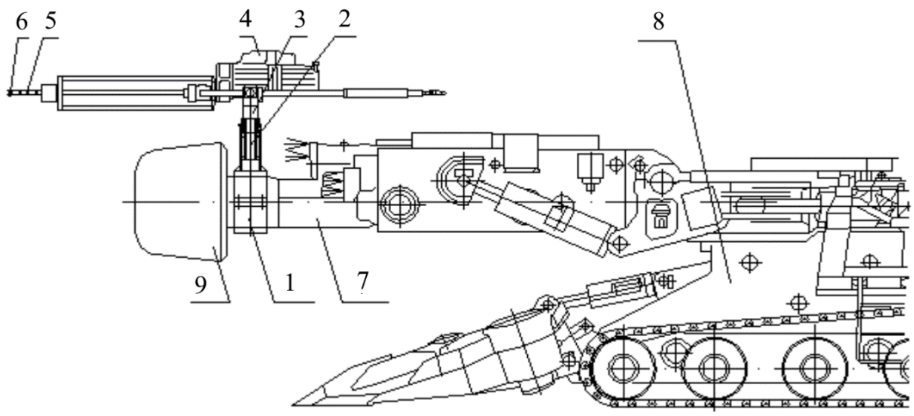

Figure 1. The device for mechanized drilling of boreholes or wells in the emission hazardous coal seam, which is placed on a telescopic boom of the operating device of a roadheader [3].

In the aggregate of its distinctive features, the device for mechanized drilling of boreholes or wells in the emission-hazardous coal seam during underground development galleries drivage with the roadheader equipped with operating device on the telescopic boom provides a new technical result – the possibility for the rock breaking tool to move in six possible degrees of freedom, which is achieved by the opportunity to perform mechanized drilling of boreholes or wells in any place of the mine face and any direction relative to its axis [3].

3.2. Development of the rock-breaking tool with vibratory and rotary loading for drilling of boreholes or wells in the medium-hard and hard rocks

For drilling of boreholes or wells in medium-hard and hard rocks, it was determined that the simplest and the most reliable way of increasing the intensity and simultaneously decreasing the energy intensity is a vibratory and rotary loading method, which is carried out without the use of additional energy suppliers. While being drilled this way, the rocks are simultaneously self-regulating the purely mechanical vibratory loading on the bottom of the borehole or well in the axial direction, and in the plane of applying torque.

The authors of the article have improved the device of vibratory and rotary loading for drilling of boreholes or wells in the middle-hard and hard rocks, in which new constructive elements ensure the technical result. It is the intensification of the process of vibratory and rotary drilling of wells in the medium-hard and hard rocks by increasing the speed of drilling and decreasing the energy intensity of the drilling process. These effects are achieved in the drilling process by simultaneous and self-regulated mechanical vibratory loading on a rock-breaking tool of the device that operates both in the axial direction and in the plane of applying a torque moment without the use of additional energy suppliers.

Figure 2 shows a device for vibratory and rotary drilling of boreholes or wells in medium-hard and hard rocks [4].

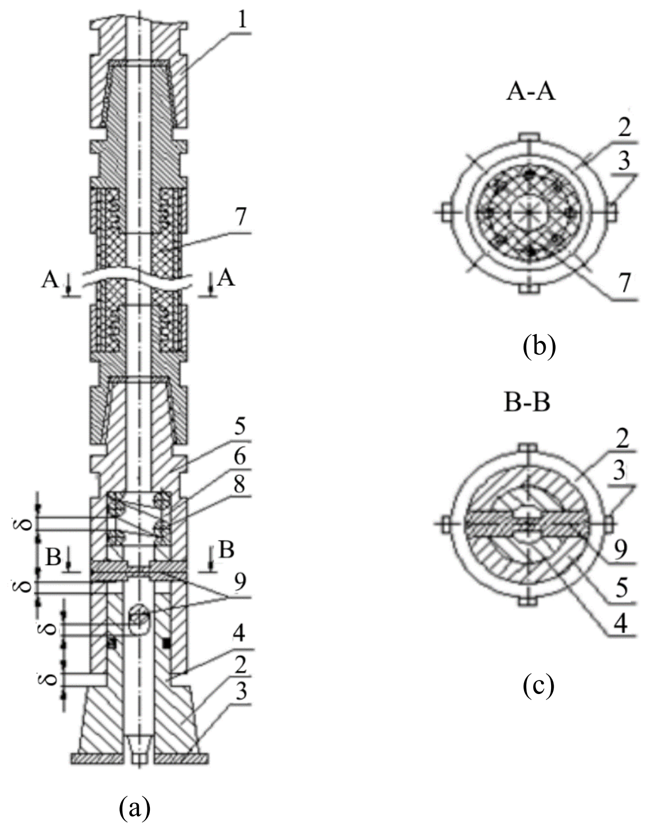

Figure 2. The device for vibratory and rotary drilling of boreholes or wells in the medium-hard and hard rocks: a - axial section; b - a section in a plane A - A; c - section in the plane B - B [4].

The device consists of a drilling rod 1; rock-breaking tool 2 with hard alloy plates 3 that reinforce its working surface and the shaft 4; a rigid adapter 5 with an axial cavity 6 which is placed to the shaft 4 with a slip fit and mechanically connected to it with the possibility of transferring to it the torque, axial displacement in cavity 6 and axial force; adapter 7 in the form of an elastic tube of a material that has a torque limit smaller than a rigid adapter 5; an axial vibratory and rotary source in the form of a steel spring 8. Elastic tube 7 is coaxially and rigidly connected on one end to a rigid adapter 5, on the other end to a drilling wheel 1 and can twist relatively to the axis of the drill rod in the opposite direction of applying torque at an angle no more than 3º and untwist to 0º. The steel spring 8 which is located in cavity 6 of rigid adapter 5 is docked with the end of shaft 4, pre-compressed and can be completely compressed and released by no more than 3.0 mm. The simplest mechanical connection of a hard adapter 5 with a shank 4 is a two-finger coupling 9, which is shown in figures 2a and 2b.

The elastic tube is necessary for the implementation of vibratory loading on the rock-breaking tool in the plane of torque application. A steel spring connected to the end face of the rock-breaking tool shank is required to vibrate the tool in the axial direction, i.e. in the direction of the bottom of the borehole or well.

It is known that rock is a fragile material with different strength. Drilling machines for medium-hard and hard rocks that perform rotary drilling always have clear technical parameters when drilling in a particular rock: the constant force of mechanical axial pressing of the rock-breaking tool to the bottom of the borehole or well and the torque applied to the tool. During drilling, these parameters must be equal to the compression and shear strength limits of the rock respectively.

In the developed device, the total compression force of the steel spring 8, which transfers the axial vibration load on the rock-breaking tool (2-4), is equal to the compressive strength of the rock during the penetration of the tool (2-4) into the rock. The torque of twisting the elastic pipe 7 to 3° in the direction opposite to the torque of the drill rod 1, which performs vibratory loading on the rock-breaking tool (2-4) in the plane of torque application, is equal to the shear strength limit of the rock on the entire face of the borehole or well.

The mathematical model for calculating the number of rock breaking cycles at the bottom of a hole or well when drilling by the device has formula

$$z = \frac{\pi \cdot D}{b}, \tag{1}$$

where z is the number of rock breaking cycles, pcs.; D is the outer diameter of the borehole or well, m; b is the geometric size of destruction products, m.

Using the formula (1), the maximum twist angle of the device elastic pipe is found according to the

$$\alpha = \frac{360° \cdot b}{\pi \cdot D}, \tag{2}$$

where α is the maximum twist angle of the elastic tube 7 of the developed device, in degrees.

According to [5], the application of normal or tangential load to the face of a borehole or well changes the nature of the stress state of the rock in the mine face zone. Instead of compression on all sides, there is a heterogeneous stress state, which is characterized by zones of compression, tension and a transition zone in which stresses of both compression and tension act. The maximum stress value in the medium-hard rock is reached on the line of action of vertical and horizontal forces resultants at distances of $0.5\text{-}1.0 \cdot 10^{-3}$ m from the face of the bottom of the borehole or well. On the surface of the mine face the maximum stress is located at a distance of $1.0\text{-}2.5 \cdot 10^{-3}$ mm from the contact point of rock with the cutter front face of the rock-breaking tool. From this factor it is concluded that in the process of rotary drilling of wells with 45 mm diameter the geometric size of the destruction products of medium-hard rock (6 units on the M. Protodyakonov scale) is 1.15 mm - 1.2 mm, and on average b = 1.17 mm.

The values of $D = 45 \cdot 10^{-3}$ m, $b = 1.17 \cdot 10^{-3}$ m, were substituted into the formula (2) and the maximum twist angle $\alpha° = 3°$ was found.

At the first stage of rock destruction at the bottom of the borehole or well, the developed device presses the steel spring 8 to full compression at a distance of up to 3.0 mm. Decompression of the steel spring 8 begins on the fourth stage and additional penetration up to 3.0 mm of rock-breaking tool (2-4) into the face of a borehole or well takes place due to the higher speed of the steel spring 8 on the rock-breaking tool (2-4) in comparison with the speed of axial pressing application of the drill rod 1 of the developed device to the bottom of the borehole or well. The steel spring 8 in the device acts instantly as gunpowder ignited in the cartridge of a firearm, and the drill rod has an inertia of action on the rock-breaking tool (2-4). So in the developed device at the beginning of the fourth stage of rock destruction at the bottom of the borehole or well it is assumed the decompression of the steel spring 8 on a distance δ, which is not more than 3.0 mm (see figure 2a). Thus, for each period of rock destruction at the bottom of a borehole or well, an additional penetration of a rock-breaking tool into the rock occurs, which can be equal to 3.0 mm, and that increases the drilling speed and its efficiency.

For the developed device new technical results consist in the following. The intensification of vibratory and rotary drilling process of boreholes or wells in medium-hard and hard rocks is achieved by increasing the drilling speed and reducing the energy consumption. These results are obtained due to simultaneous and self-regulating mechanical vibratory loading in the axial direction and in the plane of torque application of rock-breaking tool during drilling without additional energy suppliers use.

Stages of rock destruction at the bottom of a borehole or well automatically regulate without additional energy use the stages of vibratory loading on the rock-breaking tool of the device due to the dynamic properties of the elastic pipe 7 and steel spring 8.

The supply of flushing fluid under a pressure of 3.0 - 5.0 MPa to the bottom of the borehole or well in the process of double simultaneous self-regulating vibratory loading on the rock-breaking tool of the device reduces its friction against the face and increases its wear resistance.

3.3. Development of a method and technology for development gallery drivage of gas-bearing emission-hazardous coal seam with the aggregate heading set of equipment

To develop an effective method of development gallery processing on the gas-bearing emission-hazardous coal seam with the aggregate heading set of equipment, the analysis of the known methods [1, 2, 6, 7] was conducted. The disadvantage of these methods is that they do not provide measures against GDPh. These methods are dangerous.

The theory of sudden emissions of coal and gas into the open area states that one of the following conditions is sufficient to prevent GDPh:

- to reduce the stress state of the gas-bearing unworked coal;
- to reduce the gas pressure in the seam (to reduce the gas content of the massif);
- to change the properties of the seam [8].

The authors have solved the problem of creating the method that significantly increases the safety of development galleries drivage on gas-bearing emission-hazardous coal seam with a roadheader. The developed method includes processes of preliminary drilling of degassing, unloading and injection wells in the working face; injection of liquid into injection wells; collection of gas released during the process of injection from degassing and unloading holes in the gas collector and subsequent mechanical rock destruction with roadheader on the mine face. The number of degassing and unloading wells is determined by mathematical dependencies, which, when sealing the workings at a distance of no less than 30 m from the face after the completion of the process of injecting liquid into the injection wells, provide simultaneous achievements: no more than 1% of residual gas content in the atmosphere of the working sealed part and not less than 20% of unloading holes deformation as compared with their initial diameter.

Degassing holes are drilled in an number determined by the dependence

$$n_{\deg} = k_{\deg} \frac{G \cdot S}{D_{\deg} \cdot t_{\text{inj}} \cdot V}, \tag{3}$$

where: G – gas bearing capacity of the coal seam, m^3/kg; S – area of the face, m^2; $D_{\deg}$ - diameter of degassing holes, m; t_{inj} – duration of injection of liquid into injection wells, s; V – volume of liquid injected into the coal seam, m^3; k_{deg} – coefficient of proportionality, kg·s/m. Unloading holes are drilled in a number determined by the dependence

$$n_{\text{rel}} = k_{\text{rel}} \frac{f}{\gamma \cdot H \cdot D_{\text{rel}} \cdot t_{\text{inj}}}, \quad (4)$$

where: f – the hardness coefficient of rocks on the scale of M. Protodyakonov; γ – specific weight of rocks, kg/m^3; H – the distance from the surface on which the development galleries are carried out, m; D_{rel} – diameter of unloading holes, m; t_{inj} – duration of injection of liquid into injection wells, s; k_{rel} – coefficient of proportionality, kg·s/m [9].

Degassing holes are drilled along the contour of the face, unloading – horizontally at the bottom of the face, injection – in the center. A sealed wall should be built before injecting the liquid into the injection wells in the working, perpendicular to its axis at a distance no less than 30.0 m from the face. The wall is equipped with a vacuum pump, which is connected to the utilization unit of gas from the surface of the face, degassing and unloading holes, soles, roofs and sides of the working. Variable parameters (D_{deg}, D_{rel}) included in the formulas (3, 4) are taken such that when determining the required duration of liquid injection into the wells, the following safe stable and simultaneous indicators are achieved: the residual gas content in the working atmosphere should not be more than 1%, and the deformation of unloading holes should not be less than 20% of their initial diameter.

The gas collector is the space between the surface of the face and the sealed wall, which is constructed perpendicular to the axis of the working at a distance from the face of the working no less than 30 m [9].

Figure 3 shows the layout of equipment for implementation of the proposed method of development galleries drivage on the gas-bearing emission-hazardous coal seam with the heading set of equipment.

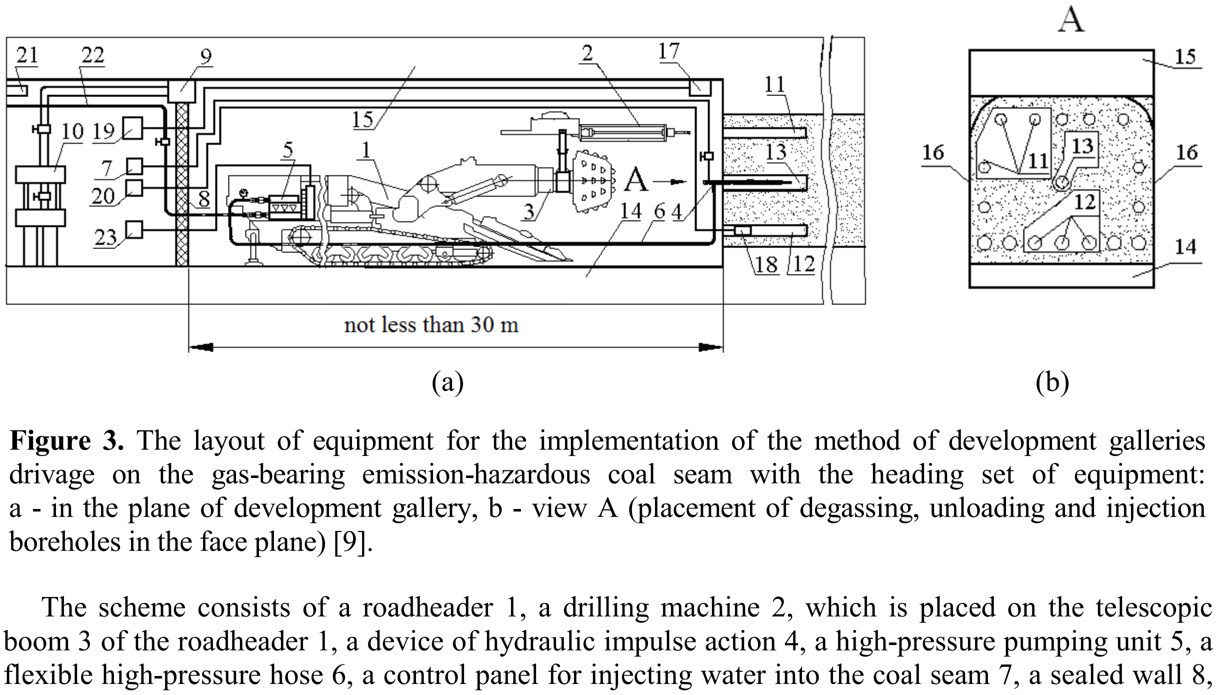

Figure 3. The layout of equipment for the implementation of the method of development galleries drivage on the gas-bearing emission-hazardous coal seam with the heading set of equipment: a - in the plane of development gallery, b - view A (placement of degassing, unloading and injection boreholes in the face plane) [9].

The scheme consists of a roadheader 1, a drilling machine 2, which is placed on the telescopic boom 3 of the roadheader 1, a device of hydraulic impulse action 4, a high-pressure pumping unit 5, a flexible high-pressure hose 6, a control panel for injecting water into the coal seam 7, a sealed wall 8, a vacuum pump 9, unit 10 for utilization of gas released from the mine face surface, degassing 11, unloading 12 and discharge 13 holes, soles 14, roof 15 and sides 16 of working, gas analyzer 17, deformer 18, remote indicator 19 of gas analyzer 17 and remote indicator 20 of deformer 18. The working is equipped with a ventilation pipe 21 and a fire pipe 22, which are connected to the sealed wall 8.

View A (figure 3b) shows the bottom of the development galleries, which shows the degassing holes 11, unloading holes 12, injection hole 13, sole 14, roof 15, and the sides 16 of the working.

Figure 3a shows the location of the drilling machine 2 [5] before drilling degassing 11, unloading 12 and injection 13 holes.

A new technical result makes possible an increase of the security level during the development gallery drivage on the gas-bearing emission-hazardous coal seam with the heading set of equipment. It is provided by the implementation of all three theoretically possible conditions to prevent GDPh. First, before the pulse hydro-loosening of the mine face zone of the working, a set of degassing, unloading and injection wells should be performed in certain quantities and the layout proposed by the authors. Also, a sealed wall in the workings at a distance of no less than 30 m from the face should be built, and, simultaneously, the gas should be pumped from the space sealed by the wall to a safe level when methane content in the sealed zone will be no more than 1%, and unloading boreholes deformation will be more than 20% of their initial diameter.

The authors conducted mining and experimental studies using the developed method to determine the number of degassing and unloading holes, at the Krasnolymanska coal mine of SE "UK "Krasnolymanska". The technical conditions were as follows: the depth of the gas-bearing emission-hazardous coal seam $H = 611$ m; type of coal - "G"; gas capacity $G = 59\cdot10^3$ m^3/kg; specific weight of coal $\gamma = 2500$ kg/m^3; the hardness coefficient of coal according to M. Protodyakonov $f = 3$; formation thickness $H = 1.7$ m; face surface area $S = 16$ m^2; diameter of degassing holes $D_{\text{deg}} = 0.045$ m; diameter of unloading holes $D_{\text{rel}} = 0.05$ m; diameter of the injection hole $D = 0.042$ m; number of unloading holes $n_{\text{rel}} = 10$ pcs.; number of degassing holes $n_{\text{deg}} = 10$ pcs. Injection parameters are as follow: productivity of the high-pressure pump installation UN-35 $Q = 0.58\cdot10^{-3}$ m^3/s; device of hydroimpulsive action on the coal seam – PGD-0,1 (designed by the IGTM NAS of Ukraine) with cavitation generator of hydroimpulsive pressure of the liquid, which is injected into the coal seam; the pressure of liquid injection into the coal seam $P = 25$ MPa. One unloading central borehole was equipped with a deformer of the borehole of IGTM NAS of Ukraine design, adjusted for 20% deformation measurement of the borehole walls, and the equipment for automatic control of methane was placed in the bottom of the mine and adjusted to output visible and audible signal if the gas content exceeds 1% in the atmosphere of the mine face zone of the working. The remote indicator of the equipment for automatic control of methane was placed near the high-pressure unit.

In addition, a KSP–32M roadheader was located at the working mine face. The working was equipped with the AK-1 forecasting equipment, which is located on the surface of the mine in the premises of the emission forecasting service and connected to the line of communication with the underground unit of sound-catching equipment, fixed on the side of the working at a distance of 2.0 m from the face.

Prior to mining and experimental works, the roadheader passed 1.0 m by mechanical rock destruction without the use of measures against GDPh. The projected dimensionless indicator of emission hazard Kv was equal to 3.2. At $Kv = 3$ the coal seam is emission-hazardous [10].

After the injection of water into the coal seam, the roadheader was moved to the mine face of the working for further mechanical destruction of rocks. At the very beginning of the destruction, a forecast of the emission hazard of the coal seam was made according to the amplitude-frequency characteristics of the acoustic signal of the sound-catching equipment. The projected dimensionless emission index Kv was equal to 0.8. This confirms that the coal seam has become emission safe.

Research results: a remote indicator of automatic methane control equipment showed that the initial gas content in the atmosphere of the mine face zone of the working was 0.05%; after 1800 s injection of liquid into the injection wells the gas content was 8.5%; and after 3600 s – 1%; the indicator of the deformer showed a 20% deformation of the walls of the unloading hole from its initial diameter.

Substitution of the technical and physical parameters obtained during these mine studies, in formulas 3 and 4, helps to determine the coefficients of proportionality $k_{\text{deg}} = 3604$ kg·s/m, and $k_{\text{rel}} = 917\cdot10^6$ kg·s/m.

According to the authors, these coefficients are universal and can be used to determine the number of degassing and unloading holes in other mining conditions.

At present, drivage with a roadheader of development galleries in the gas-bearing emission-hazardous coal seam is provided entirely in a shaking manner. The action sequence of the proposed method is following: explosive boreholes drilling on the surface of the mine face with an electric hand-held machine SER–19M; charging them with charges of explosives; moving workers to a safe distance from the face of the mine and explosion conduction in the coal seam. The depth of drilling of explosive boreholes is 3.0 m. After the explosion, the mine is ventilated, then the roadheader gets into the face and only after that it goes on to further destruction. All these processes take at least 20 hours. Taking into account the time for roadheader repairing and walls supporting, the maximum daily drivage is 3.0 m.

Usage of this method can increase the daily drivage with the heading set of equipment of development galleries on the gas-bearing emission-hazardous coal seam to 6.0-7.0 m.

To implement the developed method, mechanized drilling can be used to make a set of boreholes to a depth of 15.0 m according to [3]. A high-pressure hydraulic unit with a control device for hydroimpulsive impact on a coal seam can be used for degassing of the mine face zone of the working and reduction of its stress state by a hydro loosening [11].

4. Conclusions

A new aggregate heading set of equipment and technology for combining underground development gallery drivage in rocks prone to gas-dynamic phenomena are devised. The heading set of equipment consists of the roadheader P - 110 of PJSC "Novokramatorsky Machine Building Plant " and the device developed by the Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine based on drilling machine EBGP–1M of SPA "Chervonyi Metalist Co Ltd", which can perform mechanized drilling of boreholes or wells during in-seam workings drivage in an emission-hazardous coal seam. The roadheader is equipped with a high-pressure pumping unit UN-35 of the Teplohirskyi plant of hydraulic equipment with a device of hydroimpulsive injection of water into the gas-saturated coal seam for its hydraulic loosening; the device is designed by IGTM NAS of Ukraine. The device is equipped with a rock-breaking tool (crown) of IGTM NAS of Ukraine’s construction for boreholes drilling by vibratory and rotary loading. The technology of underground development galleries drivage on gas-bearing emission-hazardous rocks has also been developed, which includes preliminary drilling of degassing, unloading and injection wells in the working face, injection of liquid into injection holes and subsequent drivage by mechanical destruction of rocks in the mine face with the roadheader. Degassing and unloading holes are drilled in the number determined by formulas (3 and 4, given in section 3.3). Degassing holes are drilled along the contour of the face, unloading – horizontally at the bottom of the face surface, injection wells – in the center. The duration of liquid injection into the injection wells is determined by the time to reach safe stable and simultaneous values of indicators of the residual gas content no more than 1% in the face and the number of deformation of the unloading holes with no less than 20% of their initial diameter.

The new aggregate heading set of equipment and technology are developed and can be recommended for implementation in the mining coal industry for underground development galleries drivage on rocks prone to gas-dynamic phenomena.

References

[1] Minieiev S P and Rubynskyi A A 2007 *Provedenie Vyrabotok Prokhodcheskimi Kombainami po Vybrosoopasnym Ugolnym Plastam i Porodam* (Dnepropetrovsk: Dnipro)

[2] Minieiev S P 2018 The experience of the opening of the prone-to-outburst coal bed in the "Krasnolimanskaya" mine by the tunneling machine. *J. Geo-Technical Mechanics* **140** pp 106-17 https://doi.org/10.15407/geotm2018.03.106

[3] Anhelovskyi O A, Chuhunkov I F, Antonchyk V Ye et al 2013 Prystrii dlia mekhanizovanoho burinnia shpuriv i sverdlovyn u vykydonebezpechnomu vuhilnomu plasti pry provedenni v nomu pidhotovchykh plastovykh vyrobok prokhidnytskym kombainom z robochym orhanom na teleskopnii strilipистрій. Patent No 104681, Ukraine
[4] Antonchyk V Ye, Ukolova T M, Vasyliev L M et al 2013 Sposib i prystrii obertalno-vibronavantazhnoho burinnia shpuriv abo sverdlovyn u hirskykh porodakh serednoi mitsnosti ta mitsnykh porid. Patent No 121338, Ukraine
[5] Solohub S Ya 1975 *Issledovanie Protsessov, Sovershenstvovanie i Razrabotka Novykh Tekhnicheskikh Sredstv Razrusheniia Gornykh Porod Srednei Kreposti i Krepkikh pri Vrashchatelnom Burenii*. Abstract of PhD in Technical Sciences thesis, (Dnepropetrovsk: IGTM NAS of Ukraine)
[6] Laukhin O I, Dzerzhynskyi V O, Tytarenko O I et al 2019 Hirnychoprokhidnytskyi kombain. Patent No 133304, Ukraine
[7] Voloshyn O I, Laukhin O I, Dzerzhynskyi V O et al 2020 Prokhidnytskyi kombain. Patent No 140864, Ukraine
[8] Nykolyn V I and Vasylchuk M P 1997 *Prognozirovanie i Ustranenie Vybrosoopasnosti pri Razrabotke Ugolnykh Mestorozhdenii* (Lipetsk: Lipetskoe izdatlstvo Roskompechati)
[9] Trokhymets M Ya, Maltseva V Ye, Vialushkin Ye O et al 2018 Sposib provedennia pidhotovchoi vyrobky po hazonosnomu vykydonebezpechnomu vuhilnomu plastu prokhidnytskym kombainom. Patent No 122179, Ukraine
[10] SOU 10.100174088.011 2005 *Pravyla Vedennia Hirnychykh Robit na Plastakh, Skhylnykh do Hazodynamichnykh Yavyshch* (Kyiv: Minvuhleprom Ukrainy)
[11] Vasyliev L M, Usov O O, Potapenko O O et al 2012 Prystrii upravlinnia hidroimpulsnoiu diieiu na vuhilnyi plast. Patent No 68355, Ukraine