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Scientific substantiation of the technological scheme of robotized mine with the use of underground hydraulic mining equipment

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Abstract. This article analyzes and evaluates the possibility of improving the technology of underground coal mining, taking into account the achievements of the basic sciences, robotics and digital technologies in recent decades. According to the results of the analysis, it was established that at present the deposits of coal seams suitable for open-cut mining are almost completely exhausted by the industry. One of the ways to increase the volume of coal mining is the gradual replacement of the open-cut mining by manless underground method with remote control of mining processes and maximum use of digital technologies and wireless communication. Hydraulic technology is the most adaptive to manless underground excavation. The technical means for constructing the technological scheme of hydromine of a new generation and the technological requirements of the excavation robot for underground manless coal mining were substantiated.

1. Introduction

In the conditions of tough market competition of energy carriers, the role of coal remains ambiguous. The trend of a gradual decrease in the share of coal in the fuel and energy balance of Russia and leading foreign countries has led to the role of coal as the closing type of fuel and energy resources. According to the latest information in the countries of Western Europe in 2019 all unprofitable mines were liquidated. The role of coal is considered in its competition with other fuel and energy resources. It is projected to reduce the consumption of coal in almost all countries of the world by 2035 to 6.6 billion tonnes, compared with 7.2 billion tonnes in 2013 [1].

Trends in reducing the use of coal in the energy complex are planned in Russia. However, the competition of energy carriers does not take into account the prospects for the development of traditional technologies within the digital economy using modern scientific achievements. The existing traditional methods of open-cut and underground mining of coal deposits have practically exhausted resources for the increase of profitability, stabilization of the harmful effects on the ecological state of the natural and man-made environment and the safety of mining operations.

Surface mining of coal, especially in Kuzbass, has proved to be an economically viable option for subsoil users, but has led to a sharp deterioration in the environmental situation in the region. In his review I.G. Tarazanov [2] notes that in 2017 coal production in Russia increased by 6.4%, including by open-cut mining by 7.8%, and in mines by one percent. The share of coal mined by the underground method is 25.7%. These data confirm that in the coming years, the environmental situation in coal-mining areas, due to an increase in the share of open-cut coal mining, will worsen.

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At the moment, in Prokopievsko-Kiselevsky, Erunakovsky and other districts of Kuzbass a critical situation has arisen, since the borders of the coal mines are located near cities and rural settlements. For example, in the vicinity of the city of Novokuznetsk in Bunguro-Chumysh district [3] the increased intensity of mining has led to a high level of anthropogenic pressure on natural complexes and population. There is a degradation of the terrain relief, the elimination of the soil, change and destruction of plant communities. According to the results of the analysis in the article [4], at present the industry has almost completely exhausted the reserves of coal seams suitable for the open-cut mining.

One of the ways to increase the volume of coal production and maintain the ecological balance in coal mining areas is the gradual replacement of the open pit mining method with the underground one. However, the possibility of expanding the scope of the underground method in Kuzbass is limited to the manifestation of the following factors characterizing the low-tech mineral reserves for long fully-mechanized faces [4-6]:

- increase of the working depth to 700 m;
- limited capability to prepare excavation areas with optimal parameters within the mine fields for longwall mining systems: the length of the extraction panel is more than 2 km and the face length is 300–350 m, since residual reserves are located in areas of the mine field of irregular geometric shape;
- the presence of geologic faults of a discontinuous type, which are not crossede by long fully-mechanized faces;
- high methane capacity of coal seams;
- dip angle is more than 25°;
- increased geodynamic activity in coal-mining areas.

These negative factors in the application of traditional technologies reduce the extraction coefficient of coal balance reserves within the mine field to 0.4-0.7.

To improve the recovery ratio by mining of reserves of coal seams non-technological for long fully-mechanized faces, the following original technologies of coal mining were developed and are proposed for implementation at existing mines [4-8]:

- hydraulic method of extraction;
- plough technology for extraction of thin coal seams;
- auger technology;
- mining of coal seams by short longwall faces;
- mining of coal seams by room-and-pillar and pillar system systems;
- mining technology of thick coal seams by mechanized complexes with top coal caving;
- hydraulic mining by boreholes.

2. Methods of research

In accordance with the strategy of Industry 4.0, it is necessary to replace the routine and dangerous labor of miners with repetitive operations in a hazardous environment. Mining control should be carried out remotely in monitoring mode with maximum use of digitalization and wireless communication in the absence of people in the danger zone. According to the analysis results, it was found that the most adaptive to innovations is hydraulic technology according to the criteria specified in table 1 (maximum assessment of the significance of factor 10).

As follows from the results of expert evaluation of underground mining technologies of coal seams, the possibility of using hydro-mining is limited only by the dip angle of a seam less than 7°, which is necessary for gravity-based hydrotransport of the rock mass. According to the remaining criteria, the advantage of hydrotechnology is estimated to be almost 1.5 times higher compared with the traditional options of the underground mining method of coal deposits.

Table 1. Criteria for assessing the adaptability of underground coal mining technologies to the mining, geological and engineering conditions of mining operations at the mines of Kuzbass.

Criteria	Traditional technologies			Hydraulic manless mining by robots
	long fully-mechanized faces	short longwall faces	short longwall face with shearer mining	
The share of coal reserves in the mine field, geometrically favorable for the technology (100% corresponds to 10 points)	7	8	9	9
Disjunctive geological disturbances	3	5	9	9
Dip angle:				
0-7°	10	10	10	0
8-25°	9	9	7	10
26-90°	1	3	1	8
ROM transportation	5	4	3	10
Ventilation	5	4	2	8
Gas drainage	5	5	6	10
Safety	5	4	3	8
Coal dust explosion	3	5	5	10
Total	53	57	55	82

High efficiency of hydraulic technology with indicators close to ones of the best mines with traditional technology was proven in practice in the 80's of the last century (table 2).

Table 2. Main technical and economic indicators of Kuzbass mines in 1988.

Mine	Coal mining technology	Annual production, thousand tonnes	Average daily production, tonnes	Labor performance of a miner, t/month	The cost of production of 1 tonne of coal, rub. (prices as of 1988)
Yubileynaya	Hydro mining	1644.5	4583	79.7	15.44
Novaya	Traditional	1648.6	4590	97.1	11.69
Inskaya No. 2	Hydro mining	441.7	1225	72.4	12.98
Imeni Lenina	Traditional	2417.5	6712	81.1	12.55
Tyrganskaya	Hydro mining	1189.0	3317	52.9	18.61
Zenkovskaya	Traditional	1222.7	3406	47.7	19.54
Krasnogorskaya	Hydro mining	724.8	2023	69.6	21.08

The main system of coal seam development by hydraulic method was room-and-pillar with the rib width up to 12 m. With an increase in development depth of more than 200 m and in the absence of solutions for the prevention of rock bursts in coal ribs and increase in the cost of ribs maintaining, the production volumes by hydraulically method reduced [7]. The scientific research on elimination of these inconsistencies of mining systems with short longwall faces in Russia and in developed coal-mining countries has been conducted in the last 30 years in a limited amount. If we consider that over the past decades new equipment and technology of underground mining of coal seams with long fully-mechanized and partially automated faces have provided an increase in daily production by 2-3 times compared with the figures of mines in 1988, then in research and implementation of innovations in hydraulic technology the economic and social effect can be achieved according to the criteria presented in table 1. It is proposed to carry out the development of the technological scheme of a hydraulic mine with a manless coal excavation by improving the elements of the technological scheme of a hydraulic mine of the level of the 90's of the last century, developed under the guidance of V.S. Muchnik and A.A. Atrushkevich [9]. The general view of this technological scheme is given in fig. 1.

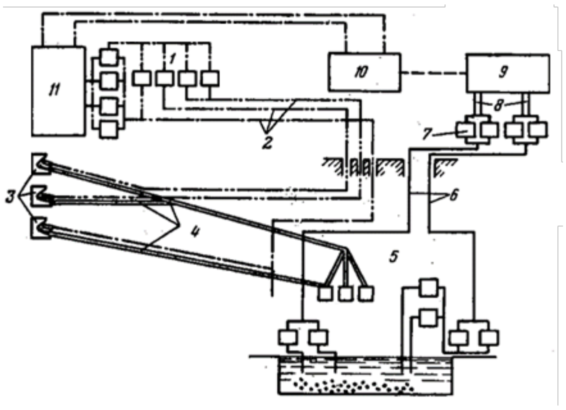


Figure 1. Technological scheme of hydraulic mine [9]: 1 – high-pressure pumping station; 2 – high-pressure conduits; 3 – the face of the hydro-mine; 4 – gravity hydrotransport system; 5 – the central chamber of the hydraulic lift; 6 – slurry pipelines; 7 – transfer station on the surface; 8 – main slurry pipelines; 9 – dehydrating factory; 10 – technical water return station; 11 – technical water tank.

When mining coal seams according to this scheme in the conditions of Kuzbass, the indicators were achieved that were close in level to the corresponding indicators of the best mines with traditional technology (table 2).

The scientific substantiation of the technological scheme of a robotized mine with manless coal mining on the basis of the technological scheme indicated in figure 1 was carried out by means of a comparative analysis of all elements of hydraulic mines and mines with traditional technology, evaluation of the possibility of improvement and application of individual elements and synthesis of a mine with manless extraction.

3. Results and discussion

Basically, the proposed version of the hydromine technological scheme of a new level with manless coal mining does not differ significantly from that shown in figure 1. The need for a new type of equipment and technological solutions to ensure robotic manless coal mining and technological processes is most fully substantiated [10 - 12].

The analysis of the extracting machine used at hydraulic mines showed that the design of the following equipment can be used to develop technological requirements and manufacture extracting robots [13].

Remotely controlled hydraulic monitors of type 12GD2, GMDTs4, 16GD (figure 2), GDMS 12-10, GDVS with a working water pressure of 12-16 MPa, designed for coal destraction with a coefficient of strength on a scale of prof. M.M. Protodyakonov f = 1.2-1.3, the distance from the remote control to the jetting machine is 14 m, the length of the jet working part is 1-15 m. The diameters of the nozzles 14-20 mm are taken in accordance with the compressive strength of coal.

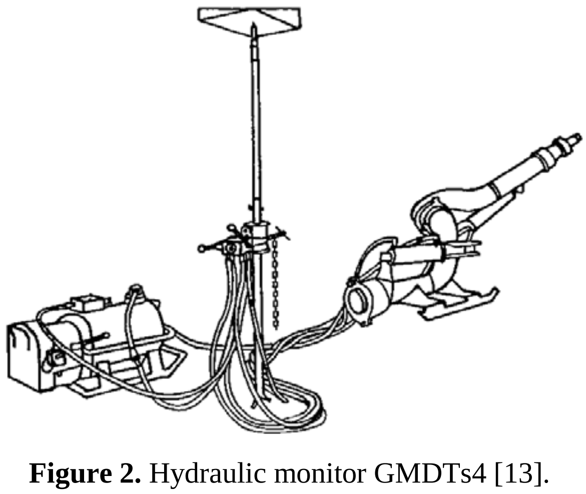


Figure 2. Hydraulic monitor GMDTs4 [13].

Remotely controlled thin-jet units [13–15], designed to form a high-pressure jet with a working pressure up to 10 MPa, include jet-forming boxes, an actuator in the form of a system of thin-jet nozzles with a diameter of 1-10 mm, devices for movement and expansion, a flexible water line, distributor (figure 3). A significant difference between thin-jet aggregates and hydro-cutters as compared to hydro-monitors is the need to bring the nozzles to the surface of the seam at a distance of 50-100 mm, move and swing the hydro-cutter at a speed of 1.0-2.5 m/s.

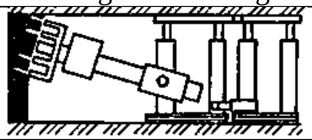
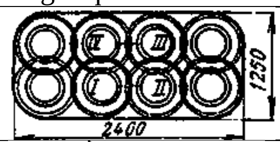
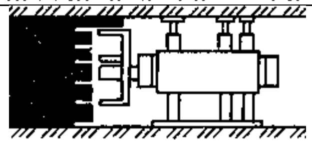
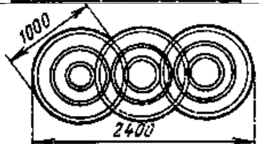
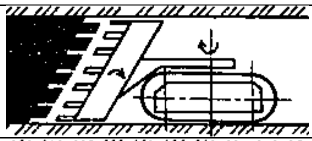
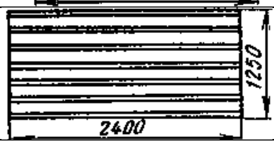
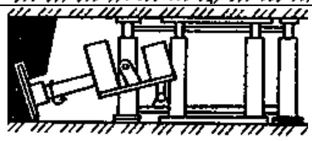
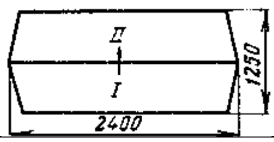
Options	Actuating element diagram	Mining sequence of the face
I		
II		
III		
IV		

Figure 3. Fine-jet extraction units [15].

The K-56MG and KPA tunnelling machines are designed for carrying out development workings and coal mining in short longwall faces with gravity hydrotransport of ROM. KPA combine (figure 4) is most adapted for manless coal mining and consists of an executive body with a cutting bit, overlapping sections of roof rocks, and a drilling rig. The combine is equipped with a support-hydraulic running gear, sliding skis with spikes, front and rear plowshares, controlled by hydraulic jacks.

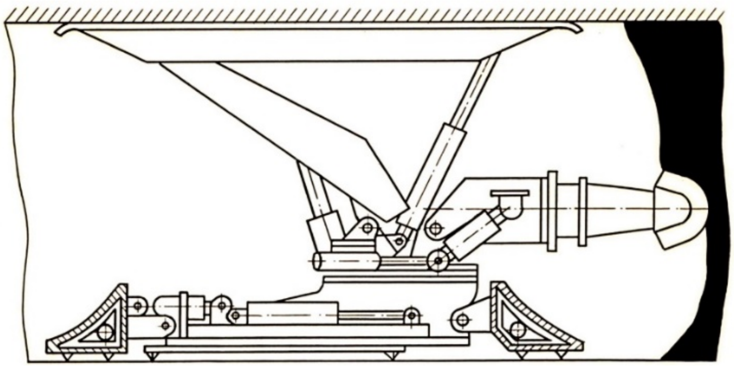


Figure 4. Tunnelling machine KPA [9].

To ensure manless extraction with the help of a robot, it is necessary to carry out modernization of hydraulic monitors, a thin-jet unit and a KPA tunneling machine in the following design directions:

- to develop a complex of sensors, software and technical means for transmitting operational information about the condition and form of the face, about the amount of coal mined, the stability of roof rocks;
- develop a system for remote control of the spatial position of the excavation robot in accordance with the geomechanical conditions in the face and the optimization of coal extraction modes to minimize energy consumption and pressure of process water;
- to develop a system of spatial positioning of the extraction robot relative to the mine workings and the boundaries of the blocks, the mining contour;
- develop technical devices and a remote control system by shifting the extraction robot;
- develop technical devices and a remote coal-rock contact recognition system to control the trajectories of the executive body of the tunneling machine;
- develop a system for controlling the optimal distance from the executive body and the surface of the fractured formation in the face in order to minimize exposures of the roof rocks.

4. Conclusion

To solve the set of scientific and practical tasks, it is necessary to conduct comprehensive studies, develop design documentation and software and produce technical means of robotic manless coal mining within the framework of the digital mine being created. A similar list of works was proposed as one of the key directions in the program of the activity of the scientific and educational center of Kuzbass.

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