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Development and Creation of a Robotic Mining Complex for Selective Extraction of Coal Seams

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Abstract. The development of coal seams located in complex mining and geological conditions presents significant technical and economic challenges when using traditional high-performance mechanized complexes. In such environments, it is practical to create and employ cost-effective, yet mobile and maneuverable robotic technologies, such as mining manipulators, automated support systems, and robotic mining complexes. this paper provides a brief analysis of the mining and geological conditions of coal seams in the karaganda basin and the current state of robotics development for coal mines. historically, the annual coal production from 27 seam layers in the karaganda basin suitable for selective extraction was about 15 million tons. However, losses of coal in these reserves due to traditional technology, which involves leaving coal pillars, reached approximately 9 million tons in 1998. The paper proposes a robotic technological complex for the selective extraction of coal seams under complex conditions.

Keywords: coal seam, complex mining and geological conditions, robotic mining complex, selective extraction, mining face, remote mining

Introduction

It is known that the Karaganda Basin is characterized by complex mining-geological conditions for the occurrence of coal seams and a high intensity of geological disturbances. The predominant form of discontinuous geological disturbances in the basin is faulting, which accounts for about 70% of all disturbances. The most common are tectonic disturbances with amplitudes ranging from 0.1 to 3.0 meters. Seam disturbances cause significant difficulties. About 20% of equipment relocations occur due to geological disturbances. Transition through these disturbances is associated with complications related to the need for stripping of surrounding rocks. As a result, the coal becomes contaminated with rock, and the mining machines are forced to operate under conditions that are not typical for them.

The main coal extraction in the basin is focused on flat and gently inclined seams with dip angles up to 18°, while extraction from steeply inclined and very steep seams, as well as from seams with complicated geological conditions, constitutes no more than 7%, even though their reserves exceed 30-40%. The difficulties in working these seams arise from the lack of effective technological schemes and extraction equipment. This situation leads to the detrimental practice of selectively mining the most favorable seams. As a result, not only are pillars left to support workings and in geological disturbance zones, but also significant reserves remain in localized areas characterized by various complex geological conditions. Therefore, the problem of developing localized areas with complex mining-geological conditions, including selective extraction of structurally complex and closely spaced thin seams, has been, and continues to be, particularly relevant [2, 3].

The development of unconventional technologies and specialized tools for working with various local geological formations (including formations with diverse purposes, layers exhibiting complex geometrics, zones intersected by geological faults, etc.), as well as for handling complex-structured and closely spaced thin layers, has been an ongoing focus. This is particularly relevant to the selective extraction of complex-structured layers (such as k1, k, k10, k12, k13, etc.) and closely spaced thin layers separated by thin interbedded rock strata (e.g., d7-d8) [1, 2].

In the Karaganda Basin, during a certain period, the annual coal production from coal seams suitable for selective extraction reached 15 million tons using traditional technology. However, significant coal losses in the reserves, with coal packs left in place, amounted to approximately 9 million tons in 1998 [2].

It is important to note that employing the costly traditional technology using a shearer-loader within a mechanized complex was highly uneconomical under conditions that did not meet their technical specifications and performance criteria (i.e., unfavorable conditions). Serial mechanized complexes are designed based on technical parameters for operation in extended mining pillars with long mining faces. Shearers with standard screw heights are intended for complete seam extraction at a specified height, dealing with relatively soft coal masses and transporting homogeneous rock (coal) via conveyor. Selective extraction mainly targets complex-structured or closely spaced thin seams separated by thin rock interbeds. The extraction process was carried out as follows: first, the upper seam or coal pack was removed, followed by the rock interbed, and finally, the lower seam or coal pack was extracted. This selective extraction technology significantly reduces the productivity and reliability of the mining equipment, often rendering it economically unviable.

Due to the complexity of the mining conditions, there was no need to create large mining fields, which would have made the use of mechanized complexes and shearers economically unfeasible. In selective extraction conditions, shearers were required to extract coal from closely spaced seams in two or even three passes, necessitating the undercutting of strong rock interbeds. In practice, selective extraction could also be carried out when encountering minor geological disruptions.

1. Paths to Solve the Problem

One approach to enhancing and advancing coal mining technology in complex mining-geological and mining-engineering conditions is the development of modern mechanization, automation, and robotics for extraction and tunneling operations.

Previous analysis of research and developments by leading scientists and specialists in the mining industry on robotics for coal mines indicates that the mining industry is among the foremost non-machinery sectors where the creation and implementation of industrial robots is of significant importance [3 - 5].

The primary justification for such decisions is that working conditions in mines are considered extreme for humans. As mining operations progress deeper, the number of injuries and underground explosions due to rock pressure increases. The frequency of accidents for underground workers is 4 to 5 times higher, and 8 to 9 times higher in deep mines, compared to surface operations. The complexity of mining-geological factors exacerbates the already challenging conditions of underground production. In coal mines in Russia, Ukraine, and Kazakhstan, the level of mechanization for extraction and tunneling processes is about 40%, while for auxiliary processes it is 10-15%. Given this situation, the development of mechanization and automation for various auxiliary technological operations, as well as mobile universal tools for working in localized sections of coal seams with complex geological conditions, is viewed as an alternative to specialized mechanization equipment [5 - 6].

The principles and concepts of industrial robotics and flexible automated manufacturing systems were established and began to be implemented in the former USSR and Kazakhstan by the early 1980s. During this period, the Karaganda Polytechnic Institute, under the guidance of Academician A.S. Saginov of the National Academy of Sciences of the Republic of Kazakhstan and Professor T.E. Ermekov, initiated work on developing the scientific and technical foundations and technological parameters of unconventional technology and methods for flank-front mining of seams with complex mining-geological conditions. Subsequently, these efforts focused on creating and refining the technology for seam extraction using short mining faces without the need for preparatory development works, thus reducing assembly and disassembly operations and ensuring effective extraction of localized areas and seams with challenging mining conditions. The following practical results were achieved [1 - 3]:

- parameters for technological schemes of frontal-flank selective mining using extraction manipulators—precursors to robotic technology systems - were developed and studied. These systems facilitate the effective extraction of localized areas and seams with complex geological conditions.
- a methodology was developed for selecting and justifying methods for selective face treatment and determining their advancement rates.
- various technology options were developed for transitioning geological disturbances such as normal and reverse faults with amplitudes up to 2 meters.
- technical specifications were developed for the creation and implementation of a robotic complex for selective extraction (KRS) and the "Tentekski" extraction complex with bidirectional movement of the KT-D.

In the 1990s, work on mining robotics using manipulators began in the United Kingdom, Japan, the United States, Germany, and the Czech Republic. Carnegie Mellon University (Pittsburgh, USA) developed and tested a model of an underground robot at a mine in Pennsylvania. In 1995, the United States began widely using robotic manipulators for drilling blastholes (by Fanuc) and installing concrete segmental lining in tunnels (by Daewoo). In the United Kingdom, mining robotics is being pursued as part of a government program. In Australia, a two-phase program for mining process automation was developed, consisting of:

- remote automated control of mining equipment with manipulators;
- transition to comprehensive automation of mining systems using robotic manipulators.

Existing mining and tunneling equipment cannot fully eliminate manual labor during technological operations. Several approaches could address this issue. One approach is to ensure that advanced technological schemes and corresponding equipment integrate interconnected technological operations comprehensively. However, many operations are performed discretely over time, and the overall reliability of the technological scheme is a significant factor. Another direction is the creation and implementation of equipment complexes in mining faces that mechanize and partially automate both primary and auxiliary processes. However, experience with automated mining face equipment has shown that the labor intensity of manual operations does not significantly change as a result of automation. Consequently, a new direction is emerging: a higher level of comprehensive mechanization and automation of underground operations through the application of robotics. This approach should enable manipulation operations using automated manipulators, information collection (via visual, acoustic, and other sensors) in the immediate work zone, and the creation of conditions that allow for the removal of human operators from these zones.

The future of underground mineral extraction is linked to the development and implementation of technology for unmanned mining, which is currently advancing in three main directions [3]:

- coal mining without the continuous presence of humans in the mining face, which involves only brief human visits to the face for equipment maintenance and inspection.

- coal mining using methods and tools that eliminate the need for human presence in the mining area.
- underground coal mining (or geotechnology) without human presence, involving the management of the entire process from the surface.

The first direction is based on the development of integrated and unit-based mining using microprocessor technology in long mining faces (primarily for thin and medium-thickness seams) with coal extraction by shearers or plows. Significant experience has been accumulated in this area.

The second direction focuses on creating remotely controlled units with programmable control for short mining faces (including the use of hydraulic mining) and developing technical and technological solutions using unconventional methods.

The third direction relies on technology and equipment that allows for the execution of the entire set of operations from the surface after the preliminary alteration of the coal's physical state.

To remove humans from complex mechanized mining faces during extraction, it is necessary to address the automation of core processes. For reliable operation of the equipment without constant human presence in the mining face, an automation system must be created, which includes subsystems for: drive control, roof support equipment and seam geometrics, hydraulic system control and monitoring, as well as data collection and processing about the condition of machines and equipment.

New sensors and hydraulic and optical systems have been developed and tested in mines. However, even with the creation of reliable control systems, it remains challenging to fully eliminate human presence from the mining face due to the imperfections of technology and unaccounted disturbances from the mining environment. As long as humans are responsible for monitoring equipment operation, environmental conditions, process adjustments for auxiliary operations, and resolving extreme situations in the mining face, the task of removing human operators remains difficult [3 - 5].

For complex mechanized mining faces, the problem of unmanned mining should be addressed in two stages. The goal of the first stage is to eliminate manual labor, which can be achieved by integrating a range of machines and mechanisms into the complex to perform individual work processes and auxiliary operations instead of humans. This may involve using teleoperated robotic manipulators equipped with universal manipulators, various sensor systems, and mechanisms for moving through mining faces. Only after this can the technological process be implemented without human presence in the mining faces, for which a necessary base of robotics and automation must be created.

Mining face equipment represents a higher level of development in mining technology compared to complexes, and the task of eliminating manual labor is primarily defined by technical solutions related to technology, equipment, and automation systems. Naturally, alongside traditional technical solutions, various types of robotic manipulators, such as informational and copying robots, may be used.

One of the conditions for the successful operation of underground manipulator robots is effective informational awareness of the working environment and the robot itself. This role is played by the robot's sensory system, which includes tactile (mandatory), visual, and other sensors. It is well known that through visual channels, humans receive 80-90% of all information about the environment. Therefore, a significant portion of the information needed for effective manipulation and movement of underground robots will come from visual sensors (video sensors). Since biotechnical robots controlled remotely are considered most promising for underground conditions and the final recipient of information is the human operator, the system involves "operator-visual sensor-manipulator-environment."

The use of visual sensors as informational devices, especially in non-standard underground equipment, opens up fundamentally new possibilities for assessing the state and relative positioning of objects in three-dimensional space for manipulation purposes. It allows for increased recognition and interpretation of observed objects, including tasks such as determining the boundaries of "rock-coal," diagnosing faults and hazardous conditions, and more. This should lead to improvements in traditional automation systems and the creation of robotic manipulative complexes.

The anticipated technical and economic benefits of robotizing production processes in mines include reducing manual labor and the labor intensity of operations, freeing up and more rationally utilizing workforce, creating conditions for increased productivity and machine operating time of mining and tunneling equipment, reducing injury rates by removing humans from the work zone, and relieving people from working in hazardous or hard-to-reach areas.

2. Robotic Complex for Selective Mining (KRS): Composition and Design Requirements

The KRS complex is designed for the selective (separate) extraction of coal and rock in seams located in complex mining-geological conditions, without the need for constant human presence in the mining face, while leaving rock in the mine [3 - 6]. The complex is intended for use in single seams with interburden or closely spaced coal seams with thicknesses ranging from 2.0 to 7.0 meters, with dip angles up to 55°, seam cutting resistance up to 400 kN/m, and strength of interburden layers up to 6 (according to Prof. M.M. Protodjakonov's classification). The thickness of interburden layers ranges from 0.4 to 1.5 meters. The system is designed to handle seams with hard inclusions and geological faults with amplitudes up to 1 - 2 meters.

Application Area of the KRS Complex [3]:

- development of flat, inclined, and steeply inclined seams with complex mining-geological conditions (e.g., complex seam geometrics, presence of hard inclusions, interburden layers, boulders, risk of outbursts, roof and floor instability, etc.);
- separate extraction of coal and rock;
- exploitation of blocks for various purposes;
- reworking of decommissioned reserves.

Applied Mining Systems: Pillar mining with lengths of 60 - 100 meters and short pillars with lengths of 25 - 60 meters without the creation of development workings. Roof Control: Complete collapse of the main part of the longwall and partial backfilling of the worked-out space along the conveyor drift (heading).

Complex KRS: The KRS complex consists of a screw backfilling device based on the "Start" drilling rig, the "Titan" backfilling complex, and hydro-electrical equipment with control systems and microcomputers utilizing microprocessors, specifying the quantity (set) and designation of its components (Table 1).

Table 1. Composition of the KRS Complex

№	Equipment Name	Designation	Quantity
1	Excavation Machine-Manipulator	VMF-5	2
2	Mechanized (Automated) Support (three sizes)	Based on AK-2, KPK-1 (“Pioma 25/45-03” or “Fazos 24/53”)	1 (for 60-100 meters)
3	Sections of Mechanized Support (four sizes)	Based on M130*	5 - 10
4	Upper Junction Support (with ventilation drift)	T6K	1
5	Lower Junction Support (with conveyor drift)	M81SK	1
6	Face Conveyor	SKU	1
7	Screw-Feed Device	“Titan”	1
5	Reversible Drift Conveyor	SP87P	1
9	Pumping Station Group	SNU-5	2
10	Electrical Equipment	-	1
11	Automatic Control System with Microprocessor Devices and Microcomputers	-	1

* *Supports, depending on technical conditions, may also be from other manufacturers.*

The primary criterion for the operation of mechanized support for mining a particular seam is the correspondence of the geological conditions of the seam to its technical specifications. Key geological conditions include: the thickness of the seam being mined, the dip angle of the seam, the load-bearing capacity of the roof and floor of the seam, and the stability of the roof.

The support for the main part of the longwall, AK-2 or KPK-1, is designed to support the roof in the immediate face area, protect the working zone from roof collapse, and manage the roof of the main part of the longwall.

The support sections for the backfill area of the longwall, M130, are intended to support the roof in the immediate face area, protect the working zone from roof collapse in the backfill section, and for the suspension of backfill pipelines and ensuring the placement of waste rock in the worked-out space behind the support sections.

The junction supports T6K and M81SK are designed to secure and support the upper and lower junctions of the longwall with adjacent workings and to prevent sliding of the linear sections of the supports. Junction supports must ensure the compact arrangement of face equipment in the end parts of the longwall. Specific design modifications for the lower junction supports will be finalized during development.

The face conveyors SKU ensure the delivery of broken coal and rock. The conveyor SKU-45 includes a drive head with an electric motor, shaker sections, a chain with cantilever folding scrapers, troughs for the track chain, and hydraulic and electrical communications for control. The face conveyor on the side of the longwall's caved section must be raised relative to the seam floor to ensure the section support base fits by 130 mm with a depth of 430 mm. The length of the linear conveyor sections is 1100 mm. The spacing of the cantilever scrapers should be 1000 mm. The load on the traction chain during the transportation of coal and rock should not exceed 843 kN.

The reversible drift conveyor based on the conveyor SP87P is intended for transporting coal to subsequent drift conveyors and for loading the broken rock into the reception hopper of the backfill device during reverse operation.

The KRS complex consists of a mining manipulator VMF-5, VMF-6 with mechanized support and conveyor, electro-hydraulic equipment, and adaptive-program control equipment with diagnostic capabilities.

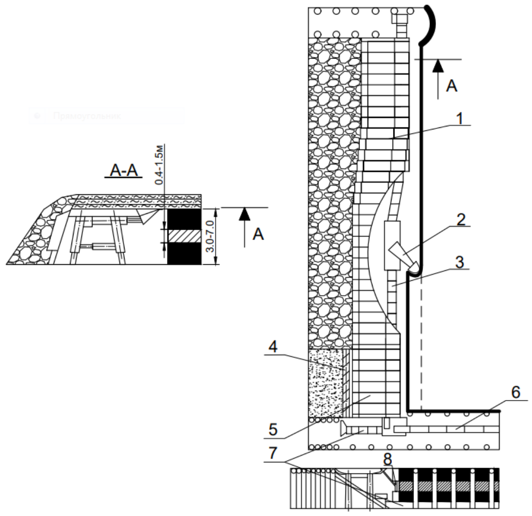
The application of the KRS complex allows:

– significantly reducing mineral losses during the operation of coal mines;

– mining closely spaced coal seams with a distance of (0.5 - 2 m) and a dip angle up to 55° using selective mining technology, leaving rock in the mine;

– decommissioning and mining technogenic reserves of mineral deposits, as well as developing blocks of various purposes in ore and non-ore deposits under complex geological conditions.

Figure 1 shows the general view of the complex with a single automatic mining manipulator in the longwall.



1) linear support sections AK-2, KPK-1; 2) mining manipulator VMF; 3) face conveyor SKU; 4) screw backfill machine "Titan"; 5) support sections M-130 with backfill device; 6) drift conveyor SP87P; 7) reclaimer; 8) support device

Fig. 1. - KRS Complex for Waste-Free Selective Mining (with one manipulator operating in the longwall)

According to the Figure, the KRS complex with a single mining unit includes linear sections of mechanized support 1, a mining machine in the form of a mining automatic mining manipulator 2, located on a base and supported by skis on the guide rails of the transporting conveyor 3, and a backfilling machine 4, support sections with a backfilling device 5, a drift conveyor 6, a loader 7, and a rib support device 8.

Based on the results from reviewing the indicators on the technical level and product quality card for the selective mining complex, the KRS complex should ensure full automation of clearing operations in panels with separate extraction of coal and rock without the constant presence of people in the mining face, while leaving the extracted rock in the mine for backfilling.

When developing a steeply inclined seam, a special transport base with speed dampers for coal fragmented by manipulators is used.

A brief summary of the KRS complex characteristics is presented in Table 2.

Table 2. Brief Characteristics of the KRS Complex

Indicator	Value
Productivity of one manipulator with automatic control, t/min	2,5
Number of manipulators per unit, pcs	10
Power of one manipulator's electric motor, kW	22
Number of degrees of freedom of the manipulator	5
Total power of the complex's electric motors, kW	240
Specific energy consumption of the unit, kWh/t	0,4
Weight of one manipulator, t	Up to 5.0
Total weight of the support complex for a face length up to 60 m, t	About 150
Mining system	Pillars along the strike
Roof control	Complete collapse
Soil types	Any type of support with a bearing capacity of not less than 1.0 MPa (10 kg/cm²)
Mine gas category	Exceedingly high category
Extractable seam thickness, m	2,0-7,0
Seam dip angle, degrees	Up to 55
Face length, m	Up to 60-100
Daily load on the complex, t/day	Up to 5000
Type of support for the support complex	AK-2, KPK-1
Type of conveyor for seam dip up to 35 degrees	SKU-45

3. Description of the KRS Complex and Operating Principle

The KRS complex, consisting of several mining units, includes mechanized support (possibly of the AK-2 or KPK-1 type), M130 support sections in the backfilling part of the panel, a face conveyor SKU or a guiding transporting device, and the working organs of manipulators.

The working organs are designed as automatic manipulators, movably installed every 10 - 12 support sections, with four legs. The guides are made with movable curved sections located on the transporting device and on the base of the mechanized support sections. These curved sections are paired and connected by hydraulic cylinders, whose cavities are parallelly connected through pipelines to a distributor. The handle is positioned to interact with a cam, which is pivotally mounted on the base of the manipulator and to which the ski grips are also pivotally attached. The hydraulic cylinders are connected to the hydraulic distributor via pipelines and a check valve. At the ends of the panel, the guides have a pair of curved sections II: both on the base of the support section and in the face area, meaning that the terminal ends of the guides have a T-shaped design.

To ensure precise positioning of the manipulator under the support section at the ends of the guides installed on the base of the support section, stops are provided.

To concentrate clearing and preparatory work, the end parts of the guides are T-shaped with movable curved sections.

Figure 2a shows the general view of the KRS complex; Figure 2b shows the general plan view of the complex; Figure 3a illustrates the structural scheme of the guides and their control system; Figure 3b shows view A; Figure 4 shows the flow technology of coal extraction using several mining manipulators VMF-5, VMF-6; Figure 5 shows the control block of the KRS complex.

The KRS complex (Figures 2 and 3) includes mechanized support sections with a base 2 and a cover 1, a mining machine in the form of a manipulator 4 located on the base 5, supported by skis 6 on the guides 7 of the transporting device 8. The guides have straight sections 9, 10 located on the transporting device and movable curved sections 11 located on the base of the support sections 2. The curved and straight sections have guides 28 that interact with the grips 29 and 30 (Figure 3), controlled by hydraulic cylinders 31 and 32 (Figure 2).

On the base of the manipulator 5, control equipment 33 is installed. The hydraulic control system consists of a control hydraulic block 34 for the boom and head of the manipulator 4, pumps, a current regulator, a distributor interacting with cam-operated check valves of the lifting-lowering hydraulic cylinders, rotation, hydraulic distributor, and grip cylinders. The control hydraulic block 34 includes a pressure relief valve, a section for controlling the lifting-lowering hydraulic cylinders, and a section for controlling the rotation of the manipulator boom.

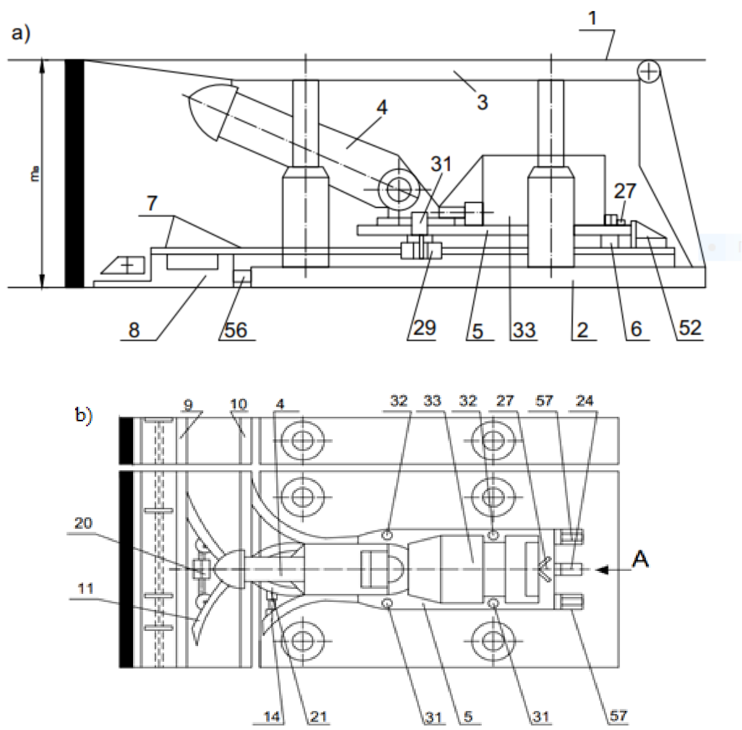


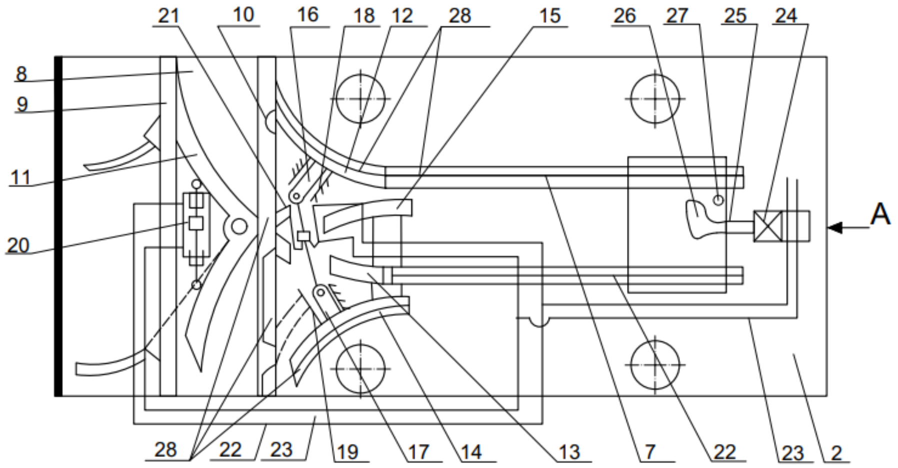
Fig. 2. – Section of mechanized support with VMF-5 manipulator: (a) general view of the KRS complex; (b) top view

The conveyor or transporting device 8 is connected to the base of the support section 2 via a hydraulic cylinder 56 (Figure 2). Fixed stops 57 are installed on the base of the support section 2. The stop 57 restricts the manipulator's movement towards the collapse, regardless of the position of the support section, helps in accurately positioning the manipulator in the initial position, and protects the handle 25 of the distributor 24 from excessive force impacts. When positioning the manipulator in the initial position, the curved sections of the guides are automatically moved to the working position by the cam 26 of the distributor 24 through the handle 25 (Figure 3). A support-rotating device carries out the rotation of the working organ (manipulator boom) in the horizontal plane with rotation hydraulic jacks 30.

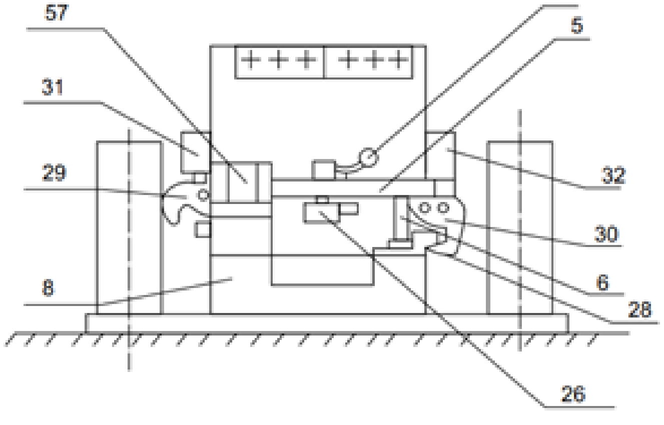
The robotic complex operates as follows. In the initial position, the manipulators are located under the support section. The handle 27 (Figure 3) is rotated to the required position, for example, for movement to the right, position "P". In this position, the cam 26, acting on the handle 25 of the distributor 24, directs the working fluid through pipeline 22 to the hydraulic cylinders 20 and 21. Under the action of the moving pistons of these hydraulic cylinders, the movable curved sections of the guides 11, 12, and 13 are tightly pressed against the straight sections of the guides 9 and 10, allowing the manipulators to move to the right, as shown in the figure.

Simultaneously, the right grips 30 are brought into the working position. For this, working fluid is supplied from the control section through pipelines via the distributor and check valve to the hydraulic cylinders 31 and 32, thus bringing the grips 30 into the working position while retracting the grips 29. At the same time, working fluid is supplied through the pipeline via the check valve to the rotation hydraulic cylinder, setting the required angle for the rotation of the manipulator boom 4 towards the face. The manipulator boom is mounted on the upper support-rotating platform, which is connected to the lower platform via hydraulic jacks for platform extension.

The preparation of manipulators I, II, III, and IV for mining operations is now complete. All preparatory work is conducted from adjacent workings: a command is given to one of the end manipulators, and the others repeat this command, as they all perform the same operation, which simplifies automation significantly.



a)



b)

Fig. 3. - Controlled curved sections of the manipulator base: (a) structural diagram of the guides and their control system; (b) view A

Next, all manipulators gradually move onto the straight sections of the guides and start cutting. When on the straight section of the guides, each manipulator performs the excavation of valuable minerals in its section (Figure

4). After finishing the processing of their sections, manipulators I, II, and III return to the initial position under the nearest support section, the conveyor and mechanized support are moved towards the face, and manipulator IV, moving along the curved section to the guide located in the working area, performs excavation to prepare this working area to a depth equal to the unit's movement step, as shown in the figure, and then also returns to the initial position.

Excavation work in the opposite direction is performed similarly to the previous operation. In this case, the handle 27 is set to the left position “L” (Figure 2b), and working fluid is supplied through pipeline 23 to hydraulic cylinders 20 and 21. As a result, the piston of hydraulic cylinder 21 moves upward, retracting the movable curved guides 12 and 13 from the working position. These guides are moved at an angle to the straight sections of the guides, aided by the positioning of the eyelet 16 in the guiding grooves 18. At the same time, the movable curved guides 14 and 15 are brought into the working position, moving towards the positioning of the eyelet 17 in the guiding groove 19, and the curved guide II is positioned in the working state by rotating around its axis.

The grip 29 is moved to the working position by supplying working fluid through pipeline 45 (Figure 3), while grip 30 is retracted from the working position, and the manipulator boom is rotated to the opposite direction, as shown in Figure 4d. The movement of grips 29 and 30 from one position to another is necessary to ensure the stability of the manipulator base. The grips are moved in such a way that the grips on the collapse side, in this case, grips 29, are active.

If any manipulator fails, for example, the nearest manipulators that have the same movement direction, as shown in Figure 4 process manipulator 1, its section.

Upon completion of the excavation work, the transporting device is moved forward, the mechanized supports and manipulators are returned to their initial positions, and the manipulator that has entered the working area performs preparatory work (deepening the working area).

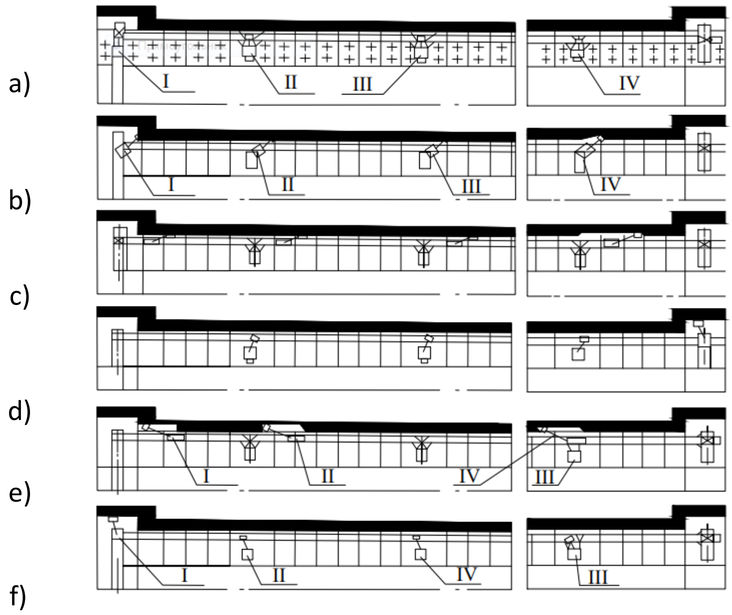


Fig. 4. – Continuous Coal Extraction Technology VMF-5, VMF-6

The continuous coal extraction technology is implemented using VMF-5 and VMF-6 manipulators. The average value of the expected current for the actuator during operation is 10 - 30 A for 6 seconds, with a variance of 4 seconds, then decreasing to 20 A and 2 A respectively, while the electric motor is loaded at 60 – 65% of its capacity.

Simultaneously, repair of the failed manipulator III is carried out, provided it does not involve accessing the electrical components, and preparation for the next cycle is undertaken (Figure 4, d).

The main advantage of the proposed unit is the ability to concentrate mining and preparatory operations within the extraction field, which provides a significant economic benefit by combining extraction and preparatory processes.

Unlike known complexes of this type, there are no issues with boom rotation, and the automation of the extraction process is facilitated since all manipulators can work simultaneously performing the same operations. The process of switching curved guide sections from one position to another is automatically handled when the machines are positioned under the support sections. If any manipulator fails, the two adjacent manipulators can replace it. During excavation work at one end, the end section of the face conveyor, conveyor line, and support sections are moved at the other end, along with other auxiliary tasks. The failed manipulator can be repaired under the support without stopping the extraction work, provided it does not involve accessing the electrical components.

Using identical manipulators for preparatory and extraction work allows mining workers to gain practical skills in their operation more quickly. The number of curved guides exceeds the number of manipulators per unit, and these (curved guides) are spaced evenly along the length of the face.

4. Control Equipment for the Robotic Complex for Selective Extraction of Coal Seams

The creation of effective control systems for mining complexes aimed at ensuring safe working conditions requires the transition to microprocessor-based technology. The control equipment for the automated complex for selective coal seam extraction should provide a combination of manual, local, and automatic control of mechanized supports, mining manipulators, and conveyors according to a programmed schedule. Remote and automatic control of the complex for selective extraction allows for the removal of personnel from the mining face, thus increasing the productivity of both the complex and the operating staff.

At the interface preparation stage, the driver loads a microprogram (communication module) into the interface's RAM, which manages the conversion of data from the working format to a format suitable for transmission to the software module. An example of connecting the VMF-5 via the CAN bus is shown in Figure 5.

The control equipment and hydraulic drives must ensure the effective operation of the KPC complex with the help of [3 - 4]:

- boundary control sensor “Coal-Rock”: according to Figure 5 (Developer - Department of Physics, KarTU);
- DMMK Sensor: A sensor for locating manipulators that operate on steeply inclined seams (used in seam development under particularly challenging conditions);
- end position sensors for combines (manipulators): Sensors for position control of the standardized DPU series. The standardized series of magneto-reed position sensors, DPU (DPU1-40, DPU2-40, DPU1-100, DPU2-100), are intended for monitoring the position of moving parts and mechanisms during various technological processes;
- upgraded sensors of the DPU series: DPG1-40, DPMG2-40, DPMG2-100, DPMG1-100, DPMG1-200, DPMG2-200 sensors are intended for controlling the movement of the monitored object (screen) perpendicular to or parallel to the working side.
- end position sensors for support sections: DPU sensors for tracking the position of the support sections during movement. The DPU-6 sensor monitors one of the end positions of the support sections; the DPU-7 sensor monitors the front position of the support sections and the stationary zone, which is equal to 60 minutes.

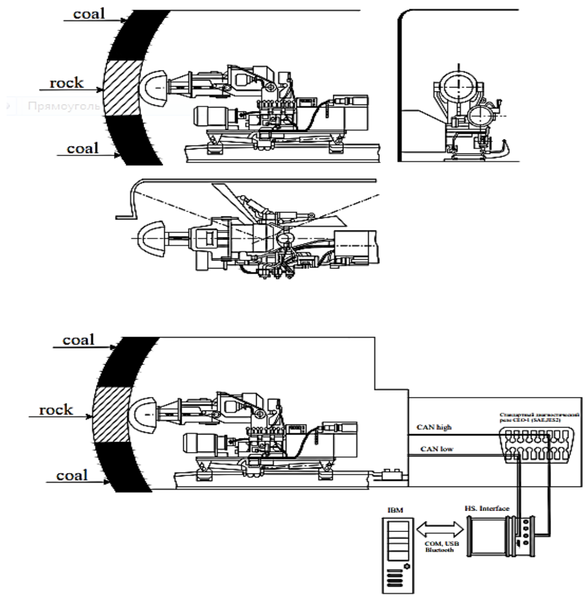


Fig. 5. - Control Block of the KPC Complex with Connection to VMF-5 via CAN Bus through "HS+Interface"

Conclusions

Based on previously conducted research and development work, a new direction for designing robotic systems and equipment using microprocessor technology for coal seam development under complex mining and geological conditions has been established. New technical solutions for creating mining complexes and equipment for the extraction of complex and closely spaced thin seams using selective mining technology are presented. These solutions are unified by the concept of using controlled mechanized supports and automated mining manipulators equipped with boundary tracking subsystems for "coal-rock" separation [7 - 10].

For the robotic complex for selective extraction (KRS), maximum use is made of standardized products based on mechanized mining supports of supporting and supporting-guard types and the actuator of the selective-action mining manipulator from serial tunneling machines. The applicability coefficient of the mining robotic complex is up to 85%.

According to the requirements for the technological and metrological support of design, production, and operation, the readiness coefficient of the KRS complex can be up to 0.8, while that of the VMF mining manipulator is up to 0.92. The service life of the SKU conveyor until the first major overhaul is 500,000 tons of transported coal.

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