Technical and technological platforms for creating robotized complexes for the development of thick seam deposits

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Abstract. The article presents technical and technological solutions for the development of thick seam fields, considered as platforms for designing robotic coal extraction complexes. Enclosing-supporting power support with controlled release to the face conveyor in the long wall version and “support-gallery” design, as well as power complete enclosing-supporting walking support are presented as platforms. For each platform, taking into account the structural differences, the devices and processes of automation and robotization are systematized within the framework of the “rock-coal” boundary determination task, conveyor loading and coal outlet initiation assessment. The prospects for the neurocomputer interface integration into the control system for solving dispatching tasks are indicated.

1. Introduction
Russia’s mining complex modern state is characterized by the accumulation of natural and man-made factors complicating the mining process. Because of readily available and rich deposits exhaustion, reserves currently involved in development are characterized by complicated mining and geological conditions for development - the depth increases, bedding is noted in thick steep and steeply inclined seams, their gas content increases.

These conditions in modern realities require appropriate advanced high-tech technical and technological solutions to ensure that coal mining remains safe and efficient. The introduction importance and coal industry readiness for digital - automated and robotic technologies transition to are noted at all levels. The government and the president have indicated the actuality of priority industry sectors transformation through digital technologies and platform solutions introduction [1]. Regional publications, with references to the Department of Coal Industry of the Administration of the Kemerovo Region, Information-Computing Center JSC, Eruda.ru portal, project of the Strategy for Kemerovo Region Social and Economic Development until 2035, etc. unequivocally declare the readiness of the industry itself to digital transformation [2]. The largest extractive companies in the course of the digital technologies evolutionary development began to automate production processes and logistics, introducing ERP systems, etc. [3].

According to the coal mining companies representatives survey, among the digital technologies that have the highest level of implementation at enterprises or planned for implementation in 2018-2020 are “The mining dispatching system based on Industrial Internet of Things (sensors and equipment in production are combined into one network with a hierarchical structure and subordinated to the unified production management system)” were identified as one of the first (introduced or to be
introduced in 2018 by 71% of respondents, with another 25% which are planned to be introduced in 2019-2020) [2].

2. Research objective

It is known that of the large number of proven technologies for the development of thick steep coal seams, the most effective and safe is a system with a gravitational outlet of minerals from a sublevel overlying bundle, previously prepared for outlet. As a scientific basis of technology, one of the most important physical effects is laid - the mechanism of the stratum destruction, based on the rock pressure forces action. Such technologies allow the complex mechanization of mining processes, improve the extraction face ventilation, ensure the work safety, reduce the loss and dilution of the mineral. For these reasons, technical solutions providing development technologies with outlet are promising platforms for creating new-generation robotic complexes for efficient and safe underground mining with the outlet of minerals from the overlying stratum and non-explosive massif softening.

Such solutions include the enclosing-supporting power support with a controlled outlet (KUV) on the face conveyor developed at the FITs UUKh Siberian Branch of the Russian Academy of Sciences (figure 1a) and the power complete enclosing-supporting walking support (figure 1b) [4–7].

![Figure 1. Platforms for creating robotized complexes, where: a – is an enclosing-supporting power support with a controlled outlet KUV to a face conveyor; b – is a complete supporting-enclosing walking support.](image)

Hydroficated power complete supporting-enclosing walking support (figure 1b) is designed to support the roof and the mine workings in the process of mining with sublevel galleries. The support consists of two sections interconnected between each other with the movement hydraulic cylinders. Each section is equipped with longitudinal top plates and transverse beams rigidly fixed to each other and it rests through hydraulic legs and supports on the working floor. At the rear of each section there is a pair of hydroficated pivoting beams - shields for controlling the outlet. Walking support is designed for sublevel mining of 6-10 meter thick steep and steeply inclined seams with inclination angles of 45-60 degrees. The technology of sublevel mining using the walking module has an estimated capacity of up to 800 tons of coal from a longwall per day.

Enclosing-supporting power support with controlled outlet to the face conveyor (figure 1a) is equipped with an outlet window and a plunger feeder designed to intensify the outlet of coal and load it onto the face conveyor [4, 8]. The feeder evenly outlets the rock mass over the entire area of the outlet window, its performance is regulated in a wide range depending on the feeder group operation mode [9, 10]. The support section with a device for controlled coal outlet to the face conveyor has been developed taking into account the geomechanical processes occurring in the coal seam and roof rocks, so it opens up a new look at the thick coal seams continuous mining high technologies development direction.
Depending on the coal seam bedding conditions, the support section construction has two manufacture versions (figure 2). For slightly sloping thick seams - in a longwall version with the feeder straight sides for loading coal onto the face conveyor (figure 1b, 2a) and coal extraction according to the technology with outlet. The proposed technology provides with a capacity of 8.0–10.0 m thickness coal seam extraction in one pass of a shearer with a coal extraction coefficient of at least 0.8 and a planned load on an extraction face of up to 15,000.0 tons / day. The second version is for sublevel coal extraction of 8–14 meters thick seams with a bedding angle of 60–90 degrees with an estimated face productivity of up to 1000 tons / day - a type of “support-gallery” manufacture type with feeder sides symmetrically turned and folding shields closing the outlet area between enclosing sections, as shown in figure 2b. Supporting elements that close the space between section tops are retractable shields.

![Figure 2](image1.png)

**Figure 2.** Extraction face power support with the outlet on the face conveyor: a – in the longwall manufacture version; b – in the support-gallery manufacture version for the sublevel extraction of thick steep seam and placer deposits.

Automated control of longwall mechanized complexes of large mining companies is already developed at a sufficiently high level, it is mostly implemented and is built, as a rule, being based on electro-hydraulic control systems. For this reason, the control schemes of the additionally included outlet technological process are considered as elements of the control systems, which in the future are integrated into the coal extraction complex electro-hydraulic control equipment being used. At the same time, the article describes only devices and processes not related to typical elements of electro-hydraulic control, such as devices for movement, support thrust, etc.

### 3. Methodology

#### 3.1. On the level of technical devices and sensors

The technologies of working out under different bedding conditions have some differences, however, the main tasks of automation and robotization for all the above supports are similar. For this reason, the approaches to the design of control systems are largely similar.

The main tasks of automation and robotization within the framework of the outlet technological process include:

- “rock-coal” boundary determination;
- conveyor load assessment;
- outlet initiation when the roof hangs up, domes, jams, etc.

As an example, in [11, 12], using the system-functional approach in the form of IDEF0 methodology [13, 14], the automation object for the longwall manufacture of KUV support with controlled outlet to the face conveyor was described in detail within the frames of “rock-coal”
boundary determination problem. Technical devices, providing the outlet of coal on the face conveyor, are a shield and a feeder. In the operating mode, in the process of the coal lower pack mining with the shearer combine the shield closes the outlet window. After this, the outlet process begins, in which the position of the shield and the feeder inclination angle regulate the flow and the rock mass loading on the conveyor. It is proposed to determine the roof sublevel coal outlet duration in real time by the moment when the threshold value of rock proportion in the mass produced is exceeded. For this purpose, it has been proposed to use different abilities of coal and rocks to reflect and pass through ionizing radiation and X-rays [15] and to consider an ash meter as a device for estimating the composition of the rock mass in the outlet window and on the feeder. To ensure the completeness of the outlet with determining ash content, the installation of several devices in a cascade is proposed. This will allow controlling the approach of a large rock mass, and will allow closing the outlet window before it falls onto the conveyor. A cascade of emitters will also reduce the likelihood of outlet window premature closing and the feeder stopping during the rock single fragment passage in the working zone of the ash meter.

3.2. At the dispatching level

Based on the model proposed by IDEF0, structural and functional diagrams of an adaptive system with a robotization element have been developed, aimed at solving the problem of controlling technical outlet devices with the account of technological environment changing parameters. Control elements are integrated into the schemes within the framework of the operator’s mobile location concept for solving dispatching tasks [16]. The main idea is a combination of neurocomputer interface (BCI), electromyography (EMG) and augmented reality (AR) technologies for technological processes’ control system for underground mining of mineral deposits.

The main aim is to organize the underground mining of mineral deposits automated process control system dispatcher work in a new quality, without constant connection to the workplace with a reduced likelihood of making mistakes, loss of visual contact with the parameters of the control object, based on the control and monitoring devices’ virtualization. It becomes possible to make better the operator's workplace ergonomics and to reduce his fatigue. The operator is able to perform control manipulations from anywhere in the control room.

Also, the operator’s psycho-emotional state monitoring with the control system increasing complexity is of great importance in the feedback formation within the human and interface interaction framework. The analysis of domestic and foreign methods and approaches for a comprehensive assessment of the functional state (FS) of a person has been carried out and the dependencies of FS on changes in the brain main frequency rhythms and their ratios have been studied. A method for studying the operator’s FS influence on the control signal generation and perception quality is proposed. The method is based on a comprehensive assessment of the physiological, psychological and emotional parameters of the operator based on polygraphic and electroencephalographic methods.

4. Results and discussion

The current results of step-by-step development of platform solutions for the robotization of technological processes for the development of thick seam fields relate both to the level of technical devices and to the level of dispatching.

For dispatching tasks, in order to create interconnection between man and machine, integration of the neurocomputer interface into the control system, the operator of the console must be provided with an interactive and informative way used technical platform on the monitor for displaying operational parameters and generating visual perception stimuli. So, to create a virtual three-dimensional image of unmanned hydrocarbon extraction technological process, a simulation model of a walking support module with integrated control algorithms and motion animation of structural elements was developed [17]. The algorithm of hydraulic actuators functioning is simulated by a finite state machine, which interprets the control commands from the walking support module control program model. Using the
created kinematic model, the transformation of the data generated by the simulation model into spatial coordinates for three-dimensional animation of the walking support model has been implemented.

In the diagrams (figures 3–5), for each of the proposed platforms, depending on the tasks, the basic data necessary for designing automation and robotization elements at the level of technical mechanisms are systematized.

In the diagram (figure 3), mechanisms and processes of automation and robotization are systematized within the framework of the “rock-coal” boundary defining task.

| Object | Outlet process |
|--------|----------------|
| Task   | “Rock-coal” boundary definition |
| Platform | KUV | Walking |
| Version | Longwall | Support - gallery | Support - gallery |
| Zone | - in an outlet window | - in outlet windows | - in front of shields |
|       | - at the feeder | - at the feeder | - at the loading mechanism |
| - in between sections |

**Figure 3.** Systematization of mechanisms and processes of automation and robotization within the “rock-coal” boundary definition task framework.

The differences in the outlet process organization for the KPV “support-gallery” version from the longwall version consist in the need to additionally assess the composition of the rock mass above the loading mechanism and accordingly change the position of the folding shields on the protection plates (figure 2) to control and stop the outlet process between the two sections.

In the walking support design the technical equipment, providing the outlet of coal on the loading mechanism, are rotating beams - shields. With the help of them the rock mass flow regulation and outlet process stopping are done.

The work of software and hardware providing the outlet should be linked to the conveyor load amount and to a much greater extent it is important when the KPV support is used, since the face conveyor is designed to transport coal both from the face when the combine works and from the feeders of the sections along the entire length of the longwall. To start the outlet, the conveyor should not be filled either with coal from the face or coal, released from the previous section or group of sections along the conveyor. For this reason, the tasks of estimating the load amount on the conveyor and initiating the outlet process are singled out as the main tasks in the development of outlet process automation and robotization (figure 4, 5).
Figure 4. Automation and robotization process devices systematization within the conveyor loading estimation task framework.

| Object | Outlet process |
|--------|----------------|
| Task   | Conveyor load assessment |
| Platform | KUV | Walking |
| Version | Longwall | Support-gallery | Support-gallery |
| Zone | - at feeder | - at conveyor | - at feeders | - at loading mechanism | - at loading mechanism |

- **Mechanisms**
  - protection plate
  - feeder
  - protection plates
  - feeders
  - folding shields
  - loading mechanism
  - shields
  - loading mechanism

- **Processes**
  - assessment of rock mass amount on the feeder and conveyor
  - protection plate position change
  - feeder angle change
  - rock mass amount assessment on feeders and on loading mechanism
  - protection plates position change (independently)
  - feeders angle change (independently)
  - rock mass amount assessment at the loading mechanism
  - shields position change (independently)
  - outlet initiation

Figure 5. Automation and robotization devices and processes systematization within the outlet initiation task framework.

| Object | Outlet process |
|--------|----------------|
| Task   | Outlet initiation |
| Platform | KUV | Walking |
| Version | Longwall | Support-gallery | Support-gallery |
| Zone | - in an outlet window | - in outlet windows | - between sections | - in front of shields |

- **Mechanisms**
  - protection plate
  - feeder
  - outlet initiating device
  - protection plates
  - feeders
  - folding shields
  - loading mechanism
  - outlet initiating device
  - shields
  - loading mechanism
  - outlet initiating device

- **Processes**
  - rock mass amount assessment at the feeder
  - roof hanging fact detection
  - protection plate position change
  - outlet initiation
  - rock mass amount assessment at feeders and at loading mechanism
  - roof hanging fact detection
  - protection plates position change (independently)
  - folding shields position change (independently)
  - outlet initiation (independently)
  - outlet initiation
  - rock mass amount assessment at the loading mechanism
  - roof hanging fact detection
  - shields position change (independently)
  - outlet initiation
The task of initiating the outlet occurs in the event of a blockage with a large lump of coal, despite the preliminary softening of the seam, or in the case of dome formation when the roof hangs in the zone above one or more outlet windows. Technical devices for the outlet initiation are described in [18]. Both variants of the situation are determined by the results of the assessment (scan) of the outlet area and the feeder (for walking support - loading mechanism). The absence of rock mass in the outlet window or a decrease in the volume of rock mass on the feeder or loading mechanism indicate the need to change the position of the protection plates, shields, as a first step towards intensification. The lack of a positive effect indicates the need to use the initiating device (figure 5).

5. Conclusion
These technological solutions allow to ensure transition to more efficient systems of mining and exclude the use of blasting to prepare the massif for release.

The technical solutions incorporated into the platforms construction allow to design the elements of the control systems, which in the future can be integrated into the applied electro-hydraulic control equipment of extraction complexes.

Automation and robotization of technological outlet process for all these platforms is based on the tasks of defining “rock-coal” boundaries, estimating conveyor loading and initiating the outlet. For each of the proposed platforms, depending on the tasks, the basic data necessary for designing automation and robotization elements at the level of technical devices are systematized.

The proposed solutions and the concept of the operator’s mobile location for creating a high-tech dispatcher station space are aimed at the safety level and working conditions improving, reducing the “human factor” influence. The outlet process automation and robotization schemes are designed to ensure the complete outlet of roof layer coal, to prevent the dilution of coal and conveyor overload, as well as to relief the extraction complex maintenance personnel located at the face.

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