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M. S. NIKITENKO[1], *Candidate of Engineering Sciences, Researcher, ltd.mseng@gmail.com*
Yu. V. MALAKHOV[1], *Leading Engineer*
S. A. KIZILOV[1], *Leading Engineer*
S. S. ZHURAVLEV[2], *Junior Researcher*

[1] *Federal Research Center for Coal and Coal Chemistry, Siberian Branch, Russian Academy of Sciences, Kemerovo, Russia*
[2] *Institute of Computational Technologies, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia*

MULTIFUNCTION WALKING ROOF SUPPORT FOR UNDERGROUND MINING OF STRATIFIED DEPOSITS AND PLACERS

The article shows the urgency of technological advance in coal mining in difficult geological conditions and describes the application prospects for an integrated multi-function platform in underground mining of different minerals. The international practice of mobile roof support design and creation of a work environment in mines is reviewed. The authors propose an integrated multi-function platform as a walking roof support module which ensures safe and efficient mining in difficult geological conditions. Within R&D project supported by the Foundation for Assistance to Small Innovative Enterprises in Science and Technology, Project No. 2566GS1/41340, the kinematics of the platform is developed so that to ensure uniform loading of the walking support systems owing to constructional linkage between the support units, and to provide stability of the support system on a composite topography floor thanks to four couples of hinge supports with adjustability of height and position. Arrangement of structural elements is proposed, and their kinematic linkage is described. The walking support advance algorithm is developed in the form of a working cycle. Within R&D project supported by the Russian Foundation for Basic Research, Project No. 18-37-00356, the control operation algorithm and control automation circuit are developed for the walking roof support. The automated control is integrable in the standard electrohydraulic control system of mine roof supports. As a result, the walking roof support with the automated control can be considered as a framework (a platform solution) for the robotic system engineering for safe and efficient underground mining of stratified deposits and diamond placers.

Keywords: *mining, underground mining, complex environment, thick seam, steeply inclined coal seam, mining machines, powered roof support, walking support, control algorithm, kinematic scheme, automated control system, robotic complex.*

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Introduction

Given the current scenarios of advance, the mineral mining sector faces new challenges connected with increasingly difficult geological conditions of steeply inclined and thick seams. In the meanwhile, safety and efficiency of deep-level mining remain a sturdy and obligatory standard. At the same time, the underground method of mining is preferable as it features minor environmental impact and consequences. The resent paper authors think the mineral mining sector to keep up the trend while being eco-friendly and efficient needs that both geotechnologies and mining machine engineering transform in accordance with Industry 4.0 principles. With this end in view, such industries as mining, machine building, defence, etc. in Russia are changing over to digital twinning [1, 2], as well as modeling and simulation of various processes in mining [3], as well as seminatural and virtual adjustment and testing of control systems [4, 5].

In the modern mining sector in China as the world's largest coal producer, there is also a mature trend toward improved efficiency, lower loss and increased robotization to ensure required safety and productivity of mining at reduced mortality [6]. The development vector of largest manufacturers of mining machines and politics in the leading coal producing countries is based on the use of mobile and self-contained mining machinery, platform solutions, automation of process flows and machine control, and robotization of process flows [7–11].

Thus, underground mining of stratified deposits and placers needs mobile facilities to ensure:

- Shielding of working area from caved rocks;
- Temporal protection of rock-breaking machines;
- Integrity of multi-functional technology platforms in underground excavations;
- Powering of mine roof support;
- Mobility in underground excavations, including continuous crawling and cyclic walking;
- Conformity of working area, heading and cutting equipment dimensions, safety and maintainability;
- Orientability and controllability;
- Automated and remote control.
- International practices and approaches

Advance in engineering of mobile facilities meant for supporting activities in underground mineral mining started since the launch of total mechanization of mines in the 1950s. These devices are quite applicable in the extraction of difficult mineral reserves and adaptation to unmanned operations in mines.

For instance, roof support advanceable toward the wall face was represented by a walking structure of two independent frames representing a temporal roof support and meant for the mechanization of heading [12], or for the support of arched roof excavations or preparation of a coal wall face, with travel ensure by gradual walking above a cutting machine [13, 14]. Sometimes, depending on application conditions and purpose, the walking mechanics was replaced by the crawler mechanism. For example, for the temporal roof support in the period of rock bolting, the support structure was represented by interlocked crawler-mounted frames advanceable and turnable after a cutting machine [15]. The same mobile crawler-mounted roof support structure was designed for the the longwall system installation and tear-down points [16]. The beneficial experience of mobile roof support in underground mines in 1997–2006 can be illustrated in terms of Harris No. 1 Mine in West Virginia, USA [17], where crawler-mounted MRS were employed during tear-down of longwall system and in relocation of lots of mining machines and facilities in a confined space.

Thus, the mobile walking or crawling type systems have for a long time being designed for mine roof support and for creating a working area in various mining technologies. The walking-type facilities have some advantages, including adaptability to complex-profile excavations, sufficient room for cutting machines. The walking-type support structure enables control of units and components by a preset cycle, which is usable in mineral mining without the presence of personnel in the working area.

The meant favorable experience of the described designs in mining of gently dipping bedded deposits is interpreted as a sure trend in engineering of mechanics and kinematics of such facilities. All such facilities have similar specifications and functionality of elements but can hardly be assumed as a universal platform for engineering self-contained machines for unmanned mining of steely dipping stratified deposits and placers. First, the facilities were unadapted to operation with caved rock outlet in mining steely dipping stratified deposits and placers. Second, the IT level was insufficient to be used as independent platforms for efficient unmanned mining with elements of robotization with complex analytical control. Such conditions include, for instance, adaptation to varying geology, or stabilization of rocks given sudden loss of contact with roof or floor. In particular, real-time pressure adjustment in pistons of hydraulic props under static change in the load on the props [18]. The proposed adaptation technique improves stability of coal mining process, enhances safety of coal cutting and protects the support for overloads.

For another thing, it should be remembered that operation of high-duty powered roof supports under the same pressure within the service properties of props necessitates static and dynamic effect on the immediate roof rocks. This can result in sagging and rock falls, and induced lose of contact between the roof and powered roof support [19]. In this case, it is necessary to analyze service properties of the roof support, to protect the props from overloading, to take into account the effective resistance of the hydraulic props within a production cycle and to generate equilibrium resistance through continuous and smooth adjustment, which mitigates the effect on the immediate roof rocks and improves adaptability of the powered roof support units to geological variations. All these factors elevate stability and efficiency of roof support but should be taken into account as early as the stage of design and engineering of the integrated platform, its kinematics and hydraulics toward creation of robotic heading and longwall systems [20].

Engineering solution

The authors believe a promising engineering solution for a mobile robotic platform for underground mining of stratified deposits and placers in difficult geological conditions is a multi-functional walking roof support [21]. The support can be used as a design framework for heading and longwalling systems, including extraction of ore reserves from safety pillars and sublevel caving of thick and steeply dipping coal seams at a dip angle to 45° [22].

The walking support is a variety of mobile supporting–shielding powered roof support, with hinged connected components, meant for creation of a working area in a longwall using the supporting and shielding elements of the structure.

The design and functions of the walking support are governed by the structural kinematic layout (**Fig. 1**). The walking support includes elements of a hydraulic system (rams, valves, pumps) and a mechanical system (beams, hinges), which all participate in translation of motion.

In the walking support design, neighbor joint assemblies (relatively movable) form two types of kinematic couples: a hinge and a ball hinge. Immovable assemblies in the walking module are the longitudinal top beams of the first and second units of the roof support.

The kinematic layout shows than main components and displacement directions according to the walking roof support algorithm (relocation, fixation and adjustment of props, control of frontal beams to provide outlet flow).

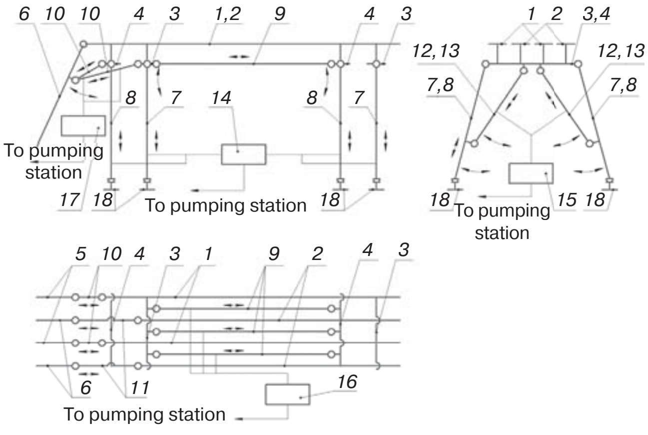

Fig. 1. Structural kinematic layout of walking roof support: *1* — longitudinal top beams of unit 1; *2* — longitudinal top beams of unit 2; *3* — cross beam of unit 1; *4* — cross beam of unit 2; *5* — frontal beam of unit 1; *6* — frontal beam of unit 2; *7* — ram-driven prop of unit 1; *8* — ram-driven prop of unit 2; *9* — hydraulic travel cylinder; *10* — frontal beam ram of unit 1; *11* — frontal beam ram of unit 2; *12* — rams of unit 1 props; *13* — rams of unit 2 props; *14* — distributor of support rams; *15* — distributor of prop rams; *16* — distributor of travel cylinder; *17* — distributor of rams of frontal beams; *18* — prop supports

Control algorithm

The structural kinematic layout of the walking roof support became the input data for the subsequent testing and adjustment of the waking support control. The developed control algorithm is inextricably connected with kinematics and the circuit of relocation, working area protection and broken rock outlet to a conveyor or reloader [23].

The operation cycle of the walking roof support as in mining thick seams with broken rock outlet [22] includes all basic operations, starting from the initial position and finishing with outlet. The operation is accompanied with appropriate sensors of automated control (**Fig. 2**). At the end of coal outlet, the walking support returns to its original position and the cycle is repeated again.

The *first position* of the *walking support* before the *increment*—the support sections are shifted, aligned horizontally and vertically. All eight *hydraulic legs* are vertically extended to provide roof support, and horizontally extended. The mobile frontal beams of the canopy are brought up. The coal outlet is stopped. The conveyor under the walking support is advanced.

With regard to the operation algorithm and kinematics of a unit of the support, the automated control has been designed (**Fig. 3**). The circuit is based on the concept of generality, to be implementable using a standard electrohydraulic control system (EHCS), which meets the requirements of the integrated multi-functional platform.

The choice of this circuit is governed by:

- the maximum separation of the systems of the robotic walking support to simplify debugging the automated control system;
- the use of common and series-produced components of the control adjustable by highly skilled service maintenance personnel from manufacturer;
- the assumed limitation of EHCS boards by the number of external sensors to be connected.

The proposed layout of the robotic walking support control is composed of 6 independent blocks (HC units) to control hydraulics, with sensors to monitor each hydraulic drive and deviation of each support unit from the horizontal and vertical axes. The backbone of each block is an EHCS console. All six boards of the robotic walking support are switched to a single commentator, which allows control using an EHCS console or a PC, either on-site or remote, and enables data exchange. The control system ensures manipulation of 6 EHCS units from the control panel (console) of EHCS of the first section, if necessary (emergency, failure of the centralized control system), and supervision of individual functions of the corresponding control panel of EHCS. The panel of EHCS allows for both automated and manual control as it is a programmable microcontroller equipped with: long-term and random-access memory, a set of digital and analog inputs–outputs, a block of function keys and an information display, being a serially produced element used to control electrohydraulics of powered roof support within a longwall system. In an emergency, the functionality of EHCS of the first unit can be transferred to any of the units of EHCS in the control system.

It is planned to use the platform in both remote and autonomous control modes, depending on the operating conditions. This is a hybrid option. The work algorithm of the coordinating unit is as follows. In normal mode, the control system operates in automatic mode. In the event that the self-diagnostic program of the control system detects a discrepancy between the data from the sensor system and the course of the program, the automation switches the control system from automatic mode to manual control. Depending on the situation, manual control can be carried out both locally (from the control panel of the corresponding EHC unit with individual functions, from the EHCS control panel of the first unit with all functions), or remotely via a local network.

The purpose and arrangement of some blocks within the automated control of the robotic walking support are described below.

Block 1: responsible for operation of four props of support unit 1. This block console enables controlling extraction/retraction of each prop support unit 1. This console receives signals from the ram position sensors, which enables accurate position of each prop, and from the pressure sensors set in the valve blocks of the rams. Each valve block is equipped with a safety valve. The first block console is connected with the sensors of the vertical and horizontal inclination of the support, installed at the front of the support unit to control the incline of unit 1. By default, this unit is the master in the

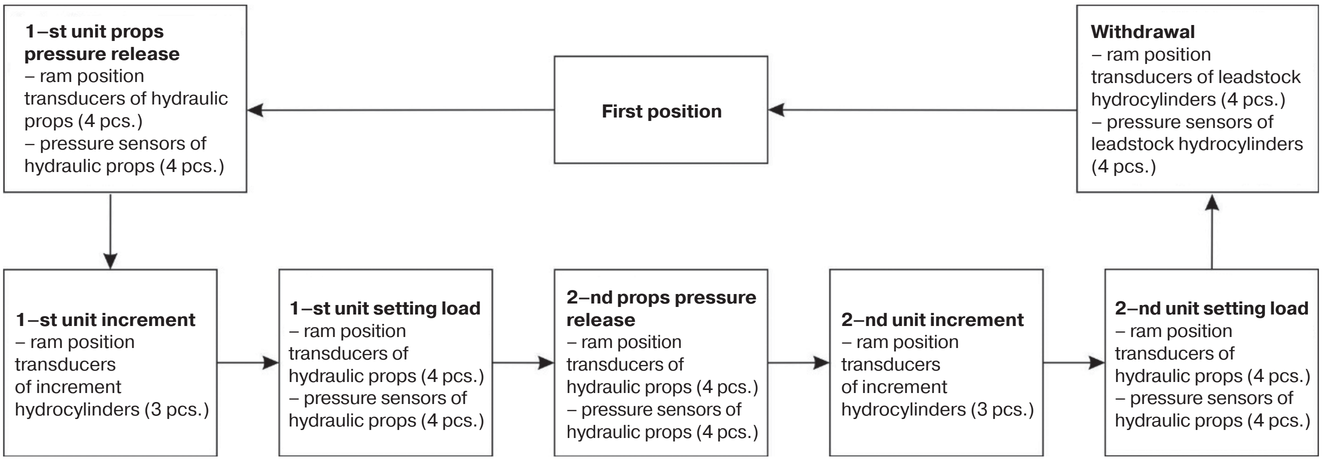

Fig. 2. Operation cycle of walking roof support

control system. In this unit, it is planned to analyze operational sensory information coming through the local network from the other fiveEHC units. In the same way, this unit transmits control signals to the EHCS of other units, allowing the robotic walking support to work autonomously, according to a predetermined program.

Block 2: ensures control of four props of unit 2 of the walking support. This block has the same structure as Block 1. The console of this block allows manual control over each of four props of walking support unit 2, and the sensors installed at the opposite end of the front of unit 1 monitor the vertical and horizontal inclines of unit 2.

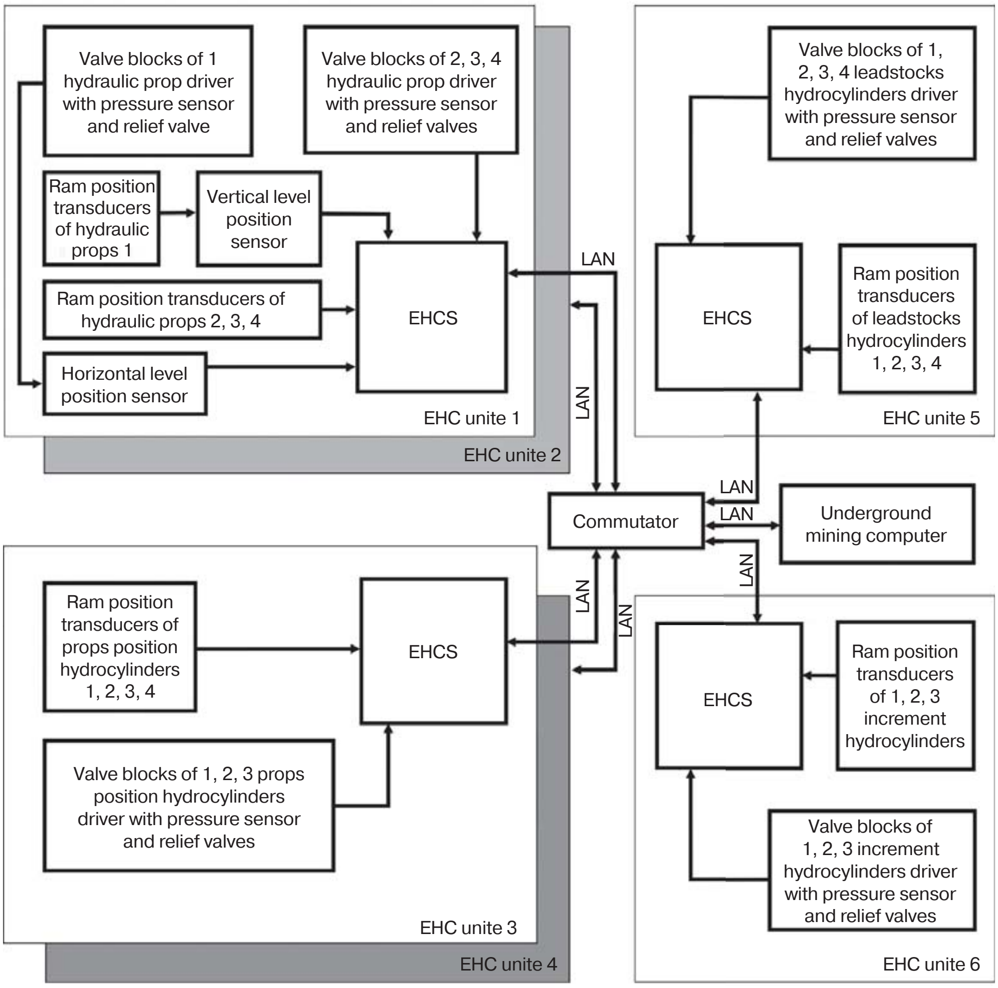

Fig. 3. Automation circuit of electrohydraulic control of robotic walking support

Blocks 3 and 4: control the horizontal relocation rams of the walking support. Each control block is meant for control over 4 rams installed on units 1 and 2 of the walking support. Each ram is monitored using the position sensor and the pressure sensor. The valve unit in each ram is equipped with a safety valve.

Block 5: control the push up/pull down rams of the frontal beams of the walking support. There are four up beams driven by individual rams. The console of this block allows adjusting the elevation angle of the four beams. The position sensors of the rams monitor position of each ram. The valve units of the rams are equipped to the fluid pressure sensor and a safety valve.

Block 6: controls three rams intended to advance the walking support units. The block design allows addition of one more ram if necessary. The block enables control of each ram separately to adjust the walking support unit positions. Each ram has the position sensor. The valve unit has the pressure sensor and a safety valve. The position sensors of the rams determine extension of each prop and warn on the horizontal skewness.

Conclusions

The robotic walking roof support with the automated control can become a platform for engineering robotic systems for safe and efficient underground mining in difficult geological conditions of stratified deposits and placers using different geotechnologies.

The control system of the robotic walking support can be integrated in the control system of the robotic longwall system in unmanned mineral mining,

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