System approach to automation and robotization of drivage

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Abstract. The authors consider the system approach to finding ways of no-man drilling and blasting in the face area by means of automation and robotization of operations with a view to reducing injuries in mines. The analysis is carried out in terms of the drilling and blasting technology applied in Makarevskoe Coal Field, Kuznetsk Coal Basin. Within the system-functional approach and using INDEFO procedure, the processes of drilling and blasthole charging are decomposed into related elementary operations. The automation and robotization methods to avoid the presence of miners in the face are found for each operation.

The present day coal industry is ranked as the industry most hazardous for life and health of miners though the fatal injury factor in industry is reduced from 1.2 man/thous in 1992 down to 0.06 man/thous in 2016. In Kuzbass this factor in the mining industry remained the highest as compared to other industries. In [1] imperfection of coal mining technology is named as a reason in 25% of accidents in Russian collieries. The most coal and gas outbursts, fires, roof caving and other emergency events fall on face zone of a development working. To lower overall injury rates in drivage it is actually reasonable to develop geotechnologies enabling to eliminate presence of miners in a face area.

Further extensive development of the coal industry in Kuzbass is planned mainly in Tersinsky geological-economic region, the Kuznetsk Coal Basin [2]. Kusheyakoskoe, Uvalnoe and Makarievskoe deposits are explored in details and are closest to the developed infrastructure locations. The first two of them have been opened already, and the tender is invited for Makarievsky deposit. In Makarievsky deposit the perspective productive seams of more than 1 meter in thickness occur in Verkhnebolokhonsky coal seam subseries. Most of them are insufficiently aged, of simple structure, thin or average in thickness. Coals in these seams are of vitrinite composition with dominating lean coals and anthracites [3], applicable in metallurgy, electric-power industry and special energy-technological processes. The main restriction in development of these deposits is nearby occurrence of table water springs and natural park “Kuznetsky Alatau”. To initiate Makarievsky deposit development requires proper geotechnologies eliminating presence of miners in a face area, provided that environment standards are fulfilled.

In [4] the researchers propose the procedure for substantiation of geotechnologies with no human participation in a face area. The procedure based on the system approach and simulation modeling
makes it possible to analyze all feasible variants of automation of technological operations and to select efficient solution, excluding human-factor errors.

First it is reasonable to describe a geotechnology conventional for the given mining-geological conditions. Verkhebalakhonsky sub-series (Makarievsky deposit) are characterized with a formation sequence of sandstone (45.4% lithologic composition), aleurolite(48%) and subordinated coal seams of about 850 m in total thickness [3]. Coalseamsarepronetoshock bumps, coal and gas outbursts. The principal ground water zone in primary deposits is in the level of 100-150 m; in greater depths it attenuates. Therefore, undertheseminingandgeologicalconditionsthecutting, hydraulicorshieldprimary mining processes are not rational or even impossible because of hardness of host rock (6-8 under Protodiakov’s scale). The primary boring-blastingmining is expedient in this case.

Next, theprocedureimpliesanalysisoftraditionalgeotechnologiesbyIDEF0 methodology within the system approach with the aim to find variants of their executors.

The drivage sequence under conditions of Makarievsky deposit in terms of the system-functional approach is shown in Figure 1:

![Figure 1. Drivage in terms of the system-functional approach.](image)

To find possible executors of each operation requires to decompose each functional block in the given diagram and to preserve interrelations between blocks at all the levels.

The first functional block to decompose is “making blastholes”. Its function is to transform the face front into two aspects: blasthole making and rock mass planned for extraction at a certain distance in compliance with the approved boring pattern. Decomposition of this operation is presented as a system of functional blocks representing blasthole-boring operation (Figure 2).

The first operation to be fulfilled is survey of local environment for proper orientation and dislocation of respective equipment in the fore-breast area. In the conventional boring-and-blasting process it is a miner who is to survey the environment by means of his sensory organs. First attempts to transmit partially this composite function to a mechanical executor are reported in [5], where a drill rig, capable to identify walls of a working by means of hydraulic jack, is described. In [6] the author sets forth a
procedure for mounting a video camera on mining equipment. In blasthole making the camera mounted on a drill rig can exclude miner’s participation in a face area, but it does not contribute to precision of positioning of a drill rig in fore-breast area. The state-of-the-art methods for scanning of a mine field imply application of laser scanners. They can be mounted on a drilling machine [11], on a separate platform with a mobile mine cartographer [7], or miners can employ them as a manual instrument [8].

Figure 2. Blasthole-boring in terms of the system-functional approach.

In conventional geotechnology a miner is engaged in processing information (identification of mining objects for further work: a face, roof, walls, other objects if required). Recently attempts are made to transfer this function to a computer system arranged as “a neuron network” [9], but so far robotization of this operation is rather expensive and implies contribution of professionals in artificial intelligence.

Spatial non-operator orientation of a drill rig can be executed by means of a position-control system. There are actual cases in practice [10]: domestic “RealTrack” mine, RTLServiceCo. and “SBGPS”, Granch Co., and foreign “ConnectedMining”, CISCO Co., and “BeckerMiningSystem”, BeckerGMbH, all the above systems are based on wireless translation inside mine workings. Access points of wireless network and individual position-control means mounted on concerned machines and in a mine working are interrelated to identify a position of a facility.

In conventional mining process a drill rig is operated by a miner in a cabin. The simplest modification of this operation is a remote control in a safe distance from a face. The main imperfection of this control process is the lack of complete visual information on an operation area [13]. That is the reason why this variant is proposed only in the cases of urgent need to remove an operator from a hazardous spot. A few companies propose automated control of mine machinery dislocation [11]: RCS 5 computer control system of AthlasCopco Co., Automine and Automate systems of Sandvik Co., Minegem control system of Caterpillar Co. Advantages of these computer control systems are less wear of discrete parts and motors thanks to optimal operation modes and an precise motion of a drill jig at a wanted distance. In this case the main function of an operator is to watch operation of a machine and he is in power to switch off an automated control at a remote mode.
In the conventional mining process a miner is to align a drill rig manipulator to a blasthole spot according to the boring pattern. RCS5 computerized blasting control system, Athlas Copco Co., provides the maximum automation of positioning of several drill rig manipulators in a computed optimal route according to the boring pattern. The automated drilling system “AutoMineDrilling”, SandvikCo., is equipped with a control system “Sandvik Intelligent Control Architecture (SICA)” allows automated positioning with precision up to 5 cm.

Boring parameters are measured by sensors mounted on a manipulator with a hydraulic perforator to measure velocity of drill rotation, its removal, turning and extension length. The computer control systems RCS 5 and AutoMine Drilling for the drilling process receive sensor information and adapt drilling parameters in view to save drill steel consumption, to prevent steel sticking, to improve drilling velocity. The computer control systems are capable to manage the drilling process and to detect variations in properties of rocks to be drilled, fractured zones. These functions provide prompt adjustment of blasthole length, their location in order to improve the coefficient of blasthole use [11].

The global producers, including Athlas Copco, Sandvik, Aramine, Robodrill, etc. propose a variety of drill machines, which can be classified by availability of operator’s cabin, arm or boom (1-4 in number) a boom with a basket for miners.

Thesecond functional block to be decomposed is “blasthole charging”. A hollow blasthole is filled with an emulsion explosive and a detonator. Decomposition of this process can be represented as a system of functional blocks in Figure 3.

![Figure 3. Blasthole charging in terms of the system – functional approach.](image)

Proposals on unmanned of a face area in operations “surrounding area scanning”, “pattern recognition”, “charge machine positioning”, and “charging machine move” are identical to similar operations described in section “blasthole drilling”.

Operation “emulsion charge” involves a few stages: hose insertion, blasthole purging, oxidizer heating, explosive emulsification, explosive charging, explosive cooling. In the conventional process preparation of explosive emulsification is automated in mixing-charging systems, but introduction of a hose into a blasthole, control of explosive amount are performed by a miner from a basket of a charging machine. The mixing – charging systems can be connected to one or two hose baskets. Machines of
Normet Co. and Orica Co. are equipped with microprocessor control system based on CAN-bus technology, this allows automation of hose supply and dosing of explosive emulsion fed to a blasthole, but a miner remains in a face area to operate a charging machine.

Up to date the unmanned versions of “detonator installation” operation are not available because of complex manual manipulations executed by a miner. The single facility required is a charging – mixing machine with a basket to deliver a miner to blastholes filled with explosive emulsion.

Automation versions under consideration indicate that the present-day producers of underground drilling-blasting equipment pay more attention to automation and robotization of mechanical operations and remain cognitive functions: observation, recognition of objects in a space and orientation in a space to an operator. The complete unmanned of a face area implies transition of the above operator’s functions to mining machines. The efficiency of proposed automation and robotization versions is verified by imitating modeling, and test results on imitating models are used to elaborate recommendations on development of novel geotechnologies.

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