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Intelligent Mining Engineering Systems in the Structure of Industry 4.0

Marina Rylnikova[1*], *Dmitriy* Radchenko[1], and *Dmitriy* Klebanov[2]

[1]IPKON RAS, 111020, 4 Kryukovsky tupik, Moscow, Russia

[2]VIST Group AO, 107078, 1/2 Dokuchaev pereulok, Moscow, Russia

Abstract. The solution of the problem of improving the human environment and working conditions at mines is based on the provision of the rationale of parameters and conditions for the implementation of an environmentally balanced cycle of comprehensive development of mineral deposits on the basis of the design of mining engineering systems characterized by the minimization of the human factor effect in danger zones of mining operations. In this area, robotized technologies are being developed, machinery and mechanisms with the elements of artificial intelligence, and mining and transport system automatic controls are being put into service throughout the world. In the upcoming decades, mining machines and mechanisms will be virtually industrial robots. The article presents the results of zoning of open-pit and underground mine production areas, as well as mining engineering system of combined development depending on the fact and periodicity of human presence in zones of mining processes. As a surface geotechnology case study, the software structure based on a modular concept is described. The performance philosophy of mining and transport equipment with the elements of artificial intelligence is shown when it is put into service in an open pit.

1 Introduction

The first three industrial revolutions have occurred as a result of mechanization, electrification and information technologies. The progress of Internet and satellite navigation have determined a new industrial epoch – the fourth industrial revolution – Industry 4.0 [1]. Global trends of each and all large production corporation entry to Industry 4.0 give clear-cut interpretation of the prospects of mining industry development – transition to intelligent control systems with the human factor role changing in design, operation of mining engineering systems and their condition monitoring [2].

Industry 4.0 is not only and not so much new technologies as a new approach to production and consumption. It is based on the collection of big data, their processing and use for the perfection of coordinated operation and processes without human interference [3]. The base trend of Industry 4.0 development is the assignment of optimization functions to machines and mechanisms and customization of their operation in autonomous mode. A

* Corresponding author: rylnikova@mail.ru

trend is now emerging, according to which the objects of industrial Internet will independently perform the monitoring of their operation, adjust the parameters sending data to the manufacturer for the elimination of machine design shortcomings and estimation of the remaining operation life of some of the machine components, replacement parts, expendable materials, depending on operation in specific geological mining and natural conditions, and climate. It means that one of the most significant aspects of the fourth industrial revolutions is the idea of mining machinery "oriented design service". For instance, for surface mining operations Komatsu has already designed a system of remote prediction of operability and condition monitoring of a diesel engine [4]. The system envisages sending of daily statistics on the variation of shovel engine operation parameters to a remote operator. These parameters include: pressure, consumption of fuel, temperature and rpm of the engine. Komatsu engineers note [4] that this system including the necessary algorithms of data processing, namely, the estimates of the engine current conditions, identification of the source of abnormal behavior and, what is most important, forecast of the remaining operation life of the diesel engine, is a pioneer system. In the upcoming decades, mining machines and mechanisms will be virtually industrial robots [5–8], and their application will change the requirements to mining engineering systems design that in its turn will result in large-scale changes in the effect of mining engineering systems on human environment.

2 Materials and methods

The solution of the problem of human environment and working conditions at mines is based on the provision of the rationale of parameters and conditions of the implementation of an environmentally balanced cycle of comprehensive development of mineral deposits on the basis of the application of mining engineering systems with intelligent control [9]. In this area, robotized technologies, automatic controls for mining and transport systems are being developed throughout the world. For design and perfection of mineral mining and processing processes it is important to find the solutions aimed at the development of resource-saving and resource-reproducing geotechnologies [10], elimination or minimization of human presence in danger zones of mining operations: development headings, faces and stopes, zones of intensive deformation of the rock mass, including those with dynamic rock pressure occurrence, areas with high radioactive background, unfavorable environment – high or low temperature of the rock mass, high gas content, low oxygen content or pressure of the atmosphere. Of significant interest is the establishment of fundamental objective laws of the interoperability of mining engineering systems employing industrial robots with the natural – human environment in the mining engineering system and in the affected area [11,12].

To provide the rationale of an environmentally balanced cycle of comprehensive development of mineral deposits on the basis of the application of mining engineering systems with intelligent control an approach has been proposed aiming at the creation of micro-climate zones characterized by particular, specified and controlled parameters of the environment listed above depending on the fact and periodicity of human presence in the zones of mining processes.

3 Results and discussion

In mining engineering systems, where it is planned to operate the equipment with the elements of artificial intelligence, all zones must be divided into three fundamentally different geotechnological areas, in each of which the specific condition of the human environment are maintained (fig. 1):

I. conditionally manless zones or, as it is referred to in the internationally established terminology, Zero Entry Production Areas (ZEPA) [13];

II. zones of human presence in a mining engineering system to perform main and auxiliary work and maintenance of machines and mechanisms;

III. zones of permanent human presence.

Such zoning dictates the necessity of top-priority solution of the problem of the joint presence of people, mechanized and robotized equipment with the establishment of relevant safety requirements.

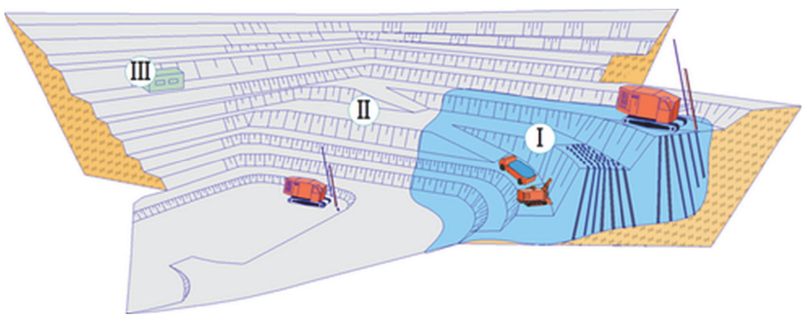

Fig. 1. Principle of zoning of a mining engineering system with the use of industrial mining and transport robots**.**

In surface mining, zones with "zero entry" will cover open-pit areas specially planned for operation of equipment with elements of artificial intelligence and characterized by smaller width ramps, greater slope angles of benches and pit walls, poorly ventilated and other danger areas. As it is shown in fig.1, equipment operation in zones I-III will be provided by the software including the appropriate modules optimizing the performance indices of an intelligent mining engineering system as a whole. For instance, to control a load-haul complex in the Intelligent Mine system a special module is provided, which combines the functions of loading and hauling control – shovels and loaders, and robotized mine dump trucks. Loading machinery control is performed by an operator from the cab in a manual mode, while dump truck control is performed autonomously without interference of operators.

The main task of the module is in automated control of dump trucks (without interference of operators), while they are on specified routes, in autonomous control mode, including loading and discharge functions. With the help of this module the system transmits data about the route, end point of travel, current task, information about the equipment in the working zone and other necessary data to on-board computers of dump trucks.

The module also includes a dump-truck remote control gear. The control is performed by the supervisor or operator of remotely controlled machinery from the control center throughout the whole route.

For robotized dump trucks the module performs the following base functions:

- monitoring of simultaneous travel of several automated dump trucks on prescribed routes in autonomous control mode with a feature of remote control from the control center throughout the whole route;
- monitoring of travel and condition of automated dump trucks, haulers, which are not furnished with autonomous/remote control equipment, and auxiliary machinery shown on the map, the required reporting, storage of the history of travel and events on a centralized server;
- providing runs for loading and discharge in autonomous and remote control modes;
- providing interoperability with the personnel for fuelling and maintenance of automated machinery in a dedicated zone;
- stop and overspeed monitoring;
- automatic identification of dump-truck hauls and routes;
- remote monitoring of the condition of on-board equipment for autonomous/remote control and a feature of connectivity with the available dump-truck diagnostic systems;
- keeping a supervisor informed on an accident hazard;
- export and e-mailing of reports;
- import of a mine map from mine surveying-geological and mine surveying systems.

For remotely controlled machinery the following functions are typical:

- remote control mode for machinery control;
- displaying the main parameters at the operator's workplace;
- augmented reality for a remote control operator. Various information helping the performance of control is displayed over the surveillance camera images;
- control of location on the map with the display of auxiliary information: current condition of every unit (speed, coordinates, fuel level, etc.);
- control of equipment condition and recording of machinery misuse;
- keeping an operator informed on emergency situation, and failure to further travel in a remote control mode;
- issue of shift tasks and formation of immediate reporting, shift reports and reports on other periods.

At a time one operator from the remote control point can remotely control one unit of equipment, and if needed, switch the control to some other machinery, thus having an opportunity of serving several units.

For drilling in autonomous mode a separate software module is provided, which performs the autonomous job of a drill rig and monitoring of drilling parameters. A drill rig is directed to boreholes and drills the rock mass without interference of an operator. The module performs the following functions:

- automatic recording of task performance;
- automatic monitoring and control of a drill rig position;
- collection of production and technical information on the equipment condition;
- collection and accumulation of geological data generated in the process of drilling;
- automatic collection of information about actually drilled boreholes (there is no need for mine surveyor to take measurements of actually drilled boreholes).

An autonomous drill rig performs the following processes without interference of an operator:

- direction to planned boreholes;
- platform alignment;
- drilling, including rod handling;
- monitoring of drill rig location on the map with the display of auxiliary information: current condition of each unit (speed, coordinates, fuel level, etc.).

Transmission of accurate information on drilling location to an on-board computer of a drill rig together with the use of a high-accuracy navigation system also helps eliminate the problem of low-quality drilling and blasting processes – great share of oversize.

The efficiency of coordinated operation of separate modules is determined by a module of static optimization. This module is activated by a supervisor from the operating control module, and it displays the results of its operation in a window of an operating control module. It automatically performs the initial distribution of dump trucks at the beginning of a shift by route groups, and redistribution of machines in the course of a shift in case of open pit situation changing (breakdown of a shovel, changes in quality requirements of ore supplied to a processing plant, etc.). The results of this module operation are used as source data for the module of dynamic optimization. The module of dynamic optimization performs the redistribution of robotized dump trucks within each optimized group in the course of a shift in compliance with the specified criteria of optimization. It is automatically activated after each discharge of a dump truck and in automatic mode transmits the instructions to the control system of a dump truck if a change of its route is needed. Change of the route is also displayed in a window of the operating control module. Change of a dump-truck route is also envisaged in a semi-automatic mode, when the system issues a notification to a supervisor on the necessity of changing a route, and a supervisor takes a decision.

One of the most important control elements of the Intelligent Mines system is a module of maintenance and repair planning. This module becomes a logical complement of accounting of all service factors of machinery operation and provides impartial estimation of time to the subsequent maintenance and repair forming the chains of intervals between maintenance and repair for equipment and machinery by motor-hour, mileage or time. Estimated time of maintenance can be adjusted manually for optimal operation of maintenance and repair crews. Maintenance planning and repair mechanism (hereinafter referred to as M and R module) provides the solution for the following tasks:

- keeping the directory of maintenance intervals. Intervals can be specified by time, mileage and motor-hour. Eventually, this information is used in automated calculation of the subsequent maintenance and repair process.
- automatic prediction of the date of the subsequent planned maintenance and repair based on the information about motor-hours, mileage or time, with a feature of manual input and updating of information. This form is intended both for planning and for accounting of actually performed work.
- accounting for mobile object availability in the formation of a shift job order.

For combined surface-underground geotechnology mining engineering systems are zoned depending on geological and mining conditions of deposit development. For instance, with a significant depth of transition from surface to underground mining zero entry zones will include in addition to the above listed the bottom elevations of an open pit (fig. 2), which are poorly ventilated areas, as well as deposit sites of the surface-underground level. For instance, in conditions of combined development of the Trubka Udachnaya deposit open pit dimensions are large in plan and in depth. Steep slope angles, risks of aggregation of mined material due to slumping, consolidation or freezing, formation of non-drainable slurry-like material in an open-pit shell, inrush of gases, pressure water or slurry to mined-out areas make preferable the mineral mining technology in "ore triangles" and open-pit bottom, which does not require human presence in a stoping zone. Without human presence in this zone the ventilation parameters can be any and they are limited only by the conditions of mining and transport machinery operation. Overlying formations of an open pit, where transport communications are preserved, belong to the second ecological zone – the one of human presence in a mining engineering system with an aim of performance of auxiliary processes and servicing of machinery and equipment. The third type of zone with human presence is characterized by comfortable conditions of work and is aimed at monitoring of automated mining processes control system. This work is performed in office buildings.

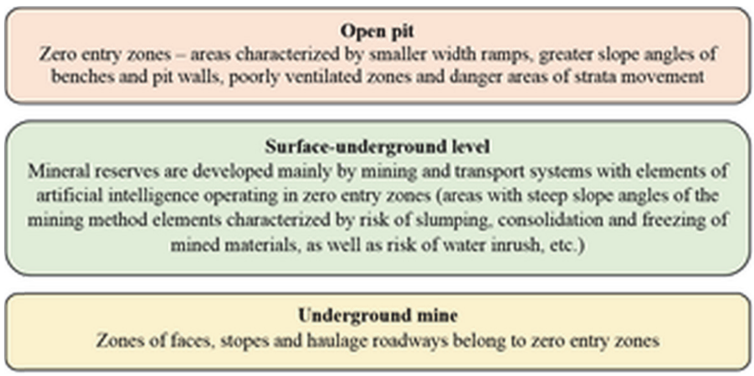

Fig. 2. The principle of identification of conditionally manless zones (zero entry areas) in a mining engineering system.

Underground mining operations are characterized by the zoning based on the above described philosophy. In zero entry zones the microclimate required only for machinery and equipment operation can be created, therefore, planning of underground workings parameters, as well as ventilation system for such conditions are completely different. Underground location with ZEPA is isolated from the mine atmosphere. New opportunities are opened of spot mine air intake and purification via a system of boreholes and pipelines, without integration of contaminated air streams into a common mine network. Human entry to a ZEPA zone, for instance, for the elimination of a possible accident consequences or for robot withdrawal, is allowed only after implementation of special ventilation measures , or without them, but with the use of special personal protection devices. New vision is acquired to industrial safety requirements concerning underground mine ventilation after blasting, ventilation of dead ends and many others. With that it is evident that a system of new requirements of industrial and ecological safety is coming into existence.

4 Conclusions

A mining engineering system, which was earlier designed based on the conditions and limitations concerning human working environment from this time onward, with the development of remote and robotized geotechnologies, autonomous means of the rock mass state monitoring and their combination will assume the grounding of parameters aimed only at the provision of conditions for the presence of robotized and autonomously controlled machinery and equipment in zones of mining operations. Removal of sanitary-hygiene requirements to human presence in these zones, as well as limitations and requirements of industrial safety determines new requirements to the formation of mining engineering systems and grounding of parameters of human environment in a mining engineering system and in the affected area.

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References

1. *Recommendations for implementing the strategic initiative Industrie 4.0. Industrie 4.0* (Working Group, 2013)
2. B. Johansson, Int. J. Min. Miner. Eng, **5:4**, 350 (2014)
3. L. Abrahamsson, B. Johansson, J. Johansson, Int. J. Min. Miner. Eng, **1:3**, 304 (2009)
4. K.N. Trubetskoy, Gorn. Zhurnal, **5**, 21 (2016)
5. B. Autonomous, Auton. Min., **1**, 30 (2012)
6. J.J. Green, Int. J. Eng. Adv. Technol., **1:4**, 8 (2012)
7. D.R. Kaplunov, Gorn. Zhurnal, **7**, 49 (2014)
8. K.N. Trubetskoy, J. Min. Sci., **47:3**, 317 (2011)
9. M.V. Rylnikova, D.N. Radchenko, Gorn. Zhurnal., **12** (2014)
10. K.N. Trubetskoy, Y.P. Galchenko, J. Min. Sci., **51:2**, 407 (2015)
11. G. A. Nikolakopoulos, IFAC., 66 (2015)
12. O. Golovina, J. Teizer, P. Nipesh, Autom. Constr. **1** (2016)
13. D.R. Kaplunov, D.N. Radchenko, Gorn. Zhurnal. **5** (2016)