Unmanned Mine of the 21st Centuries

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Abstract. The article is analytical. It considers the construction principles of the automation system structure which realize the concept of «unmanned mine». All of these principles intend to deal with problems caused by a continuous complication of mining-and-geological conditions at coalmine such as the labor safety and health protection, the weak integration of different mining automation subsystems and the deficiency of optimal balance between a quantity of resource and energy consumed by mining machines and their throughput. The authors describe the main problems and neck stage of mining machines autonomation and automation subsystem. The article makes a general survey of the applied «unmanned technology» in the field of mining such as the remotely operated autonomous complexes, the underground positioning systems of mining machines using infrared radiation in mine workings etc. The concept of «unmanned mine» is considered with an example of the robotic road heading machine. In the final, the authors analyze the techniques and methods that could solve the task of underground mining without human labor.

1 Introduction

The problem of improving the human labor safety in mining enterprises does not lose its relevance. One of the ways to solve this problem is the development and application of automation systems. The remote operation does not allow us to achieve maximum efficiency, as there is a problem concerned with the unmanned mining machines operators training. The productivity of the mining enterprise is reduced because the operator feels and coordinates the mining machine worse. Remote operation allows us to deal with the mining equipment at a considerable distance, that significantly increases the mining operations safety but still, it does not resolve the operator - "weak spot" and a source of errors and non-optimal actions [1]. The most reliable but also complex way to solve this problem (to eliminate this so called "weak spot") is the complete withdrawal of an operator from the mine opening and the creation of the fully automatic robotic systems that allow us to implement the "unmanned mine" concept.

2 Materials and methods

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The development of algorithms, methods, and technologies for "unmanned mine" is a complex scientific and technical problem that has not been solved yet. The same situation is with the problems concerning mining machines energy and resources optimization, integrating various mine subsystems into a single system, planning and managing the production and assets of a mining enterprise.

The current state of the above set problem is characterized by the use of remote-operated autonomous complexes with an arrangement in a single operator complex [3-8]. Notable examples are the mines in the area of the Pilbara (Western Australia), Quarry Bingham Canyon (Salt Lake City, USA), Mine Kadi-Ridgeway (Australia). These facilities provide the use of the automatically operated excavators, bulldozers, dump trucks and other equipment in places with the unstable ground. There are also examples of the creation of fully automatic coal mining systems for example, in the mines "Tang Shan Gou" and "Nan Liang" (PRC). Monitoring the mining machines harvesting is carried out with the help of the real time cameras through the optical fiber transmission signal. In Russia, the main research focus on this issue is the direction of developing new automated machines and complexes equipped with sensors and video cameras that can be remotely operated (e.g. 2015 the Polysaevskaya mine).

It should be noted that while concerning the implementation of the above-mentioned automation systems there was not raised an issue of the completely automatic operation of road heading machines based on specified optimality criteria and the issue of providing methods and algorithms for the excavation operations. Nevertheless, modern automation systems can significantly improve the mine's productivity, power, and resource efficiency. In order to do this, it's necessary completely redefine the concept of coal mining underground methods and to develop new technological machines, means of rocks transportation to the surface, means of electricity and drainage.

3 Results and discussion

It is necessary to consider the problem of constructing the mine automation system implementing the concept of «unmanned mine» by the example of the robotic road heading machine. (Fig. 1). Such an automation system includes both global and local subtasks, work-related actuators and movement mechanisms.

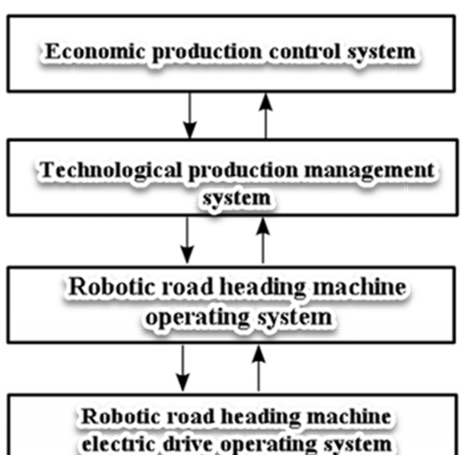

Fig. 1. Block diagram of the control system levels.

 DOI: 10.1051/e3sconf/20172101016

In order to solve local subtasks, it is necessary to form the set values of displacements, forces, and speeds of actuators and movement mechanisms from the upper-level control devices, so that the deviation from the set values is within the near-extreme error.

Systems that solve global subtasks in the operation of the robotic road heading machine can be built along a hierarchical chain from the top to bottom as follows: the economic production control subsystem (enterprise management system); the technological subsystem (the formation of common indicators and goals (for example, setting the productivity of the slaughter), robotic road heading machine control system (setting specific values of coordinates, velocities and trajectories of motion, as well as control time intervals), robotic road heading machine electric drive control system (working out the set values of technological parameters).

Integration of the presented subsystems will make the production process predictable, cost-effective and allow us to define the "neck stages" in production, to forecast and manage the production and assets of the enterprise.

One of the main tasks of development robotic road heading machine control system is the task of bottom hole space positioning. The task of controlling the movement of an object within a closed three-dimensional space bounded by a surface with apriori unknown shape and physical properties is the most difficult task of the modern robotics transferred to the robotic road heading machine.

When solving this problem, it is necessary to take into account a great number of restrictions imposed on the movement of the specified object in space: the restriction on the safety conditions of the mine or mine infrastructure, the limitations on the conditions of the minimum consumption of electric energy and the life of the elements of the robotic road heading machine, the limitations on the productivity of the transport infrastructure of the mine, unforeseen properties of the excavating rock mass (increased strength, increased explosive gases concentration going out from the layer seam, etc.). All these limitations lead to the fact that it is impossible to specify in advance the exact trajectory of motion and the robotic road heading machine speed. The organization of positioning in the underground space by known methods is difficult because of the poor admittance of the rock mass via electromagnetic waves. This task is further complicated by the lack of methods for creating landmarks (geodetic marks) in an unmanned mine, which are necessary for correcting positioning.

When creating or upgrading unmanned mining machines, the following requirements must be met: minimum infrastructure requirements; simplicity of installation and maintenance; navigation should be carried out without precise geometric mine maps; the positioning speed should be no less than with the operator; navigation should be carried out in a changing space geometry; there should be provided high work reliability with technical condition diagnostics; a high degree of integration with top-level automation systems [2].

Nowadays there are several mining machines positioning technologies in the mine space: by infrared radiation [9] using RFID (RFID) [10], using radar (Through-the-earth communication) [11] using the antennas in the form of transmission lines with radiating elements (leaky communication) [12], using a local wireless network (WLAN) [13], using a bar code applied to the surface of the mine [14]. However, the listed methods do not provide the necessary positioning accuracy and require external cues or external signals.

One of the effective solutions for the positioning of the robotic road heading machine is to use an inertial measurement unit (IMU) with information on the electric drive operating mode and the actuator's motion and movement parameters [15]. The inertial measuring unit includes a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer – all of them are located on one board. The main IMU drawback is the measurement error presence, that is insignificant but in the working process, it is able to accumulate and become much worse.

This drawback leads to the appearance and subsequent increase in the discrepancy between the positioning system readings and the actual object coordinates. It is possible to restrict this error via the use of high-precision clock generator integrated into the IMU (Timing & IMU), and the use of the hybrid navigation system with further aggregation in the data from the various navigation systems. There may also occur the emergence and accumulation of errors caused by the track mover slippage. In order to compensate track mover slippage, it is necessary to determine this mode occurrence and the slippage amount by means of the variable speed electric drive. At the same time, there is required a computer model for moving the robotic road heading machine, that takes into account the track mover slippage, as well as the limited rigidity of the robotic road heading machine construction, that in its turn affects the readings of the onboard accelerometers and gyroscopes. In the noisiness and incompleteness conditions of the measurement data, there is needed a method to restore the information on the robotic road heading machine movement using data from 3 axial accelerometers and gyroscopes [16]. Approved devices for solving this problem are the advanced Kalman filter and the artificial neural network apparatus.

When mining a bottom hole space by a robotic road heading machine there is always raised a question of the excavation operations parameters rationality (the effector movement speed, its rotation frequency and the thickness of the removed chip load). On the one hand in case of these parameters irrational selection there can be enhanced the effector intensive wear and the operations increased power consumption. On the other hand, the reduction of these parameters settings increases the operation control time, reduces the job and the movement execution speed, i.e. affects the "unmanned mine" performance. In order to solve the robotic road heading machine power and resource efficiency problem, it is necessary to divide it and consistently solve the following three subtasks.

Firstly, it is necessary to develop methods for estimating the residual operation life of the robotic road heading machine effector and its expenditure speed. In order to solve this problem, we can analyze the existing models of machine parts destruction, modifying these models in terms of accounting forms change over time force generated in the robotic road heading machine element. Also synthesizing the resource consumption model of the robotic road heading machine \mining machine, combining the destruction model the robotic road heading machine parts, the actuator model, the electric drives model, the effector model and the model of the mechanism for moving the robotic road heading machine.

Secondly, it is necessary to implement the methods of controlling the robotic road heading machine, which allow us to reduce the resource consumption of the effector and the executive mechanism as a whole. In order to do it, it is necessary, via investigating the interconnection of the mining machine elements resources and the electric drives various operating modes efforts to develop the resource-saving management principles of the robotic road heading machine. As far as all technological operations are carried out to fulfill the main task - mining, a method must be developed for managing the robotic road heading machine, that allows us to achieve the task for a given time with the minimum possible resource consumption. Thus, the task of operating a robotic road heading machine is an optimization problem with two opposite criteria. Complementing the technological task formation subsystem model based on the current value of resource consumption to the model of a robotic road heading machine, it is proposed to solve this problem via methods of the optimal and synergetic control theories.

Thirdly, it is necessary to develop a technological parameters task forming method for a robotic road heading machine on the current data basis of the residual operation life, the rate of resource consumption and on the marketing and economic performance data of the mining enterprise. This problem solution is possible by synthesizing a mathematical model of economic activity aimed at extracting minerals by a robotic road heading machine, based on the residual operation life data analysis, the electrical energy consumption, the resource consumption rate, the useful yield and the extraction volume. Further, it is necessary to develop a method for determining the specification of the production parameters for the robotic road heading machine (the rotation speed of the effector, the movement speed of the effector in the bottom hole space, the chips thickness, the final movement coordinates, the task control time) on the basis of the above given model.

4 Conclusions

Despite the evolving technologies, robotic machines and autonomously operating equipment are not still used in the underground mining. The most important challenge for the «unmanned mine» are the issues of interconnected at different functioning levels of the complicated and hazardous process complex. The solution of these problems can be realized on the basis of the optimal and adaptive control theory methods and on the comprehensive technical and economical approach application.

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