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Simulation of underground coal mining processes

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This article presents a new longwall simulation model. The model parameters are parameters of the coal seam, technical parameters of mining machines, flow schemes of the shearer operation, economic parameters, and the others. The model is intended for the decision of optimization problems in order to increase the productivity of the longwall face of a coalmine. The article provided an example of the use the longwall simulation model for one of the coalmine. For this mine, the dependence of the annual profit of the mine on the length of the face and on the flow scheme of shearer operation is obtained.

Keywords: coalmine, longwall mining, simulation, mining machines, flow schemes of the shearer operation.

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Introduction

Today many coalmines have problems in making decisions to increase productivity, to improve coal production planning, to use new mining equipment and new perspective technologies for coal mining. The most suitable way to solve these problems is simulation. Many publications support this statement [1–5]. There are also many publications on the use of simulation to solve problems for longwall mining [6–10]. These articles investigate certain aspects of longwall mining. In this work, an attempt is made to develop an integrated parameterized longwall simulation model that takes into account many aspects of the longwall mining.

The longwall simulation model was developed using the MTSS simulation system [11]. This is a visual interactive and process-oriented discrete simulation system intended to develop and execute the technological processes models.

With the help of MTSS the models of the underground conveyor network and pumping subsystem of a coalmine in Kuzbass (Kuznetsk Coal Basin, Western Siberia, Russia) were developed [12]. This new longwall simulation model also intended for simulation longwall mining processes in coalmines of Kuzbass.

1. Simulating of the longwall mining system

The proposed simulation model of the longwall mining system is intended to support decision-making on increasing the productivity of the longwall face of a coalmine, assessing the effect produced by using the different mining machines and different mining technologies. The model consists of interconnected mining machine models and a coal seam model. The mining machines in the longwall mining system are a shearer, a face scraper conveyor, and power roof supports. The model is integrated with a mining-geological and technological database. The user interface is also implemented in the model.

The main model among the models of mining machines is the model of the shearer that allows to calculate the productivity of the shearer (the amount of coal extracted per unit of time).

1.1. The mathematical model of the productivity of a shearer

The formula for the theoretical productivity (1) of the shearer when moving on a straight section of the longwall is derived in [13].

$$A = \frac{\gamma m r C \eta n K_1}{f P \cos\alpha \pm P \sin\alpha + S m K_2 K_3}(t/\min). \tag{1}$$

The productivity depends on two types of parameters. The first type is the constant technical parameters of the shearer. The second type is the parameters of the coal seam, which can change with a face length of more than one hundred meters.

In (1) the constant technical parameters of the shearer are: m is the cutting height of the shearer, r is the cutting width of the shearer, C is the capacity of the shearer drive, η is the efficiency of feed drive gearbox, n is the number of picks in a cutting line, K_1 is the coefficient taking into account a part of capacity of the shearer drive to move of the shearer, f is the coefficient of sliding friction between the shearer and the scraper conveyor, P is the shearer weight, K_2 is the coefficient, taking into account the decreasing of the cutting resistance of coal under the influence of rock pressure, K_3 is a certain coefficient taking into account the characteristics of cutting angle as well as width, dulling, and shape of picks.

In (1) the parameters of the coal seam are: γ is the coal density, α is the dip angle of coal seam, "plus" and "minus" in front of the shearer weight specify the shearer movement up and down the longwall face respectively, S is the cutting resistance of coal.

Current regulatory documents, methods and instructions for calculating the productivity of production faces, as well as publications, imply that when calculating the theoretical productivity of the shearer, invariable values of the parameters of the coal seam should be used. These values are calculated in one way or another. The scientific novelty of the proposed approach is the use of variable values of the parameters of a coal seam, which correlates with the actual system to a greater extend. With this approach, the parameters of the coal seam are considered as functions of the current position of the shearer with coordinates (x, y) in a some coordinate system. To calculate the productivity of the shearer, instead of formula (1), formula (2) is used.

$$A(x, y) = \frac{\gamma(x, y) m r C \eta n K_1}{f P \cos\alpha(x, y) \pm P \sin\alpha(x, y) + S(x, y) m K_2 K_3}. \tag{2}$$

Values of functions $\gamma(x, y)$, $\alpha(x, y)$, $S(x, y)$ are calculated with the inverse distance weighting method according to the following general function (3).

$$F(x, y) = \begin{cases} \dfrac{\sum\limits_{i=1}^{n} d_i^{-2} F_i}{\sum\limits_{i=1}^{n} d_i^{-2}}, & \text{if } d_i \neq 0, \\ F_i & \text{if } d_i = 0, \end{cases} \tag{3}$$

where: F_i are values of the corresponding parameters of the coal seam in i^{th} geological prospecting well, n is the number of geological prospecting wells nearest to longwall face that are taken into account while calculating, d_i is the distance between the i^{th} geological prospecting well and the current position of the shearer (x, y) is calculated by formula (4).

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}. \tag{4}$$

1.2. The simulation model

A proposed complex integrated model of a longwall can be used to solve the following tasks:

- Justified evaluating of the productivity of the longwall, including financial values.
- Assessing the effect of using new mining machines and new technologies.
- Decision support during the modernization of existing longwall faces and design of new ones.

This model of longwall involves the following interacting parts: the coal seam model, the shearer model, the model of face scraper conveyor, and the model of powered roof supports.

The parameters of the coal seam model are:

- Number of geological prospecting wells, their geographical coordinates, and values of coal seam parameters (the coal density, the dip angle of coal seam, and the cutting resistance of coal) in each geological prospecting well.
- Thickness of coal seam.
- Length of the longwall face, etc.

The shearer model parameters correspond to the list of parameters required to calculate the shearer productivity according to formula (2). All parameters of the mining machine models and a coal seam model correspond with the parameters of the actual mine equipment operating at one of the coalmines in Kuzbass.

The shearer simulation model calculates the shearer productivity when moving along the straight section of the longwall face in accordance with the mathematical model. At the same time, other factors also affect the shearer productivity. The shearer simulation model takes into account such factors as the flow schemes of the shearer operation, the operation of the face scraper conveyor, the movement of the mechanized support sections, and the calculation of methane emission from the coal seam.

The simulation system MTSS has a mining-geological and technological database that includes the following information:

- Geographic coordinates of underground workings.
- Geographic coordinates of exploration wells and geological data obtained during their drilling.
- Technical parameters of mining machines.
- Flow schemes of coal extraction.
- Technical parameters determining by the work procedure and safety requirements.
- Economic data, etc.

To perform a simulation experiment, the user must follow the steps below: specify the model parameters, set the technological scheme of the shearer operation, running the model in debug mode, observe the model execution process using 2D and 3D visualization, running the model in execution mode by the option to turn off visualization to speed up the simulation.

When specifying the parameters of the model, the user must specify the number and coordinates of exploration wells, as well as the values of mining — geological and geomechanical parameters of the coal seam in these wells. The database contains information about exploration wells for several underground coalmines in Kuzbass. When you select a mine, these data are automatically loaded into the model parameters.

Then, the user sets the list of mining machines (the shearer, the face scraper conveyor, roof supports) and specifies the technical parameters of these mining machines. A distinctive feature of the developed model is the possibility for the user to choose from the database mining machines. The user can expand the database and include a new existing mining machine or a hypothetical prospective mining machine. This procedure requires using of the implemented interface and filling in the appropriate data fields. When the user selects a certain mining machine, all the technical parameters of this machine are automatically loaded into the model parameters.

After that, the user sets the linear dimensions of the longwall, for example longwall length and selects the flow scheme of shearer operation. The longwall length significantly affects the productivity of the face. The longer the longwall length the less time is wasted for end face operations, but the capital and operating costs increase. The productivity of the face is also influenced by the selected flow scheme of shearer operation. Comparison of the productivity of various flow schemes of the shearer operation, made in this work, can be used to make decisions when modernizing existing faces or when designing new ones.

Then the user sets a logical condition to end the simulation. In particular, such a condition can be the value of the model time, upon reaching which the execution of the model ends. The user sets the modes of execution of the model, forms of presentation of the output parameters of the model, and launches the model for execution. The following execution modes are implemented in the model: 2D visualization, 3D visualization, no visualization. When the model is executed, the values of the output parameters are calculated. These values can be dynamically displayed either numerically or graphically.

Figure 1 shows a 2D visualization of the model execution. Longwall boundaries are shown in green. The shearer is shown in yellow. Figure 2 shows a 3D visualization of the digital

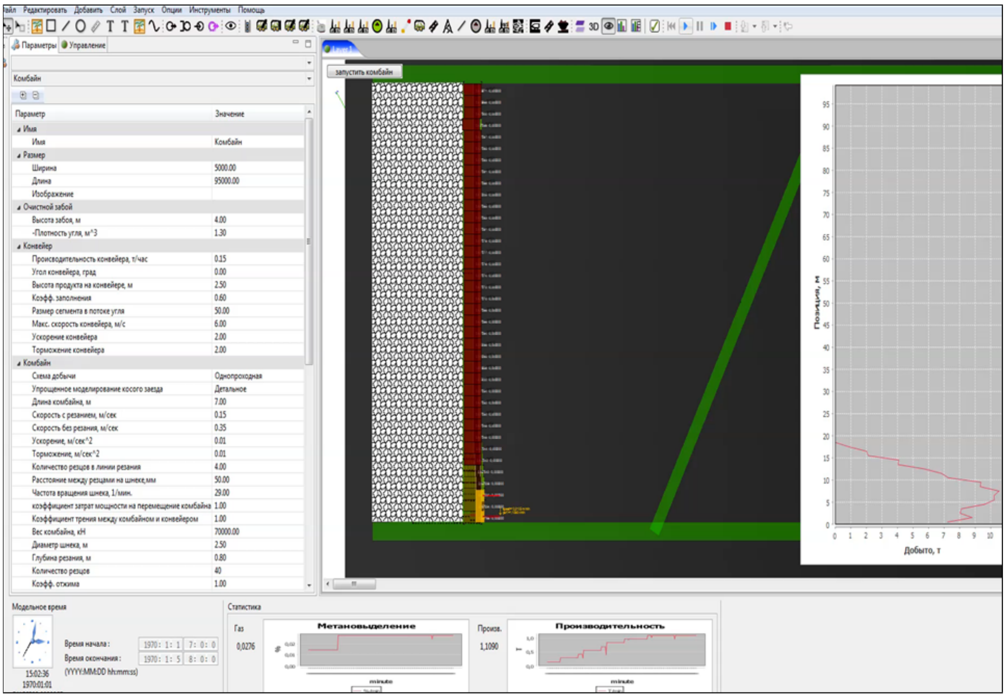

Fig. 1. 2D visualization of the model execution

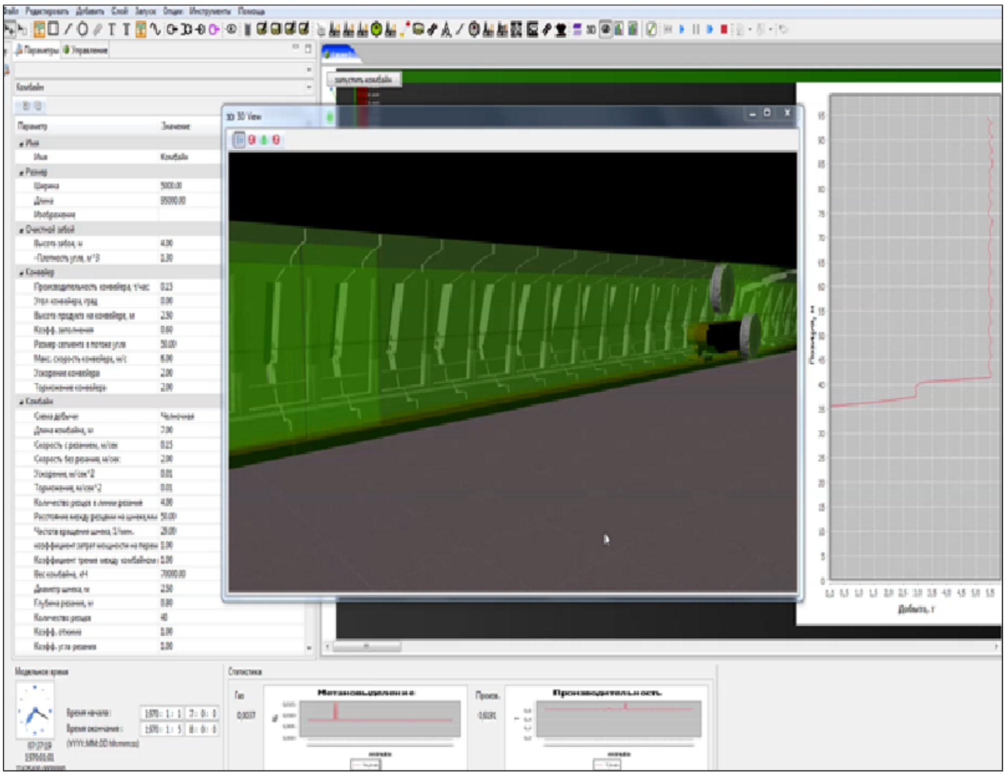

Fig. 2. 3D visualization of the model execution

model execution. The list of all model parameters and their values is displayed on the left part of the main window.

1.3. Simulation results

The Yalevsky mine in Kuzbass was selected as an example of using the simulation model of a coalmine longwall face. The purpose of the modelling was to determine the annual profit of the longwall face operation, equal to the cost of extracted coal minus depreciation costs, depending on the length of the longwall face and on flow scheme of shearer operation. The model was validated on actual data from Yalevsky mine. The amount of coal extracted per year, obtained by the model, coincides with the data in [14].

The model used the technical parameters of mining machines: shearer SL-900, scraper conveyor SH PF 6/1142, roof support DBT 220/480. To calculate the profit of the face operation, the following economic parameters were used: wholesale price of 1 ton of coal in rubles, depreciation rates, respectively, for a shearer in rubles, powered support and scraper conveyor in rubles/m.

In the model, there are parameters that set the operating schedule for the longwall face. In the considered example, the work of the longwall face was simulated for a year. Daily work was carried out in two work shifts (coal mining) and one technical shift (routine maintenance). To calculate the net profit from the operation of the face you should take into account the cost of materials, electricity, and wages. The relevant parameters are included in the model, but the values of these parameters were not available and were not used in this example.

The following flow schemes of shearer operation used in longwall mining were simulated: one-way flow scheme, two-ways flow scheme, and bench flow scheme. In the one-way flow

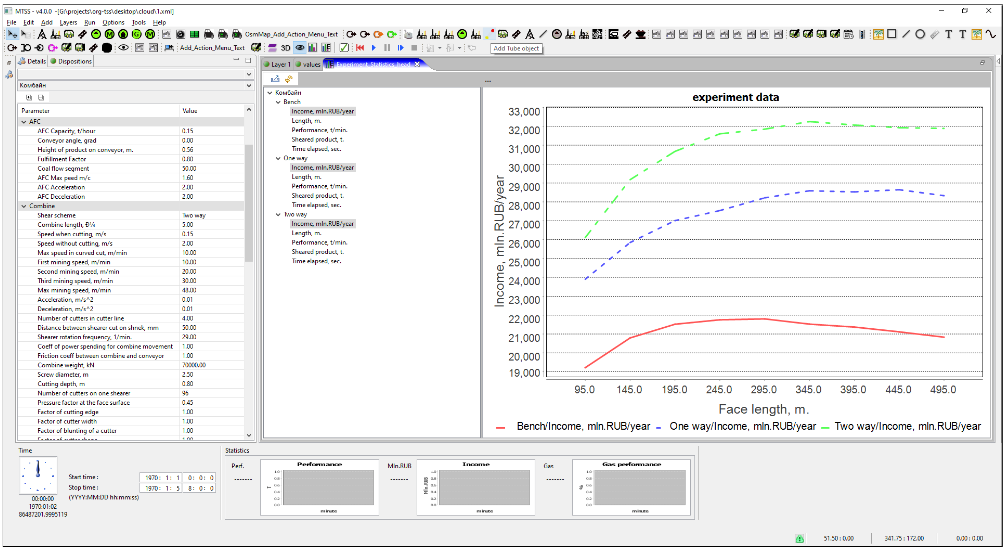

Fig. 3. The dependence of the annual profit of the mine on the length of the face and on flow scheme of shearer operation

scheme, the cycle of operation of the shearer consists of its forward motion in the operating mode and in the reverse motion in the mode of the cleaning-up. In the two-ways flow scheme, the cycle of operation of the shearer consists of its forward and reverse in the operating mode. In bench flow scheme, first the upper layer with a thickness equal to drum diameter of the shearer is cut and then, when the shearer moves reversely, the remaining lower layer of the coal seam is cut.

The subject of the research was the detailed simulating of one-way flow chart, shuttle flow chart, and bench flow chart of the shearer operation together with movement of the face scraper conveyor, and power roof supports.

Figure 3 shows the results of simulation the dependence of the annual profit of the mine on the length of the face in the range from 95 to 495 m and on the flow scheme of shearer operation. Red solid curve is the curve corresponding to the bench flow scheme of shearer operation, blue dashed curve is the curve corresponding to the one-way flow scheme of shearer operation, and the green dash-dotted curve is the curve corresponding to the two-way flow scheme of shearer operation. The figure shows that the greatest profit can be obtained using the two-way flow scheme of shearer operation and the length of the face in the range of 345–395 m. A further increase in the length of the longwall face insignificantly affects the increase in profits.

Conclusion

The longwall simulation model was developed using the MTSS simulation system. It includes the parameters of the coal seam, technical parameters of mining machines, economic parameters, etc. The model allows solving optimization problems in order to increase the productivity of the longwall face of a coalmine.

The model was validated on actual data of the Yalevsky mine in Kuzbass. The simulation model can be used to support decision-making to upgrade existing faces and to design new ones. It can be used not only for simulation of the existing coal mining technologies, but also for simulation of perspective robotized technologies and unmanned coal mining technologies.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ

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Имитационное моделирование технологических процессов подземной добычи угля

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Аннотация

Представлена новая имитационная модель длинного забоя. Учитывались параметры угольного пласта, технические параметры горных машин, технологические схемы работы угольного комбайна, экономические параметры и др. Модель предназначена для повышения производительности очистного забоя угольной шахты. Приведен пример использования имитационной модели очистного забоя для одной из угольных шахт. Для этой шахты получена зависимость годовой прибыли шахты от длины забоя и технологической схемы работы угольного комбайна.

Ключевые слова: угольная шахта, добыча угля длинными очистными забоями, имитационное моделирование, горные машины, технологические схемы работы угольного комбайна.

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