Operational Control of the Feed of the Harvester

Sergey Kubrin[1,*], and *Konstantin* Kopylov [2]

[1]EDP Institute of Comprehensive Exploitation of Mineral Resources Russian Academy of Sciences s, Editorial Department, 111020 Krukovskiy tupik 4, Moscow, Russia
[2]JSC SUEK, 115054 Dubininskay 53-7, Moscow, Russia

Abstract. Comparison of normative and actual indicators on mining testifies to inefficient work of the excavating equipment. The results of the correlation analysis of the speed of movement of the harvester relative to the section of the support with the readings of methane sensors revealed a significant dependence. When conducting mining operations in complex geological conditions at great depths, a joint step-by-step carrying out of various technological processes is required to ensure the preparation, opening and excavation of reserves and the creation of safe conditions for mining coal seams. At the same time, efforts should be made to minimize time, human and energy resources. In this regard, of particular importance is the right choice of the program of operational management of technological processes of mining, monitoring the implementation of technological operations for the timely detection of deviations from the selected mode, adjustment of the established current modes of operation of technological processes and the development, if necessary, measures aimed at reducing the risks of accidents. A promising direction of solving this problem is the use of modeling methods. The developed models of technological processes of the mining enterprise will allow planning production and supporting decision-making in the implementation of operational management.

1 Introduction

Analysis of the operation of technological equipment shows that its downtime in coal mining by underground method is within 30% of the total time. The treatment works account for 15% of downtime in underground works. In connection with the foregoing, special importance is gained by the correct choice of the mode of operational management and operational development, where necessary, of measures aimed at reduction of risks of emergency incidents. Thus, the justification and evidence of the need for operational management of high-performance complex-mechanized face is an urgent scientific task. A promising direction of solving this problem is the use of methods of modeling the complex-mechanized face. The developed models of work of the technological equipment of the mine excavation site will allow carrying out planning and operational management of the excavation site, to identify negative trends in the technological environment and early

* Corresponding author: s_kubrin@mail.ru

precursors of accidents, to assess the risks of possible downtime and accidents, to plan preventive measures to neutralize or minimize possible negative manifestations

The excavation site is a complex mining system, the simulation of which was carried out in terms of reducing the specific energy costs [1, 2], the forecast of methane [3], the maximum permissible load on the treatment face of the gas factor [4]. Physical models for prediction of methane concentration fields [5] and methane release from broken coal [6 – 9] were studied. The analysis of the considered works shows that, despite the reasonable and reliable results, they cannot be the basis for the creation of a model of the technological process that can provide current control of the harvester to achieve the maximum possible energy-efficient operation of the excavation site. One part of the work performed is of a purely theoretical nature, while others are used in the calculation of the average value.

2 Formalization

When creating a mathematical model of the excavation complex, the input factors are: the feed rate of the combine, the speed of the flight conveyor, loader, crusher, belt conveyor, the concentration of methane at the inlet and outlet of the treatment face, the relative methane content of the developed layer; the output parameter is the performance of the combine. To formalize the task, it is necessary to make the transition from verbal description to quantitative relations between input and output parameters. The first verbal description that needs to formalize defines two actions - "the destruction of the coal seam and the movement of coal to the flight conveyor."

To represent these actions in a mathematical model, it is required to specify additional variables (the location and time of the combine relative to the face), which are determined based on input parameters. When considering the problem, when the feed of the combine carried out at a constant speed, there are no special problems. However, in practice, the harvester along the lava moves at variable speed and often with stops. Therefore, in general case the motion of the excavation of the harvester along the line of slaughtering is carried out with the same velocity, V_k, is given by an arbitrary (specified by the operator of the harvester) the law $V_k = V_k(t)$. Then the location of the harvester is determined as the $x(t)$ coordinate and is found from the solution of the differential equation

$$\frac{dx}{dt} = V_k(t) \qquad (1)$$

With the constant movement of the harvester, its location changes with time x_k=$x_k(t)$. Using the parametric setting of the combine location coordinate, that is, expressing the time, you can go through the coordinate to the equation

$$\frac{dx}{dt} = V_k(x(t)) \qquad (2)$$

Thus, the number of additional variables reduced; however, this will not be correct, since if the dependence $x_k = x_k(t)$ is unambiguous, then the dependence $t = t(x_k)$ is unambiguous only with the constant movement of the harvester. If it stops or moves backwards, the certainty is lost. This is the first feature of the task to taken into account.

The second feature arises when trying to quantitatively, using mathematical notation, formalize the second verbal description of the mechanized complex - "coal, getting on the flight conveyor moves along the face." At a constant rate of flow extraction processor, the amount of repelling them coal will be permanent. The current filling of the flight conveyor with coal at the point $x_k = x_k(t)$ is determined by the volume dv of the beaten coal during dt, depending on the working thickness of a seamh, the length of the screw l and the feed rate of the harvester and will be equal to $dv = hlV_kdt$. Taking into account the specific weight of coal γ, the weight of the beaten coal volume will be $dM = h\gamma lV_kdt$. Defined in this way, the volume of dv coal weighing dM moves within the bay on the flight conveyor at a speed of V_{sk}. Then the time to move it to the exit of the bay is determined from the equation

$$\frac{dx}{dt} = -V_{sk}(t) \quad (3)$$

by the ration

$$T_i = -\frac{1}{V_{sk}} \int_{x=x_i}^{x=x_0} dx \quad (4)$$

here $V_{sk} = const$ – the speed of the flight conveyor, x_i place of the breaking portion of the coal dM, x_0– coordinate of flight conveyor from belt entries. Total weight of broken coal in the bay at time t_j defines the integration of elementary portions broken coal, for which the condition – travel time from point of cutting to conveyor drift does not exceed the transportation time by flight conveyor:

$$Q = \int_{i=1}^{i=n} dM_i \quad (5)$$

for *i* satisfying the condition:

$$t_j - t_0 \leq -\frac{1}{V_{sk}} \int_{x=x_i}^{x=x_0} dx \quad (6)$$

or

$$\int_{x_i}^{x_j} \frac{dx}{V_k} - t_0 \leq -\frac{1}{V_{sk}} \int_{x=x_i}^{x=x_0} dx \quad (7)$$

If the feed rate of the harvester is constant ($V_{sk} = const$), then the integral disappears in the left part of the condition, and an easily calculated ratio $((x\_j - x\_i)) / V\_k$ is obtained. Then, knowing the speed of the combine harvester and flight conveyor is not difficult to determine the weight of coal in the bay.

When considering the general case-determining the volume of coal on the flight conveyor, it is enough to use a simplified scheme of its operation (Fig. 1). The flight conveyor is shown by a horizontal line. The point x_0 corresponds to the joint of the crusher and flight conveyor. Let during the cutting of coal, the harvester moves along the face line with some varying feed rate $V_k(t)$. The coal repulsed by the combine is loaded on a flight conveyor, which in turn moves at a constant speed $V_{sk} = const$. By the time the approach the excavation of the harvester to the point with coordinates of x_i as the result of blasting, loading of coal harvester and moving the flight conveyor with submerged him coal, at time t_i flight conveyor loaded with coal, the volume of which (in Fig. 1 conditionally shown in gray) is described by the function $\varphi = \varphi(x)$. After a period of time dt flight conveyor moved the entire volume of coal to the side of the conveyor belt (the lower part of the figure. 1). In this case, part of the coal (after the point x_0) is overloaded to the next equipment in the transportation line (shown by a separated element on the right outside the flight conveyor). In turn, the extraction processor continues the breaking of the coal has shifted to the point x_j, and for the time dt has uploaded to flight conveyor coal, the amount of which is conventionally shown on the left.

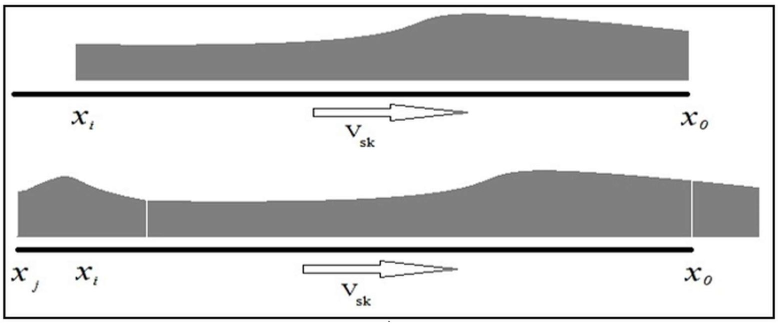

Fig. 1. Scheme of movement of coal flight conveyor.

The upper part corresponds to the loading of the flight conveyor with coal at the time t_i

The lower part corresponds to the loading of the flight conveyor with coal at the time $t_j=t_i+dt$.

Coordinate x_0 – the place of articulation of the flight conveyor with crusher, x_i is the location of the excavation of the harvester at time t_i, $x_j$location of excavation harvester at time t_j, V_{sk} - speed flight conveyor.

The analysis of the described process indicates that. Firstly, there is simply a shift in the volume of coal towards the conveyor drift at the speed of the flight conveyor, secondly, there is a replenishment of the volume of coal in proportion to the feed rate of the extraction combine, and, thirdly, there is a removal of the volume of coal poured onto other theological equipment. It should note that the process has the property of irreversibility. Thus, because the data on the volumes of coal to reload to the following process equipment are lost, it is necessary to additionally save data on the volumes of coal overloaded from the flight conveyor to be able to describe the process with a reversible time. The operation of shifting the volumes of coal along the scraper conveyor does not allow the description in the final form. In other words, in mathematics there are no such transformation operators $D(\varphi) = D\varphi(x)$, for which the action on the function should depend on the values of its arguments. That is, the action of such an operator on the function φ, should be different and allow to describe the processes (coal loading, coal movement, coal handling). In this case, the scope of the operator, at the x coordinate, changes when moving the harvester. Thus, with the help of functions of continuous description of the coal distribution on the flight conveyor, it is impossible to obtain a formal description of the processes of "loading coal by the extraction combine on the flight conveyor", "moving coal by the flight conveyor", "transshipment of coal from the flight conveyor".

Using a discrete representation of the volume of coal, that is, considering the numerous portions of coal that are "loaded by the extraction combine on the flight conveyor", "moved by the flight conveyor", "overloaded from the flight conveyor", it is necessary to introduce the equations of motion of each portion into the problem. In this case, the weights of the coal portions loaded by the combine on the flight conveyor will be different ($dM_i \neq dM_{i+k}$). Therefore, in the condition (left side) of determining the portions of coal that are in the bay, it is necessary to use an integral, which leads to the fact that for each portion it is necessary to know its current location, for which it is necessary to solve a set of equations of motion of each portion. This approach leads, firstly, to a sharp increase in the dimension of the problem by several orders of magnitude. Secondly, a need to constantly generate dependencies describing the movements along the face of the newly repulsed portion of coal by the flight conveyor, and after the overload of the elementary portion from the flight conveyor to remove these dependencies. All this leads to the fact that the discrete formulation of the problem of describing the process of complex-mechanized face today is not solved.

All these circumstances leave only one way to represent the length-distributed loading of the scraper conveyor in the form of selective different actions on the elements of the function φ. This should increase the dimension of the distribution function of coal on the scraper conveyor, adding time t presenting it as $\varphi = \varphi(x, t)$.

Then, the increase in the volume of coal by the extraction combine on the flight conveyor is written by the expression $\varphi = \varphi(x_k, t) = \varphi(x_{ki}, t_i) + dM = \varphi(x_{ki}, t_i) + h\gamma lVk\ dt$. Moving cargo flight conveyor (with speed V_{sk}) – shift operation - transformation function $\varphi(x, t)$, which is described by the expression $\varphi(x_i, t+dt) = \varphi(x_i - V_{sk}\ dt, t)$. In this case, the part of the conveyor, which is located at the top of the road, and is a section that appeared in the time interval dt and remains empty $\varphi(x_n \div x_n - V_{sk}\ dt, t+dt) = \varphi(x_i - V_{sk}\ dt, t) = 0$.

Coal, which was on the flight conveyor at the bottom of the bay, is overloaded to the following process equipment. This volume of coal is $\varphi_{out}(x_k, t) = \varphi(x_1 \div x_1 + V_{sk}\ dt, t)$. Similar to the flight conveyor as a streaming device for moving the rock mass, a loader, a crushing plant, and a belt conveyor work.

The ratios describing the technological process of moving the combine harvester, rock mass, with the help of technological equipment of complex-mechanized face the following. Submission of the combine along the face (1). The flow of coal

$$\begin{cases} \varphi_{sk}(x_i, t_i) + dM = \varphi_{sk}(x_i, t_i) + \gamma hmV_k dt\ (x_i = x_k) \\ \varphi_p(x_i, t_i) + dM = \varphi_p(x_n \div x_n - V_p dt, t_i) = \varphi_{sk}(x_1 \div x_1 + V_{sk} dt, t_i)\frac{V_{sk}}{V_p} \\ \varphi_d(x_i, t_i) + dM = \varphi_d(x_n \div x_n - V_d dt, t_i) = \varphi_p(x_1 \div x_1 + V_p dt, t_i)\frac{V_p}{V_d} \\ \varphi_{lk}(x_i, t_i) + dM = \varphi_{lk}(x_n \div x_n - V_{lk} dt, t_i) = \varphi_d(x_1 \div x_1 + V_d dt, t_i)\frac{V_d}{V_{kl}} \end{cases} \quad (8)$$

Coal movements

$$\begin{cases} \begin{cases} \varphi_{sk}(x_i, t + dt) = \varphi_{sk}(x_i - V_{sk} dt, t)\ (x_i < x_n - V_{sk} dt) \\ \varphi_{sk}(x_n \div x_n - V_{sk} dt, t + dt) = 0\ (x_i \geq x_n - V_{sk} dt) \end{cases} \\ \begin{cases} \varphi_p(x_i, t + dt) = \varphi_p(x_i - V_p dt, t)\ (x_i < x_n - V_p dt) \\ \varphi_p(x_n \div x_n - V_p dt, t + dt) = 0\ (x_i \geq x_n - V_p dt) \end{cases} \\ \begin{cases} \varphi_d(x_i, t + dt) = \varphi_d(x_i - V_d dt, t)\ (x_i < x_n - V_d dt) \\ \varphi_d(x_n \div x_n - V_d dt, t + dt) = 0\ (x_i \geq x_n - V_d dt) \end{cases} \\ \begin{cases} \varphi_{lk}(x_i, t + dt) = \varphi_{lk}(x_i - V_{lk} dt, t)\ (x_i < x_n - V_{lk} dt) \\ \varphi_{lk}(x_n \div x_n - V_{lk} dt, t + dt) = 0\ (x_i \geq x_n - V_{lk} dt) \end{cases} \end{cases} \quad (9)$$

Transshipment of coal to the following process equipment

$$\begin{cases} \varphi_{out\to p}(x, t) = \varphi_{sk}(x_1 \div x_1 + V_{sk} dt, t) \\ \varphi_{out\to d}(x, t) = \varphi_p(x_1 \div x_1 + V_p dt, t) \\ \varphi_{out\to lk}(x, t) = \varphi_d(x_1 \div x_1 + V_d dt, t) \\ \varphi_{out}(x, t) = \varphi_{lk}(x_1 \div x_1 + V_{lk} dt, t) \end{cases} \quad (10)$$

3 Simulation

For the conditions of the bay 17 – 49 mine Polysaevskaya conducted simulation of technological processes of breaking and transportation of coal at a nominal constant feed rate of the harvester 6 m/min (Fig. 2). The parameters of the bay are as follows: the seam thickness of 1.74 m, angle of seam dip12-17°, cutting resistance 140 kg/cm2, volume weight of coal 1,29 t/m3, face length 300 m, the number of mechanized support unit 177;

length of the auger shearer 1 m, the cutting mode of the shearer uni-direction cutting, production per cycle 675 tons, production 7-10 thousand tons / day, the actual gas content of the formation 3-6 m3/t, flight conveyor speed 1.32 m / s, combined ventilation scheme. In this case, the volume of coal on the flight conveyor increases linearly. The maximum loading of the conveyor is achieved only at the end of the working passage, at the top of the face, and is equal to 50 tons of coal. On all bay there will be slightly more than 70 tons of coal. For fig. 2 shows the uneven loading of equipment. To improve the efficiency of the technical resource it is necessary to find the optimal mode of change in the feed rate of the combine harvester, providing the highest performance with the accepted limitation of the volume of coal in the bay.

4 Conclusion

A mathematical model of the complex – mechanized face based on the separation of the processes of loading, movement and unloading of coal technological equipment of the excavation site. The presented mathematical model of formalization of the main technological processes taking place at the excavation site – breaking, loading, moving and unloading of coal can used to determine the effective modes of operation of complex-mechanized face, in order to achieve maximum productivity of the excavation site and to ensure trouble-free operation of the installed equipment.

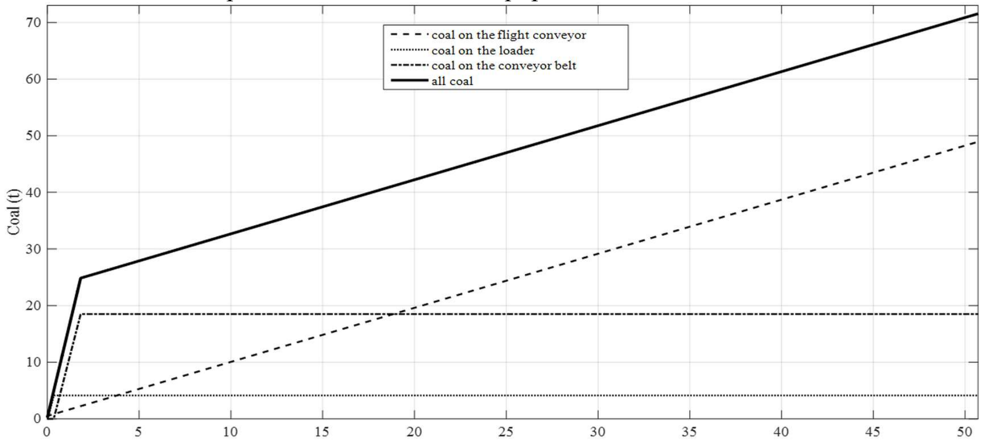

Fig. 2. The coal at the excavation bay with constant feed speed of the harvester 6 m/min**.**

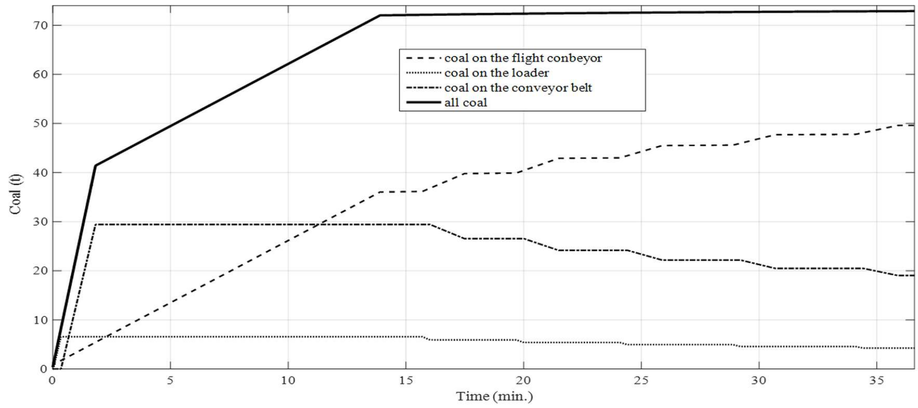

Fig. 3. The coal at the excavation bay with optimum feed speed of the harvester.

References

1. N. M. Kachurin, N. O. Kaledin, A. N. Kachurin, Tula State University Bulleting, **2,** 21, (2011)
2. S. V. Slastunov, G. G. Karkashadze, E. V. Mazanik, M. G. Lupiy, Gorny Zhurnal, 3, (2015)
3. A. M. Bordewich, R. A. Kovalev, A. A. Bukhtiyarov, I. V. Sarycheva, Tula State University Bulleting, **1,** 16 (2010)
4. N. M. Kachurin, S. A. Vorobyov, A. N. Kachurin, I. V. Sarycheva, Tula State University Bulleting, **1,** 19 (2014).
5. G. Ya. Polevshchikov, M. V. Shinkevich, methane release from the broken coal, J. KuzSTU Bulleting, **5,** 74 (2010)
6. L. A. Shevchenko, S. N. Livinskaya, KuzSTU Bulleting, **1,** 56 (2015)
7. E. V. Pugachev, E. V. Chervyakov, A. E. Chervyakov, Mining informational and analytical bulletin, **12**, 34 (2009)
8. N. M. Kachurin, A. A. Bukhtiyarov, I. V. Sarycheva, Tula State University, **2,** 86 (2010)
9. V. L. Konyukh, P. V. Grechishkin, KuzSTU Bulleting, **2,** 11 (2004)