UDC 622.647.2

R.V. Kiriya, J.V. Babenko

MODELING OF FUNCTIONING PROCESSES OF UNDERGROUND CONVEYOR TRANSPORT OF COAL MINES WITH CONTROLLED ACCUMULATIVE HOPPERS

Annotation. *Based on dynamics of average method for Markov processes we developed mathematical model of functioning of conveyer transport systems with self-similar structure with accumulative hoppers that work in the mode of maintaining the volume of cargo in them in the prescribed limits. At the same time, failures of conveyors and hoppers were taken into account.*

We determined the average capacity of these systems of conveyor transport, which exceeds by 15% the capacity of the same system, but with uncontrolled hoppers.

Keywords: *conveyer transport systems, self-similar structure, functioning, accumulative hopper, set cargo volume, average carrying capacity, efficiency criteria.*

Introduction

Conveyer transport systems of coal mines have difficult branched structure. Failures of conveyers often lead to downtime in lavas and as result to poor productivity of conveyer transport systems.

To increase carrying capacity conveyer transport systems of coal mines accumulative hoppers have received wide application. They allow for the accumulation of a certain amount of cargo in the hopper during the downtime of conveyors to increase the capacity of the underground conveyor system (temporary reservation) [1, 2].

However, despite the use of accumulative hoppers, the efficiency of the underground conveyor transport systems of coal mines is not high. This is due to large losses in the productivity of the conveyor system due to overloading of hoppers, as well as losses of electricity due to underloading of conveyors.

One of the methods of increasing the efficiency of the underground conveyor transport system of coal mines is control of accumulative hoppers by means of controllers. At the same time, cargo volume in the hopper is maintained within the specified limits in the accumulative hoppers by changing the speed of the batcher, which makes it possible not to disconnect the above-hopper conveyor line due to hopper overflow (Fig. 1) [3, 4]. And the value of these limits depends on the location of the hopper in the conveyor system.

 ISSN 1562-9945

Mathematical models for the functioning of conveyor transport systems with accumulative hoppers operating in an uncontrolled mode have been developed at present [5, 6].

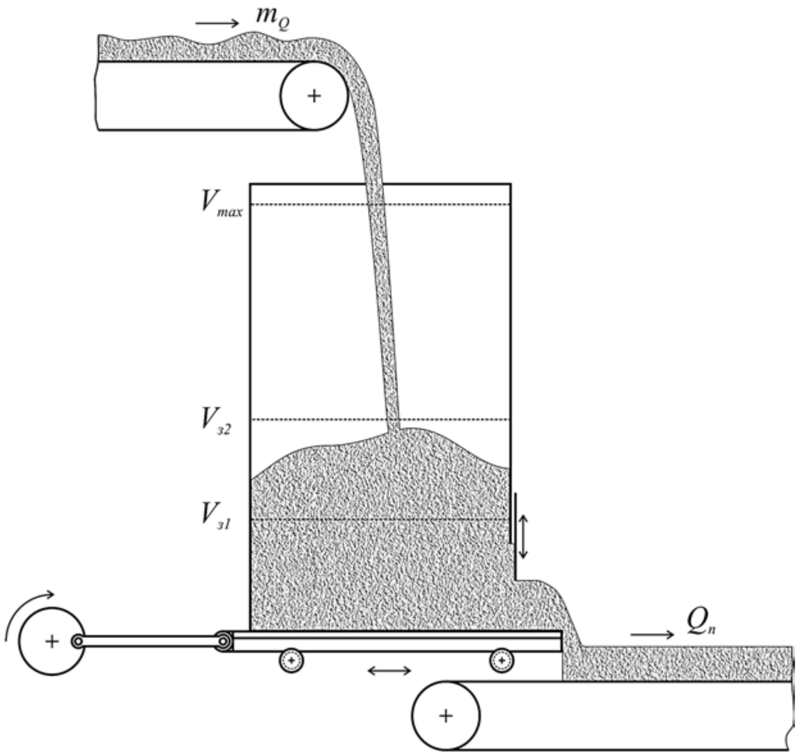

Fig. 1 – Scheme of accumulative hopper work in the mode of keeping cargo volume within prescribed limits

In paper we developed mathematical models of conveyer transport system functioning with serial and parallel connection of hoppers and also with self-similar dendritic structure. In this case accumulative hoppers work in the mode of keeping cargo volume within prescribed limits.

As in [5, 6], we base the modeling of the conveyor transport system with controllable accumulative hoppers on the method of average dynamics for Markov processes.

Consider first serial connection of conveyers and accumulative hoppers that work in the mode of keeping cargo volume within prescribed limits (fig. 2).

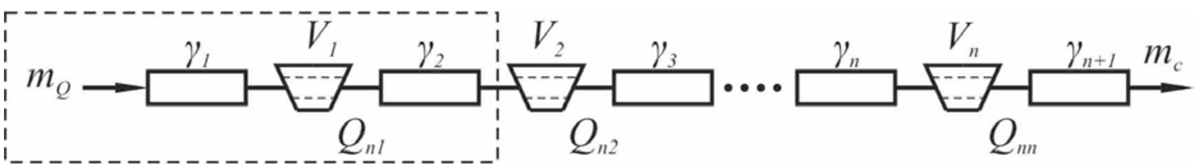

Fig. 2 – Calculation scheme of serial connection of hoppers

For getting mathematical models of conveyer transport system functioning with hoppers let's use property of self-similarity of structure with serial connection of hoppers.

Let's distinguish in this scheme from the left edge simple system «conveyer – hopper – conveyer» encircled by a dotted line (fig. 2).

When the accumulative hoppers function in the conveyor transport system in the mode of controlling the cargo volume in them within the specified limits, if the cargo volumes in the hoppers reach the maximum set value $V_{з2}$, then the batchers are turned down, and when minimal prescribed cargo volumes in the hoppers $V_{з1}$ are reached batchers are turned on. The above-hopper conveyor line is not disconnected (see Figure 1).

This mode of operation of accumulative hoppers is possible when the average cargo flow entering the hopper is less than the average batcher capacity, i.e. $\overline{m}_Q < \overline{Q}_n$.

Suppose that the average value of the cargo traffic arriving at the entrance of the first above -hopper is equal to m_Q. Coefficient of failures of first above- and under-hopper conveyers are equal to γ_1 and γ_2, productivity of first batcher of hopper is Q_{n1}, cargo volume in first hopper is equal to $V_{\max} = V_1$ and maximum and minimum set values are $V_{з2} = V_{12}$ и $V_{з1} = V_{11}$. In this case, the condition is $\overline{m}_Q < \overline{Q}_{n1}$.

If the first accumulative hopper operates in the mode of keeping the cargo volume within the specified limits and the hopper does not overflow, that is, the volume of the cargo in the hopper does not exceed the volume of the V_1 and the above-hopper conveyer line is not turned off, then the average capacity of the system is equal to the average cargo flow which goes to accumulative hopper:

$$\overline{m}_{Q_1} = \frac{\mu_1}{\lambda_1 + \mu_1} \cdot m_Q . \quad (1)$$

However, in case that the maximum prescribed volume of cargo is reached in the hopper V_{12}, if under-hopper conveyor doesn't work, the hopper may be overloaded, that is, reaching the volume of the cargo load in the hopper equal to the volume of the V_1 hopper.

Let's determine probability of this event as P_c. Then the average capacity of the "conveyor-hopper-conveyor" system will be

ISSN 1562-9945

$$m_c = P_c \cdot \overline{m}_{Q1}. \quad (2)$$

Let us determine the probability of overload of the accumulative hopper P_c. This probability is equal to the probability of the product of two independent events: the probability of failure under-hopper conveyor $\overline{P}_2$ and the probability that during the filling of the hopper with the above-hopper conveyor under-hopper conveyor will not start working.

The probability of failure under-hopper conveyor is

$$\overline{P}_2 = 1 - P_2 = \frac{\lambda_2}{\lambda_2 + \mu_2}, \quad (3)$$

where $P_2 = \dfrac{\mu_2}{\lambda_2 + \mu_2}$.

The probability that during the time T_1 under-hopper conveyor does not start working, according to the exponential law of distribution of its failure, is equal to

$$P_2' = e^{-\mu_2 T_1}. \quad (4)$$

Time T_1 of loading hopper to the volume $\Delta V_1 = V_1 - V_{12}$ by above-hopper conveyor when under-hopper conveyor does not work is determined by formula

$$T_1 = \frac{\rho \Delta V_1}{\overline{m}_{Q1}}. \quad (5)$$

According to the theorem on the probability of products of two independent events, the probability of a hopper overflow $\overline{P}_c$ is equal to

$$\overline{P}_c = \overline{P}_2 P_2'. \quad (6)$$

Substituting (3) and (4) into (6), as a result we get the probability of hopper overload

$$\overline{P}_c = \frac{\lambda_2}{\lambda_2 + \mu_2} e^{-\mu_2 T_1}, \quad (7)$$

where $T_1 = \dfrac{\rho \Delta V_1}{\overline{m}_{Q_1}}$.

Probability of hopper not overloading P_c we determined by formula

$$P_c = 1 - \overline{P}_c = 1 - \frac{\lambda_2}{\lambda_2 + \mu_2} e^{-\mu_2 T_1}$$

or taking into account (5) we obtain:

$$P_c = 1 - \frac{\lambda_2}{\lambda_2 + \mu_2} e^{\frac{\rho \Delta V_1}{\overline{m}_{Q_1}} \mu_2} . \qquad (8)$$

Substituting (8) into (2), finally we get the capacity of the system "conveyor - hopper - conveyor" in the case of accumulative hopper works in the mode of maintaining the prescribed cargo volume in the hopper, that is, in the third mode of its operation:

$$m_c = \left[1 - \frac{\lambda_2}{\lambda_2 + \mu_2} e^{-\frac{\rho \Delta V_1}{\overline{m}_{Q_1}} \mu_2} \right] \overline{m}_{Q_1} . \qquad (9)$$

Formula (7) is similar to formula in paper [7], received for an empty hopper and constantly working above-hopper conveyor.

Consequently, the average capacity of a subsystem consisting of a serial-connected first conveyor, a hopper and a second conveyor, which is part of a system of n serial connected hoppers and conveyors, can be determined from the formula (see Fig.2):

$$m_{c_1} = \left(1 - \frac{\gamma_2}{1 + \gamma_2} e^{-\frac{\rho \Delta V_1}{\overline{m}_{Q_1}} \mu_1} \right) \overline{m}_{Q_1} , \qquad (10)$$

where $\overline{m}_{Q_1} = \frac{m_Q}{1 + \gamma_1}$; $\gamma_1 = \frac{\lambda_1}{\mu_1}$; $\gamma_2 = \frac{\lambda_2}{\mu_2}$; $\Delta V_1 = V_1 - V_{12}$ ($m_Q < Q_{n_1}$).

Continuing this process n times, we determine the average capacity of the system with serial connection of hoppers in the mode of maintaining a given level of cargo in them according to recurrence formulas:

$$m_c = m_{c_n} , \qquad (11)$$

where

$$m_{c_i} = \left(1 - \frac{\gamma_{i+1}}{1 + \gamma_{i+1}} e^{-\frac{\rho \Delta V_i}{\overline{m}_{Q_i}} \mu_{i+1}} \right) \overline{m}_{Q_i} , \qquad (12)$$

$$\overline{m}_{Q_i} = \frac{m_Q}{1 + \gamma_{э_i}} = m_{c_{i-1}} ; \; \Delta V_i = V_i - V_{i2} ; \; \gamma_{э_i} = \frac{m_Q}{m_{c_{i-1}}} - 1 ; \; m_{c_0} = \frac{m_Q}{1 + \gamma_1} ; \; \gamma_i = \frac{\lambda_i}{\mu_i} ;$$

($i = 1,2,\ldots,n$).

Here $\gamma_{э_i}$ – equivalent coefficient of accidents of system, consisting of i-th first serial connected hoppers and conveyers; V_i – volumes of i -

 ISSN 1562-9945

th hopper, m^3; V_{i2} – maximum cargo volume in i -th hopper, m^3; n – number of hoppers in system.

Consider now conveyer transport system with parallel connection of hoppers, that work in the mode of keeping cargo volume within prescribed limits (fig. 3).

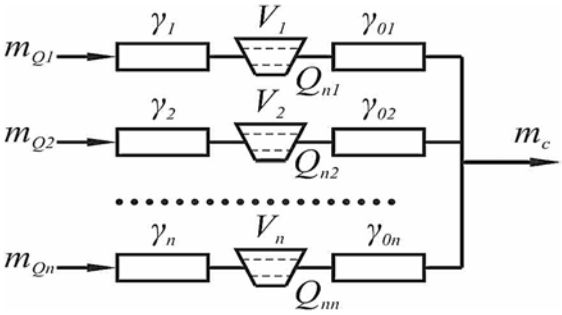

Fig. 3 – Calculation scheme of parallel connection of hoppers

For this system, just as in the previous case, using the self-similarity of its structure, as a result we get

$$m_c = \sum_{i=1}^{n} m_{c_i} , \tag{13}$$

where

$$m_{c_i} = \left(1 - \frac{\gamma_{0_i}}{1+\gamma_{0_i}} e^{-\frac{\rho \Delta V_i}{\overline{m}_{Q_i}} \mu_{0i}}\right) \overline{m}_{Q_i} ; \tag{14}$$

$$\overline{m}_{Q_i} = \frac{m_{Q_i}}{1+\gamma_i} ; \; \Delta V_i = V_i - V_{i2} \; (m_{Q_i} < Q_{n_i} ; \; i = 1,2,...,n).$$

Here γ_i, γ_{0_i} – coefficient of accidents of above- and under-hopper conveyers; n – number of branches (hoppers) in the system.

For incomplete parallel connection of hoppers (fig. 4) average capacity of conveyer transport system is determined by formulas (13) and (14), in which values of coefficient of accidents γ_{0_i} and recovery parameters μ_{0i} of above-hopper conveyers are changed into values of coefficient of accidents γ_0 and recovery parameter μ_0 of assembled conveyer ($\gamma_{0_i} = \gamma_0$, $\mu_{0i} = \mu_0$, i = 1,2,...,n).

Consider self-similar dendritic structure of conveyer transport system with hoppers, that work in the mode of keeping cargo volume within prescribed limits (fig. 5).

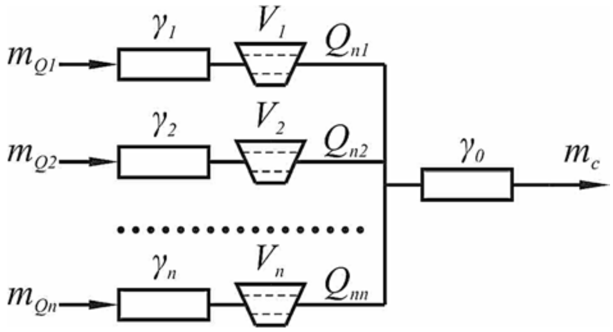

Fig. 4 – Calculation scheme of incomplete parallel connection of hoppers

On fig. 5 $Q^{(c)}_{n_i}$ – batchers productivity of shaft path (t/min); $V_i^{(c)}$ – hoppers volume of shaft path, m³; $V_{i2}^{(c)}$ – maximum cargo volume in shaft hoppers, m³; i =1,2,…,n.

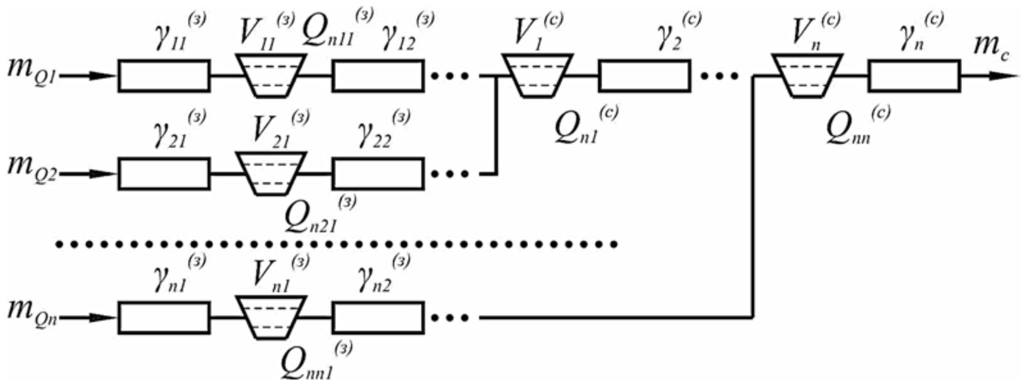

Fig. 5 – Calculation scheme of self-similar dendritic structure of hoppers connection

Using self-similarity [8], average capacity of this system is determined by recurrence formulas:

$$m_c = m_{c_n}, \tag{15}$$

where

$$m_{c_i} = \left(1 - \frac{\gamma^{(c)}_{i+1}}{1+\gamma^{(c)}_{i+1}} e^{-\frac{\rho \Delta V_i^{(c)}}{m_i^{(s)}}\mu_{i+1}}\right) m_i^{(s)}, \tag{16}$$

$$m_i^{(s)} = m_{c_{i-1}} + \frac{m_{Q_i}}{1+\gamma^{(з)}_{э_i}};\ m_{c0} = 0;\ \Delta V_i^{(c)} = V_i^{(c)} - V_{i2}^{(c)};\ (i = 1,2,\ldots,n;\ m_{Q_i} < Q_{n_i}).$$

Here $\gamma_i^{(c)}$– coefficients of accidents of shafts paths with hoppers; $V_i^{(c)}$ – hoppers volume of shaft path, m³; $V_{i2}^{(c)}$ – maximum cargo volume in shaft hoppers, m³; $\gamma^{(з)}_{э_i}$ – equivalent coefficients of accidents of faces paths with hoppers.

 ISSN 1562-9945

Here efficient coefficients of accidents of faces paths with hoppers are determined by formulas:

$$\gamma^{(з)}_{э_i} = \frac{m_{Q_i}}{m^{(з)}_{c_i}} - 1 \ (\gamma^{(c)}_{э_1} = \gamma^{(з)}_{э_1},\ i = 1,2,\ldots,n), \qquad (17)$$

where $m^{(з)}_{c_i}$ – average carrying capacity i-th face path of conveyer transport system with hoppers with dendritic self-similar structure, which is defined similarly, as for a system with a serial connection of hoppers and conveyors, according to:

$$m^{(з)}_{c_i} = m^{(з)}_{c_{ij}} \text{ when } j = k^{(з)}_i, \qquad (18)$$

where

$$m^{(з)}_{c_{ij}} = \left(1 - \frac{\gamma^{(з)}_{i,j+1}}{1+\gamma^{(з)}_{i,j+1}} e^{-\frac{\rho \Delta V^{(з)}_{ij}}{\overline{m}_{Q_{ij}}} \mu_{i,j+1}}\right) \overline{m}_{Q_{ij}}, \qquad (19)$$

$$\overline{m}_{Q_i} = \frac{m_{Q_i}}{1+\gamma^{(з)}_{э_{ij}}};\ \gamma^{(з)}_{э_{ij}} = \frac{m_{Q_i}}{m^{(з)}_{c_{i,j-1}}} - 1;\ \Delta V^{(з)}_{ij} = V^{(з)}_{ij} - V^{(з)}_{2ij};$$

$$(i = 1,2,\ldots,n;\ j = 1,2,\ldots,\ k^{(з)}_i).$$

Here $m^{(з)}_{c_{ij}}$ and $m^{(з)}_{c_{i,j-1}}$ – average capacity of the system, that consists of j -th first and (j-1) -th first serial connection of conveyers and hoppers i-th face path, t/min; $\gamma^{(з)}_{э_{ij}}$ – equivalent coefficient of accidents of system, that consists of j -th first serial connection of conveyers and hoppers i-th face path; $V^{(з)}_{ij}$ – volume of j hopper i-th face path, m^3; $V^{(з)}_{1_{ij}}$, $V^{(з)}_{2_{ij}}$ – minimal and maximum cargo volume in j-th hoppers of i -th face path, m^3; $k^{(з)}_i$ – number of hoppers in i-th face path; n – number of face paths.

Table 1 presents the initial data and the results of calculating the carrying capacity of the conveyor transport system of a self-similar dendritic structure with accumulative hoppers that work in the mode of keeping cargo volume within prescribed limits.

Calculations showed that for the system of underground conveyor transport of a self-similar tree structure with accumulative hoppers that work in the mode of keeping cargo volume within prescribed limits, with an increase in the volumes of the shaft and face hoppers, the average capacity of the transport system increases, and with an increase in the maximum specified volumes load in the hoppers of the shaft and face paths, the capacity of the transport system decreases.

Table 1

Initial data and results of calculation efficiency criteria of conveyer transport system in case of controlled hoppers m_c (n=5;i = j = 5)

m_{Q_i}, t/min	$Q_{n_i}^{(c)}$, t/min	$Q_{n_{ij}}^{(з)}$, t/min	$\gamma_i^{(c)}$	$\gamma_{ij}^{(з)}$	μ_i, 1/min	$V_i^{(c)}$, m³	$V_{2i}^{(c)}$, m³	$V_{2ij}^{(з)}$, t/min	$V_{ij}^{(з)}$, t/min	m_c, t/min
5,6	6,0	6,0	0,037	0,193	0,054	500,0	100,0	100,0	20,0	
5,6	6,0	6,0	0,037	0,193	0,054	500,0	100,0	100,0	20,0	
5,6	6,0	6,0	0,037	0,193	0,054	500,0	100,0	100,0	20,0	17,2
5,6	6,0	6,0	0,037	0,193	0,054	500,0	100,0	100,0	20,0	
5,6	6,0	6,0	0,037	0,193	0,054	500,0	100,0	100,0	20,0	

Conclusions. On the basis on method of dynamics of medium for Markov process we obtained mathematical models of conveyer transport system with self-similar tree structure with accumulative hoppers that work in the mode of keeping cargo volume within prescribed limits. At the same time, failures of conveyors and hoppers were taken into account for emergency, technological and organizational reasons.

Based on the developed mathematical models, the average capacity of the system of underground conveyor transport is determined at various ratios of cargo flows coming from the lavas and the productivity of hopper batchers.

It was found that the average capacity of the conveyor system with accumulative hoppers that work in the mode of keeping cargo volume within prescribed limits is more by 15% than the average capacity of the conveyor system with uncontrolled hoppers.

References:

1. Черкесов Г. Н. Надежность технических систем с временной избыточностью / Г. Н. Черкесов. – М.: Советское радио, 1974. – 296 с.

 ISSN 1562-9945

2. Системы подземного транспорта на угольных шахтах / В. А. Пономаренко, Е. Л. Креймер, Г. А. Дунаев [и др.]. – М.: Недра, 1975. – 309 с.
3. Брагинец Д. Д. Способы и средства поддержания защитного слоя груза в бункерах систем подземного конвейерного транспорта угольных шахт / Д. Д. Брагинец // Форум гірників – 2011: Матеріали міжнарод. конф., 12–15 жовтня 2011 р. – Дніпропетровськ: Національний гірничий університет, 2011. – С. 240–245.
4. Кирия Р. В. Управление бункерами, работающими в системах конвейерного транспорта угольных шахт / Р. В. Кирия, В. Ю. Максютенко, Д. Д. Брагинец // Збірник наукових праць НГУ. – Дніпропетровськ: Національний гірничий університет, 2012. – № 37. – С. 230–236.
5. Кирия Р. В. Математические модели функционирования систем конвейерного транспорта угольных шахт / Р. В. Кирия, Т. Ф. Мищенко, Ю. В. Бабенко // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 2′(91). – Дніпропетровськ, 2014. – С. 74–86.
6. Кирия Р. В. Определение пропускной способности и энергоемкости транспортирования горной массы конвейерным транспортом угольных шахт / Р. В. Кирия, Т. Ф. Мищенко // Збірник наукових праць НГУ. – Дніпропетровськ: Державний вищий навчальний заклад «Національний гірничий університет», 2015. – №46. – С. 96–104.
7. Хенли Э. Дж. Надежность технических систем и оценка риска / Э. Дж. Хенли, Х. Кумамото. – М.: Машиностроение, 1984. – 528 с.
8. Кирия Р. В. Применение фракталов к определению пропускной способности систем конвейерного транспорта горных предприятий / Р. В. Кирия // Системні технології: Регіональний міжвузівський збірник наукових праць. – Дніпропетровськ: 2010. – Випуск 2(67). – С. 167–174.