The Information Controlling Model Transport System During Transient Conditions

Pihnastyi Oleh, Kozhevnikov Georgii
Department of distributed information systems and cloud technologies,
National Technical University "KPI"
Kharkiv, Ukraine
pihnastyi@gmail.com, kozhevnikov.gk@gmail.com

Bondarenko Tetiana
Department of Informatics, Computer Technologies and Mathematics,
Ukrainian Engineering-Pedagogics Academy
Kharkiv, Ukraine
bondarenko_tc@uiipa.edu.ua

Abstract—This article is devoted to designing an information management system for the conveyor line of mining enterprises. The analytical design method for the transient mode of the stepped speed control system of the conveyor line was developed. The partial differential equation was used in constructing the conveyor line model. The description of the production system is fulfilled in the single step approximation. A decision was obtained which determines the state of the parameters of the production line for a technological position specified as a function of time. Has been determined the length of the transition period during which the initial condition for the distribution of labor objects along the conveyor affects the parameters of the state of the conveyor line. The method for calculating the current parameters of a conveyor line with the use of partial differential equations allows the design of control systems for production lines of conveyor type for transient modes. The originality of the results obtained is to improve the PDE-models of the conveyor-type production systems used to design highly efficient production control systems operating in transient modes.

Keywords—conveyor, PDE-model, production cycle; mass production; work in progress; balance equations; quasi-static process; stochastic process.

I. INTRODUCTION

The competitive ability of a modern industrial enterprise is largely determined by the level of optimization of the production process. Reducing the number of mineral reserves with a constant increase in the level of world standards requires the design of more and more effective management systems for the parameters of production of the mining enterprise.

This leads to the emergence of new concepts for the design of effective information systems, whose task is to increase the productivity of the production process in conditions of increasing restrictions on modes and methods of production [1].

One of the main tasks that have to be dealt with in modern mining enterprises are a) reducing the energy costs required to transport a ton of rock from the site of direct production to the place of shipment from the mine; b) increasing the capacity of mine conveyor systems [2-4]. These tasks are especially important when the mining enterprise is operating in transitional regimes, which are the results of constantly acting external and internal disturbances in the parameters of the production system [5], with a constant fluctuation of the global demand for products.

Belt conveyors are one of the main means of continuous transport in mining enterprises. Increasing the productivity of conveyors operating in quarries, their reliability, durability, and at the same time, energy saving are one of the most important conditions for increasing the technical level and efficiency of mining. In this regard, when designing information management systems for mining operations, an important place is given to the construction of efficient models of conveyor lines [2-6].

Conveyor lines of modern coal mines and quarries work for a considerable time when loading below the nominal value. Direct technological connection of prefabricated lines with conveyors of mining areas in the absence of an adjustable conveyor drive excludes the possibility of controlling the intensity of cargo flows on transport lines. The mechanical part of the conveyor has a significant inertia, which is caused by the masses of its moving elements. All this creates technical difficulties in solving the problem.

The conveyor speed is controlled in two ways: discreetly and continuously. Discrete regulation is based on a change in the speed of the conveyor belt when the input freight flow reaches certain threshold values accepted for adaptation values [6]. With continuous regulation, it is proposed to create such a mode of operation of the conveyor, in which the speed of the belt varies in proportion to the freight flow in such a way that the load on the belt remains constant and with the maximum possible design. When discrete control of conveyor speed, first of all, it is necessary to determine the required number of stages of drive speeds. The number of stages of speed regulation is determined based on the range of changes in the productivity of the mining machine, that is, based on a change in the coefficient of unevenness of the cargo flow. Wherein adhere to the recommendations: a) the conveyor should provide the maximum economically feasible and technically possible productivity of the excavating machine; 6) the average speed of movement of the traction organ should be minimal. The load on the belt from the rock material distributed along the route is directly proportional to the incoming value of the cargo flow and inversely proportional to the speed of the belt.
Analysis of modes of operation of conveyor transport shows the availability of reserves to improve the performance of transport equipment [1, 2, 6].

A significant increase in the efficiency of the use of conveyor transport can be achieved by regulating the speed of the conveyors depending on the traffic flow [4,6]. The actual task is the task of developing an informational system for automatic control of the speed of the belt conveyor in order to increase the efficiency of using the conveyor by reducing the length of the run of its traction body, reducing wear of friction parts and saving electricity. Also, the efficiency of production can also be improved if a set of conveyor belts is presented as a graph.

Particular importance in this case is the task of controlling the speed of the conveyor belt for the transitional regime, when a conveyor with unevenly distributed rock is launched along the entire transportation route.

II. CONVEYOR LINE MODEL

For the design of control systems of transport systems are used as the main models is discrete-event simulation and queuing theory models [3-5]. In this paper, to describe the continuous process of rock movement along the conveyor route, we use the PDE model (Partial differential equation is model). A detailed comparative analysis of discrete-event simulation, queuing model models and PDE-models in the field of application to the description of production systems with a streamlined method of production organization is carried out in [7, 8]. PDE-models are most in demand at the time when designing control systems that operate in transient modes or with variable capacity [9, 10], when the use of discrete-event simulation and the queuing model becomes inefficient. It should also be pointed out that PDE-models have been widely used for the design of highly efficient control systems for industrial production of semiconductor products [8, 11]. A general-purpose conveyor line model with a constant belt speed is presented in [12].

In this paper, attention is paid to designing a control system for a conveyor line in a transitional mode, when a conveyor is run on which a rock is distributed along a transport route.

The system of equations for the parameters of the production line in the single step approximation [13, 14], describing the movement of the rock along the conveyor line, can be reduced to the form:

\[
\frac{\partial \chi}{\partial t} + \frac{\partial \chi}{\partial S} = \delta(t)\lambda(t) , \int_{-\infty}^{0} \delta(S) dS = 1 ,
\]

\[
\chi(t, S) = a(t) \chi(t, S)
\]

under the initial conditions:

\[
\chi_{0}(0,S) = H(S)\psi(S), H(S) = \begin{cases} 0, & S < 0, \\ 1, & S \geq 0, \end{cases} S \in [0, S_{d}],
\]

where the parameters \(\chi(t, S)\) (t/m), \(\chi(t, S)\) (t/h) is the linear density of the rock and the rate of movement of the rock at time t (h) at the point of the route determined by the coordinate S (m). Flow parameters \(\chi(t, S)\), \(\chi(t, S)\) linked coefficient \(a = a(t)\) (meter / hour), which determines the conveyor belt speed of the conveyor line.

\(\lambda(t)\) is the intensity of the arrival of the rock on the conveyor line at the point with the coordinate \(S=0\). Define the required yield of rock from the conveyor line as \(\sigma(t)\) (t/h).

Using the new variables [12]

\[
\tau = \frac{t}{T_{d}}, \quad \xi = \frac{S}{S_{d}}, \quad \theta_{0}(\tau, \xi) = \left[ \chi(t, S) \right]_{\Theta}, \psi(\xi) = \frac{\Psi(S)}{\Theta},
\]

\[
\gamma(\tau) = \lambda(\tau) \frac{T_{d}}{S_{d} \Theta}, \quad g(\tau) = \sigma(\tau) \frac{T_{d}}{S_{d} \Theta}, \quad g(\tau) = a(t) \frac{T_{d}}{S_{d}} ,
\]

\[
\Theta = \max \left\{ \Psi(0) \frac{\lambda(0)}{a(0)} \right\}, \quad \delta(\xi) = S_{d} \delta(S), \quad H(\xi) = H(S)
\]

we write the system of (1-3) in the dimensionless form

\[
\frac{\partial \theta_{0}(\tau, \xi)}{\partial \tau} + g(\tau) \frac{\partial \theta_{0}(\tau, \xi)}{\partial \xi} = \delta(\xi) \psi(\xi) ,
\]

\[
\theta_{0}(0, \xi) = H(\xi) \cdot \psi(\xi),
\]

where \(T_{d}\) is the time during which the rock passes the entire transportation route, from the moment it enters the conveyor belt and up to the point of unloading from the conveyor; \(S_{d}\) is length of conveyor line.

The system of (5), (6) corresponds to a system of characteristics:

\[
\frac{d \xi}{d \tau} = g(\tau) , \quad \xi|_{\tau=0} = \beta ,
\]

\[
\frac{d \theta_{0}(\tau, \xi)}{d \xi} = \delta(\xi) \cdot \gamma(\tau) ,
\]

\[
\theta_{0}(0, \beta) = H(\beta) \cdot \psi(\beta).
\]

Integration of the system of (5), (6) with allowance for (7) allows us to obtain a general solution in the form

\[
\theta_{0}(\tau, \xi) = \left[ H(\xi) - H(\xi G(\tau_{s})) \right] \frac{\gamma(\tau_{s})}{g(\tau_{s})} +
\]

\[
+ H(-G(\tau_{s})) \psi(-G(\tau_{s})),
\]

where

\[
G^{-1}(G(\tau) - \tau) = \tau_{s}, \quad G(\tau) = \int g(\tau) d\tau .
\]

III. ANALYSIS OF THE SOLUTION FOR THE TIME INTERVAL OF THE TRANSITION PERIOD

The paper considers the transient mode of functioning of the conveyor line during the time interval \(T_{p}\), \(0 < T_{p} < T_{d}\). In the task of controlling the speed of the conveyor line during the transition period, we will be interested in the state of the rock density at the exit from the conveyor line \(\theta_{0}(\tau, 1)\). The tempo of issuing the rock from the conveyor \((S = 1)\) is the product of the speed of the type by the linear density of the rock at the specified point.
\[ \theta_i(r,1) = g(r) \cdot \theta_0(r,1). \] (10)

For \( \tau < T_i \) under \( \xi = 1 \)

\[ G(\tau) - \xi = G(\xi) < 0, \] (11)

That allows us to write the solution (8) in the case \( \xi = 1 \) in a simplified form:

\[ \theta_0(\tau,1) = \psi(1 - G(\tau)). \] (12)

\[ \theta_i(\tau,1) = g(\tau) \cdot \psi(1 - G(\tau)). \] (13)

In the absence of control at a constant speed of the conveyor belt \( g(\tau) = g_0 \), solution (12) is representable in the form

\[ \theta_0(\tau,1) = \psi(1 - g_0 \tau). \] (14)

Analysis of the solutions of the form (13) is represented in the work [12].

IV. THE CONSTRUCTION OF CONTROL FOR THE TIME INTERVAL OF THE TRANSITION PERIOD

Approximate methods (based on the use of the orthogonal functions) for solving the problem of optimal control of the production flow line using the PDE model of production systems are considered in [15,16]. In this paper we consider a method for designing optimal control, based on the method of characteristics. This approach allows us to obtain an exact solution of the problem under consideration.

We formulate the problem of constructing an optimal program for controlling the conveyor belt speed for the transient operation of the conveyor line (12), (13): determine output of rocks \( \theta_i(\tau,1) \) from the conveyor line for a period of time \( \tau \in [0, T_d] \) at step speed control of conveyor belt

\[ u(\tau) = (u_1, u_2), \] (15)

which leads to a minimum of the functional

\[ \int_0^{T_d} [\theta_i(\tau,1) - \partial(\tau)] d\tau \rightarrow \min \] (16)

with differential connections (5):

\[ \frac{\partial \theta_0(\tau,\xi)}{\partial \tau} + g(\tau) \frac{\partial \theta_0(\tau,\xi)}{\partial \xi} = \partial(\xi) \psi(\tau), \]

\[ g(\tau) = u(\tau), \]

restrictions

\[ \theta_0(\tau, \xi) \geq 0, \quad \xi > g(\tau) \geq 0 \] (17)

and initial conditions (6)

\[ \theta_0(0, \xi) = H(\xi) \cdot \psi(\xi). \] (18)

The definition of optimal control of the conveyor line reduces to an optimization problem of the form

\[ [\theta_i(\tau,1) - \partial(\tau)] = [u(\tau) \cdot \psi(1 - G(\tau)) - \partial(\tau)] \rightarrow \min. \] (19)

Since for the transition period

\[ \psi(l - G(\tau)) > 0, \] (20)

then it follows for optimal control \( u(\tau) \)

\[ u(\tau) = \frac{\partial(\tau)}{\psi(l - G(\tau))}, \quad \psi(l - G(\tau)) > 0. \] (21)

V. CALCULATION OF THE TRANSPORTATION TIME FOR OPTIMAL CONTROL OF CONVEYOR BELT SPEED

Duration of transportation of rock is one of the most important characteristics of the conveyor line. The task of calculating the production cycle is reduced to integrating the

\[ \tau_d = \int_0^{1} \frac{d\xi}{u(\tau)} \] (22)

and is determined by the control modes. When considering the transition period, the estimated transportation time \( \tau_d \) (22) determines in the considered case the duration of the transition period. The system of characteristic (7) makes it possible to determine the trajectory of the movement of an individual rock element in the course of movement along the transportation route. Control modes \( u(\tau) = (u_1, u_2), \)

\[ 0 < u_1 < u_2 < \infty \] (23)

allow to determine the maximum and minimum time of the transient process

\[ \tau_{\min} = \frac{1}{u_2} < \tau_d < \frac{1}{u_1} = \tau_{\max}. \]

VI. DISCUSSION AND ANALYSIS

World trends in the development of economic, industrial, telecommunication systems are associated with a constant increase in material and information flows. In the process of movement, the flow elements have the processing at network nodes. The processing is, as a rule, stochastic non-stationary character. Flows can converge and diverge. Most of the existing methods used in calculating the flow parameters of both production and growing traffic are based on the application of the Markov model of random processes [18,19]. However, with an increase in the number of nodes in the transport network (both production and telecommunication), this approach encounters a number of constraints.
The first limitation: flow models and methods for determining their characteristics in different parts of the transport network as a result of the processing in the network nodes are required. Along with the methods of statistical analysis, a successful approach is a model using a stochastic differential equation (Brownian motion model).

The second limitation is associated with a large number of nodes in the network along the transportation route. This constraint is more significant than the first. It requires considering economic, production, telecommunication systems as complex dynamic distributed systems containing a large number of nodes and elements [20]. This is of particular importance for modeling systems of great length and systems operating in a transient non-stationary mode (among which the initial motion should be highlighted). In addition, to describe the transition process, not only the flow characteristics are important, but also the time of its duration, by the completion of which a transition to simpler stationary models is possible.

Due to the presence of the indicated constraints, the solution of the following problems is currently relevant for the development of telecommunication, economic, production systems: 1) Development and further development of distributed models (PDE - models) used to describe the flow parameters: 2) The rationale for the transition from the stochastic equation (Brownian motion model) [18, 19] to the Fokker-Planck (PDE model) [20], which can be used to calculate the probability density in stochastic differential equations. 3) Construction of analytical solutions for stationary and transient modes of functioning of distributed systems. 4) Determination of the duration of the transitional modes of functioning of distributed systems.

In this paper, we focused on the detailed construction of an analytical solution for a stationary and transient process and an analysis of the duration of the transient process associated with the initial motion (the start of the system).

From the point of view of analyzing the results obtained for the functioning of transport systems, it is of practical interest to calculate the control of the speed of movement of elements $u(\tau)$ along the transport route, at which it is possible to provide a given output flow from the system depending on time. We assume that the output flow is required

$$\mathcal{A}(\tau) = \frac{1 + \sin(\pi \tau)}{2}$$

in the absence of phase restrictions and control restrictions. If the initial distribution of elements along the transportation route is constant and is presented in the form $\psi(\xi) = \psi_1 = 1$, then the optimal control, by virtue of (21), will have the form

$$u_1(\tau) = \mathcal{A}(\tau) / \psi_1 = \mathcal{A}(\tau).$$

Thus, the optimal control $u(\tau) = u_1(\tau)$ on the interval $\tau \in [0, T]$ is determined by a given function $\mathcal{A}(\tau)$ (Fig.1).

For the case when the initial distribution is represented by a linear function $\psi(\xi) = \psi_2(\xi) = \xi$, the optimal control $u(\tau) = u_2(\tau)$ (Fig.1) is determined by solving the transcendental (21)

$$u(\tau) = \mathcal{H}(\tau) \frac{1 - \int_0^\tau u(a) da}{\int_0^\tau u(a) da}, \quad G(\tau) = \int_0^\tau u(a) da$$

Since the initial distribution $\psi(\xi)$ can be represented as an expansion in a Fourier series on the interval $0 \leq \xi \leq 1$, we consider the solution of transcendental (21) for the initial conditions

$$\psi(\xi) = \psi_3(\xi) = (2 + \cos(2\pi \tau))/3, \quad \text{for} \quad u(\tau) = u_3(\tau)$$

$$\psi(\xi) = \psi_4(\xi) = (2 + \cos(4\pi \tau))/3, \quad \text{for} \quad u(\tau) = u_4(\tau).$$

The solution allows us to give a qualitative estimate for optimal control under the periodic nature of the initial conditions. The optimal controls $u(\tau) = u_3(\tau)$ and $u(\tau) = u_4(\tau)$ obtained as a result of solving (21) are presented in Fig. 1.

![Fig. 1 Optimal control for transient process](image)

The controls on the interval $\tau \in [0, T]$ form the value linear density value $\theta_0(\tau, 0)$ at the system input

$$\theta_0(\tau, 0) = \gamma(\tau) / u(\tau).$$

This process is cyclic, associated with the delay effect, depending on the flow parameters, it can lead to the development of instabilities for $\theta_0(\tau, \xi)$. This fact requires the imposition of additional restrictions on the design of control systems for streaming parameters in the models of information systems.

VII. Conclusion

The obtained results of the research are basic for the development of control systems for conveyor lines in the transitional regime. The influence of the initial conditions on the rate of rock output from a conveyor-type transport system was considered. An important result of this work is the method of calculating the duration of the transition period, based on the use of the characteristic equation. The dependence of the duration of the transition period on the initial distribution of labor objects along the conveyor line was obtained. The length of the transition period is determined by the selected speed control mode of the conveyor belt. Next perspective of the development of the issue discussed in the paper is the search for other areas of application of our model, including the field of telecommunication systems.

REFERENCES

[1] Continuous conveyors. Belt conveyors for loose bulk materials. Basics for calculation and dimensioning, DIN 22101, 2002

[2] Comprehensive belt conveyor expertise from a single source. SIMINE Conveyor - Siemens. Market-specific Solutions https://new.siemens.com/global/en/markets/mining-industry/transport/conveyor-systems.html, 2018
type at a constant speed moving subjects of labor]." Bulletin of V.
Karazin Kharkiv National University: Series «Mathematical
Modelling. Information Technology. Automated Control Systems»,
no. 32, pp. 60-74, 2016. (In Russian).

[13] V.P. Demutskiy, V.S. Pihnastaya and O.M. Pihnastyi.
"Stochasticheke opisanie ekonomiko-proizvodstvennyh sistem s
massovym vyypsukom produkci [Stochastic description of
economic-production systems with mass production]." Reports of
the National Academy of Sciences of Ukraine, Kyiv: PH
"Akaedemeriyodhya", no. 7, pp. 66-71, 2005. (In Russian).

[14] O.M. Pihnastyi. Statisticheskaja teorija sistem upravlenija
potochnym proizvodstvom [Statistical theory of control systems of
the flow production]. Beu Bassin: LAP LAMBERT Academic
Publishing, 2018.

[15] O.M. Pihnastyi. "Statisticheskaja teorija sistem upravlenija
potochnym proizvodstvom [The task of optimal operational control
of macroparameters of a production system with mass production]."
Reports of the National Academy of Sciences of Ukraine, Kyiv: PH
"Akaedemeriyodhya", no. 5, pp. 79-85, 2006. (In Russian).

[16] O. M. Pihnastyi and V. Y. Zaruba. "Zadacha programmnogo
upravlenija parametrami potochnoj linii s ispol'zovaniem
sverhurochnyh rabot [Tasks of the program control of the
parameters of the current line using overtime work] in
Informacionnye tehnologii v upravlenii: tezisy dokladov
mezhdunarodnoj nauchno-prakticheskoy konferencii (ITU-2012)
[Information Technologies in Management: Proceedings of the 5th
Russian Multiconference on Management Problems (ITU-2012)]. St.
Petersburg: CRI “Electrical appliance”", 2012, pp. 107-114. (In Russian).

[17] O.M. Pihnastyi and V.D. Khodusov. "Raschet proizvodstvennoy
cikla s primeneniem statisticheskoy teorii proizvodstvenno-
tehnicheskoy sistem [Calculation of the production cycle using the
statistical theory of production and technical systems]." Reports of
the National Academy of Sciences of Ukraine, Kyiv: PH
"Akaedemeriyodhya", no. 12, pp. 38-44, 2009. (In Russian).

[18] D.V. Ageyev and A.N. Kopyliev, "Modelirovanie informacionnyh
potokov v multiservicey seti NGN pri reshenii zadach
parametricsheskogo sinteza [Information streams modeling in
multiservice network NGN for parametrical synthesis problem
solving]." Radio electronics, informatics, control, no. 2, pp. 48-52,
2010. (In Russian).

[19] I. Norros. "A storage model with self-similar input." Queueing
Systems. vol.16, issue 3-4, pp. 387-396, 1994. DOI:
https://doi.org/10.1007/BF01158964.

[20] Bo Du, Xiuguo Lian and Xiwang Cheng. "Partial differential
equation modeling with Dirichlet boundary conditions on social
networks," Boundary Value Problems, no. 50, 2018. - DOI:
https://doi.org/10.1186/s13661-018-0964-4