https://doi.org/10.33271/nvngu/2023-5/156

O. M. Pihnastyi*,
orcid.org/0000-0002-5424-9843,
M. O. Sobol,
orcid.org/0000-0002-7853-4390

National Technical University "Kharkiv Polytechnic Institute", Kharkiv, Ukraine
* Corresponding author e-mail: pihnastyi@gmail.com

ANALYSIS OF THE INPUT MATERIAL FLOW OF THE TRANSPORT CONVEYOR

Purpose. To develop a method for analyzing the material flow entering the input of a conveyor section, based on the decomposition of the input material flow into a deterministic material flow and a stochastic material flow.

Methodology. The analysis of experimental data characterizing the input material flow was performed using the methods of the canonical Fourier representation of a random process.

Findings. A method for representing a stochastic material flow as a combination of a deterministic process and a stationary random process with ergodic properties is proposed.

Originality. The originality of the obtained results lies in the fact that, for the first time, a method of analysis based on the decomposition of the input material flow for a conveyor section has been proposed, which, unlike the existing methods of input flow typing for the mining industry, will allow us to independently perform deterministic flow typing and stochastic material flow typing in transport conveyors. The proposed approach makes it possible to highlight special characteristics separately for deterministic and stochastic material flows. This will make it possible to use the obtained regularities to increase the accuracy of the conveyor model and will accordingly increase the quality of the belt speed control systems and the flow of material coming from the input bunker. The obtained results are of particular importance due to the fact that the characteristics of the deterministic material flow are directly related to the technical or technological factors of material extraction.

Practical value. The obtained results allow determining statistically stable regularities for the incoming flow, which makes it possible, based on these regularities from the set of available control algorithms, to choose the optimal control algorithm for the parameters of the operating conveyor section. This allows reducing the enterprise's energy costs of the transportation of material. The proposed method can be successfully applied to build random number generators simulating the sequence of values of the input flow of material. The developed generators can be used both for validating existing belt speed control systems and creating new control systems based on neural networks. This opens perspectives for the design of effective systems for controlling the flow parameters of transport system, based on the transport conveyor model, which takes into account the stochastic nature of the incoming material flow.

Keywords: *transport conveyor, distributed system, stochastic flow, correlation function*

Introduction. The traditional dynamic model of the belt conveyor, which is used to synthesize systems for controlling the speed of the belt or the input flow of the material, provides for a deterministic input flow of material [1, 2], the value of which is determined by the mass of rock entering the input of the conveyor section per unit of time. The reason for this situation is the difficulty of identifying special characteristics of the input flow of material that would establish statistically stable patterns of behavior of a random variable λ that determines the average value of the flow of material entering the transport system for the time interval accepted for statistical analysis. Often, a minute interval is taken as this time interval. To simplify the simulation of the input flow of material, various types of distribution of a random variable λ are used, among which the most common is the normal distribution law with unbounded left and right tails of the distribution density function. In determining the flow characteristics of the transport system, the truncation of the accepted normal distribution law is neglected. When approximating the distribution of a random variable λ that determines the average value of the material flow over the accepted time interval, the patterns of its formation due to a number of technical and technological factors are not taken into account, which limits the scope of this approach. The construction of functional empirical relationships between the statistical characteristics of the random variable λ requires experimental research, on the basis of which a mathematical model of the random input flow of material is built. To conduct experimental studies, a set of conveyors with different characteristics of the input flow of material is required, which is a difficult task to implement. At the same time, there is a fairly large number of works in which a graphical representation of implementations of a random flow of materials entering the input section of the existing transport conveyor is given. The presented implementation of the random flow of materials for existing transport systems of conveyor type is the basis for building a mathematical model [3, 4]. This requires the development of a methodology for analyzing implementations of the input flow of material, which allows you to build functional links between the statistical characteristics of the random variable λ.

Statement of the problem. One of the urgent problems associated with reducing the unit costs of transporting material in the mining industry is the problem of synthesis algorithms for controlling the speed of the belt of the conveyor section with a random input flow of material [5]. This is explained by the fact that there is no necessary amount of information about the statistical characteristics of the input flow of material entering the input section of the transport system, when using modern cleaning and tunneling equipment. In general, the input flow of material is described as the product of random processes [6, 7]

$$\lambda(t) = \lambda_t(t)\lambda_s(t), \tag{1}$$

where $\lambda_t(t)$ the process represents a discrete sequence of pulses with a random duration of material receipt and at random intervals of its absence, and the process $\lambda_s(t)$ is a continuous random process. As a rule, in the synthesis of control algorithms for the process $\lambda_s(t)$ the normal law of distribution of mine cargo flow is assumed [6]

$$f_s(\lambda) = \frac{1}{\sigma_s\sqrt{2\pi}}\exp\left(-\frac{(\lambda - m_s)^2}{2\sigma_s^2}\right),$$

or the logarithmically normal law

$$f_s(\lambda) = \frac{1}{\lambda\sigma_\lambda\sqrt{2\pi}}\exp\left(-\frac{(\ln\lambda - m_\lambda)^2}{2\sigma_\lambda^2}\right),$$

with mathematical expectation m_s, standard deviation σ_s and correlation function [7]

$$K_s(\eta) = \sigma_s^2 \exp(-\eta / \eta_{kor}). \quad (2)$$

The correlation time η_{kor} depends on the way the production process of material extraction is organized. For the random process $\lambda(t)$ the probability density is written as

$$f(\lambda) = \frac{\mu_{12}}{\mu_{12}+\mu_{21}}\delta(\lambda) + \frac{\mu_{21}}{\mu_{12}+\mu_{21}} f_s(\lambda); \quad (3)$$

$$1 = \int_{-\infty}^{-\infty} \delta(\lambda) d\lambda, \quad \delta(\lambda) \text{ at } \lambda \neq 0,$$

with the intensity of the transition μ_{km} from the state k (the material flow does not enter the section input) to the state m (the material flow enters the section input). The representation of the input flow of material entering the input of the conveyor section in the form of a random process (1) with a distribution density of the material flow value (3) has long been used both in solving problems of choosing the performance of the conveyor section and for the synthesis of flow control systems.

For modern transport systems, the key issue is to reduce specific energy consumption, which leads to the requirements of increasing the coefficient of filling the conveyor section with material, and, accordingly, of the designing of transport systems with a continuous supply of material [8, 9]. Such systems are characterized by inequality $\mu_{21} \gg \mu_{12}$, which allows us to represent the expressions (1), (3) in the following form $\lambda(t) \approx \approx \lambda_s(t), f(\lambda) \approx f_s(\lambda)$. The normal (1) and logarithmically normal (3) laws of distribution of mine cargo flow proposed for use have unlimited tails. When constructing input material flow generators for simulation models of conveyor transport systems, this can lead to errors in the synthesis of optimal controls of the flow parameters. In part, this problem can be solved by using the truncated law of distribution.

Analysis of works [2, 10, 11] shows that the input flow of material at time t is characterized by mathematical expectation and standard deviation, whose values are determined by functions that change periodically over time, can be described by the normal and logarithmically normal distribution laws only in individual cases. The asymmetry of the distribution law depends on the equipment used. The presence of fluctuations in the magnitude of the input flow of material is determined by the speed of movement deep into the field and the rhythm of the processes of material extraction [2, 12]. In this regard, the question of developing new methods for typing input material flows is relevant.

Random material flows typing can be performed as a result of approximation of individual components of the material flow of transport systems. For approximation, publications should be used that demonstrate and analyze the implementation of random material flow for existing conveyor-type transport systems. The main difficulty in analyzing implementations of a random material flow lies in the development of a method that allows us to represent a random flow of material in the form of a superposition of a deterministic process and a stationary random process that has ergodic properties. The typing problem will be divided into two tasks: a) the problem of typing the nonstationary deterministic process; b) the problem of typing the stationary random process having ergodic properties. This study is devoted to the problem of dividing a random flow of material, represented by its separate implementation, into two flows, each of which is subject to typing.

Literature review. Analysis of publications demonstrates that the flow of material entering the input of the transport system is a continuous process, the mathematical expectation of which can be represented as a periodic time functions. Volumetric productivity $\lambda_v(t) = 0.65l(t)$ (m^3/h) of the rotary excavator SRs 2000 with material flow $\lambda(t)$ t/h, registered at the Belchatovsky brown coal quarry [10] is shown in Fig. 1.

The uneven flow of material entering the input of the transport system is formed at the material extraction site and has a periodic law. The oscillation amplitude is one third of the maximum value of the material flow at a constant oscillation period for the recorded experimental values of the material flow.

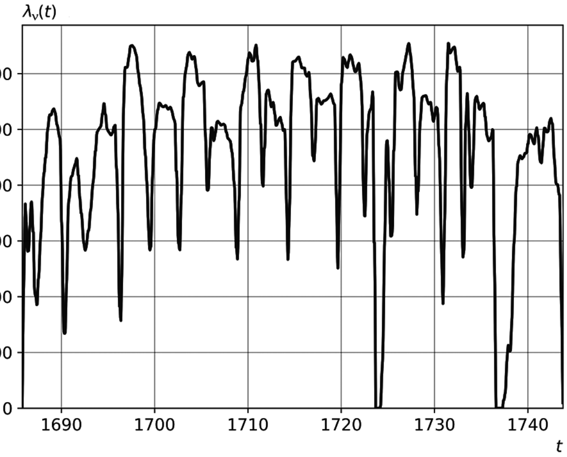

Fig. 1. Volumetric productivity $\lambda_v(t)$ m^3/h, rotary excavator SRs 2000 (Belchatov), t min [10]

The flow of material has a periodic character, whose experimental values are presented in Fig. 2 [11]. Oscillations with short and long periods of oscillations are clearly expressed.

The material flow value $\lambda(t)$ t/h is given for a scale measured in minutes. The amplitude and length of the oscillation period depends on the process equipment and the variability of its functioning.

Experimental measurements presented in Fig. 3 are used by the authors to verify the correctness and accuracy of the

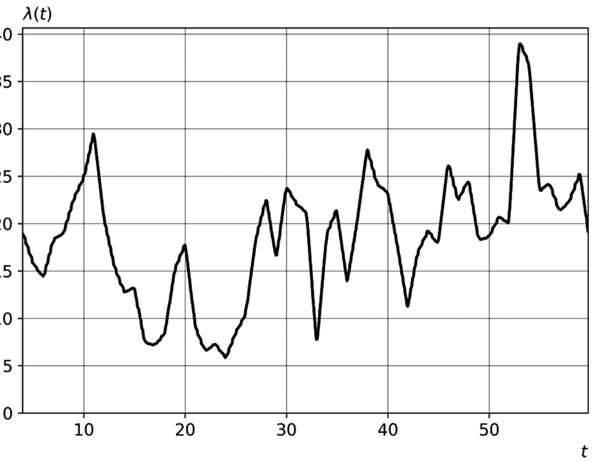

Fig. 2. Material flow $\lambda(t)$ t/h, test K07, t min [11]

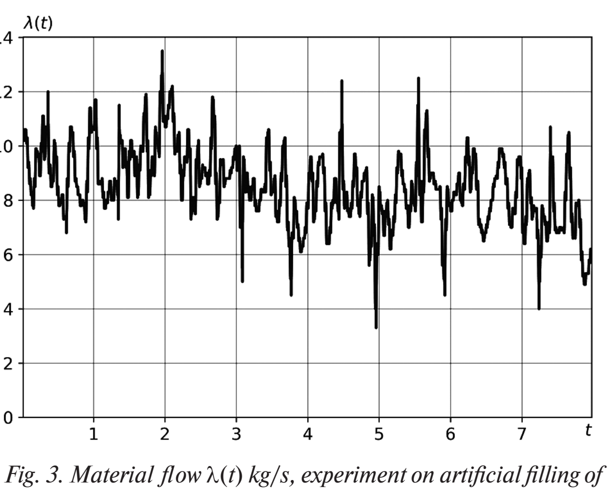

Fig. 3. Material flow $\lambda(t)$ kg/s, experiment on artificial filling of conveyor belt with iron powder, t s [2]

measurement system for the uneven distribution of bulk material [2]. During the measurement, three modes of conveyor belt speed were selected: 0.5, 1.0 and 1.5 m/s. Experiments on artificial filling of the conveyor belt from the guild chute with iron ore powder were carried out in three modes with an average material consumption: 2.971 (10 t/h); 8.911 (32 t/h) and 14.853 kg/s (53 t/h). A variant with an average material consumption: 2.971 kg/s (10 t/h) at a belt speed of 1.0 m/s is presented in Fig. 3. The study shows the dependence of the change in time of the average value of the material flow entering the input section of the conveyor. The law of change in time of the average value of the input flow is qualitatively close to the sinusoidal law.

For operated in NCC Industry (Uddevalley, Sweden) three-stage installation for the production of aggregates, the flow of material coming from the equipment to the inlet section of the conveyor is shown in Fig. 4 [12]. To measure the magnitude of material flow, mass measuring devices connected to the cloud solution were used. The collected data was recorded in cloud storage with a frequency of 0.1–0.2 Hz.

Fig. 5 shows the input flow of material for the section of the transport system, which is studied in [13]. The time intervals, the issue of which material flow has reached the maximum limit area, as well as the intervals in which the material flow was absent are discussed.

The paper emphasizes that the flow of material entering the inlet of the section has a mean deviation of 345 t/h, which is a small deviation from the average value of the investigated input flow of iron ore $\langle\lambda(t)\rangle = 8000$ t/h, entering the inlet of the conveyor section. The experimental data determining this flow of material are characterized by the representation of a random flow of material in the form (1).

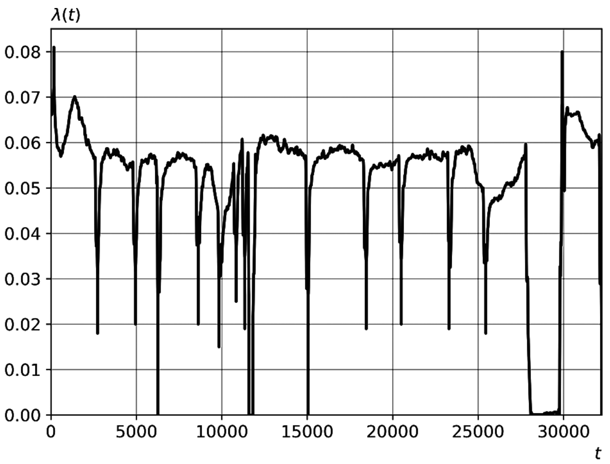

Fig. 4. Material flow λ(t) t/s, NCC Industry, t s [12]

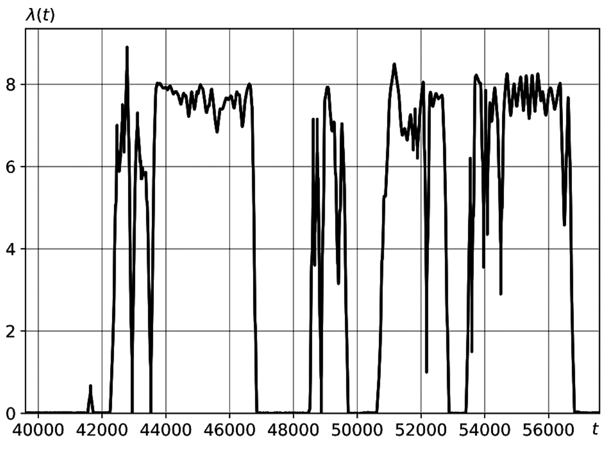

Fig. 5. Material flow λ(t) t/h, conveyor CV 1, t min [13]

Characteristics of volumetric capacity $\lambda_v(t) = 0.65\lambda(t)$ formed by bucket excavator Takraf SRs 2000.32/5 are given in [3]. The material flow enters the inlet of the conveyor section continuously with an average capacity of 2730 m^3/h with a theoretical power of 6600 m^3/h. The dynamics of material supply at the section inlet for 360 seconds is demonstrated, which is a typical characteristic of the functioning of the bucket excavator Takraf SRs 2000.32/5. The minimum peaks on the graphs characterize the length of time period during which the bucket excavator enters and leaves the section. The flow of material is a continuous random stream, whose average value can be given by a periodic function. In [4] the deterministic flow of material for constructing a training data set for a transport conveyor model based on the use of a neural network is considered.

The review of experimental data gives a general idea of the nature and qualitative regularities of material flows entering the transport system, namely: a) the implementations of the studied random flows of material at modern mining enterprises are characterized for the most part by continuity; b) they contain components that change periodically over time. This makes it impossible to use the existing method for typing input material flows for the synthesis of control algorithms [6, 7].

Data sets (λ_i, t_i) are presented in Figs. 1–7 obtained as a result of scanning graphic images at time $t_i = (t_{\min} + n\Delta t)$, $\Delta t = (t_{\max} - t_{\min})/N$, $n = 0...N$, where $t_{\min}$, $t_{\max}$ are the initial and final value of the time interval of experimental measurements. When scanning images, $N \approx 5 \cdot 10^4$ abscissa dots are used.

Research method. To determine the statistical characteristics, we represent the input flow of material $\lambda(t)$ in the form of a random process

$$\lambda(t) = \lambda_d(t) + \lambda_s(t),$$

where $\lambda_d(t)$ is a deterministic function of time t; $\lambda_s(t)$ – stationary centered ergodic process, which is determined by one-dimensional distribution density $f_{\lambda s}(\lambda)$ with mathematical expectation $m_{\lambda s} = 0$ and standard deviation $\sigma_{\lambda s}$ of a random variable λ.

Taking into account the publications devoted to the study on material flows entering the input of the transport system [6, 7], assume that the correlation function for the input material flow is (2). For the stationary ergodic process $\lambda_s(t)$ the mathematical expectation $m_{\lambda s}$, standard deviation $\sigma_{\lambda s}$ and correlation function $k_{\lambda s}(\eta)$ can be determined by integrating the implementation of the random process over time

$$m_{\lambda s} = \lim_{T\to\infty}\frac{1}{T}\int_0^T \lambda_s(t)dt; \quad \sigma_{\lambda s}^2 = \lim_{T\to\infty}\frac{1}{T}\int_0^T \lambda_s^2(t)dt; \tag{4}$$

$$k_{\lambda s}(\eta) = \lim_{T\to\infty}\frac{1}{T}\int_0^T \lambda_s(t)\lambda_s(t-\eta)dt. \tag{5}$$

A sufficient condition for the fulfillment of equalities (4), (5) is the ultimate equality $\lim_{\eta\to\infty} k_{\lambda s}(\eta) \to 0.$ If for the presented data sets (λ_i, t_i)characterizing a specific process of material receipt, the correlation function $k_{\lambda s}(\eta)$ can be represented by a dependence close to the dependence (5) and the condition $\eta_{cor} < (t_{\max} - t_{\min})$, then to calculate the mathematical expectation $m_{\lambda s}$, standard deviation $\sigma_{\lambda s}$ and correlation function $k_{\lambda s}(\eta)$ the following expressions can be used

$$m_{\lambda s} = \int_{t_{\min}}^{t_{\max}} \frac{\lambda_s(t)}{t_{\max} - t_{\min}}dt; \quad \sigma_{\lambda s}{}^2 = \int_{t_{\min}}^{t_{\max}} \frac{\lambda_s{}^2(t)}{t_{\max} - t_{\min}}dt; \tag{6}$$

$$k_{\lambda s}(\eta) = \frac{1}{t_{\max} - t_{\min}}\int_{t_{\min}}^{t_{\max}} \lambda_s(t)\lambda_s(t-\eta)dt. \tag{7}$$

Periodic function $\lambda_d(t)$ is determined from the quality criterion of the approximation process

$$\int_0^{\eta_{kor}} \left(k_{\lambda s0}(\eta)-k_{\lambda s}(\eta)\right)^2 d\eta =$$
$$= \int_0^{\eta_{kor}} \left(\sigma_{\lambda s}^2 \exp(-\eta/\eta_{kor})-k_{\lambda s}(\eta)\right)^2 d\eta \to 0. \quad (8)$$

The joint solution of equations (6, 7) with the quality criterion of the approximation process (8) allows determining an approximate type of function $\lambda_d(t)$ for given values of the correlation time η_{kor} and standard deviation $\sigma_{\lambda s}$.

Description of research methods. Let us introduce dimensionless variables and parameters

$$\gamma(\tau)=\frac{\lambda(t)}{m_d};\quad \gamma_s(\tau)=\frac{\lambda_s(t)}{m_d};\quad \gamma_d(\tau)=\frac{\lambda_d(t)}{m_d}; \quad (9)$$
$$\tau=\frac{t-t_{\min}}{t_{\max}-t_{\min}};\quad \tau_n=\frac{n}{N};\quad n=0..N;$$
$$m_d=\frac{1}{t_{\max}-t_{\min}}\int_0^{t_{\max}-t_{\min}}\lambda(t)dt=\frac{1}{N+1}\sum_0^N\lambda(t_n);$$
$$m_s=\frac{m_{\lambda s}}{m_d};\quad \sigma_s=\frac{\sigma_{\lambda s}}{m_d};\quad \tau_{kor}=\frac{\eta_{kor}}{t_{\max}-t_{\min}};$$
$$k_s(\eta)=\frac{k_{\lambda s}(\vartheta)}{m_d{}^2};\quad \sigma_s=\frac{\sigma_{\lambda s}}{m_d};\quad \tau_{kor}=\frac{\eta_{kor}}{t_{\max}-t_{\min}};$$
$$\vartheta=\frac{\eta}{(t_{\max}-t_{\min})}=\frac{(t_i-t_j)}{(t_{\max}-t_{\min})}=(\tau_i-\tau_j),$$

considering which the flow of material will be presented in dimensionless form $m_s = m_{\lambda s}/m_d = 0$

$$\sigma_s^2=\frac{\sigma_{\lambda s}^2}{m_d^2}=\frac{1}{m_d^2\left(t_{\max}-t_{\min}\right)}\int_{t_{\min}}^{t_{\max}}\lambda_s^2(t)dt=\int_0^1\gamma_s^2(\tau)d\tau; \quad (10)$$
$$k_s(\vartheta)=\frac{k_{\lambda s}(\eta)}{\sigma_s^2 m_d^2}=\frac{1}{\sigma_s^2 m_d^2(t_{\max}-t_{\min})}\int_{t_{\min}}^{t_{\max}}\lambda_s(t)\lambda_s(t-\eta)dt=$$
$$=\frac{1}{\sigma_s^2}\int_0^1\gamma_s(\tau)\gamma_s(\tau+\vartheta)d\tau;$$
$$k_{s0}(\vartheta)=\frac{k_{\lambda s0}(\eta)}{\sigma_s^2 m_d^2}=\frac{\sigma_{\lambda s}^2}{\sigma_s^2 m_d^2}\exp\left(-\frac{\vartheta}{\tau_{kor}}\right)=\exp\left(-\frac{\vartheta}{\tau_{cor}}\right); \quad (11)$$
$$\gamma(\tau) = \gamma_d(\tau) + \gamma_s(\tau). \quad (12)$$

Correlation functions $k_s(\vartheta)$ and $k_{s0}(\vartheta)$ are presented in a dimensionless form with the condition of normalization $k_s(0) = 1$; $k_{s0}(0) = 1$. Since the correlation function of a stationary random process is a paired function $k_s(\vartheta) = k_s(-\vartheta)$, at the interval [–1; 1] the correlation function can be decomposed into the Fourier series by paired harmonics. We present the correlation function in the form

$$k_s(\vartheta)=\frac{k_s(\vartheta)+k_s(-\vartheta)}{2}=\frac{1}{2\sigma_s^2}\int_0^1\gamma(\tau)\left(\gamma(\tau-\vartheta)+\gamma(\tau+\vartheta\right)d\tau+$$
$$+\frac{-1}{2\sigma_s^2}\int_0^1\gamma_d(\tau)\left(\gamma(\tau-\vartheta)+\gamma(\tau+\vartheta)\right)d\tau+$$
$$+\frac{-1}{2\sigma_s^2}\int_0^1\gamma(\tau)\left(\gamma_d(\tau-\vartheta)+\gamma_d(\tau+\vartheta)\right)d\tau+ \quad (13)$$
$$+\frac{1}{2\sigma_s^2}\int_0^1\gamma_d(\tau)\left(\gamma_d(\tau-\vartheta)+\gamma_d(\tau+\vartheta)\right)d\tau.$$

Synthesis of the deterministic component of the input material flow. Analysis of Figs. 1–5, which characterize the peculiarities of material flows entering the input of the transport system, suggests that a deterministic function $\gamma_d(\tau)$ can be approximated at a time interval $0 \le \tau \le \tau_d = 1$ by a periodic function. Let us present the function $\gamma_d(\tau)$ as a cosine decomposition by defining it in an even manner on the interval $-1 \le \tau \le 0$

$$\gamma_d(\tau)=\frac{a_0}{2}+\sum_{n=1}^{\infty}a_n\cos\left(\frac{\pi n\tau}{\tau_d}\right)=\frac{a_0}{2}+\sum_{n=1}^{\infty}a_n\cos(\pi n\tau),$$

with decomposition coefficients

$$a_0=2\int_0^1\gamma_d(\tau)d\tau;\quad a_n=2\int_0^1\gamma_d(\tau)\cos(\pi n\tau)d\tau.$$

The decomposition of the function $\gamma_d(\tau)$ by cosine is chosen to simplify further transformations, allowing us to represent the correlation function $k_s(\vartheta)$ as a harmonic series. Transform one of the integrals that define the correlation function $k_s(\vartheta)$

$$\int_0^1\gamma_d(\tau)\left(\gamma(\tau-\vartheta)+\gamma(\tau+\vartheta)\right)d\tau=$$
$$=\int_0^1\gamma_d(\tau)\gamma(\tau-\vartheta)d\tau+\int_0^1\gamma_d(\tau)\gamma(\tau+\vartheta)d\tau=$$
$$=\int_0^1\left(\gamma_d(\tau+\vartheta)+\gamma_d(\tau-\vartheta)\right)\gamma(\tau)d\tau+$$
$$+\int_0^{\vartheta}\gamma_d(\tau)\gamma(\tau-\vartheta)d\tau-\int_0^{\vartheta}\gamma_d(\tau-\vartheta)\gamma(\tau)d\tau+$$
$$+\int_{1-\vartheta}^1\gamma_d(\tau)\gamma(\tau+\vartheta)dx-\int_{1-\vartheta}^1\gamma_d(\tau+\vartheta)\gamma(\tau)dx.$$

Considering the property of the correlation function $k_s(\vartheta) = k_s(-\vartheta)$, expression (13) can be written in the following form

$$k_s(\vartheta)=\frac{1}{2\sigma_s{}^2}\int_0^1\gamma(\tau)\left(\gamma(\tau-\vartheta)+\gamma(\tau+\vartheta)\right)d\tau+$$
$$+\frac{-2}{2\sigma_s^2}\int_0^1\gamma(\tau)\left(\gamma_d(\tau-\vartheta)+\gamma_d(\tau+\vartheta)\right)d\tau+ \quad (14)$$
$$+\frac{1}{2\sigma_s^2}\int_0^1\gamma_d(\tau)\left(\gamma_d(\tau-\vartheta)+\gamma_d(\tau+\vartheta)\right)d\tau.$$

We calculate the integrals that constitute the expression of the correlation function (14). Whereas

$$\gamma_d(\tau-\vartheta)+\gamma_d(\tau+\vartheta)=$$
$$=\frac{a_0}{2}+\sum_{n=1}^{\infty}a_n\cos\left(\pi n(\tau-\vartheta)\right)+\frac{a_0}{2}+\sum_{n=1}^{\infty}a_n\cos\left(\pi n(\tau+\vartheta)\right)=$$
$$=a_0+2\sum_{n=1}^{\infty}a_n\cos(\pi n\tau)\cos(\pi n\vartheta),$$

we obtain

$$\int_0^1\gamma(\tau)\frac{\gamma_d(\tau+\vartheta)+\gamma_d(\tau-\vartheta)}{2}d\tau=\frac{a_{\gamma 0}a_0}{4}+\frac{1}{2}\sum_{n=1}^{\infty}a_{\gamma n}a_n\cos(\pi n\vartheta),$$

with coefficients $a_{\gamma 0}$, a_{gn} which are determined by ratios

$$\gamma(\tau)=\frac{a_{\gamma 0}}{2}+\sum_{n=1}^{\infty}a_{\gamma n}\cos(\pi n\tau);\quad a_{\gamma 0}=2\int_0^1\gamma(\tau)d\tau;$$
$$a_{\gamma n}=2\int_0^1\gamma(\tau)\cos(\pi n\tau)d\tau. \quad (15)$$

The coefficients $a_{\gamma n}$ in accordance with their definitions (15) make it possible to perform an approximation of the function $\gamma(\tau)$ with a sufficient degree of accuracy. The approximation of the function $\gamma(\tau)$, based on the use of n = 1000 coefficients a_{gn}, is shown in Fig. 6.

We compute the third integral in an expression for the correlation function (14)

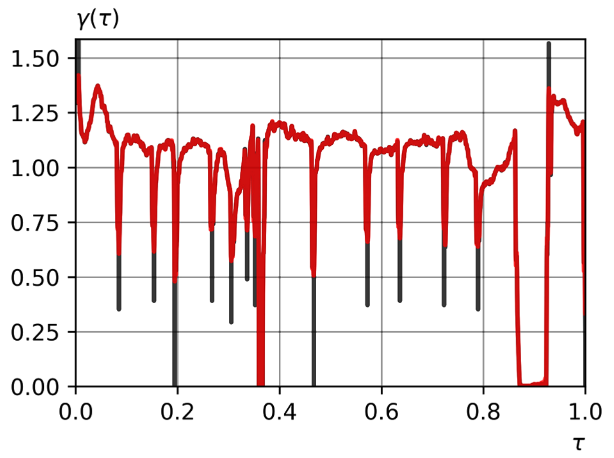

Fig. 6. Function $\gamma(\tau)$ and its approximation, n =1000

$$\int_0^1 \gamma_d(\tau)\frac{\gamma_d(\tau+\vartheta)+\gamma_d(\tau-\vartheta)}{2}d\tau=\frac{a_0^2}{4}+\frac{1}{2}\sum_{n=1}^{\infty}\cos(\pi n\vartheta)a_n^2. \quad (16)$$

Let us introduce the function $C_0(\vartheta)$

$$C_0(\vartheta)=\int_0^1 \gamma(\tau)\frac{\gamma(\tau-\vartheta)+\gamma(\tau+\vartheta)}{2}d\tau;$$

$$\gamma(\tau-\vartheta)=\gamma(\tau+\vartheta) \quad \text{at} \quad (\tau-\vartheta)<0, \quad (\tau+\vartheta)\in[0;\,1];$$

$$\gamma(\tau-\vartheta)=\gamma(\mathrm{t}-\vartheta+1) \quad \text{at} \quad (\tau-\vartheta)<0, \quad (\tau+\vartheta)>1;$$

$$\gamma(\tau+\vartheta)=\gamma(\tau-\vartheta) \quad \text{at} \quad (\tau+\vartheta)>0, \quad (\tau-\vartheta)\in[0;\,1];$$

$$\gamma(\tau+\vartheta)=\gamma(\tau+\vartheta-1) \quad \text{at} \quad (\tau+\vartheta)>0, \quad (\tau-\vartheta)<0,$$

which will allow us to present the correlation function in its final form

$$\sigma_s^2 k_s(\vartheta)=C_0(\vartheta)-2\left(\frac{a_{\gamma 0}a_0}{4}+\frac{1}{2}\sum_{n=1}^{\infty}a_{\gamma n}a_n\cos(\pi n\vartheta)\right)+$$
$$+\frac{a_0^2}{4}+\frac{1}{2}\sum_{n=1}^{\infty}\cos(\pi n\vartheta)a_n^2=$$
$$=C_0(\vartheta)+\frac{1}{4}(a_0^2-2a_{\gamma 0}a_0)+\sum_{n=1}^{\infty}\frac{\cos(\pi n\vartheta)}{2}(a_n^2-2a_{\gamma n}a_n).$$

Unknown coefficients a_n are determined from the equation $k_s(\vartheta)=k_{s0}(\vartheta)$, which has an expanded form

$$C_0(\vartheta)+\frac{1}{4}(a_0^2-2a_{\gamma 0}a_0)+\sum_{n=1}^{\infty}\frac{\cos(\pi n\vartheta)}{2}(a_n^2-2a_{\gamma n}a_n)=$$
$$=\sigma_s^2\exp\left(-\frac{\vartheta}{\tau_{cor}}\right). \quad (17)$$

The main difficulty in solving equation (17) lies in the fact that the type of $C_0(\vartheta)$ function is determined by the type of $\gamma(\tau)$ function on the interval $-1\le\tau\le 1$. At the same time, the function $\gamma(\tau)$ is set on the interval $0\le\tau\le 1$. The next section presents the results of the study on the input material flow, based on the solution of equation (17) for various ways to determine the function $\gamma(\tau)$ outside the interval $0\le\tau\le 1$.

The results of decomposition of the input material flow. Equation (17) can be solved by successive approximations. In a zero approximation outside the interval $0\le\tau\le 1$, the input flow of material can be defined as $\gamma(\tau)=0$. This will allow calculating the coefficients a_n and, considering (12), generating values $\gamma(\tau)$ both for the interval $0\le\tau\le 1$ and beyond. The function thus defined is used to solve equation (17) as the next approximation. The number of approximations is selected based on the requirement to ensure a given accuracy. The disadvantage of this approach is the slow convergence of the solution. In this regard, we focus on ways to represent a function $\gamma(\tau)$ outside the interval $0\le\tau\le 1$, which, based on the properties of the correlation function, will ensure increased convergence of the solution by the method of successive approximations.

We decompose the left and right sides of equation (17) into the Fourier series and equate the coefficients for the same harmonics, we obtain expressions for the coefficients a_n

$$a_n^2-2a_{\gamma n}a_n=B_n; \quad (18)$$

$$B_n=4\int_0^1\left(\sigma_s^2\exp\left(-\frac{\vartheta}{\tau_{cor}}\right)-C_0(\vartheta)\right)\cos(\pi n\vartheta)d\vartheta.$$

The qualitative relationship between σ_s^2 and correlation time τ_{cor} can be obtained by solving equation (18) for the zero harmonic, $n=0$

$$\sigma_s^2\approx\frac{\int_0^1 C_0(\vartheta)d\vartheta+\frac{a_n^2-2a_{\gamma n}a_n}{4}}{\int_0^1\exp\left(-\frac{\vartheta}{\tau_{cor}}\right)d\vartheta}\sim\frac{1}{\tau_{cor}\left(1-\exp\left(-\frac{1}{\tau_{cor}}\right)\right)}.$$

The standard deviation σ_s^2 is a downward function of the correlation time τ_{cor}. The correlation coefficient $k_s(\vartheta)$ (10) is determined for the random process, the implementation of which is given on the finite interval $[0;\,\tau_{\max}]$. Accordingly, to calculate the correlation coefficient $k_s(\vartheta)$, the value of the implementation of the random process $\gamma_s(\tau)$ and $\gamma_s(\tau+\vartheta)$ needs to be known. For some values τ, the value $(\tau+\vartheta)$ does not belong to the interval $[0;\,\tau_{\max}]$. In this regard, it is necessary to determine the value of the implementation of the random process $\gamma_s(\tau+\vartheta)$ at points in time $(\tau+\vartheta)\notin[0;\,\tau_{\max}]$.

Analysis of methods for calculating the correlation coefficient. Method for calculating the correlation coefficient No. 1. As the first way to determine the values $\gamma_s(\tau+\vartheta)$, equality can be used

$$\gamma_s(\tau+\vartheta)=\gamma_s(\tau+\vartheta-\tau_{\max}), \quad \text{behind } (\tau+\vartheta)>\tau_{\max}. \quad (19)$$

The correlation coefficient calculated considering the ratio (19)

$$k_{s1}(\vartheta)=\frac{1}{\sigma_s^2}\int_0^{\tau_{\max}}\gamma_s(\tau)\gamma_s(\tau+\vartheta)d\tau, \quad \tau_{\max}=1 \quad (20)$$

in zero approximation for a dynamic process $\gamma_d(\tau)\approx 1$, is shown in Fig. 9. The application of this approach to the calculation of a_n coefficients implies a systemic error in determining these coefficients. The index "$s1$" determines the type of integrand (20) for calculating the correlation coefficient.

Method for calculating the correlation coefficient No. 2. The second way to determine the values $\gamma_s(\tau+\vartheta)$ is to use the interval $[0;\,\tau_{\max}/2]$ to calculate the decomposition coefficients a_n. The correlation coefficient calculated considering the ratio (19)

$$k_{s2}(\vartheta)=\frac{1}{\tau_{\max}\sigma_s^2}\int_0^{\tau_{\max}}\gamma_s(\tau)\gamma_s(\tau+\vartheta)d\tau, \quad \tau_{\max}=2 \quad (21)$$

for zero approximation $\gamma_d(\tau)\approx 1$, is shown in Fig. 10. The calculation of the decomposition coefficients is performed on the interval $\tau\in[0;\,\tau_{\max}/2]$. To calculate the correlation coefficient, the first method and the full data interval for $\tau\in[0;\,\tau_{\max}]$ were used. When bringing variables (9) to a dimensionless form, the value m_d was used, calculated for the time interval $\tau\in[0;\,\tau_{\max}]$ of the values of the implementation of the random $\gamma(\tau)$ process. The dimensionless value of the variable τ, characterizing the process time, is defined as follows $\tau=2(t-t_{\min})/(t_{\max}-t_{\min})$. Thus, the graph is represented on the interval $\tau\in[0;\,1]$ (Fig. 7), stretched to the interval $\tau\in[0;\,2]$, $\tau_{\max}=2$, Fig. 8. Decomposition is performed for an interval $\tau\in[0;\,\tau_{\max}/2]$ containing half of the data from the implementation of the random process.

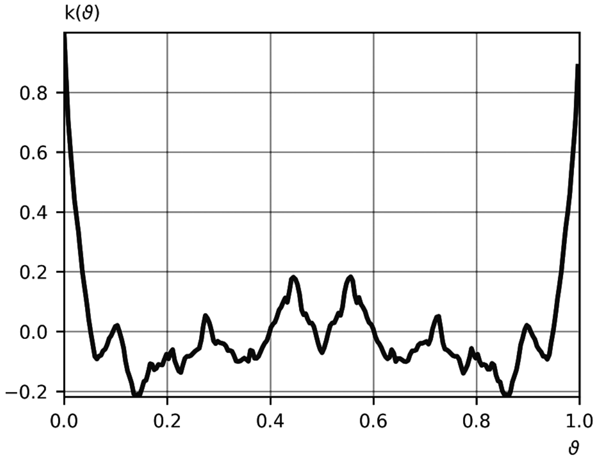

Fig. 7. Calculation of the correlation coefficient $k_{s1}(\vartheta)$ based on the method for determining the values of the process implementation $\gamma_s(\tau)$ (20):

$\gamma_s(\tau) = \gamma_s(\tau - \tau_{max}); \tau > \tau_{max} = 1$

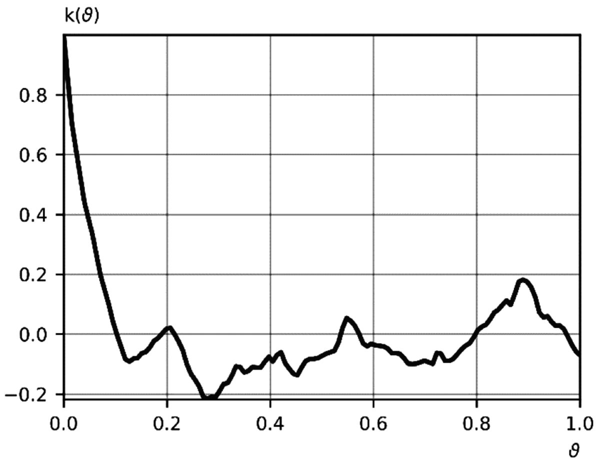

Fig. 8. Calculation of the correlation coefficient $k_{s2}(\vartheta)$ based on the method for determining the values of the process implementation $\gamma_s(\tau)$ (21):

$\gamma_s(\tau) = \gamma_s(\tau - \tau_{max}); \tau > \tau_{max} = 2$

The incomplete use of the data set is a disadvantage of this method for determining the decomposition coefficients a_n.

Method for calculating the correlation coefficient No. 3. For dynamic processes, implying a significant difference in the range of function change $\gamma_d(\tau)$ for intervals [0; $\tau_{max}/2$] and [$\tau_{max}/2$; τ_{max}], using a set of values for only one of the two intervals will lead to an additional error. It is assumed that a decrease in the magnitude of the error is achieved with an additional calculation of the decomposition coefficients a_n for the interval [$\tau_{max}/2$; τ_{max}] followed by averaging the decomposition coefficients a_n over two intervals. The number of intervals for averaging can be chosen arbitrary by specifying the value of each interval in the form $\left[\frac{\tau_{max}}{I}i; \frac{\tau_{max}}{2} + \frac{\tau_{max}}{I}i\right]$, $i = 0, 1, ..., I$. When $I = 2$ we obtain the above division into intervals [0; $\tau_{max}/2$] and [$\tau_{max}/2$; τ_{max}]. In Fig. 9 and Fig. 10 the values of the correlation coefficient are shown, calculated in accordance with the formulas

$$k_{s3}(\vartheta) = \frac{1}{\left(\frac{\tau_{max}}{2} - 0\right)\sigma_s^2} \int_0^{\tau_{max}/2} \gamma_s(\tau)\gamma_s(\tau + \vartheta)d\tau; \qquad (22)$$

$$k_{s4}(\vartheta) = \frac{1}{\left(\tau_{max} - \frac{\tau_{max}}{2}\right)\sigma_s^2} \int_{\tau_{max}/2}^{\tau_{max}} \gamma_s(\tau)\gamma_s(\tau - \vartheta)d\tau \qquad (23)$$

at integration intervals [0; $\tau_{max}/2$] and [$\tau_{max}/2$; τ_{max}], $\tau_{max} = 2$.

The difference in the methods for calculating the correlation function according to formulas (21) from (22, 23) is that for calculating the coefficients of the correlation function, for example, when integrating on interval [0; $\tau_{max}/2$] (22), both values of the implementation function $\gamma_s(\tau)$ and $\gamma_s(\tau + \vartheta)$ cannot be in the interval]$\tau_{max}/2$; τ_{max}]. Similarly, for calculating the correlation function, for example, when integrating on interval [$\tau_{max}/2$; τ_{max}] (23), both values of the implementation $\gamma_s(\tau)$ and $\gamma_s(\tau - \vartheta)$ cannot be in the interval [0; $\tau_{max}/2$[. When using formula (21) to calculate the correlation function, this possibility is allowed. It should be noted that from the above definition of the correlation function follows the ratio $k_{s2}(0) = (k_{s3}(0) + k_{s4}(0)/2)$. The histogram of the distribution of a random variable, which is constructed on the basis of the values of the implementation of a random process $\gamma_s(\tau)$ for approximation $\gamma_d(\tau) \approx 1$, is shown in Fig. 11 for the interval [0; $\tau_{max}/2$] and in Fig. 12 for the interval [$\tau_{max}/2$; τ_{max}].

The values of the standard deviation for the implementation of the random process at intervals [0; $\tau_{max}/2$] and [$\tau_{max}/2$; τ_{max}] are $\sigma_{s3}^2 = k_{s3}(0) \approx 0.5$ and $\sigma_{s4}^2 = k_{s4}(0) \approx 1.5$ respectively. These values determine the standard deviation for the imple-

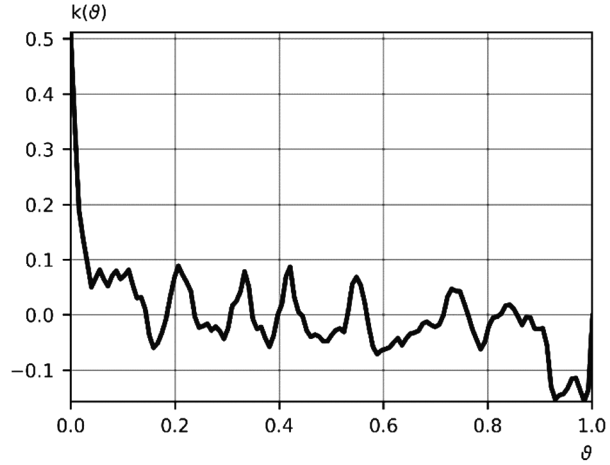

Fig. 9. Correlation coefficient $k_{s3}(\vartheta)$ calculation for interval [0; $\tau_{max}/2$] (22)

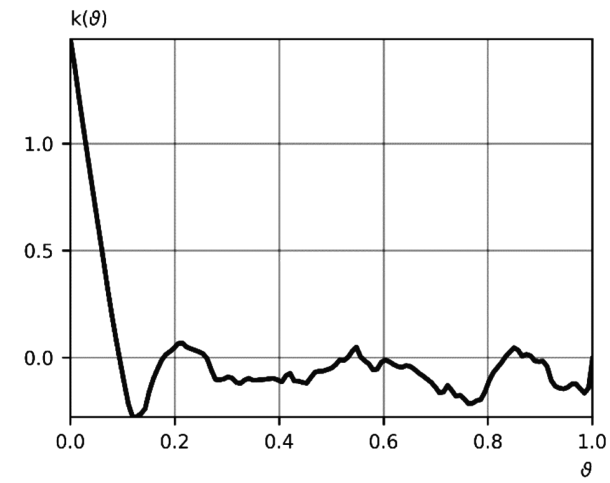

Fig. 10. Correlation coefficient $k_{s4}(\vartheta)$ calculation for interval [$\tau_{max}/2$; τ_{max}] (23)

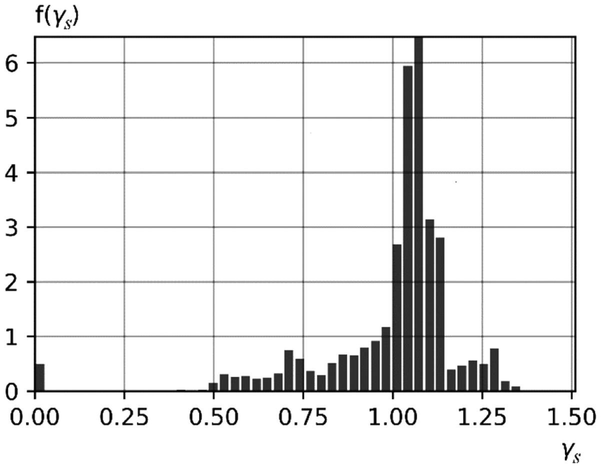

Fig. 11. Histogram of the distribution of values of dimensionless input flow of material γ_s *on the interval* $\tau \in [0; \tau_{max}/2]$

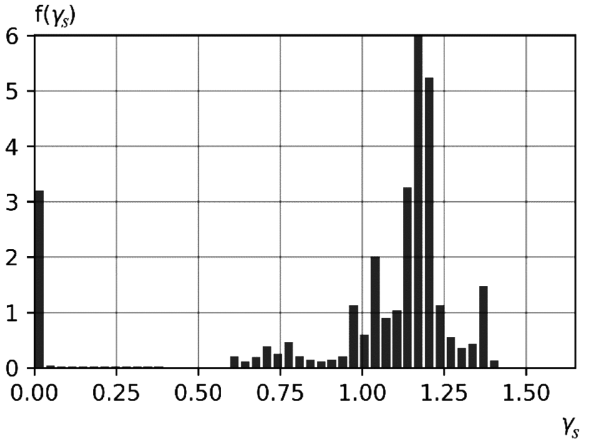

Fig. 12. Histogram of the distribution of values of dimensionless input flow of material γ_s *on the interval* $\tau \in [\tau_{max}/2; \tau_{max}]$

mentation of the random process over the entire interval $[0; \tau_{max}]$ equal to $\sigma_{s2}^2 = (\sigma_{s3}^2 + \sigma_{s4}^2)/2 \approx 1$. Histogram of distribution of values of dimensionless input flow of material for interval $[0; \tau_{max}/2]$ and for interval $[\tau_{max}/2; \tau_{max}]$, is shown in Figs. 11 and 12 respectively; the values quantitatively differ, and their standard deviations, calculated in accordance with formulas (22, 23), correlate as $\sigma_{s3}^2/\sigma_{s4}^2 \approx 0.5/1.5$. This fact suggests that the choice of the method for constructing the correlation function is important for the synthesis of the deterministic process $\gamma_d(\tau)$ and the random process $\gamma_s(\tau)$.

The third way to determine values $\gamma_s(\tau + \vartheta)$ is to use an interval $[0; \tau_{max} - \vartheta]$ to calculate the correlation function. Correlation function, calculated as follows

$$k_{s5}(\vartheta) = \frac{1}{(\tau_{max} - \vartheta)\sigma_s^2} \int_0^{\tau_{max}-\vartheta} \gamma_s(\tau)\gamma_s(\tau+\vartheta)d\tau, \quad \tau_{max} = 1 \quad (24)$$

is shown in Fig. 13. The error of the calculation increases with increasing value ϑ.

Method for calculating the correlation coefficient No. 4. This method for calculating the correlation coefficient is based on the following rules

$$k_{s6}(\vartheta) = \frac{1}{\tau_{max}\sigma_s^2} \int_0^{\tau_{max}} \gamma_s(\tau)\gamma_s(\tau+\vartheta)d\tau, \quad \tau_{max} = 1; \quad (25)$$

$$\gamma_s(\tau + \vartheta) = \gamma_s(\tau - \vartheta) \quad \text{at} \quad \tau + \vartheta > \tau_{max} \quad \text{and} \quad \tau - \vartheta \geq 0;$$

$$\gamma_s(\tau + \vartheta) = 0 \quad \text{at} \quad \tau + \vartheta > \tau_{max} \quad \text{and} \quad \tau - \vartheta < 0.$$

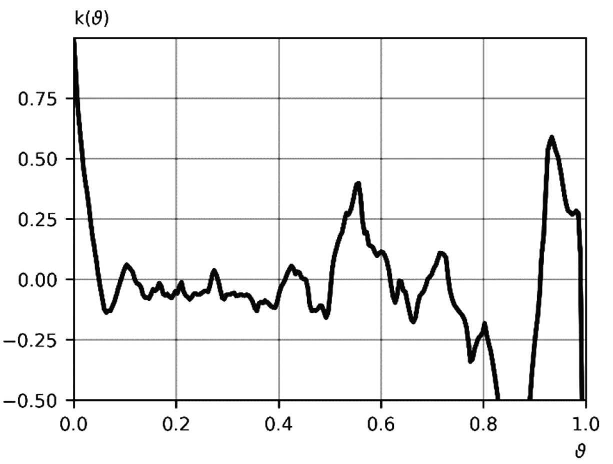

Fig. 13. Correlation coefficient $k_{s5}(\vartheta)$, $[0; \tau_{max}]$ (24)

To determine the missing values of the correlation function, the property $k_{s5}(\vartheta) = k_{s5}(-\vartheta)$ was used. The graph of the correlation function $k_{s6}(\vartheta)$is shown in Fig. 14.

Taking into account the type of function $C_0(\vartheta)$, constructed in accordance with conditions (16), we determine the values of the coefficients a_n for the implementation of the deterministic process $\gamma_d(\tau)$ and the random process $\gamma_s(\tau)$. Due to the fact that the value of the function $C_0(\vartheta)$ is calculated approximately on the interval $\tau \notin [0; \tau_{max}]$ based on conditions (16), we use the criterion to determine the coefficients a_n

$$(a_n^2 - 2a_{\gamma n}a_n - B_n)^2 \to \min, \quad (26)$$

which corresponds to the equation

$$\frac{d}{da_n}(a_n^2 - 2a_{\gamma n}a_n - B_n)^2 = 4(a_n^2 - 2a_{\gamma n}a_n - B_n)(a_n - a_{\gamma n}) = 0.$$

The implementation of the random process $\gamma_s(\tau)$ and the density of its distribution, built in accordance with the accepted criterion, are presented in Figs. 15 and 16 respectively. The correlation function $k_{s1}(\vartheta)$characterizing a stationary stochastic process $\gamma_s(\tau)$ is shown in Fig. 17. The values of the correlation function for a stationary random process $\gamma_s(\tau)$ are calculated in accordance with the expressions (19, 20). The obtained implementation for a deterministic process $\gamma_d(\tau)$ using criterion (26) for calculating the values of the coefficients a_n allows synthesizing the implementation for a random ergodic process $\gamma_s(\tau)$ with the distribution density shown in Fig. 16. The correlation function is fairly well approximated by the correlation function $k_{s0}(\vartheta)$ (11).

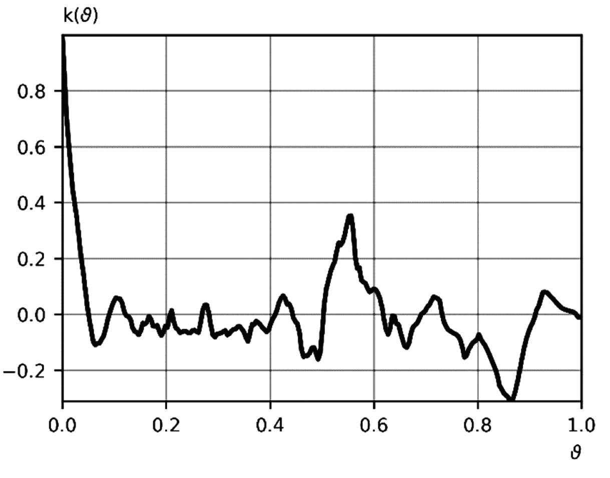

Fig. 14. Correlation coefficient $k_{s6}(\vartheta)$, $[0; \tau_{max}]$ (25)

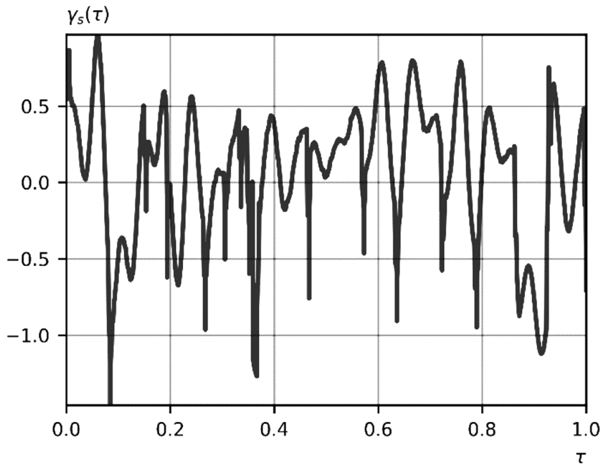

Fig. 15. Implementation of a stationary random process $\gamma_s(\tau)$

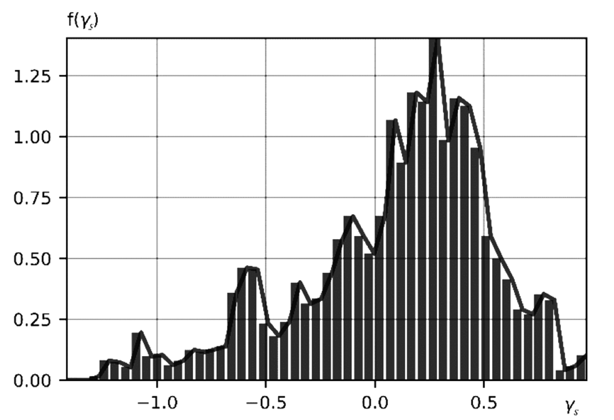

Fig. 16. Histogram of the distribution of values of dimensionless input flow of material γ_s

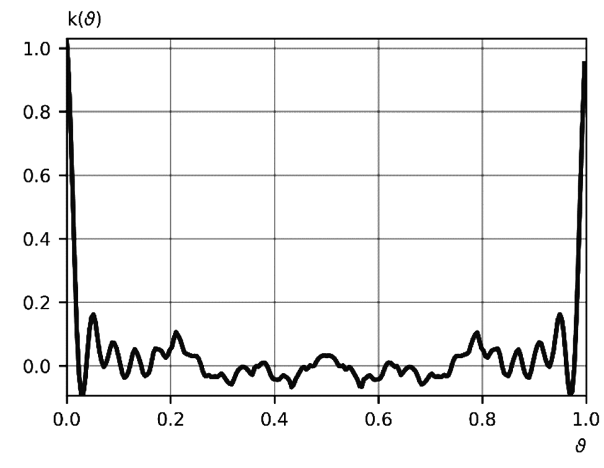

Fig. 17. Correlation function $k_{s1}(\vartheta)$ *for realization of stationary random process* $\gamma_s(\tau)$*, presented in Fig. 16*

The resulting implementation for the random ergodic process $\gamma_s(\tau)$ makes it possible to establish the numerical characteristics and the law of distribution of the values of the stochastic component of the input flow of material, which is the basis for choosing the parameters of transport conveyor.

Conclusions and further prospects for development. An analysis of experimental data corresponding to the flow of material entering the input of the existing transport system of the conveyor type is carried out, which allows us to draw the following conclusions: a) further study on the type of distribution law of mine cargo flow entering the input of the transport conveyor is required; it is necessary to clarify the assumption of the normal or logarithmically normal law of distribution of mine cargo flow; b) the correlation function determined on the basis of experimental data for the studied mine cargo flows differs from the theoretical correlation function (2). The reason for this difference is related to the fact that the mine cargo flow can be represented by a stochastic process, the mathematical expectation and standard deviation of which are time-dependent periodic functions. In this regard, existing typing methods based on the approximation of a stochastic material flow can only be used for stationary material flows. For nonstationary material flows, the solution to this problem is presented in this paper and is based on the assumption that the random flow of material can be represented as a superposition of a deterministic process and a random process that has ergodic properties. The dynamic characteristics of the deterministic material flow are directly related to the technical or technological factors of production. The average speed of movement of mine combines, the average speed of movement of the support sections, technological breaks for maintenance have a significant impact on the shape of the histogram curve of the distribution of the values of the input flow of material. During the period of experimental measurements, the shape of the distribution histogram curve can change from the normal distribution law to the uniform distribution law of the values of the input material flow. In connection with this, when solving the problem of typing of input material flows, it is initially necessary to extract the deterministic component of the input material flow, determined by the above factors. This will allow for the stochastic component of the material flow to establish statistically stable patterns, to determine the distribution law for the values of the input material flow.

Analysis of the random process that has ergodic properties led to the conclusion that the normal or logarithmically normal distribution laws of mine cargo flow can be used as the first approximation to describe the stochastic component of the material flow. Additionally, it should be noted that the correlation function of this process approaches the theoretical correlation function (2).

The advantages of the proposed method for presenting the realization of material flow in the form of a superposition of deterministic and random material flow, which has ergodic properties, are as follows: a) the existing problem of typing non-stationary transport flows is solved. In contrast to the proposed approaches [6, 7], it is proposed to use the stochastic component of the input material flow to type the input material flow, for which it is possible to determine statistically stable patterns; b) the accuracy of describing the input flow of material increases as a result of the fact that the numerical characteristics and distribution function are determined by analyzing the stochastic component of the input flow of material. At the same time, to determine these numerical characteristics, a cross-section of the random process is used, formed based on the experimental study on the material flow of the existing transport system.

The results of solving the problem of typing deterministic and stochastic components of input material flow are of practical interest for the synthesis of material flow control systems of transport conveyor. The obtained results can be used to construct criteria for similarity of input material flows, reflecting statistical patterns and allowing one to justify the choice of control algorithm.

As shown by the review of publications, in most cases fairly simple dynamic deterministic models of the input flow of material are used for the synthesis of control systems. This imposes limitations on the synthesis of algorithms for optimal control of material flow, since technical and technological factors characterizing the method of material extraction in modern mining enterprises are not considered.

A prospect for further research is the analysis of synthesized implementations of deterministic and stationary random material flows based on experimental data sets for existing mining enterprises to identify general regularities. It is assumed that the construction of these regularities will allow constructing generators of input stochastic flow of material to analyze the efficiency of material flow control systems as for existing transport systems, and in the design of new transport systems. Of particular interest is the use of these generators to form a set of data used to train neural networks, based on which effective systems for controlling the flow of material using artificial intelligence can be built.

References.

1. He, D., Pang, Y., & Lodewijks, G. (2016). Determination of acceleration for belt conveyor speed control in transient operation. *International Journal of Engineering and Technology, 8*(3), 206-211. https://doi.org/10.7763/IJET.2016.V8.886.

2. Zeng, F., Yan, C., Wu, Q., & Wang, T. (2020). Dynamic behaviour of a conveyor belt considering non-uniform bulk material distribution for speed control. *Applied Sciences, 10*(13), 1-19. https://doi.org/10.3390/app10134436.

3. Vasić, M., Miloradović, N., & Blagojević, M. (2021). Speed control high power multiple drive belt conveyors. *Research and Development in Heavy Machinery, 27*(1), 9-15. https://doi.org/10.5937/IMK2101009V.

4. Pihnastyi, O., & Ivanovska, O. (2022, May). Improving prediction quality for multi-section transport conveyor model based on neural network. *CEUR Workshop Proceedings, 8th International Scientific Conference "Information Technology and Implementation", 3132*, 24-38. Retrieved from http://ceur-ws.org/Vol-3132/Paper_3.pdf.

5. Stadnik, M., Semenchenko, D., Semenchenko, A., Belytsky, P., Virych, S., & Tkachov, V. (2019). Improving energy efficiency of coal transportation by adjusting the speeds of a combine and a mine face conveyor. *Eastern-European Journal of Enterprise Technologies, 1/8*(97), 60-70. https://doi.org/10.15587/1729-4061.2019.156121.

6. Prokuda, V., Mishansky, Yu., & Protsenko, S. (2012). Research and assessment of cargo flows on the main conveyor transport "PSP Pavlogradskaya Mine, DTEK Pavlogradugol". *Mining electromechanics, 88*(31), 107-111. Retrieved from http://ir.nmu.org.ua/bitstream/handle/123456789/880/24.pdf.

7. Kondrakhin, V., Stadnik, N., & Belitsky, P. (2013). Statistical analysis of mine belt conveyor operating parameters. *Naukovi pratsi DonNTU, 2*(26), 140-150.

8. Jeftenić, B., Ristić, L., Bebić, M., Statkić, S., Jevtić, D., Mihailović, I., & Rašić, N. (2010). Realization of system of belt conveyors operation with remote control. *Structural integrity and life, 10*(1), 21-30. Retrieved from http://divk.inovacionicentar.rs/ivk/ivk10/021-030-IVK1-2010-BJ-LR-MB-SS-DJ-IM-NR.pdf.

9. Doroszuk, B., Król, R., & Wajs, J. (2021). Simple design solution for harsh operating conditions: redesign of conveyor transfer station with reverse engineering and DEM simulations. *Energies, 14*(13), 1-13. https://doi.org/10.3390/en14134008.

10. Kawalec, W., & Król, R. (2021). Generating of electric energy by declined overburden conveyor in continuous surface mine. *Energies, 14*(13), 1-11. https://doi.org/10.3390/en14134030.

11. Curtis, A., & Sarc, R. (2021). Real-time monitoring volume flow, mass flow and shredder power consumption in mixed solid waste processing. *Waste Management, 131*, 41-49. https://doi.org/10.1016/j.wasman.2021.05.024.

12. Bhadani, K., Asbjörnsson, G., Hulthén, E., Hofling, K., & Evertsson, M. (2021). Application of optimization method for calibration and maintenance of power-based belt scale. *Minerals, 11*(4), 1-15. https://doi.org/10.3390/min11040412.

13. Carvalho, R., Nascimento, R., D'Angelo, T., Delabrida, S.G.C., Bianchi, A., Oliveira, R.A.R., Azpúrua, H., ..., & Garcia, L. (2020). A UAV-based framework for semi-automated thermographic inspection of belt conveyors in the mining industry. *Sensors, 22*(8), 1-19. https://doi.org/10.3390/s20082243.

Аналіз вхідного потоку матеріалів транспортного конвеєра

О. М. Пігнастий[*], *М. О. Соболь*

Національний технічний університет «Харківський політехнічний інститут», м. Харків, Україна

[*] Автор кореспондент e-mail: pihnastyi@gmail.com

Мета. Розробити метод аналізу потоку матеріалу, що надходить на вхід секції конвеєра, заснований на декомпозиції вхідного потоку матеріалу на детермінований потік матеріалу та стохастичний потік матеріалу.

Методика. Аналіз експериментальних даних, що характеризують вхідний потік матеріалу, виконаний з використанням методів канонічного Фур'є подання випадкового процесу.

Результати. Запропонована методика подання стохастичного потоку матеріалу у вигляді комбінації детермінованого процесу та стаціонарного випадкового процесу, що має ергодичні властивості.

Наукова новизна. Новизна отриманих результатів полягає в тому, що вперше запропоновано метод аналізу, заснований на декомпозиції вхідного потоку матеріалу для секції конвеєра, який, на відміну від існуючих методів типізації вхідних потоків для гірничодобувної промисловості, дозволить незалежно виконати типізацію детермінованих потоків і типізацію стохастичних потоків матеріалу у транспортних конвеєрах. Запропонований підхід надає можливість виділити особливі характеристики окремо як для детермінованого, так і для стохастичного потоку матеріалу. Це дозволить використовувати отримані закономірності для підвищення точності моделі конвеєра, і, відповідно, підвищити якість систем управління швидкістю стрічки й потоком матеріалу, що надходить зі вхідного бункера. Особливої важливості отримані результати набувають у зв'язку з тим, що характеристики детермінованого потоку матеріалу безпосередньо пов'язані з технічними чи технологічними факторами видобутку матеріалу.

Практична значимість. Полягає в тому, що отримані результати дозволяють визначити статистично стійкі закономірності для вхідного потоку, що дає можливість, ґрунтуючись на даних закономірностях, із безлічі доступних алгоритмів управління вибрати оптимальний алгоритм управління параметрами секції діючого конвеєра. Це дозволяє знизити енерговитрати підприємства на транспортування матеріалу. Запропонований метод може бути успішно застосований для побудови випадкових генераторів чисел, що імітують послідовність значень вхідного потоку матеріалу. Розроблені генератори можуть бути використані як для валідації існуючих систем управління швидкістю стрічки, так і для побудови нових систем управління, заснованих на нейронних мережах. Це відкриває перспективи для проектування ефективних систем керування потоковими параметрами транспортної системи, заснованих на моделі транспортного конвеєра, що враховує стохастичний характер вхідного потоку матеріалу.

Ключові слова: *транспортний конвеєр, розподілена система, стохастичний потік, функція кореляції*

The manuscript was submitted 20.02.23.