DYNAMIC PROPERTIES OF SCREW CONVEYOR UNITS FOR TRANSPORTING AND CLEANING COTTON LINT

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Abstract. *The article presents an analysis of the characteristics of screw conveyors used for transporting and cleaning cotton lint, as well as the results of a dynamic analysis of the machinery units aimed at substantiating their operating modes and parameters. The motion laws of the screw conveyor were determined by accounting for the zone-specific impact of the technological resistance exerted by the cotton lint. Recommended values for the conveyor parameters are provided based on an analysis of the relationship graphs across the different zones.*

Keywords: *screw conveyor, wavy surface, mesh surface, vibration, elastic support, stiffness, dissipation, process resistance, cotton lint, law of motion, moment of inertia, non-uniformity, friction force.*

Introduction. Cotton linters are considered a key raw material for the global chemical industry, primarily because the highest-quality paper products are manufactured from cellulose derived from them. High-purity cotton linters yield nearly 100 % cellulose. Consequently, scientific and technological progress in the cotton industry is closely linked to the design and manufacture of new machinery capable of maximizing the purification of cotton linters. Accordingly, key priorities in the field include creating flexible automated systems for removing impurities from cotton linters; developing new purification methods and approaches; engineering high-productivity, resource-efficient technologies and equipment; creating vibration- and noise-reducing drive mechanisms; and designing new screw conveyors for transporting and cleaning the linters [1,2].

To date, the technology for transporting raw cotton materials (seed cotton, cotton seeds, and cotton lint) using screw conveyors has been thoroughly researched, and its parameters have been scientifically established. However, insufficient attention has been paid to issues such as the formation of blockages during transport—which cause

productivity losses due to the forced stoppage of key production machinery—and the possibility of cleaning the cotton lint simultaneously during the transport process. Therefore, it is currently considered important to develop a high-efficiency screw conveyor design that enhances the removal of impurities from the transported lint, extends the machine's service life, reduces noise levels, and ensures the production of high-quality lint [3].

Efficient designs for lint-conveying and cleaning screw conveyors have been developed, featuring improvements such as an oscillating mesh surface, a wavy screw profile, and a roller chain drive mechanism incorporating elastic elements. Based on theoretical research, the laws of motion for the working elements were determined, and optimal parameter values were established. The dynamics of the lint-conveying and cleaning conveyor were analyzed [4, 5].

Dynamics and mathematical models of machine assemblies based on screw conveyor configurations. The screw flight of the screw conveyor designed for transporting and cleaning fluff features a wavy profile; this agitates the material and enhances its loosening, thereby intensifying the separation of waste and its discharge through the slots of the three-section mesh casing [6,7].

It should be noted that the movement of the screw conveyor's screw is driven by an electric motor and transmission mechanisms (Figure 1). The motion characteristics of the screw vary depending on the type and parameters of the electric motor and transmission mechanisms. Therefore, for the purpose of comparison, three different variants of transmission mechanisms were examined:

a – when motion is transmitted to the screw shaft via an electric motor, coupling, gearbox, and gear transmission (modeled as a single-mass system);

b – when motion is transmitted to the screw shaft via an electric motor, chain drive, gearbox, and coupling (modeled as a three-mass system);

c – when motion is transmitted to the screw shaft from an electric motor-gearbox unit (i.e., the motor and gearbox are integrated) via a belt drive, coupling, and the screw shaft (modeled as a four-mass system).

The calculation schemes for the resulting screw conveyor machine assemblies have been examined based on the diagrams shown in Figure 1.

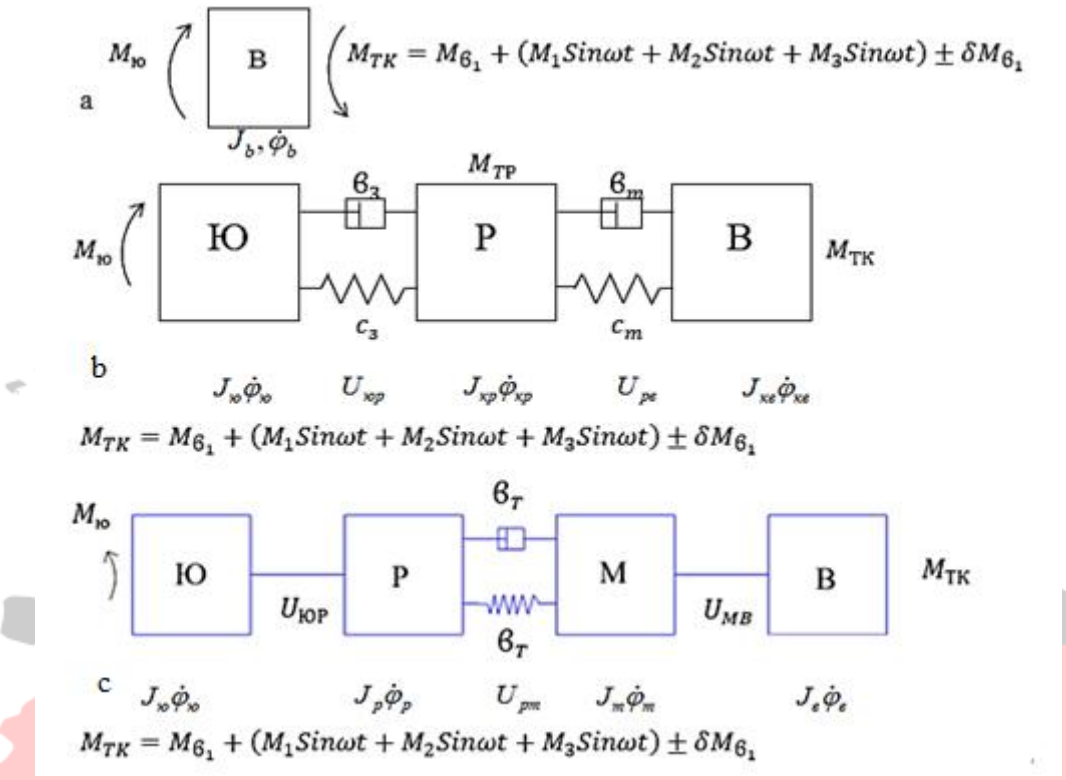


Figure 1. Dynamic models of screw conveyor machine units with various drive mechanisms.

a – machine unit reduced to a single mass;

b – three-mass machine unit with an electric motor, chain drive, gearbox, coupling, and screw shaft;

c – four-mass machine unit with a motor, gearbox, belt drive, coupling, and screw shaft.

The mathematical model of the machine assembly was derived using Lagrange's equations of the second kind [8]:

$$\frac{d}{dt}\left(\frac{dT}{d\dot{\varphi}_i}\right) - \frac{dT}{d\varphi_i} + \frac{dP}{d\varphi_i} + \frac{dF}{d\dot{\varphi}_i} = M(Q_i) \quad (1)$$

Here, T, P, and F are the kinetic energy, potential energy, and Rayleigh dissipation function, respectively; φ_i is the generalized coordinate; $M(Q_i)$ is the generalized moment of force; and t is time.

To derive the differential equations describing the motion of the screw conveyor machine units for each of the three variants, Lagrange equations were formulated for each generalized coordinate, and their constituent terms were determined. Consequently, systems of differential equations were established for each machine unit.

The electric motor torque and the technological resistance at the screw constitute the moment of external generalized forces.

We determine the electric drive torque using the mechanical-dynamic characteristic recommended by I.S. Pinchuk [8, 9]:

$$\frac{\omega_0-\dot{\phi}_{yu}}{\omega_0}=\frac{s_k}{2M_k}M_{yu}+\frac{1}{2\omega_c M_k}\dot{M}_{yu} \quad (2)$$

Here, M_n and M_k are the nominal and critical values of the driving torque; ω_c is the angular frequency of the source; ω_0 is the angular velocity during ideal no-load operation; s_k are the nominal and critical slip of the drive.

The value of the maximum torque of the electric motor rotor [10, 11]:

$$M_k = 9550\frac{P_H}{n_П}\lambda \quad (3)$$

The slip value, representing the extent to which the electric motor rotor lags behind the stator's rotation, is determined by the following expression [12]:

$$s_k = \lambda s_n\left(1+\sqrt{1-\frac{1}{\lambda^2}}\right)$$

$$s_n=\frac{\omega_0-\omega_n}{\omega_0} \quad (4)$$

here, λ represents coefficients equal to the ratio of critical torques to nominal torques on the drive rotor shaft;

$$\omega_0=\frac{\omega_c}{P}=\frac{2\pi f_c}{P} \quad (5)$$

Here, P is the number of pole pairs, and f_c is the frequency of the current source variation.

Technological resistance [13,14]:

$$M_{TK}=M_{б_1}+(M_1 Sin\omega t+M_2 Sin\omega t+M_3 Sin\omega t)\pm\delta M_{б_1} \quad (6)$$

Here, $M_{б_1}, M_1, M_2, M_3$ represent the mean value, amplitude of variation, and random values of the resistance moments of the cotton being transported.

In contrast to our previous studies, the working part of the screw was analyzed by considering three distinct zones, taking into account technological resistances and the degree of cotton loosening. The results were analyzed through a comparative assessment.

The values of the torsional stiffness dissipation coefficients for the belt drive in the screw conveyor mechanism are determined by the following expressions [15]:

$$C_T=\frac{4KR^2EF_T}{l_p};\qquad б_t=\frac{\Psi c_T}{2\pi(2\pi/T)} \quad (7)$$

Here, K is the coefficient determining the initial belt tension in the K-drive, R is the pulley radius, E is the elasticity coefficient, F_T is the cross-sectional area of the belt, l_p is the working length of the belt, Ψ is the coefficient representing the operating mode, and T is the oscillation period.

The parameters of the chain drive and the flexible coupling element were determined using the described method.

Analysis of research results. Based on experimental research results, if the load is selected within the $\Delta\dot{\phi}_{\text{в}} \leq (2{,}5 \div 3{,}5)\text{c}^{-1}$ range—taking into account that the wave-like screw shaft operates within the $M_{вс}/M_{вс}^{x} = (1{,}2 \div 1{,}4)$ range—it is recommended that the wave height on the screw be within the limits of $(0{,}8 \cdot 1.25) \cdot 10^{-2}$. It should be noted here that the majority of the $\Delta\dot{\varphi}_{\text{в}}$ values were found to be higher on the graphs than the experimental results. However, it can be observed that the torque and technological resistance forces associated with screw rotation during lint transport and cleaning decrease in each zone (taking into account the degree of lint opening) as the screw shaft's angular velocity range is reduced to 5.5–9.5% (Figure 2; graphs 6, 7, 8, 9, and 10).

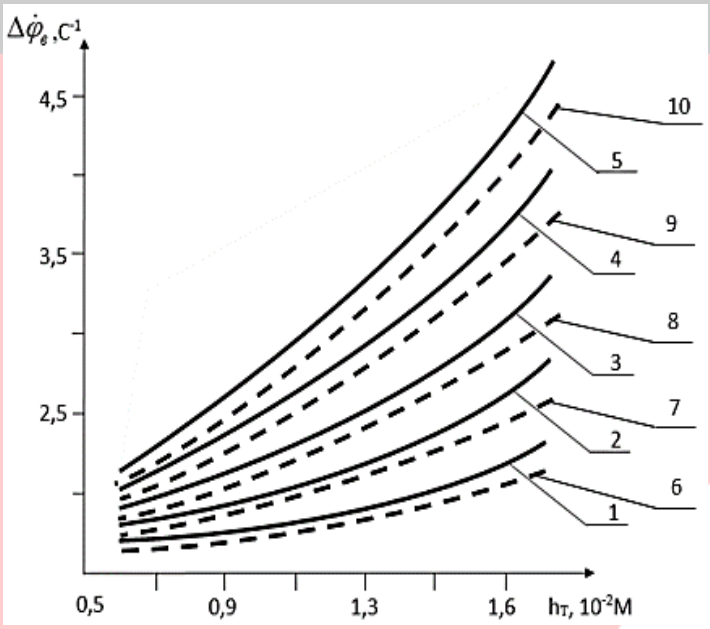


Figure 2. Graphs showing the dependence of the change in the screw's angular velocity range on the increase in wave height on the screw surface.

Therefore, it is recommended to select the height of the waves on the screw within the range of $(0{,}71 \div 1{,}16) \cdot 10^{-3}$ m.

1, 2, 3, 4, 5 – graphs plotted with technological resistances aggregated by zone; 6, 7, 8, 9, 10 – graphs plotted with technological resistances considered individually by zone $1{,}6 - M_{вс}/M_{вс}^{x} = 0{,}7$; $2{,}7 - M_{вс}/M_{вс}^{x} = 1{,}0$; $3{,}8 - M_{вс}/M_{вс}^{x} = 1{,}3$; $4{,}9 - M_{вс}/M_{вс}^{x} = 1{,}6$; $5{,}10 - M_{вс}/M_{вс}^{x} = 1{,}9$.

Conclusion. A system of equations of motion was derived for the drives of screw conveyor systems used for transporting and cleaning cotton lint of impurities. Based on the solutions to these equations, the law of motion for the screw conveyor was determined, accounting for the technological resistances acting across all three working

zones. Recommended parameter values were established based on the identified functional relationships.

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