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Development of An Efficient Screw Conveyor Design and Calculation of Traction Force Along the Working Zones of a Wavy Screw Surface for Fiber Material

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Abstract: The article presents the theoretical results of determining the traction force of cotton fiber transported and cleaned using an efficient three-zone vibrating mesh surface system. The system is designed with a wavy screw conveyor, inclined perforations, and elastic supports. Formulas for calculating the traction force across all three working zones of the mesh surface are derived, and corresponding graphical relationships are established. Based on the analysis of these relationships, recommended parameter values are provided.

Keywords: Screw conveyor, mesh surface, wavy surface, inclined holes, elastic supports, mass, force, reaction, friction, fiber, traction force, displacement, inclination angle.

INTRODUCTION:

In screw conveyors used in cotton processing enterprises, insufficient loosening of fibrous materials during transportation leads to inadequate removal of various impurities contained in cotton and lint. In addition, due to insufficient friction between the screw surface and the fibrous material, the material tends to lag behind during conveying, which results in additional mechanical damage to the fibers (cotton and lint). The interaction between the screw surface and the fibrous material occurs monotonously in one direction with a constant driving force, which does not ensure effective cleaning. The design of a mesh surface allows for intensive cleaning of cotton from fine impurities [1,2].

Development of an efficient screw conveyor design. To ensure sufficient loosening of the transported fibrous material and uniform cleaning along the entire length of the screw conveyor, as well as to enable intensive removal of waste through the mesh surface, the conveyor design was improved by increasing the working zone. This improved design increases the friction force and also changes the direction of interaction forces between the screw and the material along the entire length of the vibrating mesh surface.

The essence of the design is as follows: the screw conveyor consists of a semi-cylindrical trough rigidly mounted at the bottom, covered сверху with a casing, and equipped with a driven screw installed along its axis on bearings inside the trough. The lower working part of the trough is made in the form of a mesh surface. The movement of fibrous material along the trough is achieved by the rotation of the screw flights, whose working surface is designed in a wavy shape.

The lower part of the mesh surface is attached to the trough using rubber gaskets (shock absorbers), divided into three sections along its length, with the thickness of the rubber absorbers adjusted according to the direction of material movement. The mesh openings are made curvilinear and arranged perpendicular to the screw direction. At the same time, during the conveying process along the screw length, the curvature radius of the openings gradually increases.

It should be noted that in the initial section of the screw, the fibers (cotton) are less loosened, while toward the end they become more intensively loosened. Therefore, in the first zone, the vibration of the mesh surface is maximal due to the greater thickness of the rubber shock absorbers (up to 5.0 mm), whereas in the third (discharge) zone, the vibration amplitude is minimal (with a rubber absorber thickness of about 3.0 mm).

In the first zone, the curvature radius of the mesh openings and their relatively larger area allow for the removal of a significant amount of impurities. In contrast, in the discharge zone, the area of the openings decreases, which enables the removal of the remaining smaller impurities.

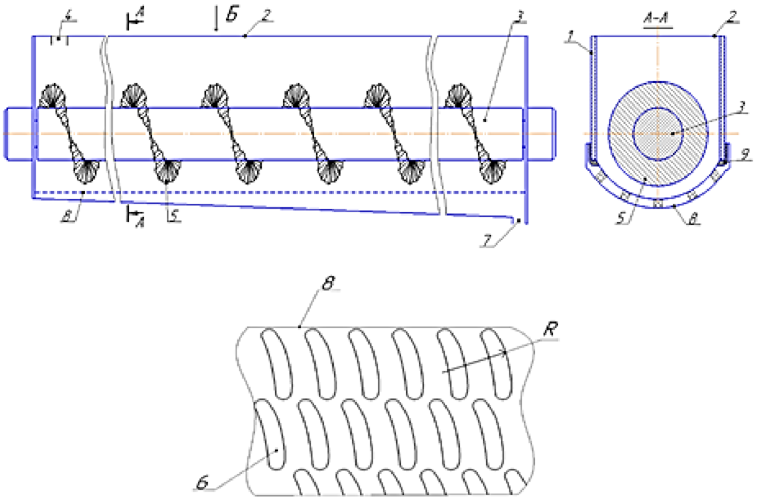


Figure 1. Screw conveyor

The screw conveyor consists of a trough (1), whose lower part has a semi-cylindrical shape and is covered сверху with a casing (2). Inside the trough (1), along its axis, a screw (3) is installed to transport the material. The trough (1) has an inlet opening (4) and, at the end of its lower part, a discharge opening (7). The lower working part of the trough (1) is made in the form of a mesh surface (8).

The working surface of the screw (3) can be designed in a wavy form (5). The lower part of the trough, implemented as a mesh surface (8), is attached to the trough (1) through rubber gaskets (shock absorbers) (10). In this case, the mesh surface (8) is divided into three equal sections along the length of the screw (3), and the thickness (9) of the rubber cushions is selected according to the direction of material movement. The curvature radius R of the openings (6) increases along the conveying direction.

Calculation of the traction force of a fiber element

In the proposed screw conveyor with a wavy surface, the trajectory of the transported fiber (lint) is known, and the path length increases [3,4]. The force diagram acting on a fiber element moving along this wavy surface is shown in Figure 1.

The transported fiber element is subjected to the following forces: gravitational force (G)(G)(G), reaction force (N)(N)(N), driving (pushing) force (Fu)(F_u)(Fu), and the friction force between the fiber and the wavy surface (Ff)(F_f)(Ff). The equilibrium condition [3] is expressed as:

$$\overrightarrow{G_1} + \overrightarrow{F}_{u_1} + \overrightarrow{N} + \overrightarrow{P} = 0$$

$$\overrightarrow{G_2} + \overrightarrow{F}_{u_2} + \overrightarrow{N} + \overrightarrow{P} = 0$$

$$\vec{G_3} + \vec{F}_{u_3} + \vec{N} + \vec{P} = 0 \quad (1)$$

where G_1, G_2, G_3 are the weights of the fiber in the respective working zones, and $F_{u_1}, F_{u_2}, F_{u_3}$ are the friction forces between the fiber and the screw surface in the three zones.

It is known [3,5] that in screw conveyors, the movement of material along the screw surface is generally considered as motion along an inclined plane. In this case, the equilibrium forces acting on the fiber element moving along the wavy screw surface are determined through their projections onto the X and Y axes [3]:

$$\sum_{i=1}^{i=4} F_i(\mathrm{x}) = 0; \sum_{i=1}^{i=4} F_i = 0 \quad (2)$$

The projection schemes of the acting forces onto the respective axes are shown in Figure 2. Then, the system of equations can be written in general form as:

$$\vec{P}_x + \vec{N}_x - \vec{F}_u^x - \vec{G}_x = 0$$

$$-\vec{P}_y + \vec{N}_y + \vec{F}_u^y - \vec{G}_y = 0 \quad (3)$$

Based on Figure 2, the calculation relationships can be written as follows [6]:

$$\vec{P}_x = P\,cos\,\alpha\,; \vec{P}_y = P\,sin\,\alpha\,;$$

$$\vec{G}_x = G\,sin\,\alpha\,; \vec{G}_y = G\,cos\,\alpha\,;$$

$$\vec{N}_x = N\,sin\,\beta\,; \vec{N}_y = N\,cos\,\beta\,; \quad (4)$$

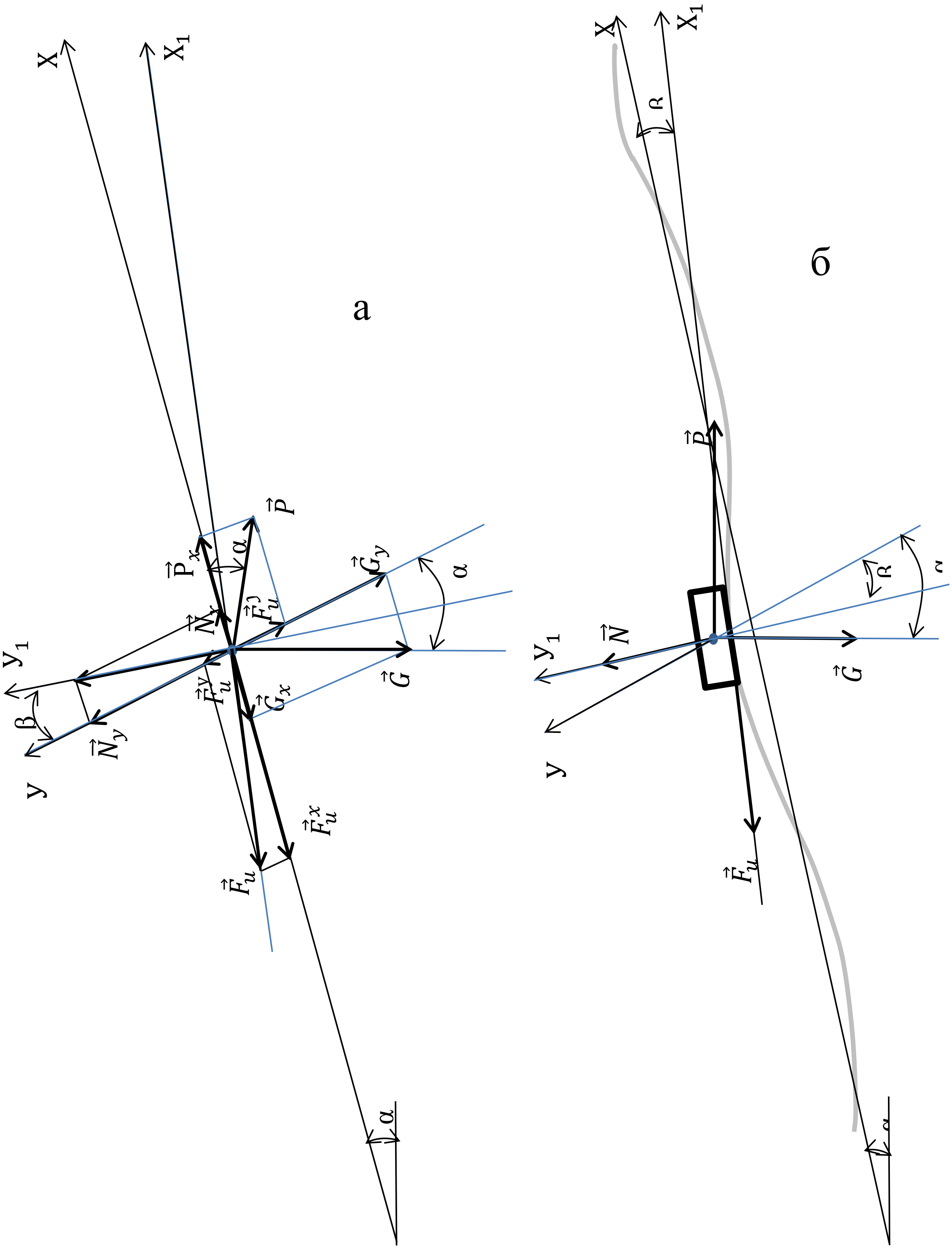
$$\vec{F}_u^x = F_u\,cos\,\beta\,; \vec{F}_u^y = \vec{F}_u\,sin\,\beta\,;$$

Substituting expression (4) into (3), we can separately determine the required components [3,7]:

$$\vec{F}_u = \frac{1}{cos\,\beta}(P\,cos\,\alpha + N\,sin\,\beta - G\,sin\,\alpha)$$

$$\vec{N} = \frac{1}{cos\,\beta}(P\,sin\,\alpha - F_u\,sin\,\beta + G\,cos\,\alpha)$$

(5)



a – force diagram, b – components of forces

Figure 2. Scheme of forces acting on a fiber element on the wavy surface of the screw

Taking these factors into account, the expressions for calculating the driving (traction) force of the fiber along all three zones can be obtained as:

$$\overrightarrow{P_1} = \frac{m_1 g(\sin\alpha + f_1\cos\alpha) - K_u F_{u_1}\sin\beta}{\cos\alpha - f_1\sin\alpha}$$

$$\overrightarrow{P_2} = \frac{m_2 g(\sin\alpha + f_2\cos\alpha) - K_u F_{u_2}\sin\beta}{\cos\alpha - f_2\sin\alpha}$$

$$\vec{P}_3 = \frac{m_3 g(\sin\alpha + f_3\cos\alpha) - K_u F_{u_3}\sin\beta}{\cos\alpha - f_3\sin\alpha} \quad (6)$$

where: m_1, m_2, m_3 – mass of the fiber element by zones;
g–gravitational acceleration;
α– screw inclination angle;
β – angle determining the position of the fiber on the wavy surface;
F_u– coefficient of friction between the fiber and the wavy surface;
f_1, f_2, f_3– friction force;
$K_u = (1 - f^2)f^{-1}$– constant characterizing the degree of the friction coefficient [9,10].

The displacement distance of a fiber element along the wavy surface depends on the wave pitch of the sinusoid and its radius. The total displacement can be determined by:

$$X = \beta \cdot R + 2\pi R\kappa \quad (7)$$

where R is the radius of the sinusoidal wave, π=3.14 = 3.14 and k is the number of repetitions of the sinusoid along the screw length.

By differentiating expression (7) along the screw, the velocity of the fiber moving along the wavy surface is obtained:

$$V_m = \frac{dx}{dt} = R\frac{d\beta}{dt} \quad (8)$$

Based on expression (8), the friction force in each zone depends not only on the friction coefficient but also on the mass of the fiber and its phase position on the wavy surface (i.e., angle β\betaβ). Moreover, the friction force is proportional to the square of the friction coefficient, forming a nonlinear relationship.

For the recommended inclined wavy surface, when the average mass of a fiber element in the three zones is taken within $(1{,}0\div3{,}0)\cdot10^{-3}$ kg and the friction coefficient is within the range (0,22÷0,4), the average friction force is in the range of $(0{,}13\div0{,}9)10^{-2}$ N for fiber masses of $(0{,}5\div2{,}0)\cdot10^{-3}$ kg and μ=0.25–0.45.

If the productivity of the wavy screw conveyor is (350–380) kg/s, then at a given moment the conveyor contains about (2.5–3.5) kg of fiber. Accordingly, the average friction force is (7.5–10.5) N [3].

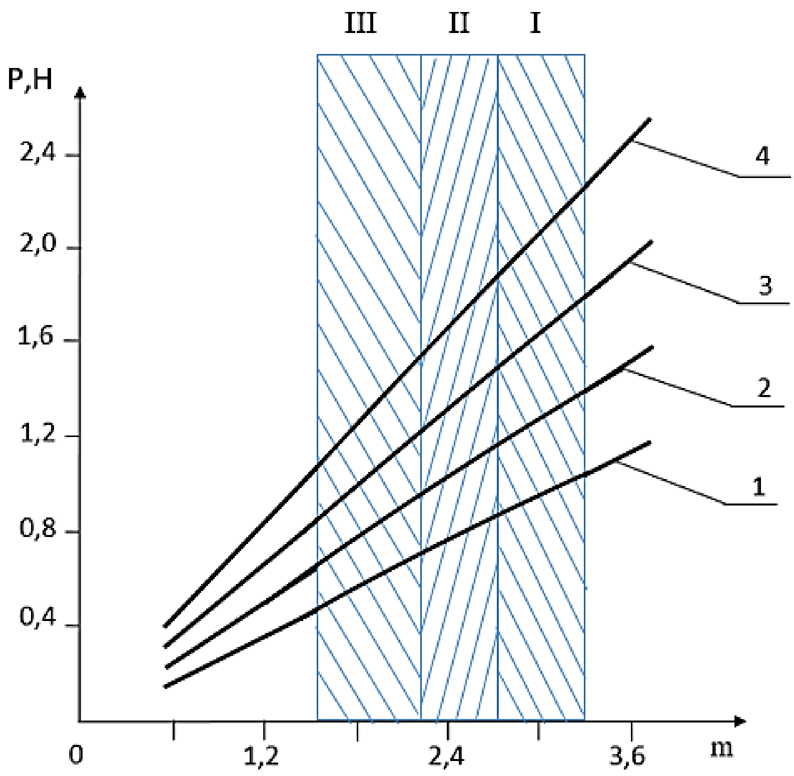
Numerical solution of the problem and analysis of results

The relationships obtained from the numerical solution are presented graphically in Figure 3. Based on the analysis of these graphs, it was found that when the mass of the transported and cleaned fiber increases from 0.6 kg to 3.6 kg, the driving force increases linearly from 0.19 N to 1.21 N.

In addition, when the screw inclination angle increases, the driving force rises from 0.45 N to 2.57 N [3]. This is because an increase in the inclination angle leads to an increase in the number of screw turns. Consequently, the transportation (cleaning) distance of the fiber decreases, and the required driving force increases.

To prevent excessive growth of this force, the following recommended values are proposed [3,13]:

Taking into account the gradual decrease of traction force along the working zones of the screw, it is determined that:



in the first zone: 2.4–2.62.4–2.62.4–2.6 N,

in the second zone: 2.1–2.32.1–2.32.1–2.3 N,

in the third zone: 1.8–2.01.8–2.01.8–2.0 N.

Figure 3. Graphs of the dependence of the driving force of fiber on its mass in a screw conveyor with a wavy screw surface used for conveying and cleaning

In a screw conveyor, selecting the optimal wave height and pitch of the screw surface is of great importance to ensure sufficient loosening of the fiber in the cleaning and conveying zones without increasing its mechanical damage.

The dependence of the driving force of the fiber on its phase position along the wavy surface of the screw is presented in Figure 4. Based on the analysis of these graphs, it was observed that when the phase position of the fiber increases from β1\beta_1β1 to β2\beta_2β2, the driving force decreases from 1.54 N to 3.35 N.

When the coefficient of friction increases up to 0.4, the required force for moving the fiber in the first zone also increases, while its variation range is observed between 2.37 N and 0.81 N.

Thus, it is considered optimal for the phase position of the fiber to be within the recommended range of β ensuring efficient transportation and cleaning without excessive force and material damage [3,14].

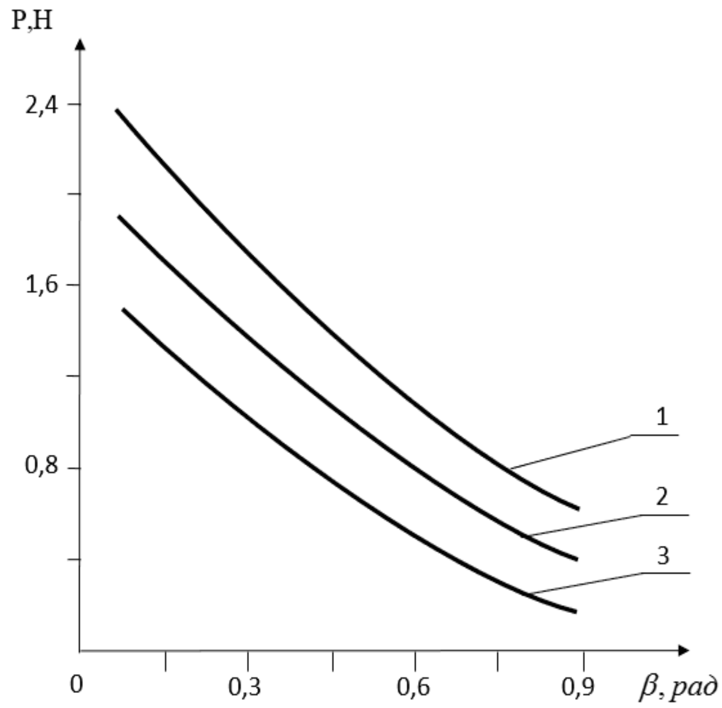
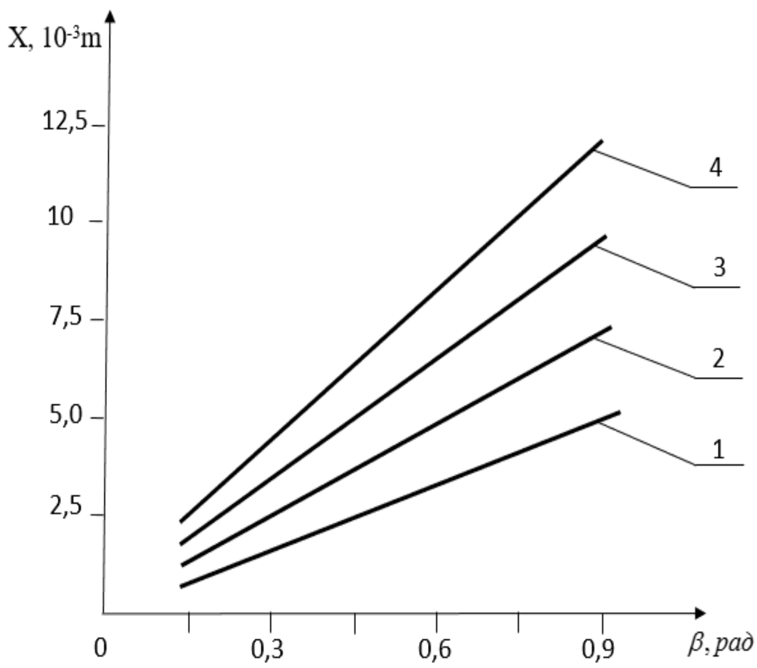


Figure 4. Graphs showing the dependence of the driving force of fiber on its phase position on the wavy screw surface of a conveying and cleaning screw conveyor.

$1 - f = 0{,}4(1 - zone)$; $2 - f = 0{,}35(2 - zone)$;

$3 - f = 0{,}30(3 - zone)$.



$1 - R = 2{,}5 \cdot 10^{-3} m$; $2 - R = 5{,}0 \cdot 10^{-3} m$; $3 - R = 7{,}5 \cdot 10^{-3}$м; $4 - R = 10 \cdot 10^{-3} m$;

Figure 5. Graphs showing the dependence of the movement distance of fiber on its phase position in a screw conveyor with a wavy surface

Based on the analysis of the graphs, it is observed that the movement path of the fiber increases along the wavy surface of the proposed screw conveyor, which enhances fiber loosening and improves cleaning efficiency. Figure 5 presents the dependence of the displacement distance of the fiber along the wavy surface on its phase position.

Here, the increase in this distance is also influenced by the height of the screw waves, i.e., the value of the curvature radius. When the phase position of the fiber on the wavy surface increases from However, when the curvature radius increases to $1{,}0\cdot10^{-2}$ m, the displacement distance rises from $2{,}1\cdot10^{-3}$ m to $12{,}2\cdot10^{-3}$ m.

Therefore, to improve cleaning efficiency, it is advisable to increase α\alphaα and recommend optimal values for β and R [3,14].

A gradual decrease in the fiber mass across the three zones ensures faster discharge of the material from the working zone. This prevents clogging in the conveying section of the conveyor and contributes to increased productivity.

CONCLUSION

For the proposed new screw conveyor design, formulas have been derived to calculate the driving force of cotton fiber along a three-zone mesh surface with inclined holes and elastic supports. Based on the numerical solution of the problem and the analysis of the obtained graphical relationships, recommended values of the screw conveyor parameters have been determined.

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