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Theory of the Dependence of the Friction Coefficient of the Screw for the Cleaning of Small Impurities in the Primary Processing of Cotton on the Frictioning Surface

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Abstract: In the article, the new improved auger design of the unit for cleaning small impurities in cotton preliminary processing is theoretically designed and the friction coefficient of this auger depends on the rubbing surface. Bond graphs were obtained from theoretical calculations.

Keywords: Cotton raw material, cotton preliminary treatment, fiber, screw, screw conveyor, small and large impurities, coefficient of friction, strength.

One of the main working organs of the cleaner developed by us to increase the efficiency of cleaning cotton from small impurities is a screw auger [1]. The study of the process of cleaning cotton from impurities performed in this has a great impact on the alternative of the entire cleaning procedure, therefore, the movement of cotton in the screw working part of such a cleaner was theoretically analyzed.

Figure 1 shows the diagram of the forces acting on cotton during transportation on a screw conveyor. The screw surface is formed in the form of a line sliding trace, which rotates around some axis, and at the same time creates the movement of the axis in advance [2-7].

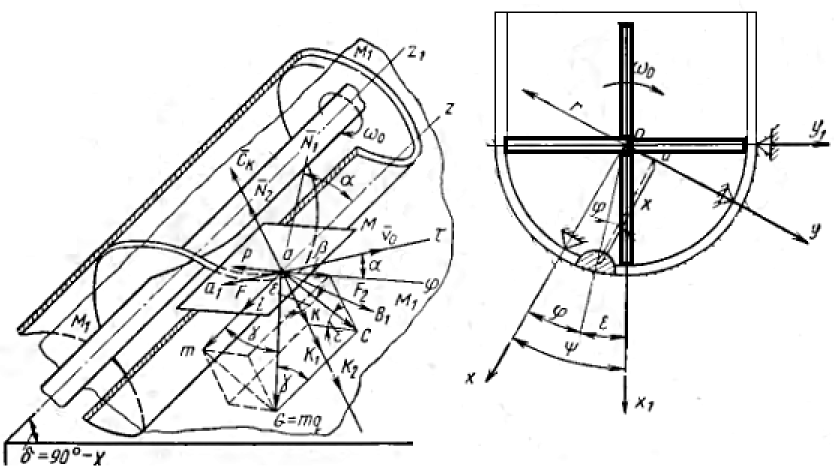

Figure 1. Positioning of forces and fixed and moving coordinate systems on a material point on a screw conveyor

It is known that the movement of cotton on the conveyor is considered complicated X=$r\cos\varphi_1$, У=rsinφ, Z=aφ can be presented in the following form according to the axes [8-15]:

$$N_1 \cos\alpha - f_1 N_1 \sin\alpha - ma\left(\frac{d^2\phi}{dt^2}\right) - G\cos\gamma\sin\varepsilon + f_2 N_2\cos\beta - f_1 N_1\cos\alpha - N_1\sin\alpha - mr\left(\frac{d^2\phi}{dt^2}\right) = 0;\ G\sin\gamma\cos\varepsilon + mr\omega_0^2 + mr\left(\frac{d\phi}{dt}\right)^2 - N_2 - 2mr\omega_0\frac{d\phi}{dt} = 0 \quad (1)$$

Here: N_1 - normal reaction of inclined plane; f1-the coefficient of friction of the material to the screw blade; α- the angle of elevation of the screw line:

$$\alpha = arctg\frac{S}{2\pi r}; \quad (2)$$

S- screw pitch; *r*- outer radius; $m = \frac{G}{g}$ - elemental mass of the material; *G*- the weight of it; γ - the angle of inclination of the shaft axis to the vertical; N_2-shell moderate reaction; f_2- coefficient of friction of the material to the shell wall; β - velocities are transferred $\bar{v}_n$ and absolute $\bar{v}$ angle or angular index medium vectors; a $= rtg\alpha$- indicator of the screw working body;

$$\sin\beta = \frac{a\frac{d\phi}{dt}}{v};\ \cos\beta = \frac{r\left(\omega_0 - \frac{d\phi}{dt}\right)}{v}; \quad (3)$$

trigonometric indicator [16, 17] function; φ - constant angle ω_0 angle of deviation of the particle in the rotation of the screw working body with a speed [1/sec]; $\varphi = f(t)$; *t*- time; $\frac{d\varphi}{dt} = \omega'$ – Angular velocity of the relative motion of the material point; ε - the angle defining the relative position of the point in relation to the vertical plane:

$$\varepsilon = \psi + (-\varphi); \quad (4)$$

$\psi = \ \omega_0 t$ - the angle of rotation of the screw conveyor in time; $mr\frac{d^2\varphi}{dt^2}$ - inertia effort force; $m\omega_0^2 r$ - centrifugal force of inertia in the transferred motion; $mr\left(\frac{d\phi}{dt}\right)^2$- centrifugal force of inertia in relative motion; $2m\omega_0 r\frac{d\phi}{dt}$- Coriolis force; $ma\frac{d^2\varphi}{dt^2}$ - axial force of inertia.

Based on the theoretical study of the movement of cotton mass on a screw conveyor [18-24], it was shown that when the mass of cotton pieces moves along the screw conveyor in a length equal to the entire screw pitch, it moves with a variable speed depending on the screw pitch of the screw working body, the filling coefficient of the screw conveyor, and the viscosity of the cotton pieces mass. (Figure 2).

System (3) into the third equation

$$v_1 = a\frac{d\phi}{dt} = v\sin\beta = \frac{\omega_0\cos\alpha\sin\beta}{\sin(\alpha+\beta)};\ \frac{d\phi}{dt} = \frac{v\sin\beta}{a} = \frac{\omega_0\cos\alpha\sin\beta}{\sin(\alpha+\beta)} \qquad \omega = \frac{V_2}{r} = \omega_0 - \frac{d\phi}{dt} = \frac{v\cos\beta}{r} = \frac{\omega_0\cos\alpha\sin\beta}{\sin(\alpha+\beta)} \quad (4)$$

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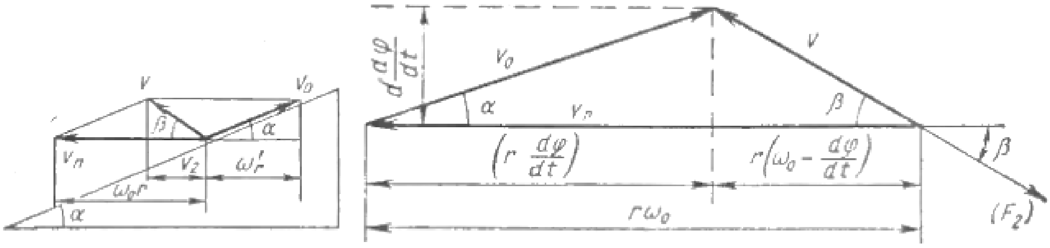

Figure 2. Parallelogram view of speeds

When considering the theory of motion of a separate material point, including a piece of cotton, the equation with an angular index for any screw working body can be written in the following form [25, 26, 27]:

$$\frac{f_2\left[\omega_0^2 r\sin^2\alpha\cos^2\beta+g\sin\gamma\cos\varepsilon\sin^2(\alpha+\beta)\right]\left[\cos\beta-\sin\beta tg(\alpha+\varphi_1)\right]}{g\sin^2(\alpha+\beta)\left[\cos\gamma tg(\alpha+\varphi_1)-\sin\gamma\sin\varepsilon\right]}=1 \qquad (5)$$

$\gamma=90^0$ when the equation applies to the working body with a horizontal screw in our case [28].

The following can be derived from equation (5) to determine the limit orders and performance of the screw working body:

$$[\cos[\![\beta-\sin\beta\,\mathrm{tg}(\alpha+\varphi_1)]\!]]=\frac{\mathrm{g}\sin^2(\alpha+\beta)[\cos\gamma\,\mathrm{tg}(\alpha+\varphi_1)-\sin\gamma\,\sin\varepsilon]}{f_2\left[\omega_0^2 r sin^2\alpha\,cos^2\beta+g sin\gamma\,cos\varepsilon\,sin^2(\alpha+\beta)\right]} \quad (6)$$

All quantities in the denominator of equation (6), exceptω_0^2, have a final value

$\omega_0\to\infty$ when , we have the following:

$$\cos\beta-\sin\beta\,\mathrm{tg}(\alpha+\varphi_1)=0;\ \beta=90^0-(\alpha+\varphi_1) \qquad (7)$$

When $\gamma=90^0$ for a horizontal screw working body, the expression (16) is formed, independent of ω_0, and taking into account that ε=0.

For all types of screw working bodies, no matter how large the value of ω_0 is, the average size of the angle β will not exceed the value according to the formula (7). But in the case of horizontal screw working bodies, when β=90^0, the cotton piece moves along them parallel to the axis of the screw working body.

When $\beta=90^0$:

$$\upsilon_1=\upsilon\sin\beta=\omega_0\,\mathrm{r\,tg}\alpha. \qquad (8)$$

In this case, equation (5) takes the following form

$$f_2\sin\gamma\cos\varepsilon=-\cos\gamma+\frac{\sin\gamma\,\sin\varepsilon}{tg(\alpha+\varphi_1)} \qquad (9)$$

$\gamma=90^0-\delta$ when changed to, here δ- the angle of inclination of the axis of the screw to the horizon, expression (9) takes the following form.

$$f_2\cos\delta\cos\varepsilon=-\sin\delta+\frac{\cos\delta\,\sin\varepsilon}{tg(\alpha+\varphi_1)} \qquad (10)$$

For horizontal screw working body δ=0, in that case:

$$f_2\cos\varepsilon=\frac{\sin\varepsilon}{tg(\alpha+\varphi_1)};\ tg\varepsilon=f_2\,tg(\alpha+\varphi_1) \qquad (11)$$

It follows from equation (11) that ε=0 from the bottom

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ε_0= arctg $[f_2\ tg(\alpha + \varphi_1)]$ (12)

when turning to an angle, a piece of cotton moves at a speed determined by the formula (8) along the generator of ω_0 at any value of the horizontal screw working body.

When the screw working body is installed obliquely;

$\varepsilon_{н} = \varepsilon_0 + \lambda,$ (13)

Here:

$\lambda = \arcsin[tg\delta\ tg(\alpha + \varphi_1)\ cos\varepsilon_0]$ (14)

A piece of cotton ε=0 so as not to have an axial shift in the lower position $\beta = 0, \upsilon_1 = 0$ should be

In this case, from equation (5) we have the following:

$$\omega_0 = \sqrt{\frac{gcos\gamma\ tg(\alpha+\varphi_1)}{f_2 r} - \frac{gsin\gamma}{r}}. \quad (15)$$

The working body of the proposed cleaning screw is located horizontally, in which case:

$$\omega_0 = \sqrt{-\frac{g}{r}}, \quad (16)$$

And this is impossible Ø empty set.

It is known that in the case of ε=0, the angle b for the horizontal working body must correspond to the expression (17) and is equal to zero under the following condition $\beta = 0$:

$\alpha = 90^0 + \varphi_1,$ (17)

i.e., the irrational elevation angle of the screw line is zero in the condition that the cotton cannot be transported:

In the considered screw working body with a constant axial speed, it is appropriate to enter the average angle β_{medi} the absolute and partial speeds [29, 30].

Then we have the following:

$$\upsilon_{1medi} = \upsilon_{zmedi} = \upsilon\ sin\beta_{medi} = \frac{\omega_0 r\ sin\alpha\ sin\beta_{medi}}{\sin(\alpha + \beta_{medi})};$$

$\omega_{ўр} = \omega_\theta r\ sin\alpha\ sin\beta_{betw}/\sin(\alpha + \beta_{betw})$ (18)

Here $\omega_\theta = \omega_0$- angular speed of the shaft of the screw working body;

$$\omega = \sqrt{\frac{gtg\ (\alpha+\varphi_1)cos\gamma}{rf_2\ [cos\beta_{medi} - sin\beta_{medi} tg(\alpha+\varphi_1)]}}. \quad (19)$$

The alternate angles of the risers of the screw lines of the working body of the cleaner have a great influence on the movement of the cotton pieces.

Maximum axial speed and productivity are ensured by the alternate pitch angle of the screw lines.

$$\alpha_r = \frac{1}{2} arctg \frac{{\omega_0}^2 r f_2}{gcos\gamma} - \frac{\varphi_1}{2} \quad (20)$$

In the horizontal screw working body, g=900, cos g=0, the formula (21)

gives the following expression:

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$$\alpha_{\text{г}} = \frac{arctg\infty}{2} - \frac{\varphi_1}{2} = 45^0 - \frac{\varphi_1}{2}. \qquad (22)$$

In screw conveyors, the critical radii are considered a classification indicator, they determine the boundaries of the part where the cotton pieces have an angular speed of the conveyor ω_0 and their axial displacement stops [31-35].

(6) from Eq, $\gamma = 90^0 - \delta, \beta = 0$ after substitution, we get the following expression:

$$\frac{l_2 〚(\omega)〛_0^2 r + g cos\delta\, cos\varepsilon)}{g\,[sin\delta\, \text{tg}(\alpha+\varphi_1) - cos\delta\, sin\varepsilon\,]} = 1. \qquad (23)$$

From equation (2) we can see ω_0 as the required quantity, where r and α correspond to the edge screw line of the conveyor.

At any ω_0 we have the following:

$$r_{\text{кр}} = \frac{g[sin\delta\, \text{tg}(\alpha+\varphi_1) - cos\delta\, sin\varepsilon - f_2 cos\delta\, cos\varepsilon]}{f_2\omega_0^2}. \qquad (24)$$

According to the equation (23), it is possible to determine the influence of all indicators on the magnitude of $r_{\text{кр}}$.

For horizontal conveyor ($\delta = 0^0$)

$$r_{\text{кр}}^{г} = \frac{g(-sin\varepsilon - f_2\, cos\varepsilon)}{f_2\omega_0^2}. \qquad (25)$$

In this case, the effect of a and r on the edge and the step S on $r_{\text{кр}}^{г}$is dropped. In the lower case $\varepsilon = 0$, $r_{\text{кр}}^{г}$ has an insignificant value

Буни физикавий мазмуни маълум, чунки горизонтал ишчи органларда ҳар қандай шароитларда жисм $\beta = 90^0 - (\alpha + \varphi_1)$ бурчак остида ҳаракатлана бошлайди: $\beta = 0$ ва $\alpha_{\text{кр}} = 90 - \varphi_{1.}$ ҳолати ҳам бўлиши мумкин.

The physical meaning of this is known, because in horizontal working bodies under any conditions the body begins to move at an angle $\beta = 90^0 - (\alpha + \varphi_1)$: $\beta = 0$ and $\alpha_{\text{кр}} = 90 - \varphi_{1.}$ can also be the case

In this:

$$S = 2\pi\, r_{\text{кр}}^{г}\, tg\alpha_{\text{кр}} = 2\pi\, r_{\text{кр}}^{г}\, ctg\alpha_{\text{кр}}\varphi_1 = \frac{2\pi\, r_{\text{кр}}^{г}}{f_1}, \qquad (26)$$

In this:

$$r_{\text{кр}}^{г} = \frac{Sf_1}{2\pi}. \qquad (27)$$

$tg\varepsilon_0 = tg\varepsilon = f_2 tg(\alpha + \varphi_1)$ determined by the condition $\varepsilon = 0$ in an angled position $r_{\text{кр}}^{г}$ it is possible to know what value it will have, in which the cotton moves parallel to the axis along the shell cylinder on the horizontal conveyor [36-41].

Substituting equation (26) we determine the following:

$$r_{\text{кр}}^{г} = -\frac{g[\text{tg}(\alpha+\varphi_1)+1]}{f_2\omega_0^2\sqrt{1+f_2^2\text{tg}(\alpha+\varphi_1)}} = f(\alpha, f_1, f_2, \omega_0). \qquad (28)$$

In the next part of our research, we will consider the influence of design and layout factors on the performance of the cleaning screw working body.

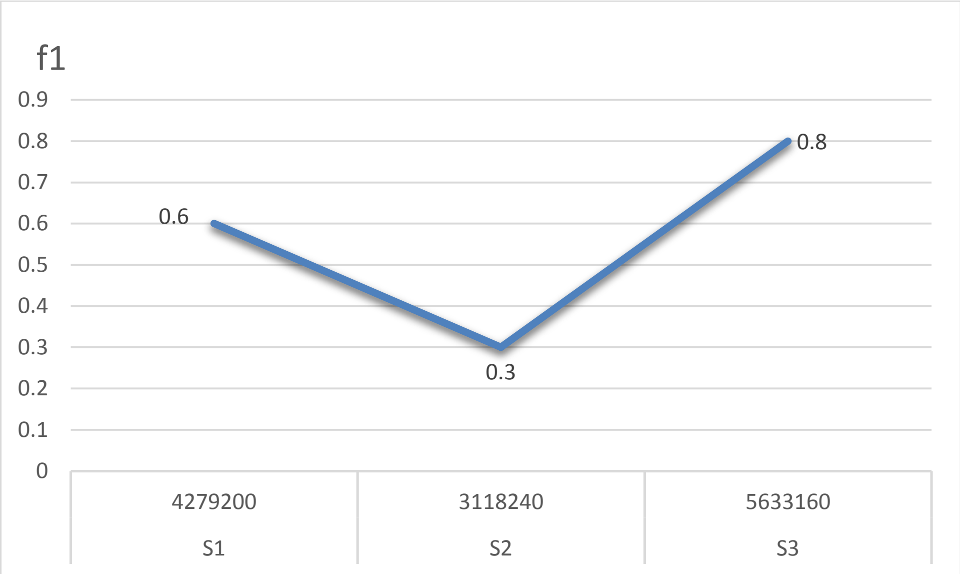
In a cleaner with a screw working body, mathematical models representing the dependence of the cotton axis speed on the axis of the screw working body inclination angle γ, critical radius r, the angle of elevation of the screw line α, angular velocity ω_0, cotton friction coefficients f_1 and f_2 were obtained and the indicators were calculated as a result of the performed calculations. r = 230 mm; α = 300; f_1=0.3; f_2=0.4; n_0=260 min^{-1}; S=300 mm.; b = 200 mm. It was found that the curve of the change of the average axial speed in the cleaner with a screw working body has a sinusoidal form.

$$\vartheta_{1\text{medi}} = a\left(\frac{\gamma}{\gamma_1} - \frac{1}{2\pi}\sin\frac{2\pi}{\gamma_1}\gamma\right). \qquad (29)$$

Here a −coefficient to be determined; γ_1 − quarter the period of the function, in this case equal to 90^0.

Tape length of the screw $L = \sqrt{s^2 + (\pi D)^2}$, mm, and to find the surface of the tape [42-45]. $S = L * b$, mm^2 formulas are known. The length of the peg installed instead of the tape L = 2πr, mm, and finding the pile surface$S_1 = L_1 * b_1$, mm^2.

It is necessary to determine the values of cotton friction coefficients f_1 and f_2, because the coefficients of friction of cotton with a tape or pile with a flat surface have different values depending on the value of the surface. We can see this in the graph below (Figure 3):



S_1- the surface of the screw tape; S_2- surface of screw piles; S_3- the surface of the screw conveyor belt.

Figure 3. Dependence of the coefficient of friction on the rubbing surface

It can be seen from this graph that the smaller the friction surfaces (S_1, S_2, S_3), the smaller the coefficient of friction (f_1), and we conclude that the smaller the coefficient of friction, the less fiber and seed damage.

Taking into account that the number of revolutions of the screw "n" and the angle of elevation "α" have a great influence on the cleaning process, the following graph of the number of revolutions and the angle of elevation is drawn (Fig. 4).

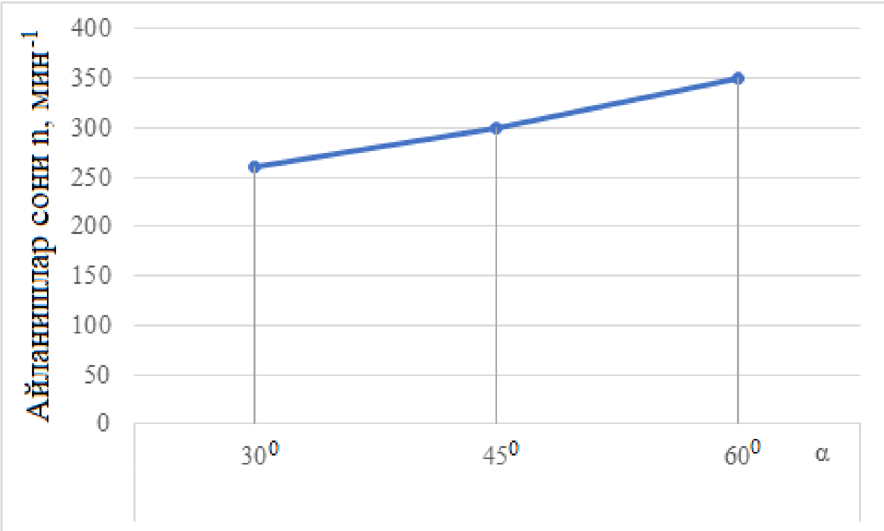


Figure 4. Graph of dependence of the number of revolutions on the angle of ascent

It can be seen from the relationship in the given graph that the number of revolutions increases correspondingly [46-50] with the increase of the angle of ascent, and such a relationship has the form of a straight line.

The formula for calculating the average axial speed:

$$\vartheta_{1\text{medi}} = \frac{\vartheta_{1\,(0^0)} + \vartheta_{1\,(10^0)} + \dots + \vartheta_{1\,(350^0)}}{n_1}, \qquad (30)$$

By calculating the axial velocity average using this formula, $\varepsilon = 0;\ 10^0,\ 20^0, \dots\dots, 350^0$ all information can be obtained for screw working bodies with precise indicators in the change.

In particular, $f_1 = 0 \div 1{,}0$; $f_2 = 0 \div 1{,}0$; $\alpha = 5 \div 60^0$; $r = 0{,}025 \div 0{,}3\ m$; $n_0 = 10 \div 500\ min^{-1}$; $\gamma = 0 \div 90^0$ Changes in the range for all cases:

$$\vartheta^{b}_{1\text{medi}} < \vartheta^{\text{н}}_{1\text{medi}} < \vartheta^{\text{г}}_{1\text{medi}}. \qquad (31)$$

Based on the analysis of this process, the axial average in the horizontal screw working body $\vartheta_{1\text{medi}}$ the speed f_2 A graph of the variation of the friction coefficient was developed (Fig. 5).

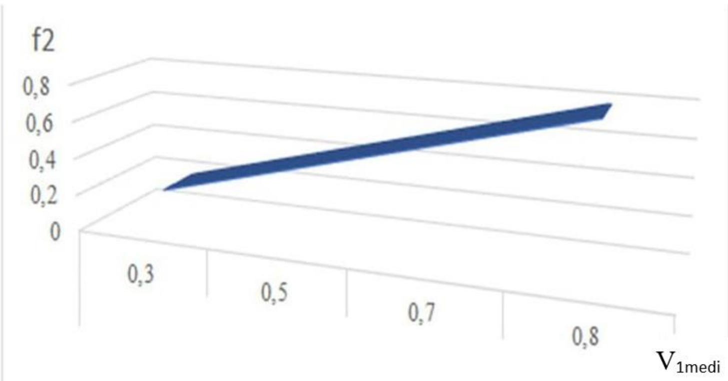


Figure 5. The graph of the change of the axial average speed $v_{1\text{medi}}$ depending on the coefficient of friction f_2 in a horizontal screw working body

In the horizontal screw working body $\delta = 0$, $\omega_0 - \omega\sqrt{\sin\delta} = \omega_0$.

From a physical point of view, this means that in the screw working body in the cleaner developed by us [51], a piece of cotton reaches the screw line maker at an angle ε_0 (13) when determined according to the lower case β (8) and moves along (9) at the speed of progress ϑ_1.

Summary.

1. In order to speed up the process of cleaning cotton from small impurities in the cleaner, a new design of the screw auger, one of the main working organs of the cleaner, was developed and a force scheme was built.

2. In order to increase the cleaning efficiency and quality of the processed product, a theory of a new supply device for cleaners was developed.

3. The theory of the dependence of the friction coefficient of the auger cleaning from small impurities in the initial processing of cotton on the rubbing surface was explained, and connection graphs were obtained.

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