Structural and parametric synthesis of screw modules of technological machines

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Abstract. The article examines the screw modules of technological machines that feed materials under pressure and move loads in the vertical direction to various working bodies. The main disadvantage of these screw modules is low productivity due to the spiral movement of the material, with a significant deviation from the longitudinal axis of the screw module. The paper considers the possibility of increasing the operational performance of screw modules of technological machines by reducing the rotational component of the material movement. This goal is achieved by installing ribs on the inner surface of the module. The angle of ribs installation is determined by the kinematic and geometric parameters of the conveyor auger shaft and the properties of the supplied and moved loads. The results of theoretical studies show that correctly selected geometrical parameters of the ribs can increase the screw module productivity by 18 – 20%.

1. Introduction.
At present, screw modules are part of various machines, assemblies, and technological complexes, transport, and stationary equipment in the mining industry, the construction industry, and the food industry. Along with traditional screw modules, in recent years, shaftless augers and flexible screw conveyors have become widespread. A wide range of applications in the technological transportation and supply of various materials under pressure is due to such advantages of screw modules as reliability and maintainability, tightness, small dimensions, the possibility of continuous transportation in any direction, the simplicity of laying routes between technological machines, and the ability to move toxic cargo [1].

Flexible screw conveyors do not require additional space for their installation and are used both in designed and existing workshops. The object of research is the structure and parameters of the working bodies of technological and transporting machines, including screw modules, processes occurring in arrays of processed and moving materials, and on the surfaces of their contacts with working bodies. These parameters are determined by the physicomechanical properties of these materials based on modern computer technologies for the selection of technical solutions and design features [2].
During vertical transportation and feeding under pressure, the material in the screw module moves along a spiral path. Moreover, the angle between the direction of material movement and the longitudinal axis of the screw module is about 800. This method significantly reduces the performance of the module [3, 4].

To a large extent, this is due to the lack of adequate mathematical models that give an accurate quantitative and qualitative assessment of the processes occurring in the material array and on the surfaces of its contact with the working bodies of technological machines. A more accurate quantitative assessment of the process of movement of the material in the screw module gives a mathematical description of the process of movement of the material flow, taking into account the shape of its cross-section [5].

2. The apparatus, operating principles, and basic parameters of screw conveyors

To develop mathematical models of the formation of cargo flows in technological and transporting machines and complexes, it is necessary to establish factors that influence the formation of these cargo flows and justify the dependence of the volume of material at the output on influencing factors [6].

The movement of cargo along a helical line with a small pitch significantly reduces the operational performance of the transportation process. To partially eliminate these shortcomings, design measures are carried out aimed at reducing the coefficient of friction of the load on the surface of the blade and increasing the coefficient of friction of the load on the conveyor body [7]. Screw conveyors have cylindrical bodies with a smooth surface, which weakly prevents the rotational movement of the load inside the conveyor.

In technological machines having screw assemblies that feed material under pressure to forming, grinding, and other working bodies, they have bodies with ribs on the inner surface, which prevent the material from turning with the screw.

Consider the possibility of improving the performance of a vertical screw conveyor by installing ribs on the inner surface of the housing.

3. Disadvantages of screw conveyors and ways to improve them

Technological machines and complexes are designed for use in a particular field of application, and without its specification, the choice of optimal parameters is impossible [8]. When performing a theoretical study of the processes occurring in materials under the action of the working bodies of technological machines, an important step is the identification of the medium and, depending on this, the choice of the design scheme and mathematical model of the stress-strain state of the processed material. Analysis of the movement of cargo in a vertical screw shows that the cargo moves in a spiral and the direction of its movement is about 78 – 82 degrees with the longitudinal axis of the conveyor [9]. This indicator is less than the angle of friction between the metal and most goods transported by screw conveyors. Therefore, if the ribs are arranged in a spiral with a rational angle of cutting the helix, then it can reduce the angle between the direction of movement of the load and the longitudinal axis of the conveyor and thus increase its productivity (Figure 1).

The following forces act on the part of the cargo in the intercostal space (Figure 2). Driving force, from the central part of the load

$$F_{dr} = N_c f_c \cos(\beta - \varphi),$$  

where $N_c = m_c R \omega^2 \left(\frac{\sin \alpha \sin \beta}{\cos(\beta - \alpha)}\right)^2$ is the force acting on the load in the intercostal space;

$f_c$ – coefficient of internal friction of the cargo;

$\varphi$ – the angle between the ribs and the axis of the conveyor (Figure 2);

$m_c$ – mass of cargo;
The force that prevents the movement of cargo between the turns of the ribs

\[ F_R = m_h g f_h \sin \varphi + m_l g \cos \varphi + N_h f_h. \]  \hspace{1cm} (2)

where \( m_l \) is the mass of cargo between the turns of the ribs;
\( f_h \) – coefficient of friction of cargo on the body;
\( N_h = m_h R \omega^2 \left( \frac{\sin \alpha \sin \beta}{\cos(\beta - \alpha)} \right)^2 + m_l R \omega^2 \left( \frac{\sin \alpha \sin \varphi}{\cos(\varphi - \alpha)} \right)^2 \) – the force of the normal pressure of the load moving part and the part located between the turns of the ribs on the conveyor body.

The movement of cargo between the ribs occurs if

\[ N_c f_c \cos(\beta - \varphi) > N_h f_h + m_l g (f_h \sin \varphi + \cos \varphi). \]  \hspace{1cm} (3)

The force that prevents the movement of goods along the ribs
\[ F_{Z_1} = N_h f_h + m_h g (f_h \sin \varphi + \cos \varphi). \]  

The force that prevents the movement of the load perpendicular to the ribs

\[ F_{Y_1} = N_c f_c. \]  

From dependences (4) and (5), the coefficient of friction of the load along the ribs \( f_{Z_1} \) and the coefficient of friction across the ribs \( f_{Y_1} \) are respectively equal:

\[ f_{Z_1} = f_h + \frac{m_h g}{N_h} (f_h \sin \varphi + \cos \varphi). \quad f_{Y_1} = f_c. \]  

The most significant effect of the ribs will be obtained if condition (3) is satisfied. In this case, the central part of the transported material will move along the surface of the conveyor body under conditions of anisotropic friction.

Consider the movement of cargo in the conveyor when \( f_{Z_1} < f_{Y_1} \). Under these conditions, the direction of the load friction force on the conveyor body does not coincide with the direction of movement of the load (Figure 3). The friction force modulus is

\[ F_c = \sqrt{F_n^2 + F_\tau^2}, \]  

where \( F_n \) – the standard component of the friction force of the load, directed perpendicular to the load velocity vector (Fig. 3); \( F_\tau \) – the tangential component of the friction force of the cargo, in the direction that coincides with the velocity vector of the cargo.

The friction force of the load on the conveyor body is

\[ F_R = N_c f_\beta, \]  

where \( f_\beta = \sqrt{f_{Z_1}^2 \cos^2 (\beta - \varphi) + f_{Y_1}^2 \sin^2 (\beta - \varphi)} \) – the friction coefficient of the load on the inner surface of the conveyor body in the force direction \( F_R \).

The standard component of the friction force of the load on the inner surface of the conveyor housing

\[ F_n = N_c f_{(90 - \gamma)}, \]  

where \( f_{(90 - \gamma)} = \sqrt{f_{Z_1}^2 \sin^2 (\gamma - \varphi) + f_{Y_1}^2 \cos^2 (\gamma - \varphi)} \) – the coefficient of friction of the load on the inner surface of the conveyor body in the direction of the force \( F_n \);

\( \gamma \) – the angle between the direction of movement of the cargo and the longitudinal axis of the conveyor.

The tangential component of the load friction force

\[ F_\tau = N_c f_\gamma, \]  

where \( f_\gamma = \sqrt{f_{Z_1}^2 \cos^2 (\gamma - \varphi) + f_{Y_1}^2 \sin^2 (\gamma - \varphi)} \) – the load friction coefficient on the inner surface of the conveyor body in the direction of the force \( F_\tau \).
The equations of motion of a cargo particle [2] do not allow finding the angle $\gamma$ between the direction of its movement and the axis of the conveyor. To determine the direction of movement of the load on the inner surface of the conveyor housing $f_{Z1} < f_{Y1}$, we use the theorem on the change in kinetic energy.

Since the speed of the load $v$ is maximum in the direction of its movement, the maximum kinetic energy of the load and the sum of the work of all external forces in this direction will also be maximum

$$T = \sum A_i^E = \text{max}. \quad (11)$$

We find the work of all the forces acting on the load in the direction of its velocity vector (Figure 3).

The operation of the normal reaction of a helical blade

$$A_{N_{bl}} = N_{bl} \ l \ \cos(\gamma - \alpha), \quad (12)$$

where $l$ – is the magnitude of the movement of the cargo.

The work of the friction force of the load on the blade

$$A_{F_{fr, bl.}} = N_{bl} \ f_{bl} \ l \ \sin(\gamma - \alpha). \quad (13)$$

The work of the tangential component of the friction force of the load on the inner surface of the conveyor housing

$$A_F = -N_c f_{\gamma} \ l, \quad (14)$$

where $N_c = m_c R \omega_0^2 \left( \frac{\sin \alpha \sin \gamma}{\cos(\gamma - \alpha)} \right)^2$.

Substituting (8, 10, 12 – 14) in (11) we obtain:

$$N_{bl} (\cos(\gamma - \alpha) + f_{bl} \sin(\gamma - \alpha)) - N_c f_\gamma = \text{max}. \quad (15)$$
The angular velocity of the relative movement of the load at $f_{Z1} < f_{Y1}$ is

$$\frac{d\phi}{dt} = \frac{\omega_0 \cos \alpha \cos \gamma}{\cos(\gamma - \alpha)}. \quad (16)$$

The system of equations [4], which describes the movement of cargo in a vertical screw conveyor at $f_{Z1} < f_{Y1}$, has the following form

$$N_b \cos \alpha - f_{bl}N_{bl} \sin \alpha - f_{p}N_c \cos \beta - m_g = 0;$$

$$f_{p}N_c \sin \beta - f_{bl}N_{bl} \cos \alpha - N_{bl} \sin \alpha = 0;$$

$$-N_c + m_cR\alpha_0^2 \left(\frac{\sin \alpha \sin \gamma}{\cos(\gamma - \alpha)}\right)^2 = 0. \quad (17)$$

The joint solution (17) and (15) allows determining the direction of movement of the material in the screw module depending on the angle between the ribs and the axis of the module, the angle of the screw blade, the radius of the screw blade, the angular velocity of the screw, the coefficients of external and internal friction of the material and the radius of the screw the blades.

4. Results

The effect of the ribs on the module case will be more significant; the higher the ratio of the coefficients of internal and external friction of the load. Figure 4 shows the dependence of the angle $\gamma$ on the ratio of the coefficients of external and internal friction of the load with the following conveyor parameters: radius of the helical blade is $R = 0.2m$, screw blade cutting angle is $\alpha = 20^\circ$; frequency of rotation of a screw blade is $n = 200rpm$; coefficient of internal friction of cargo is $f_c = 1$.

Lines 1 (Figure 4) show the angle of deviation of the direction of the cargo from the vertical under conditions of anisotropic friction at $f_{Z1} < f_{Y1}$ and for various values of the angle of twisting of the ribs $\phi$. Lines 2 reflect the angle of deviation of the direction of movement of the cargo from the vertical with isotropic friction of the cargo against the conveyor body at $f_{Z1} = f_{Y1}$. Lines 3 are the boundaries of the region of propagation of anisotropic friction when the cargo moves along the surface of the conveyor body. The region of anisotropic friction is located on the left side of these lines, and the region of isotropic friction is on the right side, respectively.

The value of the ratio of the coefficients of external and internal friction at points A (Figure 4) at the intersection of curves 1 and 3 is critical. With its further increase, the movement of material in the space between the corrugations ceases, and the direction of movement of the transported material (angle $\gamma$) in the corrugated casing becomes the same as in a screw conveyor, the casing of which has a smooth inner surface. On the graph, this is reflected by the transition of the angle $\gamma$ from point A on curve 1 to point B on curve 2 (angle $\beta$).

5. Discussion

The results obtained allow concluding that correctly selected corrugation parameters of the housing can significantly increase the performance of the screw module. The geometrical dimensions and the angle of twisting of the ribs should be determined depending on the particle size distribution and the friction coefficients of the transported goods, in order to achieve the maximum value of the coefficient of material output due to its movement under anisotropic friction.
Figure 4. Dependence of the angle between the flow velocity vector and the conveyor axis on the ratio between the flow frictional coefficient and the ridge slope angle $\varphi$:

- $\varphi = 0^\circ$;
- $\varphi = 20^\circ$;
- $\varphi = 40^\circ$;
- $\varphi = 60^\circ$;
- $\varphi = 70^\circ$.

6. Conclusion
An analysis of the results shows that correctly selected geometrical parameters of the corrugation of the casing can increase the performance of the screw module by 18-20% by reducing the rotational component of the movement of the material.
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