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SUBSTANTIATION of FLEXIBLE SCREW CONVEYOR METAL CONSUMPTION UNDER PRODUCTIVITY MAINTENANCE CONDITIONS

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Summary. *Transportation, as well as loading and unloading, of bulk materials by flexible screw conveyors has wide practical application and its share is approximately 40–45%. The flexible screw conveyors are also widely used as they can change the trajectory and height of technological raw material transportation. The above-mentioned mechanisms consist of separate rigid sections which are pivotally connected between each other. Though, high metal consumption is one of their disadvantages. Taking into account that the load on section is increasing from the unloading area to the working body, it has enabled us to reduce their metal consumption.*

Some theoretical substantiation of productivity determination and energy values of flexible screw conveyors depending on the type of technological raw material and the height of transportation has been given in the article under discussion. The obtained characteristics have made possible to substantiate the force factors acting on separate sections. The rigid sections where the rotary moment transmission is taking place due to the flat plates action have been used in the flexible screw conveyor. Therefore, some recommendations on the mechanism metal consumption reduction without its productivity decrease due to the plates size optimization have been made in the article under discussion.

Key words*: productivity, section, moment, plate, flexible screw mechanism.*

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Statement of the problem. The most important disadvantage of flexible screw mechanisms consisting of the same rigid sections is their high metal consumption. Taking into account that the sections in the unloading area are almost unloaded while they are maximal loaded in the loading area, it is possible to reduce the size of their bearing elements, namely plates.

Analysis of the well-known results of the research. In papers [1, 2, 3, 4] some experimental-analytical study of productivity and power consuming dependences of flexible screw conveyors with rigid sections has been carried out. In paper [5] some recommendations on metal consumption reduction of separate elements of rigid sections relative to their location in the loading area have been given.

Paper purpose. To substantiate the design parameters of separate elements of flexible screw conveyor rigid sections without the transporting mechanism productivity reducing.

Problem statement. To determine the boundaries of the most efficient design parameters of plates of bearing elements of flexible screw conveyor rigid sections.

Results of the research. The main working bodies of the most loading-unloading agricultural machines are screw conveyors. They are rather specific mechanisms due to a great variety of technological processes which they perform and also physical and mechanical properties of the transported material determining the design parameters and stock list of the transporting screw conveyor. The process functional diagram of the flexible screw conveyor which consists of separate sections is shown on fig. 1. Technological granular material is delivered to the bunker – 5, where the vibration arch breaker is mounted – 6 to move the raw material out of location. After that the granular material is delivered to the flexible conveyor –

3, which is located on the screw conveyor ends in metal pipes – 10 connected between each other by a flexible hose tube – 4.

The screw conveyor is driven due to the electric engine – 1 and the gearing – 2. The bunker is fixed on the supports – 7. The raw material is being technologically unloaded into a container – 8, the screw conveyor end is fixed by a support arm – 9.

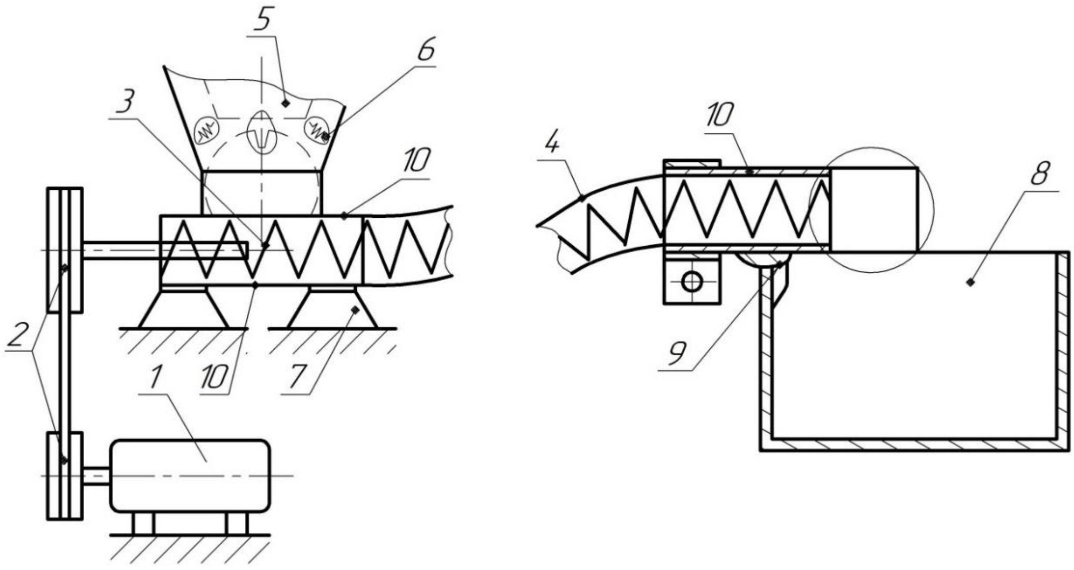

Figure 1. Schematic picture of the flexible screw conveyor

Any changes in the productivity with the rotation frequency change depend on physical and mechanical properties of the transported raw material and geometrical characteristics of flexible screw conveyor and can be found by the formula [1]:

$$Q_0 = \frac{\psi \cdot \varphi_0 \left(1+\sqrt{1-\varphi_0}\right) \cdot \pi \cdot D^3 \cdot \omega \left(T^2 + 0{,}5\pi \cdot \mu \cdot D \cdot T \left(1+\sqrt{1-\varphi_0}\right)\right)}{16\left(T^2 + 0{,}25\pi^2 D^2 \left(2+\varphi_0 - 2\sqrt{1-\varphi_0}\right)\right)}, \quad (1)$$

where D – conveyor external diameter, $D = D_J - z$;

D_J – pipe (trough) diameter where the conveyor is located;

z – clearance between the conveyor external edge and the pipe, $z = 0{,}02\, D_J$;

μ – raw material friction coefficient with the conveyor surface;

T – pitch of the conveyor flight, $T = 0{,}7\, D_J$;

φ_0 – the coefficient of the transporting mechanism volume filling, $\varphi_0 = 0{,}8$;

ψ – coefficient depends on the width of the conveyor flight,

$$\psi = \frac{4k_\psi \cdot B\left(D_J - B - 2z\right)}{D_J^2};$$

k_ψ – the coefficient depends on the raw material, $k_\psi = 1$ – for granular materials ;

B – width of the conveyor flight, $B = 0{,}3D_J$;

ω – angular velocity of the conveyor, $\omega = \dfrac{\pi \cdot n}{30}$,

n – conveyor rotation frequency.

By the obtained formula the material volume Q_0 has been found in m^3 which was transported during one second. To obtain the raw material amount Q transported in an hour one should carry out some transformations by formula:

$$Q = 3600 \cdot Q_0 \cdot \gamma_c, \quad (2)$$

where γ_c – the specific weight of the material (raw material) which is transported.

The results of analytical research of the productivity of flexible screw conveyor of the pipe diameter $D_J = 100$ mm depending on the raw material type which is transported (sand, wheat, manure, animal feed) and the rotation frequency *n* of the conveyor working body are shown on figure 2.

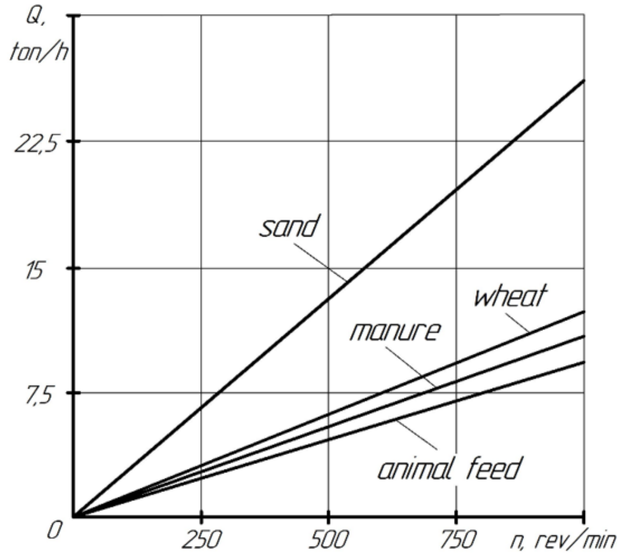

Figure 2. Dependences of productivity of the flexible screw conveyor on frequency of rotation of a working body and transported raw materials

The characteristics of the transported raw material have been used in the study, table 1.

Table 1

Characteristics of transported raw materials

	Sand	Wheat	Animal feed	Manure
γ, kg/m^3	1280	760	600	1020
μ	0,7	0,37	0,4	0,2

Power and force characteristics of flexible screw conveyor, axial force F_z and torque M are described by the following dependencies [1]:

$$F_z = \gamma_c Q \int_0^L \frac{g \sin \gamma_T + \mu \cdot \rho \cdot \omega^2 \cdot \sin \beta}{v_{oc}} dL; \tag{3}$$

$$M = \frac{\rho \cdot \gamma_c \cdot Q(\sin \alpha_\rho + \mu \cos \alpha_\rho)}{\cos \alpha_\rho - \mu_1 \sin \alpha_\rho} \int_0^L \frac{g \sin \gamma_T + \mu \cdot \rho \cdot \omega^2 \cdot \sin \beta}{v_{oc}} dL; \tag{4}$$

where ρ – radius of raw material flow, $\rho = \frac{D}{4}\left(1 + \sqrt{1-\varphi}\right)$;

α_ρ – acceptance angle of auger flight, $\alpha_\rho = arctg\,\frac{T}{2\pi\rho}$;

γ_T – screw conveyor inclination angle against horizon, $\sin \gamma_T = \frac{H}{L}$;

H – height of the material lifting;

L – screw conveyor length;

β – inclination angle of the raw material motion trajectory on the screw conveyor surface,

$$\sin \beta = \frac{T}{\sqrt{T^2 + \pi^2 D^2}};$$

v_{oc} – raw material axial velocity in screw conveyor; $v_{oc} = \frac{4Q}{\varphi_0 \cdot \pi \cdot D_J^2 \cdot \psi}$.

Having analyzed the formulae (3) and (4) we have constructed the curves of force parameters change depending on the raw material lifting height and the rotation frequency of the working body for the screw conveyor of length $L = 6m$. (fig. 3, 4, 5)

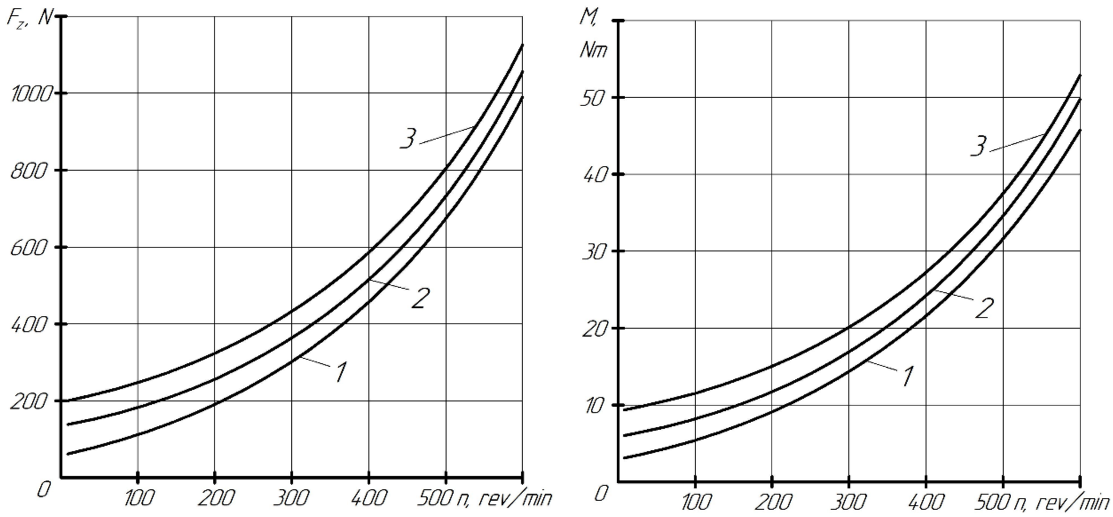

Figure 3. Diagrams of changes in the force parameters of the flexible screw conveyor for transporting sand for the lifting height: 1 – H = 1m; 2 – H = 2m; 3 – H = 3m

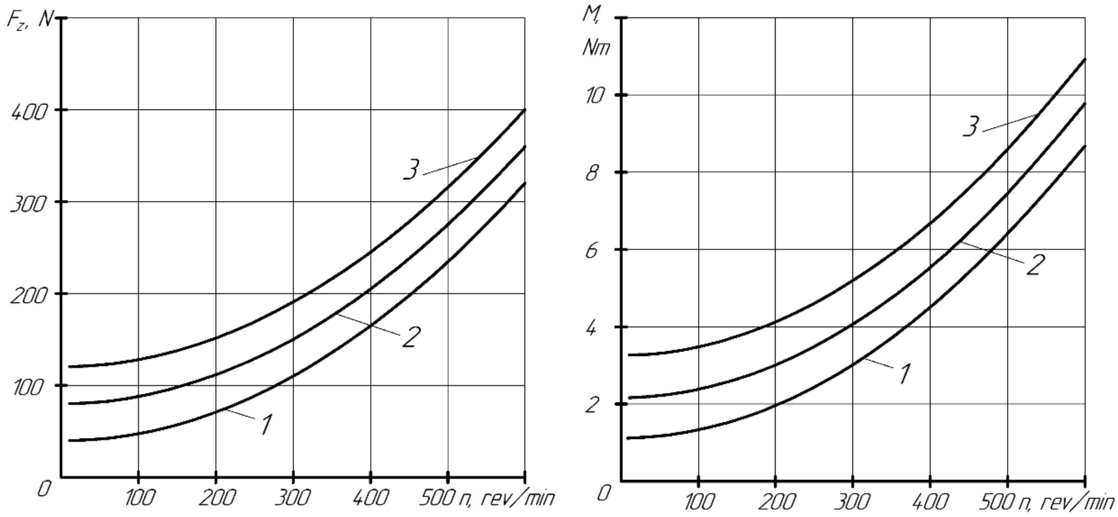

Figure 4. Diagrams of changes in the force parameters
of the flexible screw conveyor for transporting
wheat for the lifting height: 1 – H = 1m; 2 – H = 2m; 3 – H = 3m

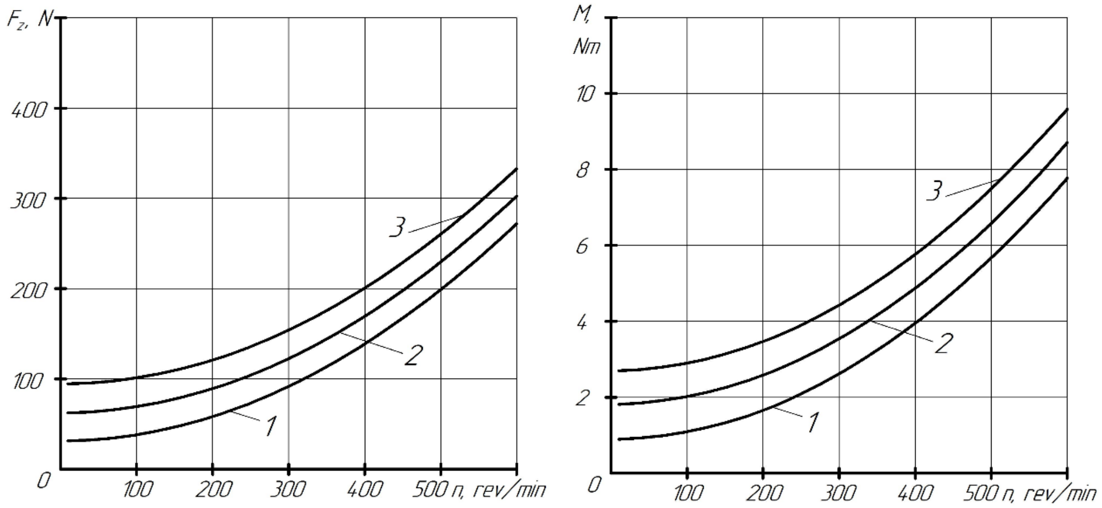

Figure 5. Diagrams of changes in the force parameters of
the flexible screw conveyor for transporting
animal feed for the lifting height: 1 – H = 1m; 2 – H = 2m; 3 – H = 3m

Flexible screw conveyor (auger) consists of n- number of rigid sections, (fig. 6 a) which are movable and connected between themselves (fig. 6 b, c).

The raw material transportation is taking place due to the engine rotary moment. The load transmission (moment) between the neighboring sections is taking place du to the big rectangular joining elements and plates.

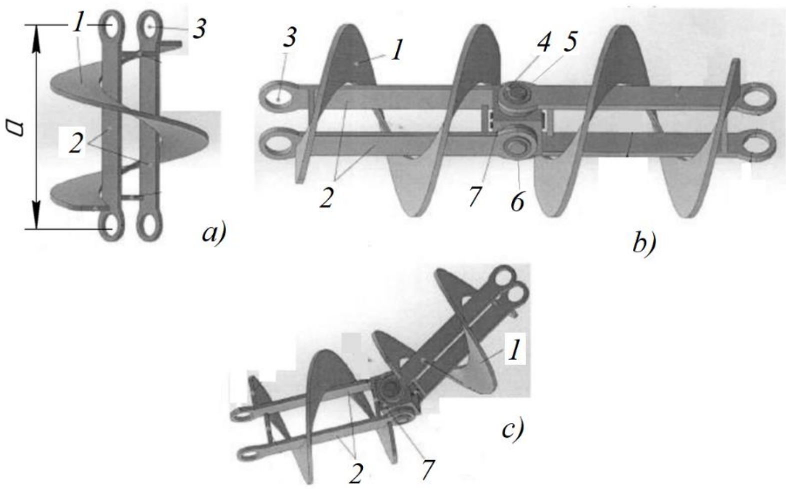

Figure 6. Elements of the flexible transport mechanism, and – section; b, c – movable connection of sections, b – horizontal trajectory, c – curved trajectory

The articulated screw conveyor contains pivotally connected screw sections made as spiral ribs 1, which are fixed on two parallel flat plates 2. On the ends of flat plates 2 the holes are made 3, where through the stepped antifriction bushings 4 the cylindrical radial fingers are mounted, the central of which 5 has been made as a solid one. Two fixing fingers 6 are located to the central finger 5 in perpendicular plane of the square footing 7.

Schematic description of the loads acting on the connecting elements and the strip is shown on fig. 7.

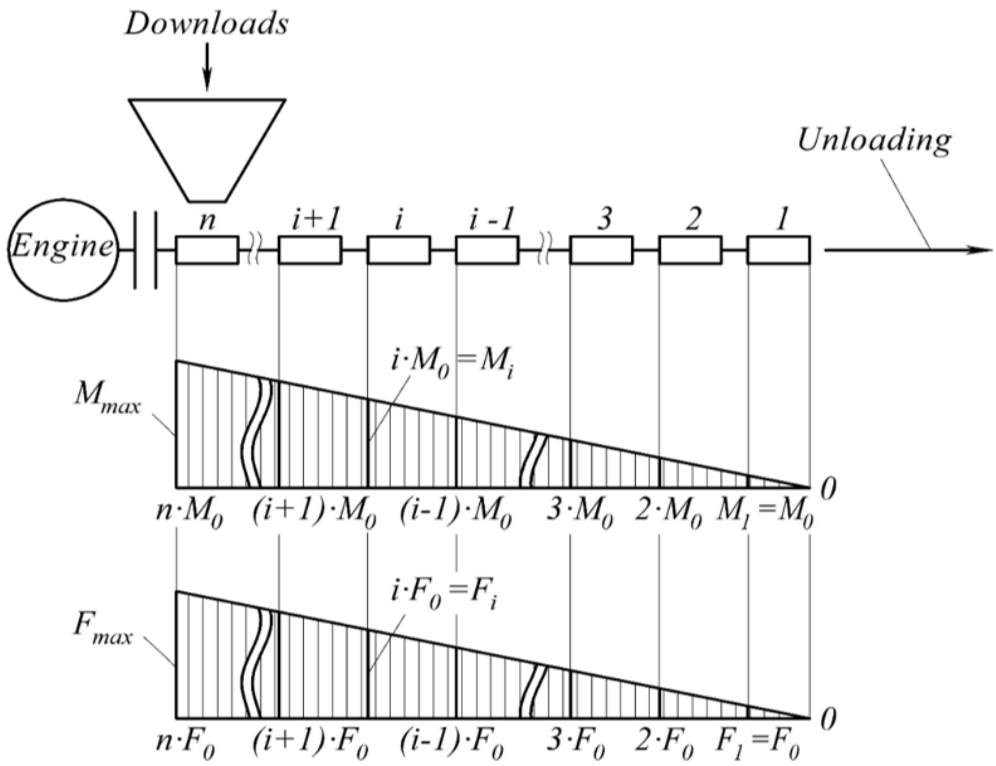

Figure 7. Schematic of the loads of the sectional screw mechanism and the distribution of torque along its length: 1, 2, 3… n – screw sections; *i* – the *i*-th connecting element of the mechanism; M_i is the torque transmitted by the *i*-th connecting element; F_i is the axial force transmitted by the *i*-th connecting element

Under transportation by a flexible screw conveyor conditions (fig. 6) the force loading is accepted by the plates working on deformation of bending and compression, whose schematization is shown on fig. 8 [6].

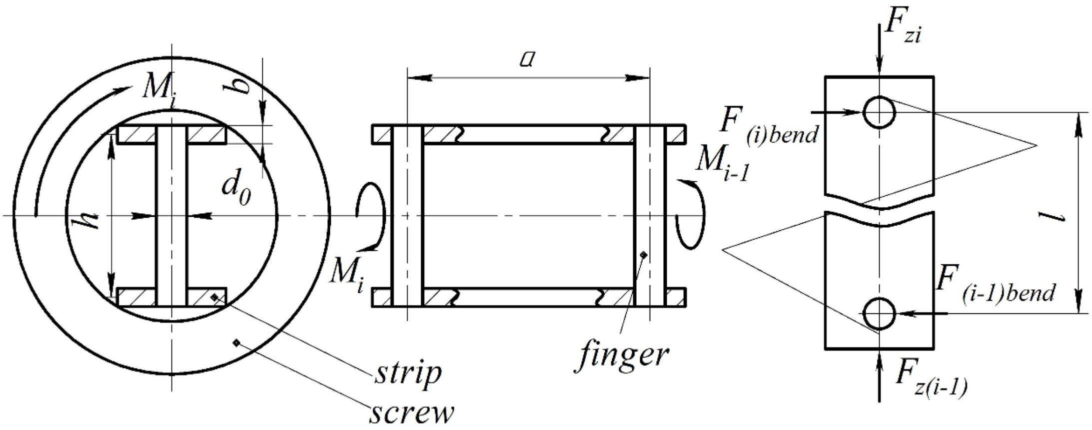

Figure 8. Schematization of the current power loads on the *i*-th section of the flexible screw mechanism

The joints between the sections are made by Hook's joint connecting two neighboring sections by means of two mutually perpendicular fingers. Moment M_i and axial force F_{Zi} from *i*-th to (*i*-1) of the Hook's joint are conveyed through the finger and plates.

Power dependencies, axial force and torque, taken by plates, for the specified transported raw material, the specified rotation frequency of the working body and the height of lifting are described by rectilinear dependencies, fig. 9.

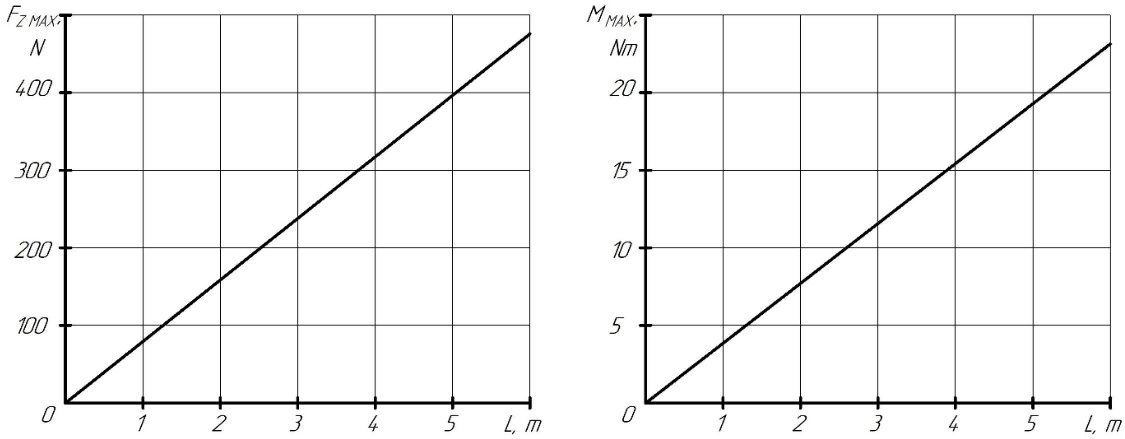

Figure 9. Graphs of changes in axial force and torque of sand transportation to a height of H = 1 m, at n=400 rev/min

The length of the section of the flexible conveyor whose design is given on fig.6 equals to a=120 mm. Thus, the number of sections of the flexible conveyor of the length $L = 6000$ mm is equal to:

$$n = \frac{L}{a} = \frac{6000}{120} = 50\,p.$$

Each separate section conveys a part of the torque and the axial force.

$$M_0 = \frac{M_{max}}{n}; \qquad F_0 = \frac{F_{max}}{n}.$$

The loading of each section is increasing from the unloading area to the working body (see fig. 7)

To reduce the metal content of the flexible conveyor under discussion without any change in its screw section design parameters, namely the screw diameter, the section length, we will calculate the dependence of the plates thickness on their location relative to the working body. We determine the boundary parameter b_{min} – thickness of *n* plate (see fig. 8). Bending moment in the cross section weakened by the hole of a finger.

Maximum internal force factors acting in the cross section of the plate weakened by the hole (fig. 7)

$$M_{z\max} = \frac{M_{\max}}{h} \quad l;$$

where $M_{z\max}$ – maximum bending moment occurring in the plate for the specified transporting mechanism;
h, l – design parameters of the conveyor section, *l*=120 mm, *h*=34 mm.

Geometrical characteristics of the bar in the dangerous cross section (fig. 10).

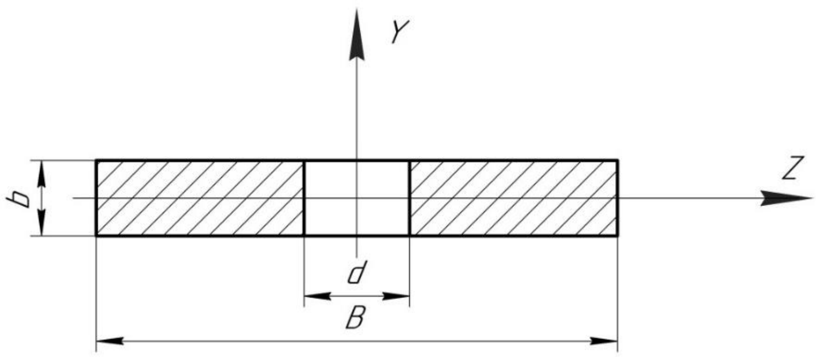

Figure 10. The cross section of the plate weakened by the hole, B = 25 mm; d = 15 mm

Cross section axial moment of inertia [7]: $I_y = \frac{bB^3}{12} - \frac{bd^3}{12} = 1021b$.

Cross section axial moment of resistance: $W_y = \frac{I_y}{B/2} = 81{,}7b$.

Cross section area: $A = B \cdot b - b \cdot d = b(B-d) = 10b$.

Maximum normal stresses [7]: $\sigma_{\max} = \sigma_{зг} + \sigma_{ст} = \frac{M_{z\max}}{81{,}7b} + \frac{F_{\max}}{10b} \leq [\sigma]$,

where $[\sigma]$ – acceptable normal stresses, we have assumed, $[\sigma] = 160\, N/mm^2$.

Minimum thickness of the plate: $b_{\min} \geq \frac{1}{[\sigma]} \left(\frac{M_{z\max}}{81{,}7} + \frac{F_{z\max}}{10} \right)$.

We are constructing the curve of dependence of plate thickness on their location relative to the working body (fig. 11)

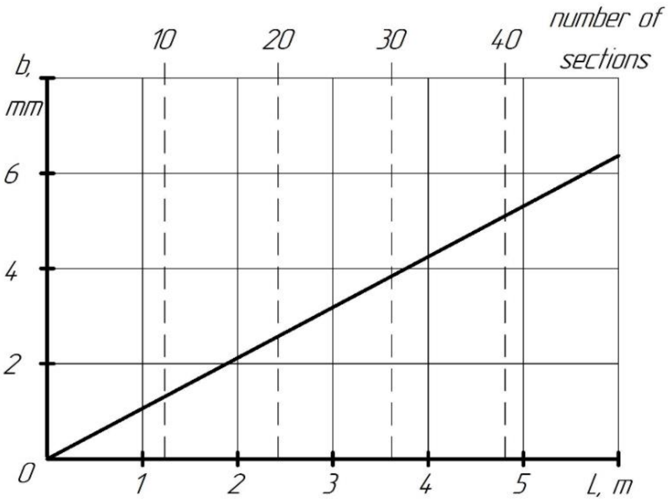

Figure 11. Dependence of plate thickness on their location relative to the working body (Sand, transport height H = 1 m)

The obtained dependence has enabled us (fig. 11) to minimize the plates thickness, for example, for the first ten plates (starting from the unloading area) we have accepted the cross section $b_1 = 2mm$, for the further ten plates $b_2 = 2{,}5\ mm$ and so on, which have resulted in the reduction of the screw conveyor working body mass.

Conclusions. The technique under discussion has made possible to calculate the plates thickness for the specified design of the conveyor in transportation of any kind of raw material due to the height determination at different rotation frequencies of the working body and has resulted in the metal consumption reduction of the transporting mechanism.

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УДК 621.867.42

ОБҐРУНТУВАННЯ ЗМЕНШЕННЯ МЕТАЛОЄМНОСТІ ГНУЧКОГО ШНЕКОВОГО ТРАНСПОРТЕРА ЗА УМОВИ ДОТРИМАННЯ ПРОДУКТИВНОСТІ

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Резюме. *Шнекові транспортуючі механізми посіли значне місце в навантажувально-розвантажувальних машинах, їх частка складає 40–45%. Значну нішу у їх номенклатурі займають гнучкі шнекові механізми, які мають можливість змінювати траєкторію та висоту транспортування технологічної сировини. Такі механізми складаються з окремих жорстких секцій, які шарнірно з'єднанні між собою. Одним із недоліків таких механізмів є висока металоємність. Враховуючи, що навантаження на секції збільшуються від зони вивантаження до робочого органу, дає можливість зменшити їх металоємність. Наведено теоретичне обґрунтування визначення продуктивності та енергетичних величин гнучких шнекових транспортуючих механізмів залежно від технологічної сировини та висоти транспортування. Встановлені характеристики дають змогу обґрунтувати силові фактори, які діють на окремі секції. У гнучкому шнековому механізмі використано жорсткі секції, у яких передавання обертового моменту здійснюється за допомогою плоских пластин. Наведено рекомендації за зменшення металоємності механізму, не зменшуючи його продуктивності, за рахунок оптимізації розмірів пластин.*

Ключові слова: *продуктивність, секція, момент, пластина, гнучкий шнековий механізм.*

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