DETERMINATION OF INTERACTION PARAMETERS AND GRAIN MATERIAL FLOW MOTION ON SCREW CONVEYOR ELASTIC SECTION SURFACE
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ВИЗНАЧЕННЯ ПАРАМЕТРІВ ВЗАЄМОДІЇ ТА РУХУ ПОТОКУ ЗЕРНОВОГО МАТЕРІАЛУ ПО ПОВЕРХНІ ЕЛАСТИЧНОЇ СЕКЦІЇ ШНЕКА

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ABSTRACT

The article presents a new design of a screw conveyor with sectional elastic surface aimed at reducing the grain material damage degree whilst its transportation. Theoretical calculations of a grain-screw conveyor elastic section interaction were made. A dynamic model was developed for determining both the impact of design, kinematic and technological parameters of the elastic screw conveyor on the time and free path of granular material particles whilst their motion between sections and for preventing grain material-screw nonworking surface interaction to reduce the material damage.

РЕЗЮМЕ

У статті представлено нову конструкцію шнека з секційною еластичною поверхнею, яка призначена для зменшення ступеня пошкодження зернового матеріалу при його транспортуванні. Проведено теоретичний розрахунок взаємодії зернини з еластичною секцією шнека. Розроблена динамічна модель для визначення впливу конструктивних, кінематичних і технологічних параметрів еластичного шнека на час та шлях вільного переміщення частинок сипкого матеріалу при їх переміщенні між секціями, а також виключення можливості взаємодії зернового матеріалу з неробочою поверхнею шнекового робочого органу, для зниження його пошкодження.

INTRODUCTION

The problem of reducing the grain materials damage whilst their transportation by screw conveyors hasn’t been solved completely despite of a great number of researches dealing with determination of the best parameters of screws. Agricultural materials damage during their transportation can be reduced considerably by using the elastic surfaces of screws the parameters of which minimize the damage and power capacity of the technological process and simultaneously provide the necessary efficiency.

Some papers are dedicated to the solving of above-mentioned problems, namely the development of energy-saving designs of screw conveyors and choosing their most efficient parameters and working modes *(Baranovsky V.M., et.al., 2018; Boyko A.I. and Kulykivskyi V.L., 2011; Haydl H.M., 1986; Hevko B.M., et.al., 2018; Hevko R.B., et.al., 2015; Hevko R.B., et.al., 2016; Hevko R.B., et.al., 2017; Hevko R.B., et.al., 2018; Lech M., 2001; Naveen Tripathi, et.al., 2015;* Owen P.J. and Cleary P.W., 2010*)*.

The results of investigations on grain-working surfaces contact interaction and also the directions of screw conveyors operational life increase are described in some papers *(Loveikin V. and Rogatynska L., 2011; Lyashuk O.L., et.al., 2015; Qi J. et.al., 2017; Roberts Alan W. and Bulk Solids, 2015).*

Some structural concepts aimed at more comprehensive solution of the above-mentioned problems have occurred more and more often in scientific literature and patents for inventions and they mostly deal with elastic elements use on working surfaces. Some theoretical investigation in this direction is described in the papers *(Lyashuk O.L., et.al., 2018; Manjula E.V.P.J., et.al., 2017; Mondal D., 2018; Tian Y. t.al., 2018; Yao Y.P. et.al., 2014; Wang D.-X., 2012)*.

Thus, a new design of screw conveyors with sectional elastic screw surface has been developed to solve the problems dealing with loose materials damage. Some theoretical substantiation on the design, technological and kinematic parameters impact on loose material flow behaviour has been carried out, which will enable to determine the most efficient parameters and operating modes of screw conveyors suggested design.

MATERIAL AND METHOD

To reduce the degree of grain material damage whilst its transportation by screw conveyors we suggest to fasten some elastic sections to the rigid screw base which would bend when some corns are in a clearance between fixed internal surface of a guiding jacket and rotational peripheral surface of the screw.

For this purpose, an elastic screw conveyor with adjacent elastic sections overlapping has been developed the general view of which is presented in Figure 1. A photo of the spiral conveyor with elastic sections overlapping is given in Figure 2. It consists of a central shaft *1* with rigid base *2* on which elastic sections *3* are fixed by screw bolts with cup heads *4* and screw nuts *5*. Whilst agricultural loose materials transportation in the guiding jacket 6 the elastic sections are bending when some grains are pinched between the jacket fixed surface and rotational surface of the elastic sections. This results in less damage of grain material.

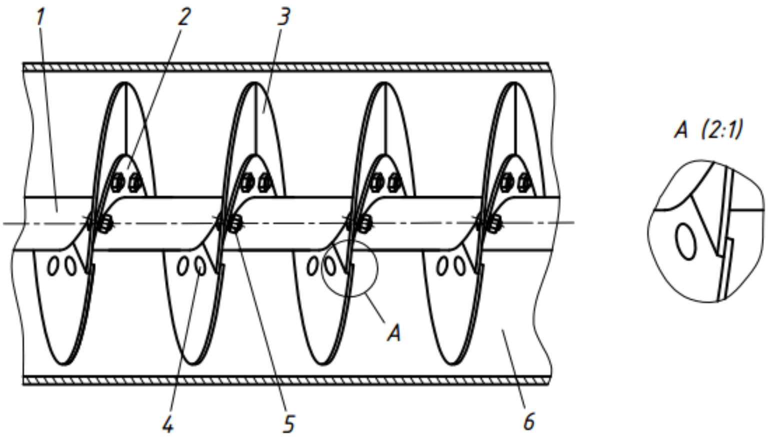

Fig. 1 – General view of the screws with elastic sections overlapping

The transported material while in operation will be rolling off the top edge of the upper section on the lower end of the next section which will have some positive effect on energy consumption of the transportation process and reduce the damage degree of the loose material.

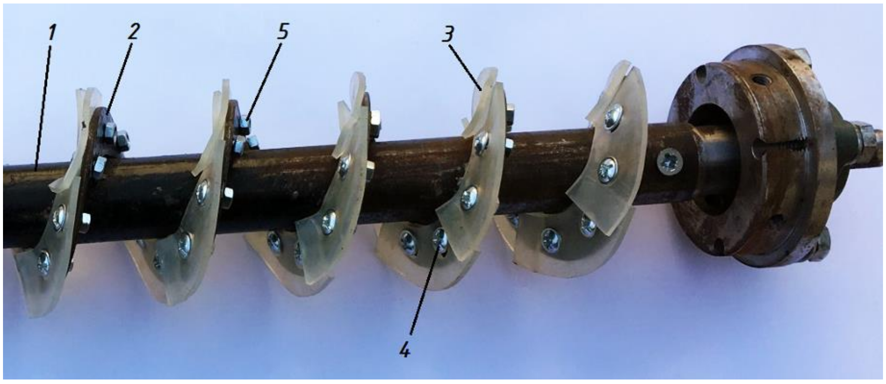

Fig. 2 – Photo of the screw conveyor with elastic sections overlapping

Let's consider a grain of corn with the shape looking like a kind of semi-sphere changing into a cone as grain material *(Hevko R.B., et.al., 2016)* when we determine the force which occur at the direct interaction of the screw elastic edge.

The position of a corn grain which can be the most probably pinched is presented in Figure 3. Let's consider the process of interaction between the screw elastic section and semi-sphere surface of a corn 1 which is pinched between the internal surface of the guiding jacket 2 and the peripheral surface of elastic section 3.

While pinching, the corn is touching the jacket internal surface with its conical surface but its spherical surface is interacting with the screw elastic surface.

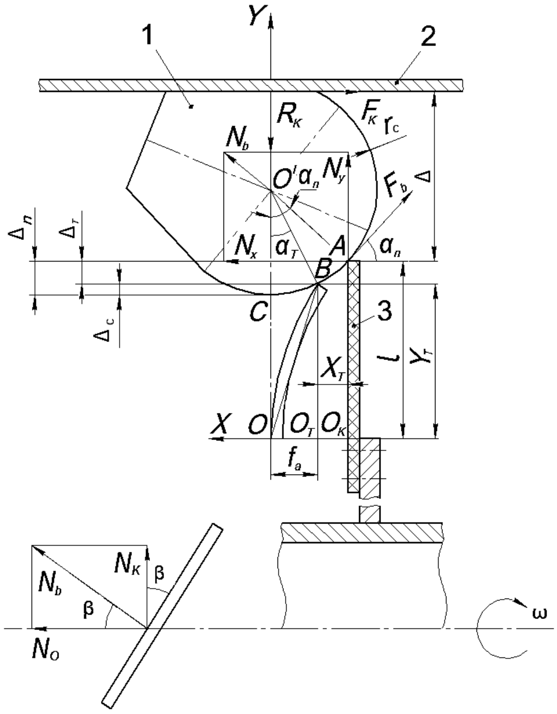

Fig.3 – Schematic diagram of forces, movements and deformations which occur between the screw elastic section and a pinched corn (semi-sphere-cone shape)

The corn pinching takes place in case when the maximum initial angle α_n between normal force of interaction of the screw elastic edge with the corn surface N_b and the plane perpendicular to the screw rotation axis is smaller than the angle of corn friction on the internal surface of the guiding jacket.

With this pinched corn the elastic section is sliding towards it in circumferential and axial directions with a certain deformation. Here the force direction N_b is approaching the axis *OY* and its value is increasing.

The theoretical calculations are aimed at defining such parameters of the corn-elastic section interaction where its damage will be impossible. It means that the screw elastic section will bend towards the pinched corn without its damage.

Let's consider the process of the elastic section movement from the beginning of its contact with the corn (point *A*) which is determined by angle α_T till the certain position (point *B*).

As the elastic section is not completely flexible and its deflection value can be neglected we will take in the first approximation that the chord length *OB* is equal to the overhang length of the elastic section *l*.

First of all, we'll find the height of the elastic section without any deformation Y_T whilst its free end motion from p. *A* to p. *B*, i.e. from the initial contact angle α_n to the current one α_T. Then

$$y_T = l - \Delta_T \,, \tag{1}$$

where Δ_T – value of the current clearance between the elastic section and the internal surface of the guiding jacket, m;

Value Δ_T is found from the expression

$$\Delta_T = \Delta_n - \Delta_c \,, \tag{2}$$

where Δ_n – value of the initial elastic section overlapping with a corn, m; Δ_c – value of the residual elastic section overlapping with a corn, m.

Values Δ_n and Δ_c are found respectively

$$\Delta_n = r_c - r_c \cos\alpha_n = r_c\left(1 - \cos\alpha_n\right), \tag{3}$$

$$\Delta_c = r_c - r_c \cos\alpha_T = r_c\left(1-\cos\alpha_T\right), \tag{4}$$

where r_c – radius of a corn hemispheric surface, m.

By substituting dependences (3) and (4) into (2) we obtain

$$\Delta_T = r_c\left(1-\cos\alpha_n\right) - r_c\left(1-\cos\alpha_T\right) = r_c\left(\cos\alpha_T - \cos\alpha_n\right). \tag{5}$$

By substituting (5) into (1) we obtain

$$y_T = l - r_c\left(\cos\alpha_T - \cos\alpha_n\right). \tag{6}$$

Then we find the current value of the elastic section bending from the triangle BOO_T

$$f_a^2 = l^2 - y_T^2,$$

$$f_a = \sqrt{l^2 - \left(l - r_c\left[\cos\alpha_T - \cos\alpha_n\right]\right)^2}. \tag{7}$$

After some transformations we obtain

$$f_a = \sqrt{r_з\left(\cos\alpha_T - \cos\alpha_n\right)\left(2l - r_з\left[\cos\alpha_T - \cos\alpha_n\right]\right)}. \tag{8}$$

According to the known dependencies of strength of materials *(Pysarenko H.S., et.al., 1988)* the motion of loaded end of semi-beam is found as

$$f_a = \frac{Nl^3}{3EI}k. \tag{9}$$

where N is a force of elastic section and a corn surface interaction, N; E – elastic modulus of elastic section, Pa; I – inertia moment of elastic section, m^4; k – coefficient calculating the shape of the auger elastic section;

By substituting f_a from the equation (8) into the equation (9), and taking into account inertia moment of elastic section the force N_b appearing between the peripheral elastic section and a corn is found by the dependence

$$N_b = \frac{E\left(b^4 - a^4\right)\sqrt{r_c\left(\cos\alpha_T - \cos\alpha_n\right)\left(2l - r_c\left[\cos\alpha_T - \cos\alpha_n\right]\right)}}{16l^2\left(b-a\right)k}. \tag{10}$$

In case when the elastic section width is changing by the length l from a to b the coefficient k in the first approximation is equal to $k = 1 - \dfrac{b-a}{4l}$.

While analyzing the dependencies (10) we have defined the impact of various interaction parameters on the value N_b as a preliminary.

For this reason, some possible limits of parameters values changing were found.

We assume that elastic section parameters are of trapezium shape and can be made of rubber, low or high pressure polyethylene, and also polypropylene.

According to the data *(Pysarenko H.S., et.al., 1988)* elastic modulus for these materials are: rubber (at small deformation): E = (0.01…0.1)·10^9 Pa; low pressure polyethylene: E = 0.2·10^9 Pa; high pressure polyethylene: E = 0.8·10^9 Pa.

We assume, that we analyse the dependence (10) within the range of values E = (0.05…0.25) 10^9 Pa, at average value E = 0.15·10^9 Pa.

The value of cantilever beam of elastic section was changed within boundaries l = 0.024…0.032 m, at average value l = 0.028 m.

The width of larger base b and smaller base a of a trapezoid elastic section were assumed within boundaries: b = 0.020…0.024 m (mean value b = 0.022 m); a = 0.014…0.018 m (mean value a = 0.016 m).

According to the well-known research *(Tsarenko O.M. et.al., 2003*) a corn length is within boundaries 0.0052…0.014 m; width– 0.005…0.011 m; thickness – 0.003…0.008 m.

Thus, the radius of its hemispheric surface was assumed within r_c = 0.0015…0.0045 m (mean value r_c = 0.003 m).

The range of corns friction angle change on different kinds of materials and guiding jacket internal surface roughness *(Tsarenko O.M., et.al., 2003)* was assumed within boundaries α_n = 6°…14° (mean value α_n = 10°). The current angle α_T is changing from α_n to zero.

Angle β of screw surface inclination of screw elastic edge was assumed within boundaries 10°…30° (mean value β = 20°).

While determining the impact degree of the above-mentioned parameters on the value N_b we assume the boundary value α_T = 0°. Thus in the formula (10) the value cos α_T = 1.

Then the dependence (10) is taking the form

$$N_b = \frac{E\left(b^4-a^4\right)\sqrt{r_c\left(1-\cos\alpha_n\right)\left(2l-r_c\left[1-\cos\alpha_n\right]\right)}}{16l^2\left(b-a\right)k}. \tag{11}$$

Force N_b, acting perpendicular to the edge plane is divided into the axial N_o force acting towards the screw axis and centrifugal force $N_к$ acting in its cross-section.

Axial and circumferential forces are taking the form respectively

$$N_o = \frac{E\left(b^4-a^4\right)\sqrt{r_c\left(1-\cos\alpha_n\right)\left(2l-r_c\left[1-\cos\alpha_n\right]\right)}}{16l^2\left(b-a\right)k}\cos\beta; \tag{12}$$

$$N_k = \frac{E\left(b^4-a^4\right)\sqrt{r_c\left(1-\cos\alpha_n\right)\left(2l-r_c\left[1-\cos\alpha_n\right]\right)}}{16l^2\left(b-a\right)k}\sin\beta; \tag{13}$$

To determine the parameters of loose material flow motion between adjacent elastic sections we consider the general view of position of adjacent elastic sections edges which are fixed to the screw rigid base (Figure 4).

Figure 4 specifies: ξ – helix angle of screw surface of auger base; ξ_1 – inclination angle of external section edge.

The size of overlapping between the edges of adjacent elastic sections and the numeric values of above-mentioned angles are defined constructively and can be chosen depending on transportation conditions.

The aim of conducting theoretical investigation is to define the motion path of loose material flow after its leaving the elastic section overhang depending on the design and kinematic parameters of the operating device, and also determining the conditions for the further motion path of loose material flow in case of its landing on the next elastic section *(Zalutskyi S.Z., et.al., 2018*).

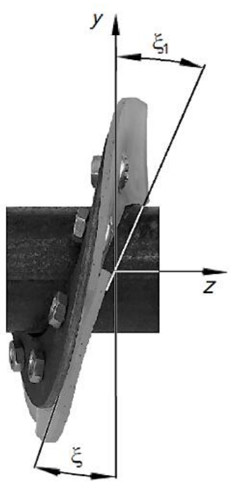

Fig. 4 – General view of position of adjacent elastic sections edges

The research results are necessary to prevent the impact interaction of loose material flow leaving the section edge with the rough base of the further screw turn where some metal joints are located which can cause the increased damage of material.

Let's analyse some loose material flow motion in case there are some overhangs on the screw surface caused by edges overlapping of adjacent elastic sections (Figure 5).

Figure 5 contains the following symbols: h – height of position of external blade edge above the lower blade; R_κ – jacket radius; N_1 – screw response on the load; F_1 – friction force caused by reaction N_1; N_2 – jacket response on the load; F_2 – friction force caused by reaction N_2; μ_1 – load friction coefficient on screw surface; μ_2 – load friction coefficient on jacket surface; χ – direction angle of load particle motion against jacket; ψ – angular position of load particle in its rotational motion; z – longitudinal coordinate of the particle along the jacket axis.

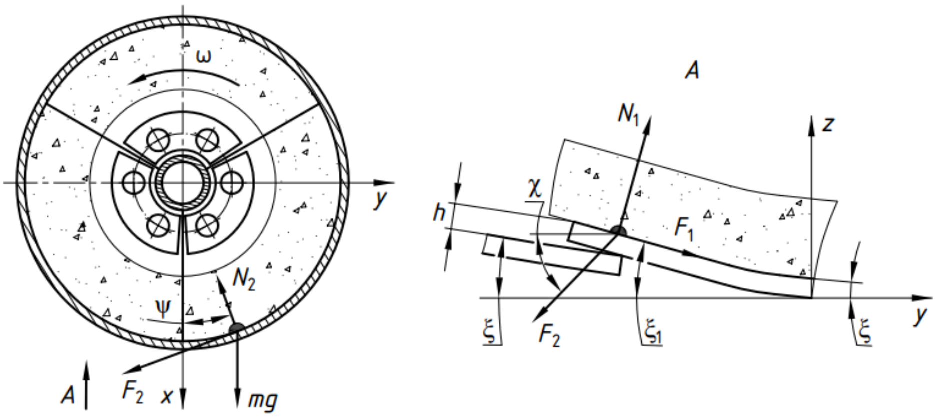

Fig. 5 – Forces acting on an elementary particle of loose cargo flow

We extract an elementary part of loose material which is simultaneously touching the jacket and the screw. Then we define the forces acting on this part and on their basis we set up the equation of its motion. On the jacket side, a reaction is taking place on the elementary particle of the flow which is perpendicular to its surface N_2, and friction force F_2, directed at the side opposite to the direction of particles motion against the jacket. Jacket's reaction is determined by the vector sum of forces obtained from the force of weight of material flow particle and centrifugal force caused by rotation. The particle is also influenced by the screw blade surface N_1 which is perpendicular to the screw surface in the contact point and correspondent force of friction F_1 acting in the direction opposite to the flow motion against the screw conveyor, i.e. tangentially to the screw edge.

The equation of motion of a certain particle of load with mass m transported by horizontal screw conveyor can be written as a system of equations *(Zalutskyi S.Z., et.al., 2018*).

$$m\frac{d^2z}{dt^2} = N_1\cos\xi - F_1\sin\xi - F_2\sin\chi\,; \tag{14}$$

$$mR_\kappa\frac{d^2\theta}{dt^2} = N_1\sin\xi + F_1\cos\xi - F_2\cos\chi\,; \tag{15}$$

$$N_2 = mg\cos\psi + mR_\kappa\left(\frac{d\psi}{dt}\right)^2; \tag{16}$$

$$F_1 = \mu_1 N_1\,; \tag{17}$$

$$F_2 = \mu_2 N_2\,. \tag{18}$$

The following geometrical dependences can be written between the directions of particle motion and screw conveyor geometry at its rotation with angular velocity ω

$$\mathrm{tg}\chi = \frac{\dot{z}}{R_\kappa\dot{\psi}}\,; \tag{19}$$

$$\mathrm{tg}\xi = \frac{\dot{z}}{R_\kappa\left(\omega-\dot{\psi}\right)}\,. \tag{20}$$

To solve the system of equations (14) - (20) we use transformations and substitutions to get rid of the unknown force and express all parameters in the terms of angle ψ value. At first, the system looks like

$$m\ddot{z} = N_1\left(\cos\xi - \mu_1 \sin\xi\right) - \mu_2\left(mg\cos\psi + mR_\kappa\dot{\psi}^2\right)\sin\chi\,; \tag{21}$$

$$mR_\kappa\ddot{\theta} = N_1\left(\sin\xi + \mu_1\cos\xi\right) - \mu_2\left(mg\cos\psi + mR_\kappa\dot{\psi}^2\right)\cos\chi\,. \tag{22}$$

The differential equation of material particle motion for variable ψ will eventually have the form

$$\ddot{\psi} + \dot{\psi}^2 A + B\cos\psi = 0\,. \tag{23}$$

In this equation the coefficients *A* and *B* are found by the following dependencies

$$A = \mu_2\left[\cos\left(\chi+\xi\right) - \mu_1\sin\left(\chi+\xi\right)\right]; \tag{24}$$

$$B = \frac{\mu_2 g}{R_\kappa}\left[\cos\left(\chi+\xi\right) - \mu_1\sin\left(\chi+\xi\right)\right]\cos\xi\,. \tag{25}$$

While some loose material flow is moving it is necessary for the centrifugal force to be bigger than the weight force. Otherwise, the flow particles won't move constantly, and their overflow and mixing will take place, which will spoil badly the whole picture of flow transportation. Thus, this will be obtained under conditions

$$\dot{\psi} > \sqrt{\frac{g}{R_\kappa}}\,. \tag{26}$$

The equation (23) is a second-order nonlinear differential equation the analytical solution of which is impossible and we must use a numerical method of such equations integration, namely Runge-Kutta method.

The important moment of motion is separation of a particle of the material flow from the external blade overhang and free motion of the flow on the jacket surface till the moment of contact with the next screw blade.

Separation of a flow particle from the blade surface is taking place at angle $\xi_1 > \xi$, which is defined by the geometry of adjacent blades relative position (Figure 4). Here, the velocity of material flow against the screw surface due to the negligible change of angle ξ_1 remains steady. The value of linear velocity of relative motion *V* of material flow is found from the kinematic dependence

$$V\sin\xi = \dot{z}\,. \tag{27}$$

Therefore, at angle change of flow descending off the overhang

$$V\sin\xi_1 = \dot{z}_1\,. \tag{28}$$

Thus, the velocity values of loose material flow motion while descending off the overhang and taking into account the equations (19, 20) and (27, 28), are calculated by the formulae

$$\dot{z}_1 = \dot{z}\frac{\sin\xi_1}{\sin\xi}\,; \tag{29}$$

$$\dot{\psi}_1 = \dot{\psi}\frac{\cos\xi_1}{\cos\xi} + \omega\left(1 - \frac{\cos\xi_1}{\cos\xi}\right). \tag{30}$$

Free motion of particles on the jacket surface in case of separation from the blade is written in the form of two second-order differential equations

$$m\frac{d^2z}{dt^2} = -F_2\sin\chi\,; \tag{31}$$

$$mR_{\kappa}\frac{d^2\psi}{dt^2}=-F_2\cos\chi-mg\sin\psi\ , \tag{32}$$

with initial conditions at the beginning of loose material leaving the section edge

$$\dot{z}(0)=\dot{z}_1,\quad z(0)=z_1+h\ ,$$

where h – the value of overhang of external section edge above the internal surface

$$\dot{\psi}(0)=\dot{\psi}_1;$$

$$\psi(0)=\psi_1; \tag{33}$$

$$\mathrm{tg}\chi=\frac{\dot{z}_1}{R_{\kappa}\dot{\psi}_1}\ .$$

After transformation we obtained

$$m\ddot{z}=-\mu_2\left(mg\cos\psi+mR\dot{\psi}^2\right)\sin\chi\ ; \tag{34}$$

$$mR_{\kappa}\ddot{\psi}=-\mu_2\left(mg\cos\psi+mR_{\kappa}\dot{\psi}^2\right)\cos\chi-mg\sin\psi\ . \tag{35}$$

Free motion of material flow will take place until the moment of contact with one of the next screw blades. To calculate the moment and place of contact we assume that further part of screw surface is without any overhangs.

The condition of free motion of a flow particle on the screw jacket is described by the inequality

$$R_{\kappa}\omega t\,\mathrm{tg}\,\xi<z+R_{\kappa}\psi\,\mathrm{tg}\,\xi\ , \tag{36}$$

where the expression for the screw surface ascending at its rotation is on the right-hand side, integrated motion of the flow particle along the axis z and towards rotational motion is on the left-hand side.

The material particle doesn’t touch the screw surface being in free motion when the inequality is satisfied. The values *z* and ψ are in the solution of the system of equations (34, 35) with correspondent initial conditions.

From the inequality (36) at solving the system of equations of motion at each step the satisfaction of the above-mentioned condition, the time when a particle stops free motion t_2, and also the value of axial movement of a flow particle z_2 are defined.

Therefore, it’s necessary to find the value of angle of screw relative turning and flow particle φ_2 till the moment of their next contact in time point t_2. Its value is found by the formula

$$\varphi_2=\frac{z_2}{R_{\kappa}\ \mathrm{tg}\,\xi}\ . \tag{37}$$

RESULTS

While defining the impact of any interaction parameter on values N_o and N_k its value was changed within a certain range. The other parameters remained unchangeable, and their average values were substituted in formulae (12) and (13). It was found that the elasticity modulus of elastic section screw surface had the maximal impact on values N_o and N_k, i.e. the properties of material of which the section screw surface was made.

The second in importance after the above-mentioned elasticity modulus regarding impact depth on the value N_o are the initial angle of interaction of elastic section with the grain surface α_n, length of cantilever overhang of screw elastic edge *l* and inclination angle β of elastic section screw surface.

The increase of a grain radius r_c results in increase both N_o and N_k.

Design parameters of trapezoid elastic section, namely the parameters *a* and *b* have minimum impact on values N_o and N_k.

As for the centrifugal force N_k, the inclination angle β of elastic edge screw surface is second in importance after modulus of elasticity regarding the impact power on its value.

Thus, within the boundaries of parameters values range change for the axial force N_o its increase is as follows: for *E* – 5 times increase; for α_n, – 2.34 times increase; for r_c – 1.79 times increase; for *b*– 1.42 times increase; for a –1.27 times increase. The decrease of value N_o is as follows: for l – 1.49 times decrease; for β – 1.15 times decrease.

For the centrifugal force N_k its increase is as follows: for E – 5.12 times increase; for β – 2.88 times increase; for α_n – 2.32 times increase; for r_c – 1.79 times increase; for b – 1.4 times increase; for a – 1.32 times increase. The decrease of value N_o is only for l – 1.33 times decrease.

For the given boundaries of interaction parameters values for the central point where plots are met the axial force value N_o is 2.76 times larger than the centrifugal force value N_k.

To analyse the obtained dynamic model (formulae 14 – 37) the program based on the language Delphi was developed. The program helped to determine the numerical characteristics and to plot parameters of the flow free motion versus the change of main coefficients of the mathematical model.

The aim of the analysis was to find the positive effect of mathematical model parameters on free motion of loose material flow. The results of modelling are shown in Figures 6 - 11. Each plot shows the effect of a certain parameter on the x-axis. Here, on y-axis, the plot time t_p and path l_p are shown of material particle free motion till its contact with the next section.

The plot in Figure 6 shows that the increase of helix angle of screw base screw surface ξ results in decrease of distance covered l_p and, correspondingly, time t_p of free motion of particles till the contact with the next section due to the decrease of velocity of loose material flow against the screw surface as exemplified by the analysis of dependency (20). So, the increase of value ξ from 10° to 30° causes the 4.2 times shorter path l_p and 3,1 times less time t_p.

Figure 7 presents plots t_p and l_p versus friction coefficient of loose material on the screw elastic sections μ_1.

Similar to the previous case, increase of value μ_1 results in decreased values t_p and l_p. Thus, the increase of friction coefficient value μ_1 from 0.2 to 0.8 results in 1.6 times shorter path l_p and 1.09 times increase of time t_p.

Figure 8 presents plots t_p and l_p versus friction coefficient of loose material on the jacket internal surface μ_2.

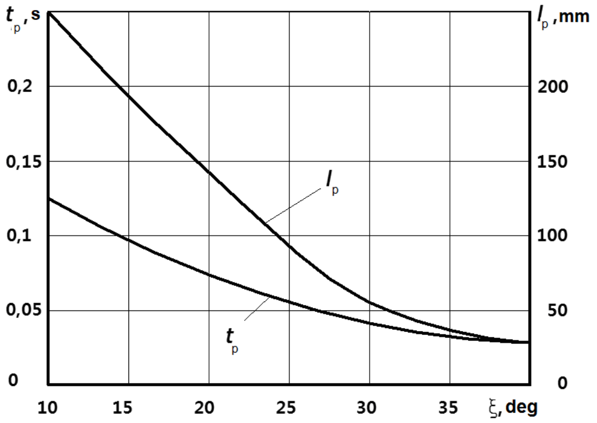

Fig. 6 – Dependencies t_p and l_p versus helix angle ξ of screw base screw surface

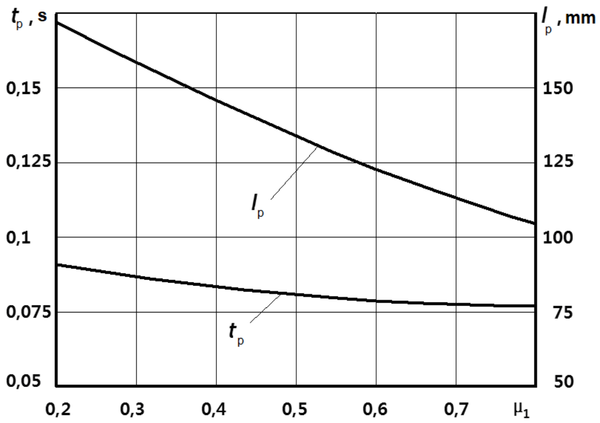

Fig. 7 – Dependencies t_p and l_p versus material friction coefficient μ_1 on screw elastic sections

Analysis of plots data shows that decreasing tendency of values t_p and l_p at increasing friction coefficient μ_2 is the same as in the previous case but the impact force is much bigger. Increase of friction coefficient μ_2 from 0.2 to 0.8 results in 2.1 times decrease of path l_p, and 1.5 times decrease of time t_p.

The following parameters have the opposite effect on the values t_p and l_p behaviour.

Figure 9 presents plots t_p and l_p versus rotation frequency n of screw operating device.

Rotation frequency n increase results in significant increase of value l_p due to the increase of velocity of particle's rolling off the external blade edge.

Thus, increase of value n from 200 to 800 rev/min results in approximately 5 times increase of value l_p.

In this case, time t_p is not changing greatly. It can be explained by the increase of angular velocity of screw rotation in such a way that the next section has approximately the same period of time to approach the flow particles.

Figure 10 presents plots t_p and l_p against height h external blade edge position above the lower blade.

It was found that the given parameter has a little influence on the flow free motion, but the increased value h causes the increase of values t_p and l_p. In fact, time difference is proportional to the time of screw rotation by value *h*. Thus, increase of value *h* from 0.5 to 0.35 mm causes the 1.24 times increase of l_p and 1.14 times increase of t_p.

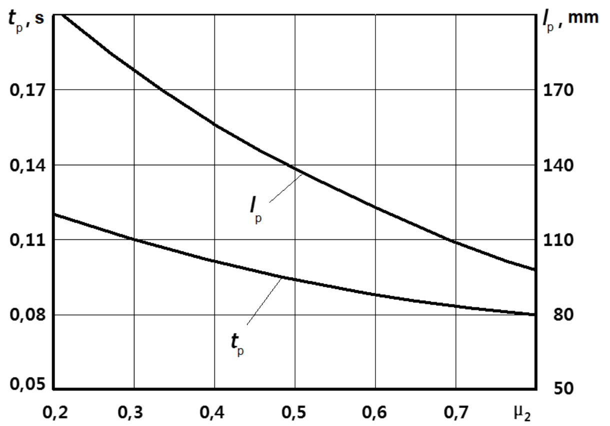

Fig. 8 – Dependencies t_p and l_p versus friction coefficient μ_2 of material on the jacket surface

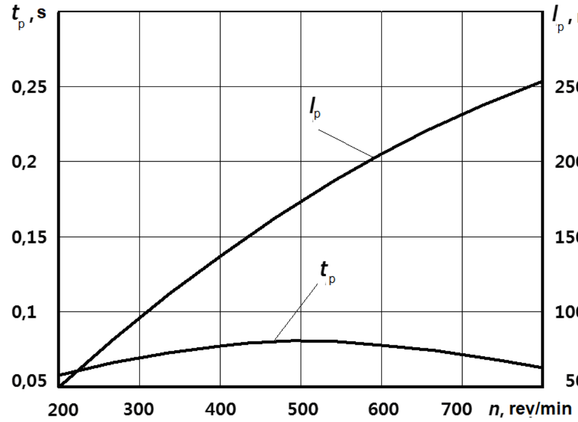

Fig. 9 – Dependencies t_p and l_p versus rotation frequency *n* of screw operating device

Figure 11 presents plots t_p and l_p versus material convergence angle which is determined by the inclination angle of external section edge ξ_1.

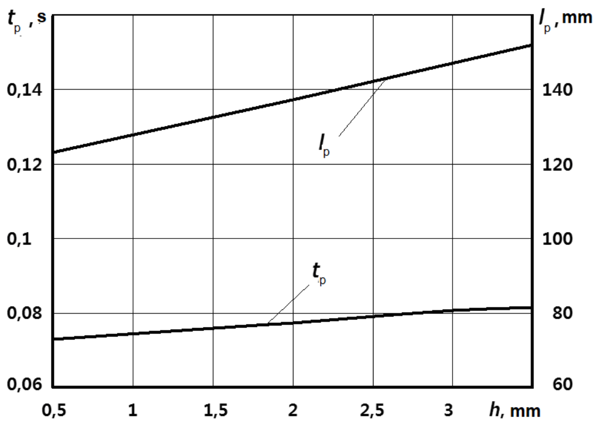

Fig. 10 – Dependencies t_p and l_p versus height *h* of external blade edge position above the lower blade

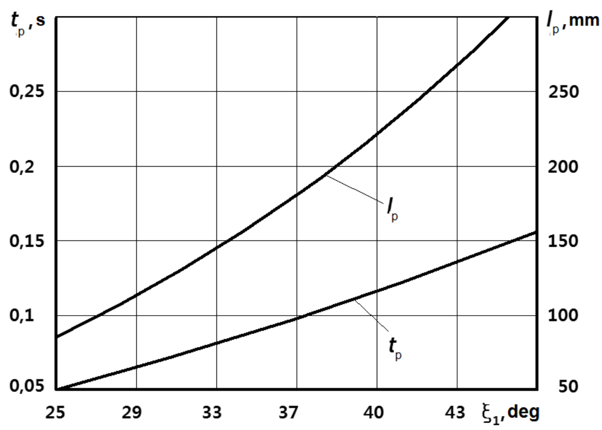

Fig. 11 – Time dependencies t_p and l_p versus inclination angle ξ_1 of external section edge

Unlike the previous case the change of inclination angle ξ_1 of external section edge greatly affects the value t_p and l_p. So, the increase of angle value ξ_1 from 25° to 45° results in 3.53 times longer path l_p and 3.16 times increase of time t_p.

Analysis of diagrams in Figures 6 – 11 allows evaluating the impact of each parameter of the system on the loose material flow behaviour at its passing through the obstacle like a step between the screw plates.

CONCLUSIONS

The most efficient parameters of elastic sections interactions with the grain material of hemisphere-cone shape were substantiated on the basis of obtained analytical dependencies.

The impact depth of interaction parameters of screw elastic section and a corn grain on the values of axial N_o and centrifugal force N_k was determined. It was found that elasticity modulus of screw elastic section has the maximal impact on the values N_o and N_k. The second in importance on the value N_o are the initial angle of interaction of screw elastic edge with grain surface, length of cantilever overhang of screw elastic section and its inclination angle.

As for the centrifugal force N_k, the second in importance after the elasticity modulus regarding impact depth on its value is the inclination angle of elastic section screw surface.

The impact of elastic screw design and kinematic parameters on the loose material flow behaviour in the area between the adjacent sections which are overlapped was determined.

On the basis of obtained analytical dependencies and their analysis we came to the conclusion that the increase of friction forces both on the screw surface μ_1 and jacket surface μ_2 results in decrease of time t_p and path l_p of particles free motion of loose material flow. The increase of friction coefficient value μ_1 from 0.2 to 0.8 causes the 1.6 times shorter path l_p and 1.09 less time t_p. The increase of friction coefficient value μ_2 from 0.2 to 0.8 causes the 2.1 times shorter path l_p and 1.5 less time t_p.

The increase of screw helix angle ξ results in shorter path l_p and time t_p due to the decrease of loose material flow velocity against the screw surface. The increase of screw helix angle ξ from 10° to 30° results in 4,2 times shorter path l_p and 3,1 times more time t_p.

The change of rotation frequency of operating device n from 200 to 800 rev/min causes the 5 times increase of path l_p of particle free motion. In this case, the time of the particle free flight t_p does not change greatly, and it can be explained by the increase of angular velocity of screw rotation, so that the next section is able to approach the flow particles in approximately the same period of time.

It was found that height h of external section free end position over the lower section has a negligible effect on material flow though the increase of value h causes the increase of values of time t_p and path l_p.

The change of departure angle of loose material flow particles which if defined by the inclination angle of external elastic section edge ξ_1 essentially affects the time t_p and path l_p of particles free motion.

Increase of value of inclination angle of external section edge ξ_1 from 25° to 45° results in 3.53 times longer path l_p and 3.16 times more time t_p.

REFERENCES

[1] Baranovsky V.M., Hevko R.B., Dzyura V.O., Klendii O.M., Klendii M.B., Romanovsky R.M. (2018) – Justification of rational parameters of a pneumoconveyor screw feeder, *INMATEH: Agricultural engineering*, vol.54, no. 1., pp.15-24, Bucharest/Romania;

[2] Boiko A.I., Kulykivskyi V.L. (2011) - Study of grain contact interaction in clearance “turn-jacket” of screw feeder of grain-cleaners (Дослідження контактної взаємодії зерна в зазорі “виток-кожук” шнекових живильників зерноочисних машин), *Scientific bulletin of National University of Life and Environmental Sciences of Ukraine* (Науковий вісник Національного університету біоресурсів і природокористування України), vol.166, pp.267-274, Kiev/Ukraine;

[3] Haydl H.M. (1986) – Design aspects of large-diameter tubular conveyor galleries, *Proceedings of the institution of civil engineers, Part 1 – Design and construction,* vol.80, pp. 633-639, London/England;

[4] Hevko B.M., Hevko R.B., Klendii O.M., Buriak M.V., Dzyadykevych Y.V., Rozum R.I. (2018) - Improvement of machine safety devices. *Acta Polytechnica, Journal of Advanced Engineering*, Vol.58, no.1, pp.17-25, Prague/Czech Republic;

[5] Hevko R.B., Zalutskyi S.Z., Tkachenko I.G., Klendiy O.M. (2015) – Development and investigation of reciprocating screw with flexible helical surface, INMATEH: Agricultural engineering, vol.46, no.2, pp.33-138, Bucharest/Romania;

[6] Hevko R.B. Dzyadykevych Y.V., Tkachenko I.G., Zalutskyi S.Z. (2016) - Parameter justification for interworking relationship of elastic screw operating element with grain material, *Bulletin of Ternopil Ivan Puluj National Technical University (Вісник ТНТУ ім. І.Пулюя)*, vol.81, no.1, pp. 77-87, Ternopil/Ukraine;

[7] Hevko R.B., Yazlyuk B.O., Liubin M.V., Tokarchuk O.A., Klendii O.M., Pankiv V.R. (2017) - Feasibility study of mixture transportation and stirring process in continuous-flow conveyors, *INMATEH: Agricultural engineering*, vol.51, no.1, pp.49-59, Bucharest/Romania;

[8] Hevko R.B., Liubin M.V., Tokarchuk O.A., Lyashuk O.L., Pohrishchuk B.V., Klendii O.M. (2018) - Determination of the parameters of transporting and mixing feed mixtures along the curvilinear paths of tubular conveyors, *INMATEH: Agricultural engineering*, vol.55, no.2, pp.97-104, Bucharest/Romania;

[9] Hevko R.B., Strishenets O.M., Lyashuk O.L., Tkachenko I.G., Klendii O.M., Dzyura V.O. (2018) – Development of a pneumatic screw conveyor design and substantiation of its parameters, *INMATEH: Agricultural engineering*, vol.54, no.1, pp.153-160, Bucharest/Romania;

[10] Lech M. (2001) - Mass flow rate measurement in vertical pneumatic conveying of solid, *Powder Technology*, Vol.114, Issues 1–3, pp. 55-58;

[11] Loveikin V., Rogatynska L. (2011) - A Model of Loose Material Transportation by Means of High-Speed Conveyers with Elastic Operating Devices (Модель транспортування сипкого вантажу

швидкохідними гвинтовими конвеєрами з еластичними робочими органами*).* *Bulletin of Ternopil Ivan Puluj National Technical University (Вісник ТНТУ ім. І. Пулюя)*, vol.16, pp.66-70, Ternopil/Ukraine;

[12] Lyashuk O.L., Rogatynska O.R., Serilko D.L. (2015) - Modelling of the vertical screw conveyer loading*,* *INMATEH Agricultural Engineering*, vol.45, no.1, pp.87-94, Bucharest/Romania;

[13] Lyashuk O.L., Sokil M.B., Klendiy V.M., Skyba O.P., Tretiakov O.L., Slobodian L.M., Slobodian N.O. (2018) - Mathematical model of bending vibrations of a horizontal feeder-mixer along the flow of grain mixture, *INMATEH Agricultural Engineering*, vol.55, no.2, pp.35-44, Bucharest/Romania;

[14] Manjula E.V.P.J., Hiromi W.K. Ariyaratne, Ratnayake Chandana, Morten C. Melaaen (2017) - A review of CFD modelling studies on pneumatic conveying and challenges in modelling offshore drill cuttings transport, *Powder Technology*, Vol.305, pp.782-793;

[15] Mondal D. (2018) - Study on filling factor of short length screw conveyor with flood-feeding condition, *Mater. Today Proc*., vol.5, pp.1286–1291.

[16] Naveen Tripathi, Atul Sharma, S.S. Mallick, P.W. Wypych (2015) - Energy loss at bends in the pneumatic conveying of fly ash, *Particuology*, vol.21, pp. 65-73;

[17] Owen Philip J., Cleary Paul W. (2010) - Screw conveyor performance: comparison of discrete element modelling with laboratory experiments. *Progress in computational fluid dynamics*, vol.10, Issue 5-6, pp.327-333, Geneva/ Switzerland;

[18] Pysarenko H.S., Yakovlev A.P., Matveev V.V. (1988) - Reference on strength of materials (Справочник по сопротивлению материалов), *published by Naukova Dumka (видавництво Наукова думка)*, 736p. Kiev/Ukraine.

[19] Qi J., Meng H., Kan Z., Li C., Li Y. (2017) - Analysis and test of feeding performance of dual-spiral cow feeding device based on EDEM, *Trans. Chin. Soc. Agric. Eng*., vol.33, pp. 65–71.

[20] Tian Y., Yuan P., Yang F., Gu J., Chen M., Tang J., Su Y., Ding T., Zhang K., Cheng Q. (2018) - Research on the Principle of a New Flexible Screw Conveyor and Its Power Consumption, *Applied Sciences*, vol.8, no.7.

[21] Tsarenko O.M., Voityuk L.M., Shvayko M.V. and others (2003) – Mechanical-technological properties of agricultural materials: course-book (Механіко-технологічні властивості сільськогосподарських матеріалів: підручник), *published by Meta (видавництво Мета)*, 448p., Kiev/Ukraine.

[22] Roberts Alan W., Bulk Solids (2015) - Optimizing Screw Conveyors. *Chemical engineering*, vol. 122(2), pp.62-67, New York/USA;

[23] Yao Y.P., Kou Z.M., Meng W.J., Han G. (2014) - Overall Performance Evaluation of Tubular Scraper Conveyors Using a TOPSIS-Based Multiattribute Decision-Making Method, *Scientific World Journal*, New York/USA;

[24] Wang D.-X. (2012) - Research on Numerical Analysis and Optimal Design of the Screw Conveyor, *Univ. Technol*., vol. 27, pp. 32–36.

[25] Zalutskyi S.Z., Hevko R.B., Hladio Y.B., Tkachenko I.H., Klendii O.M. (2018) – Loose material flow motion on surface of screw with overlapping elastic sections (Рух потоку сипкого матеріалу по поверхні шнека з еластичними секціями, що перекриваються між собою), *Kharkiv P. Vasylenko National Technical University of Agriculture (Харківський національний технічний університет сільського господарства імені Петра Василенка)*, vol.11, pp.81-90, Kharkiv/Ukraine.