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PARAMETER JUSTIFICATION FOR INTERWORKING RELATIONSHIP OF ELASTIC SCREW OPERATING ELEMENT WITH GRAIN MATERIAL

Roman Hevko[1]; Yuriy Dzyadykevych[1]; Ihor Tkachenko[2]; Serhii Zalutskyi[2]

[1]Ternopil National Economic University, Ternopil, Ukraine
[2]Ternopil Ivan Pulyuy National Technical University, Ternopil, Ukraine

Summary. *Famous constructions of auger operating elements with elastic surfaces and screw operating conveyors have been analyzed. New construction of auger conveyor with elastic screw surface was developed and designed. The influence of constructive and technological parameters of elastic screw operating element upon force value acting on stuck grain was theoretically grounded. Experimental research findings concerning evaluation of impact of elastic blade section constructive parameters on its deformation value were provided.*

Key words: *auger conveyor, elastic screw blade, elastic blade section, deformation, blade width, overhang size.*

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Type Codes

α_n – *starting angle of interworking relationship of auger elastic rib with grain material, deg;*
α_T – *current value angle of interworking relationship of auger elastic rib with grain material, deg;*
β – *tilt angle of screw blade of auger elastic rib, deg;*
N_b – *normal force of interworking relationship of auger elastic rib with grain material, N;*
N_y – *vertical element from interworking relationship of auger elastic rib with grain material, N;*
N_x – *horizontal element from interworking relationship of auger elastic rib with grain material, N;*
$F_к$ – *friction force between grain and internal surface of auger conveyor jacket, N;*
F_b – *friction force between grain and the surface of auger elastic rib, N;*
$R_к$ – *reaction of interworking relationship reaction of grain material with internal surface of auger conveyor jacket, N;*
$r_з$ – *radius of dome-shaped corn grain surface, m;*
l – *overhang length of auger elastic rib, N;*
δ – *backlash size between elastic rib and internal surface of auger conveyor jacket, m;*
N_o – *axial element of force action* N_b*, N;*
N_k – *circular element of force action* N_b*, N;*
f_a – *magnitude of movement of auger elastic rib end, m;*
N – *force acting on running end of auger elastic rib, N;*
E – *module of elasticity of auger elastic rib, Pa;*
I – *moment of rib inertia,* m^4*;*
k – *coefficient taking into account auger elastic rib profile;*
$в$ – *width of bigger base of trapezoidal rib, m;*
a – *width of smaller base of trapezoidal rib, m;*
Δ_n – *value of starting overlap of elastic rib with a grain, m;*
Δ_T – *value of the current value overlap of elastic rib with a grain, m;*
$\Delta_з$ – *value of residual overlap of elastic rib with a grain, m.*

Problem statement. One of the problems arising at transporting bulk agricultural products is high degree of their damage because of stuck of grain particles between internal static surface of guiding jacket and rotational peripheral surface of screw operating element. Because of this, it is also possible stuck of operating element causing its breakdowns and energy costs increase. This problem can not be solved completely by the selection of different operating modes of screw conveyors, rational constructive, kinematic and technological parameters, backlashes change between auger conveyor periphery and surface of guiding jacket, use of

Corresponding author: Tkachenko Ihor; e-mail:tkachenko@tstu.edu.ua

different profiles of external ribs of screw blades depending on geometrical and rheological parameters of bulk products.

Analysis of recent investigations and publications. The actuality of the stated above problem was proved by analysis of famous investigations. Solution of the given tasks, in particular development of original constructions of screw operating elements and selection of their rational parameters and operating modes were discussed in the following works [1, 2, 3, 4, 5].

In patent literature, constructive solutions are written more and more often, issuing effective determination of the given tasks [6, 7, 8, 9]. «Lundell Plastics Corp» Company (USA) suggests using of polymer spiral laps in screw ribs. Italy Company «WAM Group» suggests screw operating element design, metal base of which is covered with polymer material. There is a famous construction of auger conveyor made by Australian Company «Bulknet», peripheral surface of which was developed in the form of elastic brush.

The main drawback of such constructions of auger conveyors and their designs is displacement of elastic laps and, as a result, there are backlashes between them causing uneven wear of auger conveyor blade. Besides, labor input and energy costs increase manufacturing auger conveyors and their repairability is also decreased. Mainly, the majority of operating blades of auger conveyors are inhomogeneous and thus, in transition from entire spiral to elastic brush owing to centrifugal forces, there may be changes of speed and directions of movement of transported material causing its increased damage.

The research objective is to develop new constructions of auger conveyor with changeable elastic screw blade, make its design and provide theoretical grounds concerning the impact of constructive and technological parameters of elastic screw blade upon force value influencing stuck grain and also to design bench and make test investigations.

Problem definition. To evaluate the impact of constructive parameters, tilt angles and module of elasticity of auger elastic rib section upon values of axial and circular forces, and test the impact of overhang size of auger elastic rib upon deformation size of its running end for a case of stuck grain on the base of theoretical investigations.

Results of investigation. New construction of auger conveyor with elastic screw blades and design options of auger elastic rib in the form of petals (sections) [10] depicted in Fig. 1 were developed for the implementation of set tasks.

Auger conveyor with elastic screw blade consists of shaft 1, in which band screw spiral 2, to which elastic spiral 3, which can be made as entire one or of separate petals (sections) was fixed with the help of sectional blades 4 and bolt connections with half-round heads 5 and nipples 6.

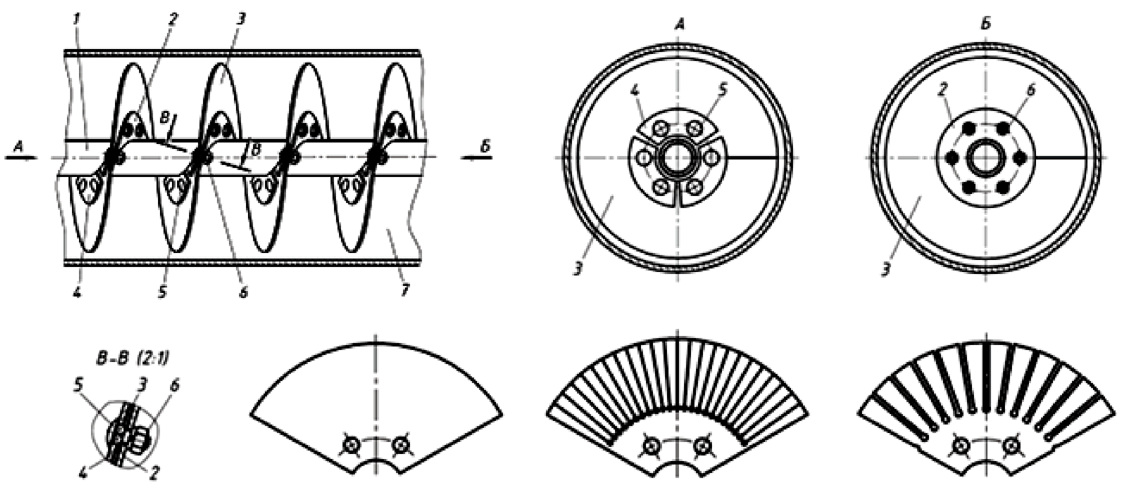


Figure 1. Auger conveyor with elastic screw blades and blades design options

Width and stiffness of petals are chosen depending on physical and mechanical qualities of transported material.

Granular materials interact with operating elastic screw blades while their transporting in guiding jacket 7. In case, when grain falls and it is stuck between unmovable blade of guiding jacket and rotational elastic screw blade, cut petals bend to protect grain from its decay.

An offered construction of auger conveyor with elastic screw blade gives the opportunity to change quickly an operating elastic spiral in case of its runout or when it is necessary to transport materials of another rheological quality.

Defining efforts arising during close interaction of elastic rib screw blade, corn grain is going to be investigated, the form of which can be described as half-sphere transiting to cone.

Performing theoretical calculations (on the first stage), we take the following hypotheses: the grain form is ideal and it is described by basic mathematical formulas; peripheral surface of operating element is ideal and it is described by the form of right angle; friction coefficient in the process of elastic rib screw blade interworking with grain products is stable; elastic surface of operating element is up to parameters of absolutely elastic blade (for small deformations); we ignore movements of radial and angular grain; centrifugal forces are not taken into consideration; fluctuation between elements interaction are not taken into account; deformation of elastic sections fixed on the surface of auger conveyor rib is defined according to common formulas of products resistance; in the process of deformation the bend line of elastic rib screw blade is formalized by ideal span.

The process of interworking screw auger blades (Fig. 2) with half-spherical corn grain surface 1 stuck between internal surface of guiding jacket 2 and peripheral surface of auger elastic rib 3 is going to be investigated.

Corn grain position, which can be much more likely stuck, is shown in Fig. 2. In this case, corn grain touches surface of internal jacket surface with its cone surface and spherical surface interworks with auger elastic rib.

There is stuck corn grain only when maximal starting angle α_n between normal force of interaction of auger elastic rib with the surface of grain N_b and plane, which is perpendicular to axis of rotation of auger conveyor, is less than angle of grain friction on internal surface of jacket.

In the process of grain stuck, auger conveyor rotates and its elastic blade slips in circular and axial directions with corresponding deformation regarding to grain. During this process force direction N_b approaches to axis OY and its size increases.

The aim of theoretical calculation is defining such parameters of interaction of auger elastic rib with grain material, which protect its possible decay. That is to say, auger conveyor rib will rotate with definite deformation relatively to grain not damaging it. Interaction parameters include constructive and geometrical system parameters, and rheological qualities of transporting object and materials used for manufacturing auger elastic rib.

Stuck corn grain is deformed in the process of rotation of auger elastic rib. The process of rotating of elastic rib from the start of its contact with grain p. A, which is defined by angle α_T to definite the current value position p. B is going to be investigated.

As far as auger elastic rib is not absolutely elastic and its deflection size is insignificant, then in first approximation we take that length of span OB is equal to overhang length of elastic rib l.

Preliminary let us define the height of elastic rib in deformed state Y_T at transporting its running end from p. A to p. B that is from starting angle of contact α_n to the current value α_T. Then

$$У_T = l - \Delta_T. \quad (1)$$

Value Δ_T is defined in statement

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

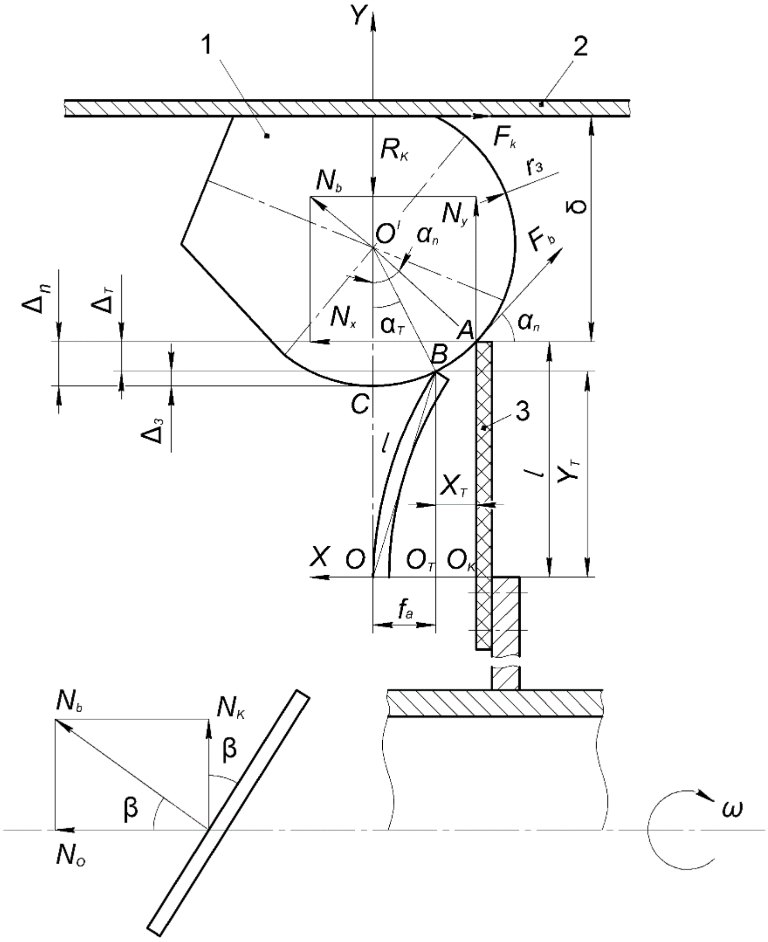


Figure 2. Design model for the evaluation of transpositions, deformations and forces, which occur between elastic rib screw blade and stuck grain

Values Δ_n and $\Delta_з$ are correspondingly defined

$$\Delta_n = r_з - r_з \cos \alpha_n = r_з (1 - \cos \alpha_n), \tag{3}$$

$$\Delta_з = r_з - r_з \cos \alpha_T = r_з (1 - \cos \alpha_T). \tag{4}$$

Substituting dependences (3) and (4) into (2), we get

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

Substituting (5) into (1), we get

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

Then in triangle BOO_T we define the current value meaning of sag of elastic rib

$$f_a^2 = l^2 - y_T^2, \tag{7}$$

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

After transformations we get

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

According to known dependences of resistance of materials [11] transporting of loaded cantilever fitted beam end is defined as

$$f_a = \frac{Nl^3}{3EI}k. \quad (9)$$

In case of using elastic rib in the form of trapezium, its moment of inertia is defined by dependence $I = \frac{l\left(b^4 - a^4\right)}{48\left(b-a\right)}$.

Substituting meaning f_a from equation (8) into equation (9), and also taking into account the moment of inertia of rib of force N_b, which appear between periphery of elastic rib and grain is defined by dependence

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

To the case when width of element of elastic rib changes in length l from a to b, coefficient k in the first approximation will be equal $k = 1 - \frac{b-a}{4l}$.

Analyzing dependence (10) we preliminary define the intensity impact one or other parameters of interaction on value of N_b.

For this, possible limits of change of value of parameters should be defined. Elastic rib section of auger conveyor is in the form of trapezium and can be made of rubber, polyethylene of law and high pressure, and polypropylene can be accepted as the fact. According to data [11] module of elasticity for these materials is: rubber (at law deformation) – $E = (0.01\ldots0.1)\cdot10^9$ Pa; polyethylene of law pressure – $E = 0.2\cdot10^9$ Pa; polyethylene of high pressure – $E = 0.8\cdot10^9$ Pa.

Let us accept that analysis of the dependence (10) will be done in the range of meanings $E = (0.05\ldots0.25)\ 10^9$ Pa, at medium meaning $E = 0.15\cdot10^9$ Pa.

Overhang size of auger elastic rib will be changed in the range of $l = 0.024\ldots0.032$ m, at average meaning $l = 0.028$ m.

Width of bigger $в$ and less a base of auger rib section in the form of trapezium is accepted in the range of $в = 0.020\ldots0.024$ m (average meaning $в = 0.022$ m); $a = 0.014\ldots0.018$ m (average meaning $a = 0.016$ m).

According to known investigations [12] corn grain is from 5.2 to 14 mm long; from 5 to 11 mm wide; from 3 to 8 mm thick. That is why radius of its dome-shaped surface is considered in the range of $r_з = 0.0015\ldots0.0045$ m (average meaning $r_з = 0.003$ m).

According to [12] let us take the range of change of friction angle of corn grains along different types of materials and roughness of guiding jacket internal surface in the range of $\alpha_n = 6°\ldots14°$ (average meaning $\alpha_n = 10°$). The current value angle α_T varies from α_n to zero.

Tilt angle β of elastic screw blade is considered ranging from 10°…30° (average meaning β = 20°).

Then in the evaluation of intensity impact of stated above parameters on value of N_b let us take the last meaning $\alpha_T = 0°$. Correspondingly in formula (10) value of $\cos\alpha_T = 1$. Then dependence (10) takes the form

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

Force N_b, which acts perpendicular to rib plane, expands on axial N_o acting in the direction of auger axis and circular $N_к$ acting in its cross-section. Then axial and circular forces are defined correspondingly

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

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

The meaning of one of interworking parameters was changed within a definite range evaluating the impact on values N_o and N_k. The other ones were unaltered and their average meanings were substituted in formulas (12) i (13).

Graphic dependencies for the evaluation of intensity impact of interworking parameters of auger operating surface and corn grain on the value of axial force N_o and circular force N_k were shown in Fig. 3 and 4.

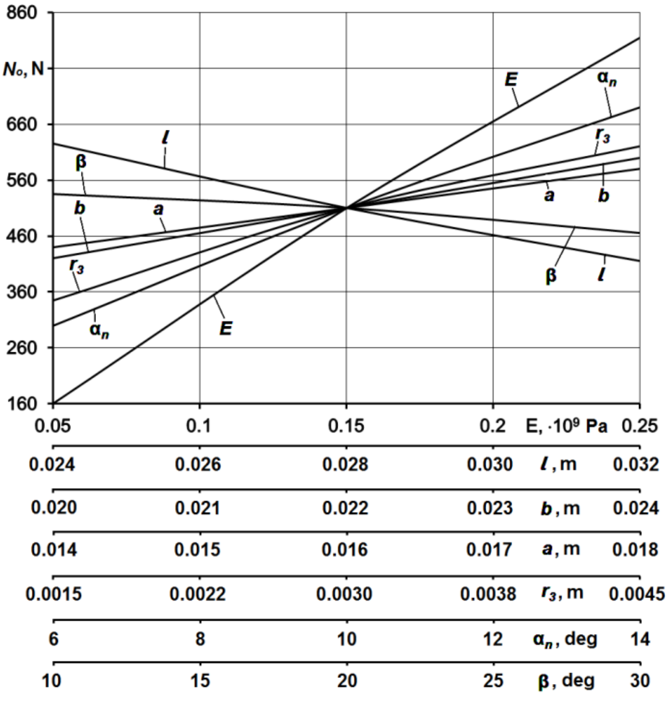


Figure 3. Graphical dependencies for the evaluation of intensity impact of interworking parameters of auger operating surface and corn grain on the value of axial force N_o

Having analyzed shown graphic dependences, we can make the following conclusion that modulus of elastic screw blade of auger elastic rib that is to say quality of material used in manufacturing screw blade has a great impact on the meanings N_o and N_k within variation values of stated above parameters for interworking relationship. Next, according to intensity impact on the value of N_o is starting angle of interworking relationship of auger elastic rib and grain surface α_n, overhang length of auger elastic rib l and tilt angle β of screw blade of auger elastic rib.

Radius increase of grain $r_з$ causes increase both N_o and N_k.

Constructive parameters of auger elastic rib section in the form of trapezium especially parameters a and $в$ have minimal impact on values N_o and N_k.

Regarding to circular force N_k, tilt angle β of screw blade of auger elastic rib is the next after elasticity modulus according to intensity impact on the meaning of circular force N_k.

Thus, changes of parameter values for axial force of N_o and its increase are ranging: for E is in 5 times; for α_n, is in 2.34 times; for $r_з$ is in 1.79 times; for $в$ is in 1.42 times; for a is in 1.27 times. Increase of meaning N_o is for l is in 1.49 times; for β is in 1.15 times.

Increase for circular force N_k is the following: for E in 5.12 times; for β is in 2.88 times; for α_n is in 2.32 times; for $r_з$ is in 1.79 times; for $в$ is in 1.4 times; for a is in 1.32 times. Decrease of meaning N_o is only for l in 1.33 times.

Axial force intensity N_o is in 2.76 times bigger than circular force intensity N_k for indicated values limit of interoperating parameters and for central point where graphical dependences are crossed.

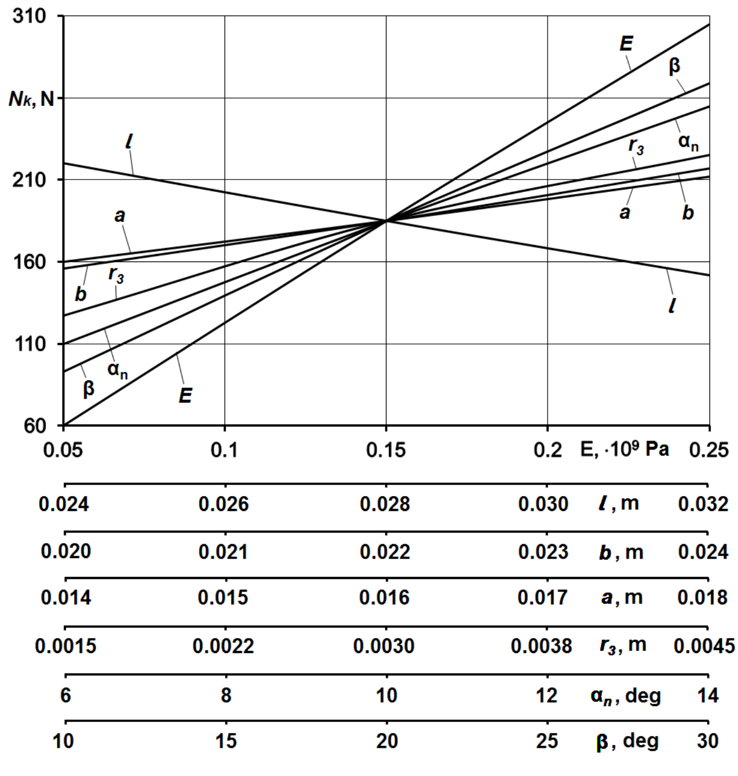
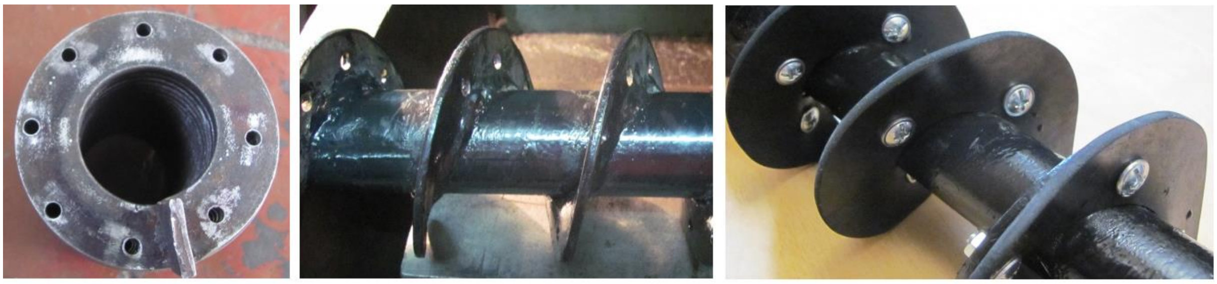


Figure 4. Graphical dependencies for the evaluation of intensity impact of interworking parameters of auger operating surface and corn grain on the value of circular force N_o

Process of manufacturing of the given operating element is depicted in Fig. 5. Firstly, flat is wrapped on arbor on rib in pile and then holes are made regularly and diametrically in arbor (Fig. 5a). Then pile is set on shaft and spiral is extended in specified interval to its full contact with haft, after this spiral is welded to shaft (Fig. 5b). The following step is that elastic spiral or its sections, which create auger elastic rib, are fixed to holes of holding spiral.



а б в

Figure 5. Manufacturing method for auger conveyor with elastic screw blade

Test bench, depicted in Fig. 6 was developed and made for evaluating the impact of width *B* and overhang size *h* of petal (section) of auger elastic rib on its deformation value Δ. It consists of two hard planks 1, which are compressed together by bolted joints 2. There is elastic blade 3 between them modeling auger elastic rib section. The bar 4 is fixed to blade running end on which on the other side is cup for measured weight 6.

Since, load intensity of blade should be insignificant and bar shift should be vertical, balls of diameter 4.5 mm were used as measured weight to be uniformly distributed on the bottom of cup.

Because of elastic blade load, its running end bends and deformation value is fixed to vertical wall 7, where horizontal lines with distance of 1 mm between them are drawn.

Test investigations were done for material of elastic blade «polyurethane PU-60» 2.5 mm thick.

Overhang size and elastic blade width were determined discretely with 5 mm step ranging: h = 25…10 mm; B = 25…5 mm.

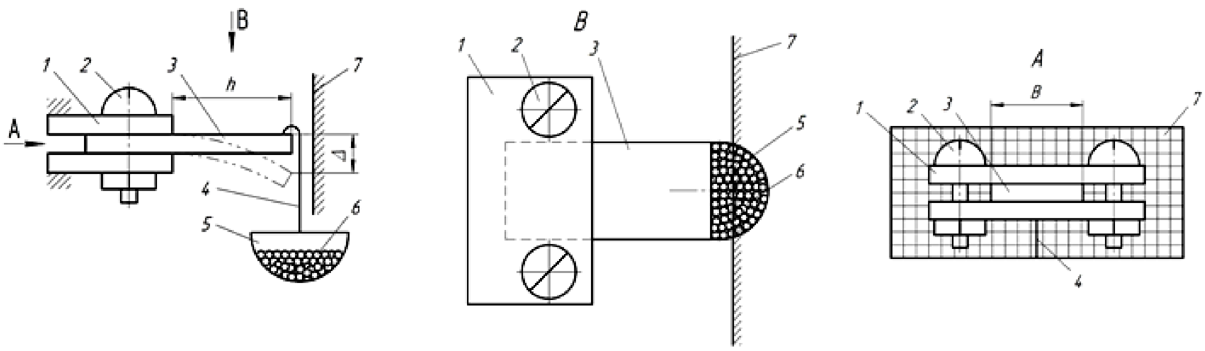


Figure 6. Test bench scheme for evaluation of impact on elastic blade section deformation value Δ of its width *B* and overhang size *h*

Experimental research findings for the dependency of blade running end deformation value Δ from measured load mass *m* for different values of *B* and *h* were shown in Fig. 7.

Having analyzed the given dependencies, we made the following conclusions, that dependencies are mostly linear, moreover for overhang size of elastic blade h = 25 mm, its increase in width from 5 to 25 mm causes increase of load intensity for Δ = 2 mm – in 4.9 times; for Δ = 4 mm – in 5.6 times; for Δ = 6 mm – in 5.8 times; for Δ = 8 mm – in 5.3 times.

For overhang size of elastic blade h = 20 mm, analogical meanings are the following: for Δ = 2 mm – in 4.8 times; for Δ = 4 mm – in 4.6 times; for Δ = 6 mm – in 4.4 times; for Δ = 8 mm – in 4.3 times.

For overhang size of elastic blade *h* = 15 mm, analogical meanings are the following: for Δ = 2 mm – in 4.8 times; for Δ = 4 mm – in 5.8 times; for Δ = 6 mm – in 5.9 times; for Δ = 8 mm – in 5.7 times.

For overhang size of elastic blade *h* = 10 mm, analogical meanings are the following: for Δ = 2 mm – in 4.8 times; for Δ = 4 mm – in 4.1 times; for Δ = 6 mm – in 4.0 times; for Δ = 8 mm – in 4.2 times.

Error δ_n between minimal and maximal meanings of increase of load for range Δ = 2...8 mm and stated above values of elastic blade width is: for *h* = 25 mm – δ_n = 15.5 %; for *h* = 20 mm – δ_n = 10.4 %; for *h* = 15 mm – δ_n = 18.7 %; for *h* = 10 mm – δ_n = 16.7 %.

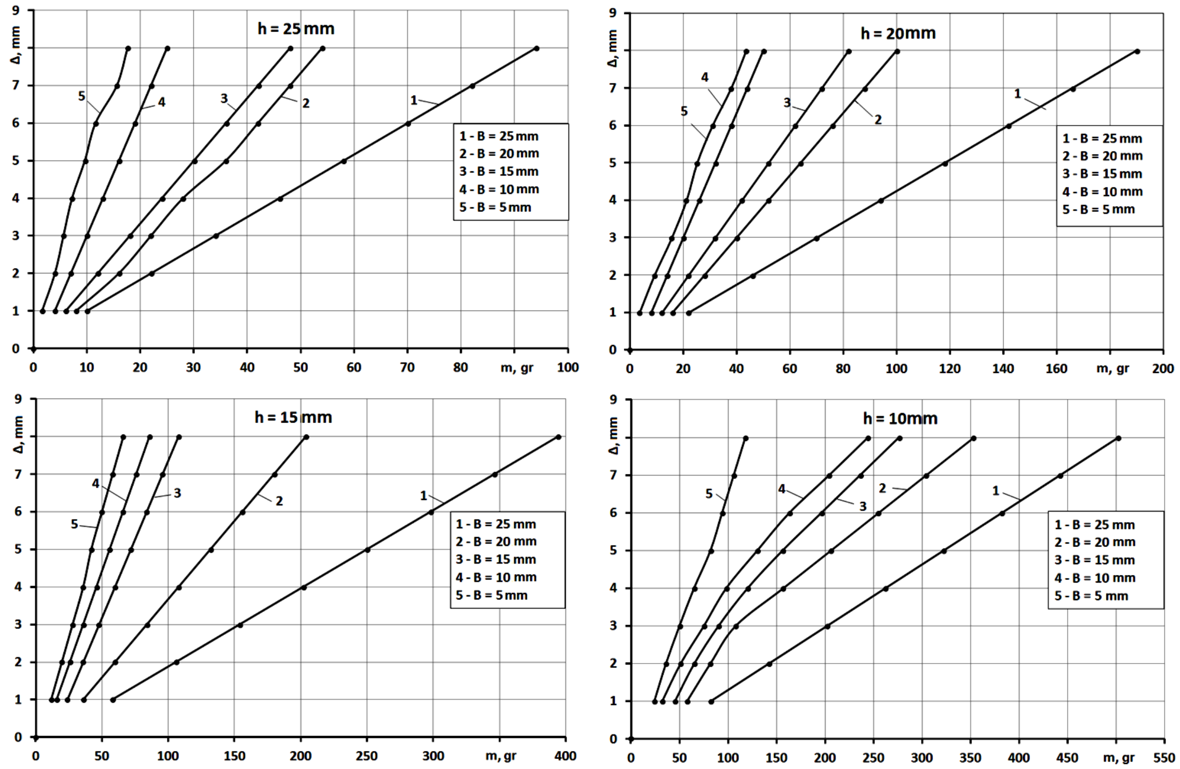


Figure 7. Experimental research findings for the dependency of blade running end deformation value Δ from measured load mass *m* for different values of *B* and *h*

Experimental research findings for the dependency of impact of overhang size value *h* of elastic rib from load mass *m* in deformation of running rib end Δ = 8 mm were shown in Fig. 8.

Having analyzed graphical dependencies, depicted in Fig. 8, we can make such conclusions, that load mass should be increased in 2.8 times, from 180 to 500 gr; for *h* = 15 mm in 4.8 times; for *h* = 20 mm in 4.2 times; for *h* = 25 mm in 4.3 times for overhang size of elastic blade *h* = 10 mm, the increase of its width ranging from *B* = 5 mm to *B* = 25 mm for support of deformation value of running end of elastic blade Δ = 8 mm.

It should be noted that the character of graphical dependences of elastic blade overhang size *h* from measured load mass *m* changes from linear to curvilinear in decreasing of elastic blade width *B*.

Conclusions. Based on the patent search analysis of screw operating surfaces and literary sources concerning the evaluation of their operating modes a new design of auger conveyor with elastic screw blades and its manufacturing method has been proposed.

Theoretical predictions have been conducted to evaluate the impact of design parameters, tilt angles and elasticity coefficient of elastic rib screw as well as its interoperation specifications with multiple-shaped stuck corn grains on axial and circular force values.

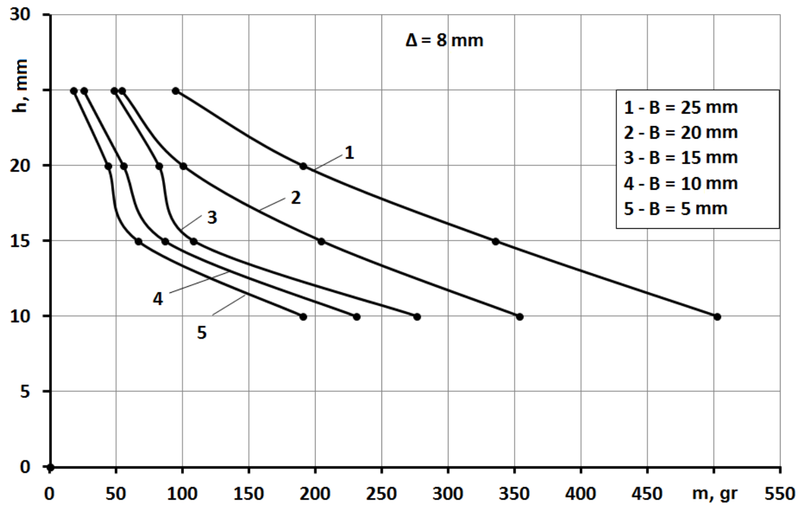


Figure 8. Experimental research findings for the dependency of impact value of elastic blade overhang size *h* from measured load mass *m* at blade running end deformation Δ = 8 mm

Based on theoretical research analysis impact degree of elastic rib screw interoperating specifications with grain has determined on delimitations that prevent grain bulk damage, and those specifications have been set, which impose dominant effect on grain decay process.

A test bench for conducting experimental research has been developed and designed. Experimental research findings have been produced to determine the impact of elastic blade section, its width, overhang size and measured load mass upon deformation value.

Obtained findings may find practical application in designing different types of auger operating parts with elastic operating surfaces according to deformation characteristics of conveying bulk agricultural material and intensity accepted values leading to its decay.

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ОБГРУНТУВАННЯ ПАРАМЕТРІВ ВЗАЄМОДІЇ ЕЛАСТИЧНОГО ГВИНТОВОГО РОБОЧОГО ОРГАНУ ІЗ ЗЕРНОВИМ МАТЕРІАЛОМ

Роман Гевко[1]; Юрій Дзядикевич[1]; Ігор Ткаченко[2]; Сергій Залуцький[2]

[1] Тернопільський національний економічний університет, Тернопіль, Україна
[2] Тернопільський національний технічний університет імені Івана Пулюя, Тернопіль, Україна

Резюме. *Здійснено аналіз відомих конструкцій робочих органів шнеків з еластичними поверхнями та процесів роботи гвинтових конвеєрів. Запропоновано нову конструкцію шнека з еластичною гвинтовою поверхнею та спосіб його виготовлення. Проведено теоретичне обґрунтування щодо визначення впливу конструктивних і технологічних параметрів еластичної поверхні гвинтового робочого органу на величину зусиль, що діють на защемлену зернину. Наведено результати експериментальних досліджень щодо визначення впливу конструктивних параметрів секції еластичної пластини на величину її деформації.*

Ключові слова: *шнек, еластична гвинтова поверхня, секція еластичної пластини, деформація, ширина пластини, величина консольного виступу.*

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