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INSTALLATION FOR THE INVESTIGATION OF SCREW WORKING BODIES WITH ELASTIC SURFACES AND THE RESULTS OF THEIR EXPERIMENTAL TESTS

Ivan Hevko; Oleh Liashuk; Oleg Tson; Taras Dovbush; Serhii Zalutskyi; Andrii Stanko

Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine

Summary. *Screw conveyors are widely used in various sectors of the economy determining specific requirements for them. One of such requirements is the possibility of safe movement of brittle elements and products with possible increased damage (injury) in pharmaceutical industry, electronics, food industry, as well as in agricultural production during the transportation of seed grain materials. The theoretical substantiation of the increase of efficiency of bulk cargoes transportation by screw conveyors is given in this paper. The problem of their progressive structures development with the possibility of minimal damage of grain materials remains important. The paper presents Recommendations for the auger rotation speed selection in order to minimize the damage of brittle elements and products are presented in this paper. The rational angle at which productivity of the screw conveyor reaches its maximum values is deteermined.*

Key words*: screw conveyors, damage, transportation, elastic surfaces.*

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Statement of the problem. Despite the significant amount of researches carried out in the field of transportation of brittle elements and products, there is the problem of improving the strain-free movement of brittle elements and products by screw elements, determining the need of further scientific investigation of advanced screw working bodies with elastic surfaces.

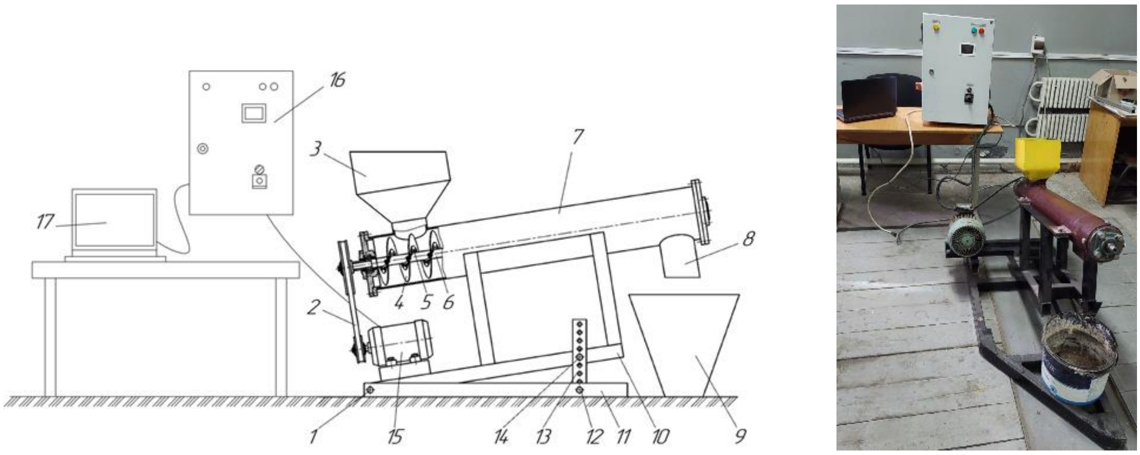
Analysis of available investigations and publications. The researches of A. M. Hryhoriev [9], H. Herman [8], B. M. Hevko [3], V. S. Loveikin [14], R. M. Rohatynskii [3, 19] and many others are devoted to the investigation of screw working bodies of transport-technological mechanisms and screw conveyors. The substantiation of screw parameters for agricultural materials transportation for the purpose of their damage reduction during transportation is considered by R. B. Hevko [5–7, 18, 21, 22], M. E. Merchalova [15]. O. P. Tarasenko [20], A. I. Boyko and V. L. Kulikovskii [1; 2; 12; 13]. They found that the destruction of grains depends mainly on the stresses of its clamping in the gap «turn of the screw working body – case» and while this gap is increased from 2 to 7 mm and at constant speed of material movement the grains damage increases. In the practical field, in order to ensure the reliable implementation of the technological process in bulk materials transportation and reduce the damage degree, a number of screw working bodies with working elastic surfaces are developed. However, the problems related to the possibility of safe transportation of brittle items and agricultural materials with minimal damage require further investigation.

The objective of the paper is the experimental investigationn of the screw mechanisms parameters with developed elastic surfaces for minimal damage to grain materials.

Statement of the problem. In order to increase the efficiency of bulk cargo transportation by screw conveyors, the problem of developing their advanced structures with the possibility of minimal damage to grain materials remains important.

……………………………………………………………… *Corresponding author: Ivan Hevko; e-mail: gevkoivan1@ukr.net*

Investigation results. Effective screw mechanisms include screw conveyors equipped with screw working bodies with elastic surfaces [5–7, 11, 18, 21, 22]. Based on the carried out patent search and analysis of scientific literature, we have developed and prepared applications for patents for the inventions for a number of designs of screw working bodies with elastic surfaces, for the investigations of these boodies the experimental setup is designed and manufactured. The structural scheme and general view of this setup is shown in Figure 1 [4, 11].



a) b)

Figure 1. Installation for the investigation of screw conveyors equipped with working bodies with elastic surfaces: a) structural diagram; b) general view

The installation for the investigation of screw working bodies with elastic surfaces (Fig. 1) includes the support 11, on which by means of hinged joints 1, 12 and 14, and arm support bracket with holes 13, the frame 10 is mounted with the possibility of angle change. The electric motor 15 with belt drive 2 driving elastic screw working body with elastic surface is mounted on the frame. It is made in the form of the shaft 6 with fixed supporting spiral element 5, on which periphery the investigated elastic elements 4, acting as an auger are fastened. This auger is installed in case 7, which contains the hopper 3 and the discharge sleeve 8 with capacity 9. During the investigation of the characteristics of elastic screw working bodies, the bulk material is filled into the hopper 3 of the installation. Then, the signal is fed from PC 17 to the frequency converter (Altivar 71) 16 which provides the starting of electric motor 15, which rotates the investigated screw working bodies with elastic surfaces. This equipment due to frequency converter and PowerSuite software v.2.5.0 [11] makes it possible to carry out the investigation in a wide range of the test auger speeds and obtain data on changes in torque and power during test material transportation the on the personal computer display.

The investigated screw working bodies with elastic surfaces are presented in Fig. 2, and their general view in the hopper is presented in Fig. 3. Particularly, Fig. 2.a, Fig. 2.c and Fig. 2.e show their structural schemes, and Fig. 2.b, Fig. 2.d and Fig. 2.f are the general views. Here is a brief description of them.

The screw working body shown in Fig. 2.a (general view Fig. 2.b) [16], consists of the hollow shaft 1, in which, holes are made perpendicular to its central axis along the helical line. In this holes the hollow cylindrical tubes 2 protruding above the outer surface of the hollow shaft with beams of elastic brush-like elements (elastic brushes) are fixed.

Fig. 2.c (general view Fig. 2.d) [17], represents the screw working body consisting of the hollow shaft 1, on which the helical spiral 2 with holes for mounting the elastic brush-like elements 3 with fasteners 6 is fixed rigidly. Elastic brush-like element 3 is made of elastic base 4 and peripheral elastic brush-like part 5.

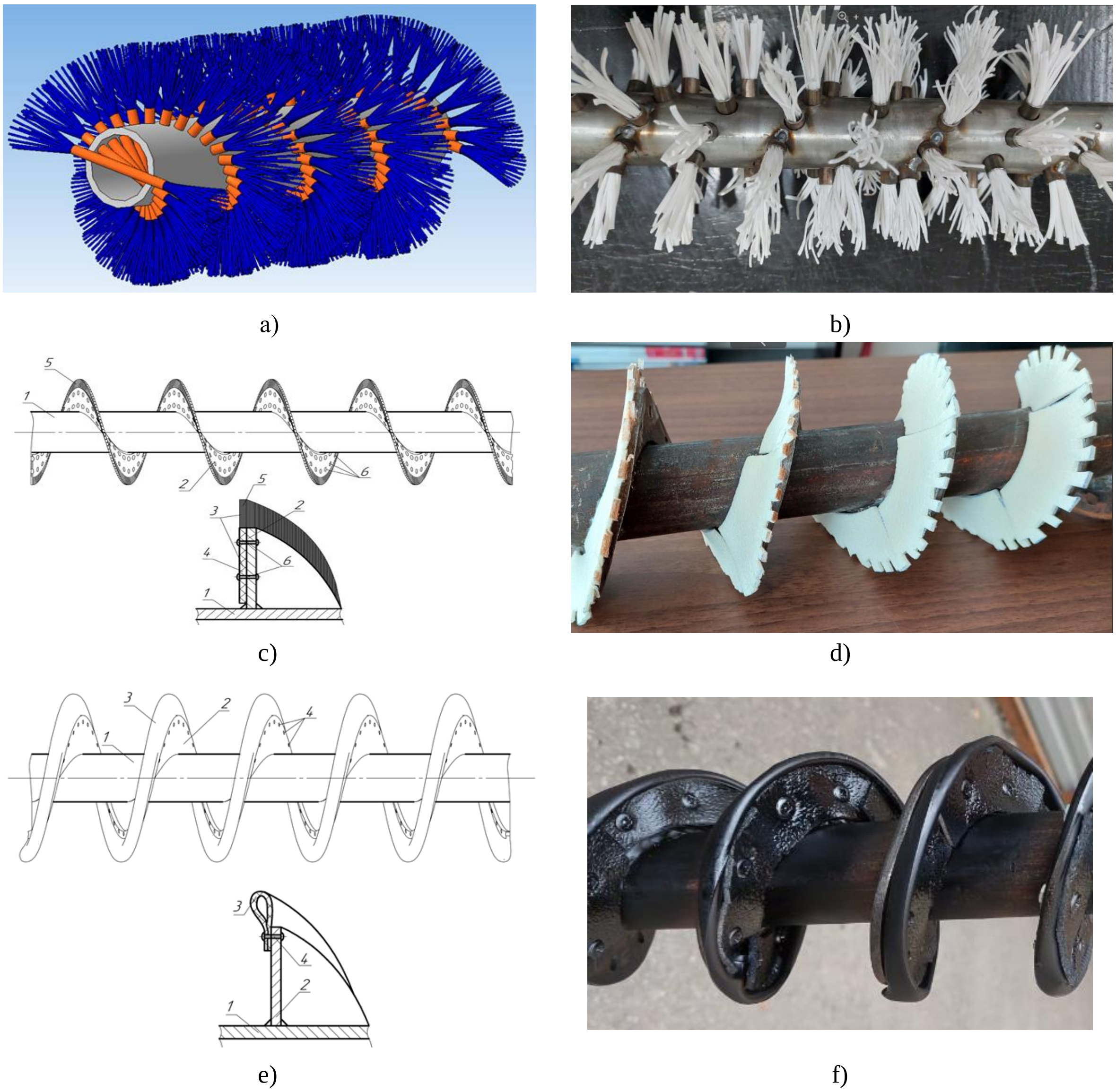


Figure 2. Screw working bodies with elastic surfaces: a), c), e) constructive schemes; b), d), f) general views

The screw working body shown in Fig. 2.e (general view Fig. 2.f), consists of the hollow shaft 1, on which the helical spiral 2 with holes for mounting the continuous elastic chamber-like element 3 with fasteners 4 is fixed rigidly.

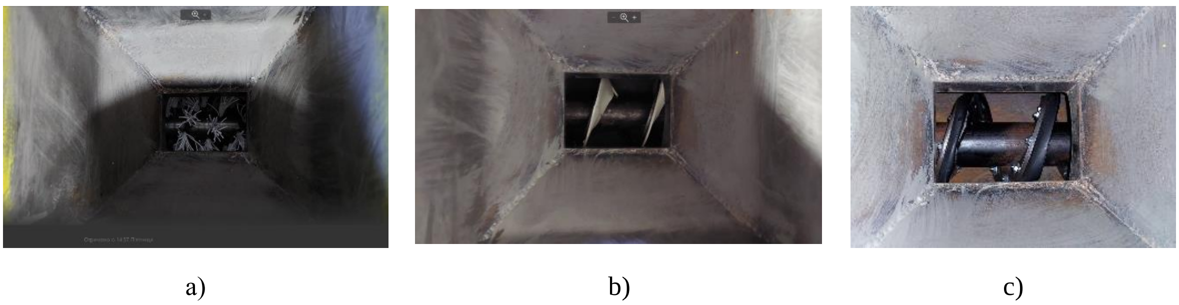


Figure 3. General view in the auger hopper with elastic surfaces: a) with brush-like element; b) with peripheral elastic brush-like part; c) with continuous chamber-like element

Experimental investigations concerning the determination of productivity Q (t / h) of transportation and the amount of damage Tp (%) by developed screw working bodies with elastic surfaces were carried out for grain material for barley and corn transportation. The investigations were carried out without the gap between the case and the auger (Δ = 0 mm) at: auger speed n = 284 rpm; n = 397.6 rpm; n = 511.2 rpm (which corresponded to 10; 14; 18 Hz frequency control indicators of ALTINAR-71 oscilloscope); the inner case diameter D = 96 mm; D = 102 mm; D = 108 mm D = 96 mm; the conveyor inclination angle $\alpha = 0^0$; $\alpha = 15^0$; $\alpha = 30^0$. While carrying out the investigations using full-factor experiment [10] the productivity for barley and corn transportation by various screw working bodies, such as: Q_1 is elastic body with continuous chamber-like element; Q_2 is elastic one with peripheral elastic brush-like part; Q_3 is elastic body with brush-like element. The general view of productivity regression equation Q (t/h) of the screw conveyor depending on the change of inner diameter of casing D, mm; auger speed, n, rpm; the conveyor inclination angle, α deg; i.e. $Q_{(x_1,x_2,x_3)} = f(D,n,\alpha)$ according to the results of full-factor experiment 3^3 in natural values for barley and corn:

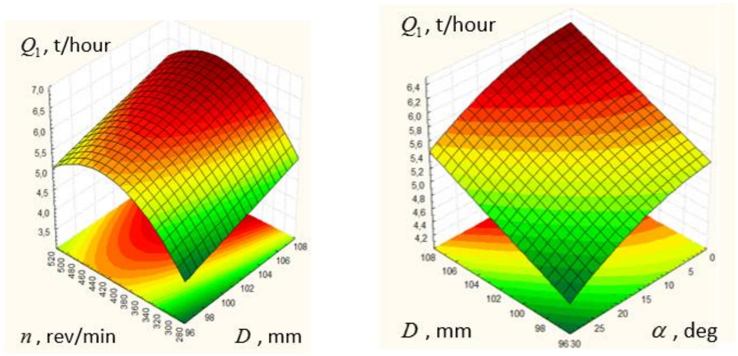
$Q_{1ячменю} = -14.72 + 0.083D + 0.59\alpha - 0.00003D\alpha - 0.00007n^2 - 0.000009n\alpha - 0.00075\alpha^2;$	(1)
$Q_{2ячменю} = -9.83 + 0.055n + 0.00041D^2 - 0.000063n^2 - 0.0011\alpha^2;$	(2)
$Q_{3ячменю} = -8.83 + 0.083D + 0.018n - 0.013\alpha - 0.000019n^2 - 0.00062\alpha^2;$	(3)
$Q_{1кукурудза} = 1.55 + 0.00015Dn - 0.000012n^2 - 0.000058n\alpha;$	(4)
$Q_{2кукурудза} = -2.6 + 0.0169n + 0.00021Dn - 0.000041n^2 - 0.00087\alpha^2;$	(5)
$Q_{3кукурудза} = -8.95 + 0.083D + 0.022n + 0.015\alpha - 0.000023n^2 - 0.000016n\alpha - 0.0013\alpha^2.$	(6)

The obtained regression equations (1–6) can be used to determine the productivity for barley and corn transportation of Q screw conveyor depending on the change of the above mentioned factors ($284 \le n \le 511,2$ (rpm); $0 \le \alpha \le 30$ (deg.); $96 \le D \le 108$ (mm)).

Using the application program, we constructed the graphical reproduction of intermediate general regression models in the form of quadratic response surfaces the productivity for barley and corn transportation Q as a function of two variables $x_{i(1,2)}$ at constant level of the corresponding third factor $x_{i(3)} = const$ (Fig. 4 – Fig. 9).

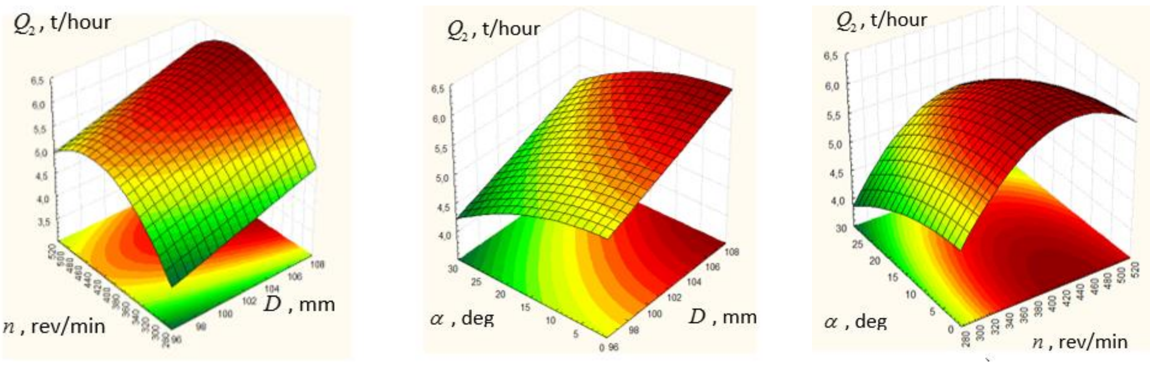
The analysis of the given regression equations shows (Fig. 4– Fig. 6) that the main factor influencing the increase in productivity for transportation is the factor $x_2(n)$ and to a lesser extent the factor x_1 (D). The decrease of the factor x_3 (α) value results in the productivity increase.

It is evident from Fig. 4 – Fig. 6 that with the increase of the case inner diameter and rotation speed and decrease of the inclination angle, the transportation productivity increases. The maximum productivity for the auger with continuous chamber-like element at barley transportation is 6.5 t/h and the minimum is 4.1 (t/h); for the auger with peripheral elastic brush-like part it is 6.4 t/h, and the minimum is 3.9 t/h; for the auger with brush-like element it is 4.3 t/h, and the minimum is 2.5 t/h. Therefore, it can be stated that for barley transportation, the auger with continuous chamber-like element provides much higher productivity in comparison with the auger with brush-like element (1.51… 1.64 times). It should be also noted that the productivity of barley transportation by augers with continuous chamber-like element and peripheral elastic brush-like part practically does not differ. If we compare the known results [11] of the productivity of grain material transportation by rigid auger, the productivity of barley transportation by augers with continuous chamber-like element and peripheral elastic brush-like part is higher (1.12… 1.31 times), and while using the auger with brush-like element it is lower (1.19… 1.46 times) This can be explained by the fact that the brushes have significant length, deflection and uneven filling of the screw line space, and, consequently, the imperfection of the given auger design.



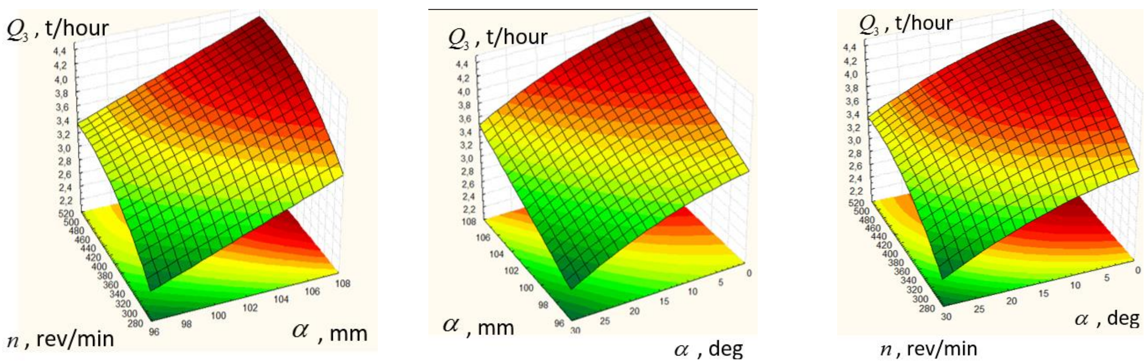
a) b) c)

Figure 4. Response surfaces of the change for productivity of barley transportation by the auger with continuous chamber-like element a) $Q_1 = f(D,n)$; b) $Q_1 = f(D,\alpha)$; c) $Q_1 = f(n,\alpha)$



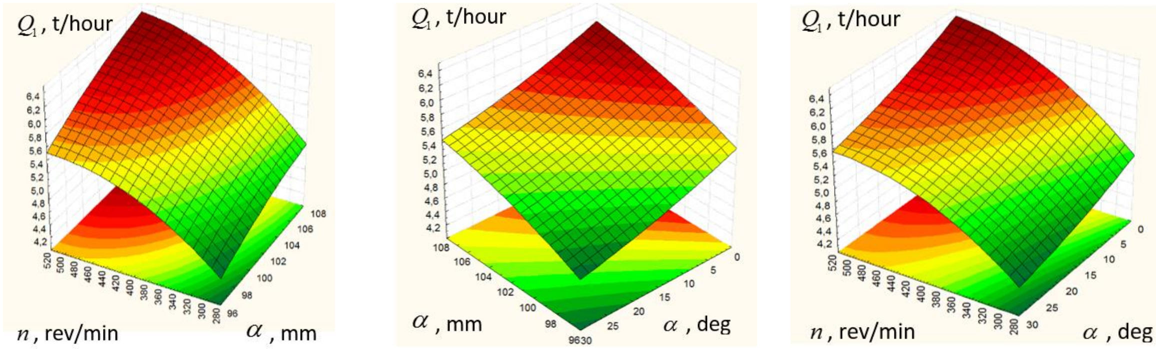
a) b) c)

Figure 5. Response surfaces of the change for productivity of barley transportation by the auger with peripheral elastic brush-like part a) $Q_2 = f(D,n)$; b) $Q_2 = f(D,\alpha)$; c) $Q_2 = f(n,\alpha)$



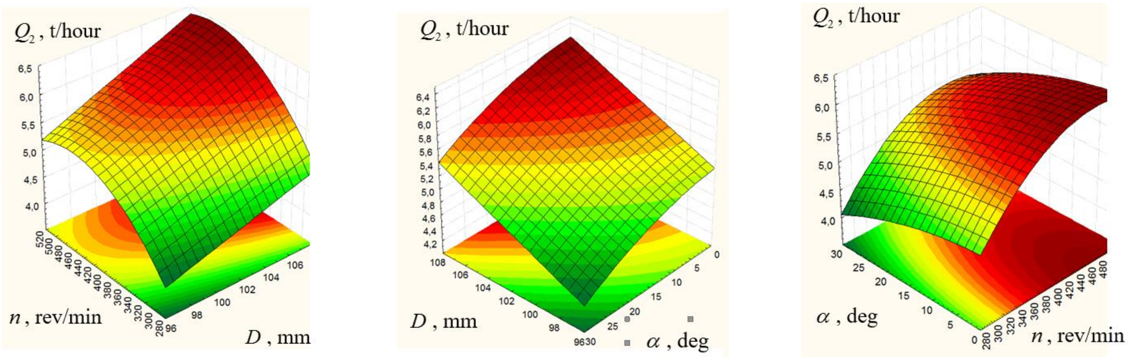
a) b) c)

Figure 6. Response surfaces of the change for productivity of barley transportation by the auger with brush-like element a) $Q_3 = f(D,n)$; b) $Q_3 = f(D,\alpha)$; c) $Q_3 = f(n,\alpha)$



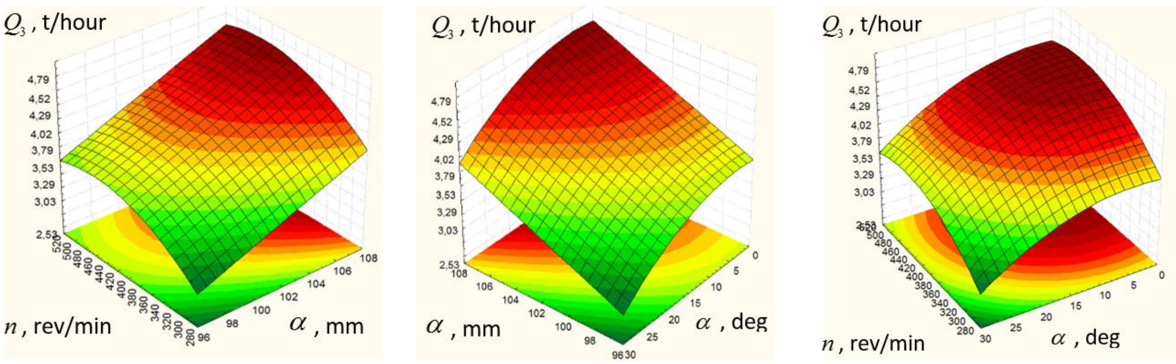
a) b) c)

Figure 7. Response surfaces of the change for productivity of corn transportation by the auger with continuos chamber-like element a) $Q_1 = f(D,n)$; b) $Q_1 = f(D,\alpha)$; c) $Q_1 = f(n,\alpha)$



a) b) c)

Figure 8. Response surfaces of the change for productivity of corn transportation by the auger with peripheral elastic brush-shaped part a) $Q_2 = f(D,n)$; b) Q_2 ; c) $Q_2 = f(n,\alpha)$



a) b) c)

Figure 9. Response surfaces of the change for productivity of corn transportation by the auger with brush-like element a) $Q_3 = f(D,n)$; b) $Q_3 = f(D,\alpha)$; c) $Q_3 = f(n,\alpha)$

After checking the adequacy of the approximating models and evaluating the significance of the coefficients of regression equation (4–6) according to Fisher's and Student's criteria, the response surfaces (Fig. 7 – Fig. 9) were constructed for corn transportation. From the presented results it can be concluded that:

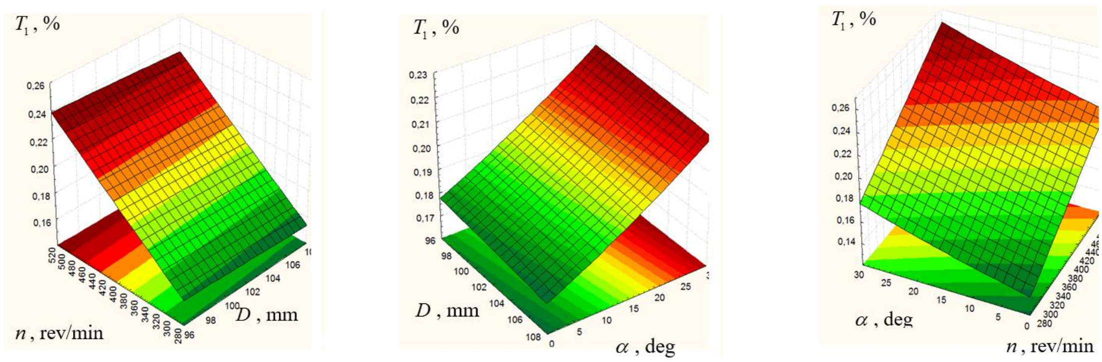
– the maximum productivity of corn transportation is reached: for the auger with continuous chamber-like element is 4.5….6.3 t/h; for the auger with peripheral elastic brush-like part is 4.1….6.4 t/h; for the auger with brush-like element – 3….4.7 t/h;

– while transporting corn, the auger with continuous chamber-like element provides much higher productivity compared to the auger with brush-like element (1.34… 1.5 times) and differs little in the productivity of transportation by the auger with peripheral elastic brush-like part;

– with the increase of inclination angle within the range of 0….30 deg. productivity of transportation by the screw conveyor decreases. The rational angle at which productivity reaches maximum values is 0….13 deg.;

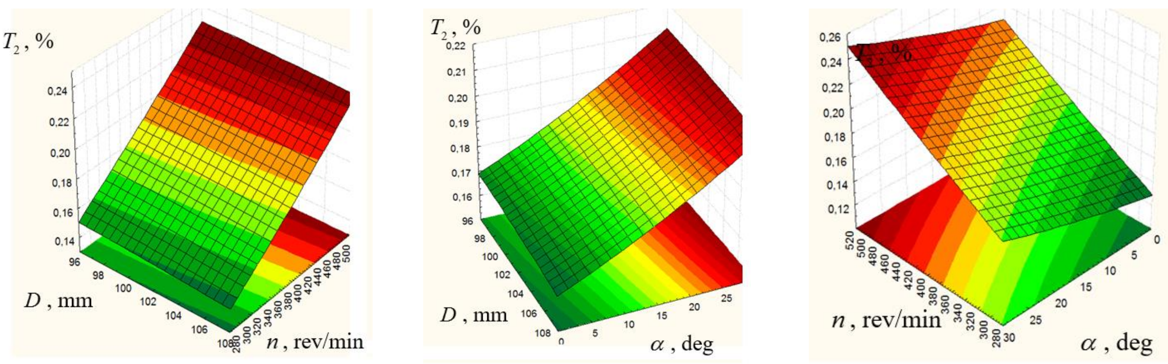
– rational parameters of the screw conveyor during corn transportation by various elastic screw working bodies are: D = 104 mm; α = 13 deg.; n =426 rpm.

Experimental investigations concerning the determination of grain material (corn) damage degree by multifactorial experiment were carried out according to the known methods [10]. While carrying out the multifactorial experiment dealing with the determination of grain material damage degree by screw elastic working bodies (Fig. 10 – Fig. 12), the following factors were variable: the angle of the working body inclination to the horizon – α (deg.); the working body rotation speed – n (rpm); the inner diameter of the case D (mm).



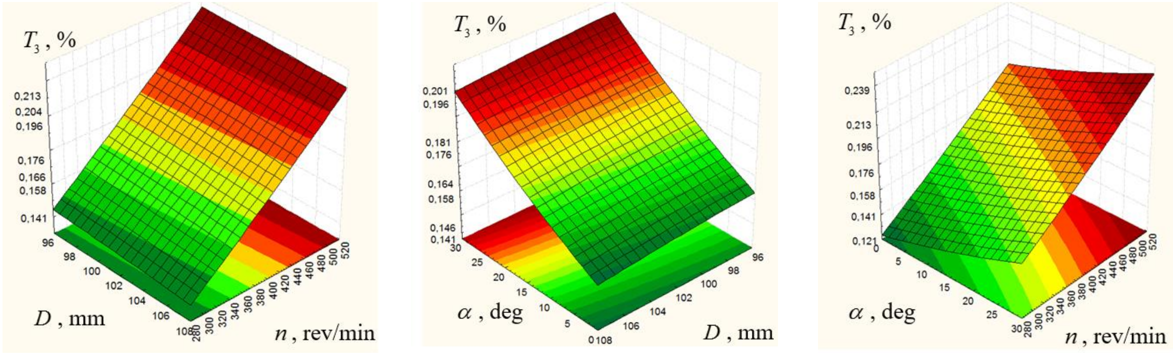
a) b) c)

Figure 10. Response surfaces of corn damage by the auger with continuous chamber-like element
a) $T_1 = f(D,n)$; b) $T_1 = f(D,\alpha)$; c) $T_1 = f(n,\alpha)$



a) b) c)

Figure 11. Response surfaces of damage by the auger with peripheral elastic brush-like part
a) $T_2 = f(D,n)$; b) $T_2 = f(D,\alpha)$; c) $T_2 = f(n,\alpha)$



a) b) c)

Figure 12. Response surfaces of corn damage by the auger with brush-like element
a) $T_3 = f(D,n)$; b) $T_3 = f(D,\alpha)$; c) $T_3 = f(n,\alpha)$

The regression equations in the form of approximating quadratic model of complete square polynomial for the determination of corn damage during its transportation by elastic auger are as follows:

$$T_1 = 0.066 + 0.0033n + 0.00093\alpha - 0.000002D^2 + 0.00000054n\alpha + 0.0000081\alpha^2 \quad (7)$$

$$T_2 = 0.073 + 0.00025n + 0.00093\alpha - 0.000002D^2 + 0.00000009n^2 + 0.00000044n\alpha + 0.0000096\alpha^2 \quad (8)$$

$$T_3 = 0.065 + 0.00026n + 0.00091\alpha - 0.000002D^2 0.000000082n^2 + 0.00000044n\alpha + 0.0000099\alpha^2 \quad (9)$$

From the analysis of the response surfaces of the corn damage degree *Te* by screw elastic working bodies (Fig. 10 – Fig. 12) it is determined that the dominant factor influencing value *Te* is the value of the auger rotation speed *n* and is slightly inferior to the auger inclination angle to the horizon *α*. Thus, the increase in speed *n* within the above mentioned ranges of parameters changes from 284 to 511 rpm. results in the increase of value *Te* from 0.145 to 0.23% (by 1.35 times), and change in the auger inclination angle to the horizon α from 0 to 30 ° causes the increase in value *Te* from 0.121 to 0.204% (by 1.27 times).

It was found that the corn damage degree *Te* by the auger with continuous chamber-like element is higher (up to 1.09 times) in comparison with the auger with brush-like element, and practically does not differ in damage degree by the auger with peripheral elastic brush-like part.

If compared with the results [11] the damage of grain material transportation by rigid auger, the corn damage during transportation by augers with continuous chamber-like element and peripheral elastic brush-like part is lower by 4.06… 4.32 times, and while using the auger with brush-like element is lower by 4.5 times, due to the higher elasticity of this auger. Also, the material damage is slightly lower, compared with the application of the investigated auger with sectional elastic working surface [11].

Analysis of the results of experimental investigations showed that increasing the absolute values of all the above mentioned parameters results in the increase in power value P on the drive of the experimental setup. It should also be noted that the increase in the rotational speed of the screw elastic working body *n* from 284 to 511.2 rpm results in the increase in power value *P* on the drive of the screw conveyor from 0.34 to 0.63 kW (by 1.9 times). Changing the auger inclination angle *α* to the horizon from 0 to 30 ° causes the increase in power value *P* by 1.23 times. In general, the power consumption *P* when using the investigated screw elastic working bodies in the gap-free $\Delta = 0$ transmission between the elastic screws and cases differ slightly.

Conclusions. In order to increase the efficiency of transportation and minimal damage to grain materials by screw conveyors, a number of designs of screw working bodies with elastic surfaces, as well as the experimental installation were developed and manufactured.

As a result of experimental investigations concerning the determination of transporting productivity Q (t/h) and the value of damage Tp (%) by the developed screw working bodies with elastic surfaces and processing the obtained data, the regression equation of productivity for the screw conveyor equipped with augers with continuous chamber-like element, with peripheral elastic brush-like part and with brush-like element for barley and corn depending on the change of the following factors: $284 \leq n \leq 511{,}2$ (rpm); $0 \leq \alpha \leq 30$ (deg.); $96 \leq D \leq 108$ (mm), as well as the degree of corn damage during transportation is derived. Using the application program, graphical reproductions of intermediate general regression models in the form of quadratic response surfaces are constructed.

It is determined that the main factor influencing the increase in productivity for transportation is the auger rotation speed. It is defined that with the increase of the case inner diameter and rotation speed and with the decrease of inclination angle the transportation productivity increases. The maximum productivity for the auger with continuous chamber-like element for barley transportation is 6.5 t/h, and the minimum is 4.1 (t/h); for the auger with peripheral elastic brush-like part it is 6.4 t/h, and the minimum is 3.9 t/h; for the auger with brush-like element it is 4.3 t/h, and the minimum is 2.5 t/h. It is defined that during barley transportation the auger with continuous chamber-like element provides much higher productivity in comparison with the auger with brush-like element (by 1.51…1.64 times). It is established that the productivity of barley transportation by augers with continuous chamber-like element and peripheral elastic brush-like part is higher in comparison with rigid auger (by 1.12…1.31 times), and while applying the auger with brush-like element it is lower (by1.19… 1.46 times), due to the significant length of brushes, their significant deflection and uneven filling of the screw space, and, consequently, the imperfection of this auger design.

It is determined that the maximum productivity during corn transportation is achieved: for the auger with continuous chamber-like element – 4.5….6.3 t/h; for the auger with peripheral elastic brush-like part – 4.1….6.4 t/h; for the auger with brush-like element – 3….4,7 t/h. It is defined that during corn transportation, the auger with continuous chamber-like element provides much higher productivity in comparison with the auger with brush-like element (by 1.34…1.5 times) and differs insignificantly in productivity of transportation by the auger with peripheral elastic brush-like part. It is established that with the increase of inclination angle within the range 0….30 deg. the productivity of transportation by screw conveyor decreases and the rational angle at which productivity reaches its maximum values is 0….13 deg.

It is determined that the dominant factor influencing the corn damage degree is the value of the screw rotation speed n and is slightly inferior to it in terms of the auger inclination angle to the horizon α. Thus, the increase of rotation speed n within the given ranges of parameters changes from 284 to 511 rpm. results in the increase of value Te from 0.145 to 0.23% (by 1.35 times), and the change of auger inclination angle to the horizon α from 0 to 30 ° causes the increase of value Te from 0.121 to 0.204% (by 1.27 times). It is found that the degree of corn damage Te by the auger with continuous chamber-like element is higher (up to 1.09 times) in comparison with an auger with brush-like element, and practically does not differ in the damage degree by the auger with peripheral elastic brush-like part. It is established that the corn damage during transportation with augers with continuous chamber-like element and peripheral elastic brush-like part in comparison with the grain transportation by rigid auger is 4.06…4.32 times lower, and while using the auger with brush-like element it is 4.5 times lower.

It is determined that the increase of absolute parameters values (screw rotation speed, case inner diameter and conveyor inclination angle) results in the increase of power value P on the drive of the experimental setup. It is defined that the increase of the rotation speed of screw elastic working body *n* from 284 to 511.2 rpm results in the increase in the value of power P on the screw conveyor drive from 0.34 to 0.63 kW (by 1.9 times). Changing the auger angle α toward the horizon from 0 to 30 ° causes the increase of power value *P* by 1.23 times. In general, the power consumption *P* while using the investigated screw elastic working bodies in the gap-free Δ = 0 transmission between the elastic screws and cases differs insignificantly.

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УСТАНОВКА ДЛЯ ДОСЛІДЖЕННЯ ГВИНТОВИХ РОБОЧИХ ОРГАНІВ ІЗ ЕЛАСТИЧНИМИ ПОВЕРХНЯМИ ТА РЕЗУЛЬТАТИ ЇХ ЕКСПЕРИМЕНТАЛЬНИХ ВИПРОБУВАНЬ

Іван Гевко; Олег Ляшук; Олег Цьонь; Тарас Довбуш; Сергій Залуцький; Андрій Станько

Тернопільський національний технічний університет імені Івана Пулюя, Тернопіль, Україна

Резюме. *Гвинтові транспортери знайшли широке використання у різних галузях економіки, що зумовлює і специфічні вимоги, які ставляться до них. Однією з них є можливість безпечного переміщення крихких елементів та продуктів із можливим підвищеним пошкодженням (травматизмом) у фармацевтич-ній галузі, галузях електроніки, харчової промисловості, а також у сільськогосподарському виробництві при транспортуванні насіннєвих зернових матеріалів. Наведено результати експериментальних досліджень ефективності транспортування сипких вантажів гвинтовими робочими органами з еластичними поверхнями.*

В результаті проведених експериментальних досліджень з визначення продуктивності транспортування та величини травмування розробленими гвинтовими робочими органами із еластичними поверхнями та опрацювання отриманих даних виведено рівняння регресії продуктивності для гвинтового конвеєра, оснащеного шнеками з суцільним камероподібним елементом, з периферійною еластичною щіткоподібною частиною та з щіткоподібним елементом для ячменю та кукурудзи, а також ступеня травмування при транспортуванні кукурудзи. Встановлено, що зі збільшенням внутрішнього діаметра кожуха та частоти обертання та зі зменшенням кута нахилу продуктивність транспортуванням зростає. Встановлено, що при транспортуванні кукурудзи шнек з суцільним камероподібним елементом забезпечує значно вищу продуктивність у порівнянні зі шнеком із щіткоподібним елементом (в 1,34…1,5 раза) й мало відрізняється за продуктивністю транспортування шнеком із периферійною еластичною щіткоподібною частиною. Встановлено, що домінуючим фактором, який впливає на ступінь травмування кукурудзи, є величина частоти обертання шнека і несуттєво поступається їй за впливом кут нахилу шнека до горизонту, а також те, що ступінь травмування кукурудзи шнеком з суцільним камероподібним елементом у порівнянні зі шнеком з щіткоподібним елементом є вищим, він практично не відрізняється за ступенем травмування шнеком з периферійною еластичною щіткоподібною частиною.

Ключові слова: *гвинтові транспортери, пошкодження, транспортування, еластичні поверхні.*

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