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Justification and calculation of structural-power parametersof screw loaders

Abstract. Existing designs of screw working bodies of transport and processing machines cannot always provide the required performance and avoid overloading, which causes deformation and damage to parts of the mechanisms. Thus, it is necessary to establish new efficient screw working bodies that would ensure the execution of the technological process. The purpose of the study was to substantiate and explore the design and methodology for calculating the main structural-power parameters of the developed screw loader, to synthesise screw loaders using the method of morphological analysis to obtain designs of mechanisms with better technical and economic characteristics.

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The methods of surface theory, analytical and differential geometry, computer graphics and mathematics were used to conduct the research. As a result of theoretical and experimental studies, the designs of screw conveyors with hopper loading and screw conveyors with nozzle loading are presented. In addition, a classification of loaders for screw transport and technological mechanisms is presented. The dependencies for calculating the design of screw conveyor loaders are determined. The synthesis of loaders and mixers by the method of morphological analysis was performed to obtain designs of mechanisms with the best technical and economic characteristics and competitive designs of mechanisms were established. A system of coding and synthesis of structural elements and mechanisms of screw implements with improved technological properties is proposed, and competitive designs of screw implement that perform technological processes efficiently and effectively are selected. A methodology for calculating the main structural and power parameters of a screw loader has been developed, which allows for determining the parameters of a screw loader. The materials of the research can be used in further studies of screw conveyors and, in particular, screw loaders to determine their design, technological, energy and power parameters

Keywords: screw conveyor; nozzle; transport and technological mechanism; structural elements; structural synthesis; morphological analysis; calculation method

INTRODUCTION

One of the most significant criteria for the operation of screw conveyors is the productivity of the transport-technological machine, which must be ensured with minimal energy consumption. Thus, to efficiently perform the technological process of reloading bulk materials using transport-technological machines in the form of screw conveyors, it is necessary to ensure their rational loading. In addition, note that screw conveyors can be loaded with hoppers, nozzles and loading devices.

The issues of theoretical design of screw reloading mechanisms with flexible lines and methods of designing and calculating their parameters, development of efficient designs of screw conveyors for transporting bulk materials along curved routes are discussed in [1; 2], and the issues of synthesis of machine structures by morphological analysis are discussed in [3] etc. Particular attention should be paid to the coverage in the literature of the issues of calculation and selection of parameters of screw working bodies and transportation of grain materials, mineral fertilisers and other bulk agricultural materials by screw conveyors [4; 5; 6] since the problem of injury to materials during the transportation is open.

The design calculations of mechanisms with screw working bodies are covered in many scientific works, in particular [7-9] and many others, but the presented calculations of each mechanism or part have their specifics since each of the given structures is characterised by the presence of certain structural details that affect the nature of their operation and operation. In addition, in [10; 11], studies were conducted on the development of working bodies for flexible screw conveyor lines, which significantly increase their length and expand technological capabilities.

The issues of exploring the functional, operational, and resource characteristics of screw conveyors in their interaction with agricultural materials are discussed in [12; 13]. The study of the movement of particles of agricultural materials by the screw surfaces of the working bodies of conveyors is devoted to [14; 15]. Works [16; 17] substantiate the design, kinematic and technological parameters of screw working bodies by considering their functional purpose. The possibility of using a helical surface for the manufacture of conveyor working bodies was considered in [18]. The theoretical foundations of the design and construction of linear screw surfaces are presented in [7; 19]. Research [20] justify using a helical surface in conveyor working bodies and reloading nozzles, and research [21] explored the injury of grain material by a screw conveyor working body. Works [22; 23] justify using elastic working bodies to minimise damage to grain material when it is overloaded by screw conveyors.

However, the known designs of the working bodies of screw conveyors do not fully satisfy the operational requirements, and therefore the task of developing new designs of working bodies of screw conveyors and justifying their competitive design and technological parameters that could provide better performance while reducing material consumption and simplifying the design is relevant.

The purpose of the research – justification, design of elements of screw conveyors, development of a methodology for calculating the main structural-power parameters of a screw loader and synthesis of screw loaders.

MATERIALS AND METHODS

The mathematical modelling of the processes of movement of bulk materials is described using the laws and postulates of analytical geometry, differential mathematics, theoretical and applied mechanics, surface theory and computer graphics systems. The study was conducted using the method of morphological analysis, elements of the theory of experiment, methods of mathematical statistics and mathematical methods of optimal experiment planning. The analysis of the results of the presented research was performed using applied computer programmes, in particular Excel, Word, and SolidWorks, and was conducted according to standard and developed methods, in particular, the methodology for systematisation and classification of research results, their analysis, preparation of tables and graphs reflecting the results of research, calculation of errors, literature analysis, modelling, experimentation, and work experience that require research.

The methods of morphological analysis and synthesis were used to effectively search for new constructive solutions since they are the most common methods for establishing new designs of mechanisms that use elements of classification and systematisation. Morphological analysis means that a specific number of the most characteristic functional or structural morphological features are identified for a given product, which allows for specific search options for these characteristic features. In the course of the analysis, a list of specific variants of particular designs is determined for each morphological feature. All defined variants of morphological traits are compiled in the form of a so-called morphological table or "matrix". The term "morphological" can be explained by the fact that variants of constructive features are defined by the letters of the Ukrainian alphabet. By designing random combinations of variants, new design options can be discovered that might be missed by simple searching. The search for the most appropriate variants of mechanism designs should be conducted using computer software (electronic computers). The method of morphological analysis uses elements of combinatorics, i.e. a systematic study of all theoretically possible variants of constructive schemes that arise from the specific patterns of construction of the mechanism considered. The synthesis of these mechanisms involves both well-known and new, unusual design options. The method of morphological analysis has several varieties and is designed to overcome bias in existing opinions about the possibility and ways of solving a problem. It allows the task to be described and analysed using a set of all possible structural (i.e. morphological) relationships and relationships between its elements. Before conducting a morphological analysis, morphological tables or graphs should be developed and compiled. Using the method of morphological analysis does not result in new or original ideas, but it does provide an opportunity to find new combinations of known structural parts. Therefore, it is advisable to use it when a mechanism or product consists of several structural parts. The classification of structures allows for faster and more accurate orientation in a large number of terms and factors, and therefore morphological analysis is based on classification.

RESULTS AND DISCUSSION

The functional purpose of screw conveyor hoppers is to accumulate, store and ship bulk material for a short period to the discharge line of screw conveyors, provided that the screw working body is not overloaded. The shape of the hoppers of screw conveyors can be square, rectangular, round, etc. The purpose of the nozzles for screw conveyors is to insert the screw spiral into the bulk material without deformation and to perform productive loading of the screw conveyor casing while preventing the phenomenon of technological overload and breakage of the working bodies. Nozzles for screw conveyors are available with adjustable openings or with permanent openings. Loading mechanisms are used to transfer bulk materials from flat surfaces and containers to screw conveyors by delivering them to the working body. The loading devices are divided into two types: for loading the conveyor with materials that spill out of containers and for picking up loose materials from flat surfaces and moving them into the conveyor.

Figure 1 demonstrates a typical screw conveyor equipped with a hopper load, which is described in detail in [24].

Figure 1. Hopper-fed screw conveyors: a) tractor PTO drive; b) and c) mobile screw conveyors

Figure 2 demonstrates screw conveyors with rigid and flexible shafts, in which the loading is performed using nozzles. All of them do not provide a process for regulating the loading of the lines, which can result in the overloading of the screw conveyors caused by the process.

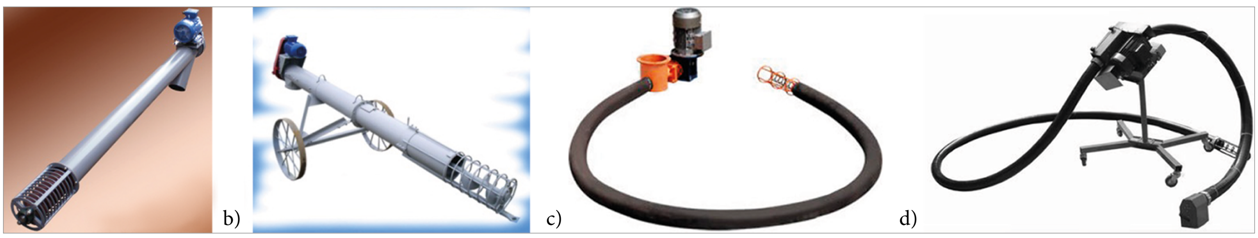

Figure 2. Screw conveyors with nozzles for loading: a) manufactured by PJSC "Elevator Equipment Plant"; b) manufactured by LLC "Promstroykomplekt"; c) manufactured by LLC "TechResource"; d) manufactured by LLC TD "BMZ"

The transport-technological machines presented in Figures 3a-3g, it is possible to load conveyors with bulk materials from flat surfaces, and Figures 3e-3f presents wagon unloaders with screw working bodies.

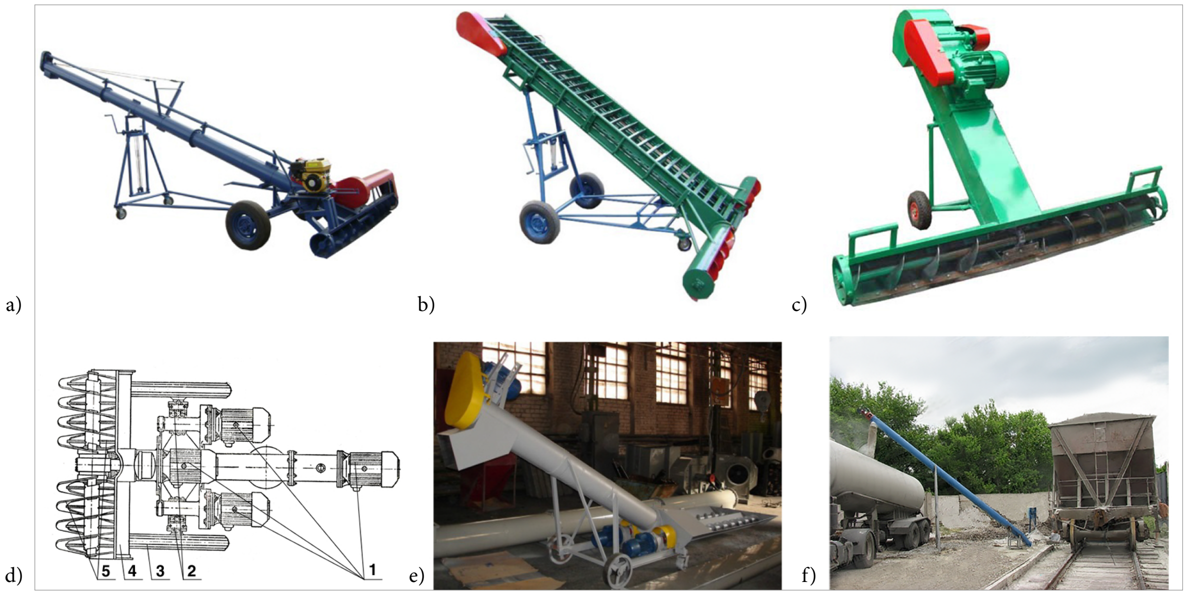

Figure 3. Loading mechanisms: a) auger loader; b) scraper-screw conveyor; c) auger working body for picking up bulk materials; d) auger pick-up trolley; e) screw wagon unloader; f) screw wagon unloader

To ensure the reliable and productive operation of screw conveyors and prevent their damage, which can be both accidental and as a result of the technological process, it is, therefore, necessary to use regulatory and protective mechanisms. For example, in screw conveyors, which are loaded through a hopper or nozzle, it is necessary to use regulating mechanisms in addition to protective grids, which can ensure that a specific volume of material enters the main line per unit of time.

It will ensure optimum loading of the main lines and maximum productivity when transporting various materials. In addition, for screw conveyors that are loaded with a nozzle, safety devices can be used to stop the loading of the main line if foreign material enters the nozzle, which can cause damage to the screw working body. It is difficult to ensure the optimum amount of material loaded in conveyors that have loading devices, therefore, their transport lines must be designed for maximum loading. In addition, loading mechanisms must be equipped with safety clutches. The classification of loaders of screw transport and technological mechanisms by design features is presented in Figure 4 [24].

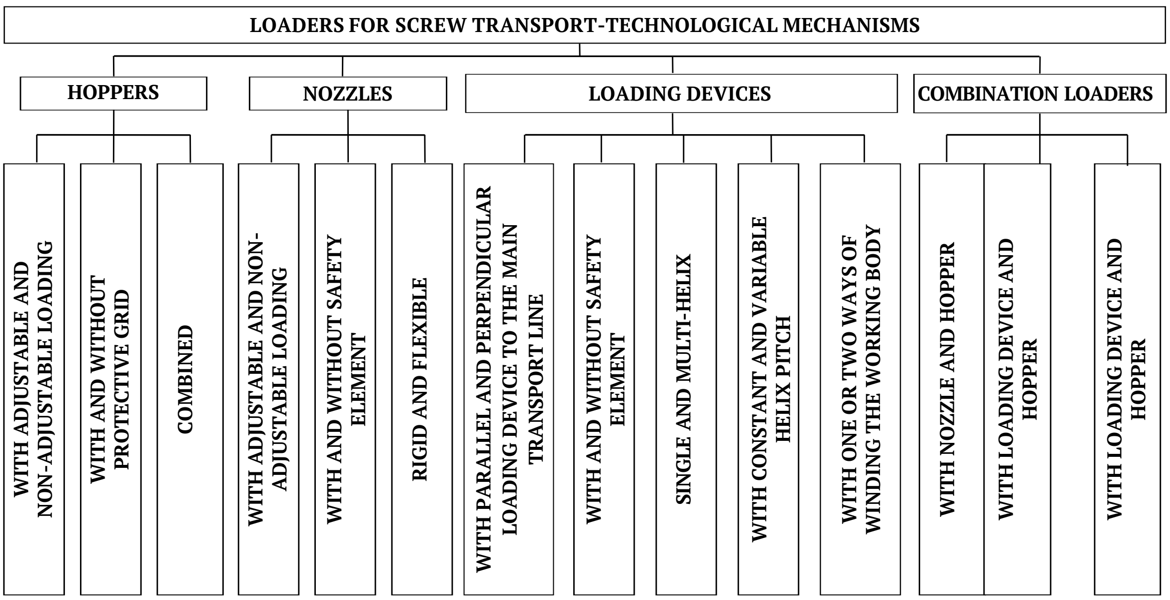

Figure 4. Classification of loaders of screw transport-technological mechanisms by design features
Source: developed by the authors based on [24]

Based on the above and considering the fact that the issue of material flow through the hopper gates has been thoroughly explored [25], it is necessary to address the problem of developing and researching screw conveyor nozzles that will ensure a regulated process of loading the main lines.

Loading and protective nozzles have been established for screw conveyors, the designs of which are presented in Figure 5 [24]. The design of the self-loading nozzle, presented in Figure 5a, protects the working body from deformation, and the presence of holes allows the transported material to penetrate it.

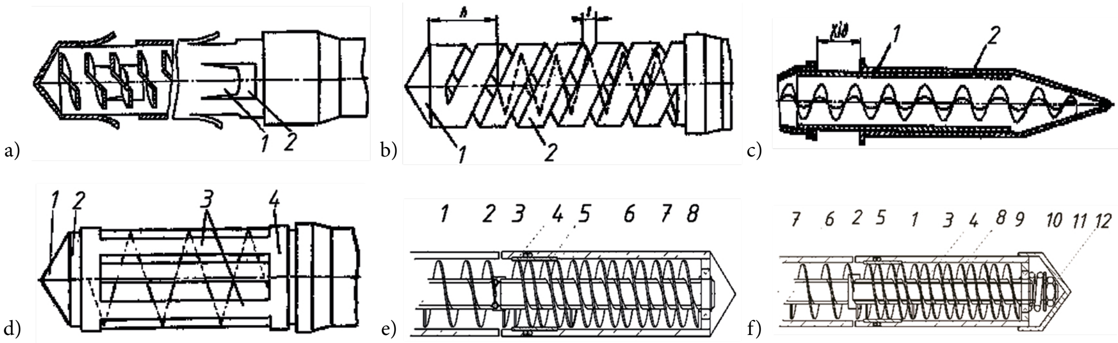

Figure 5. Designs of loading-protective nozzles for screw conveyors
Source: developed by the authors based on [24]

When the self-loading nozzle (Fig. 5b) is inserted into the bulk material, only the coils of the cylindrical spring 2 are deformed, not the auger working body. At the end of the injection process, spring 2 returns to its original position and moves the bulk material into the nozzle.

In the self-loading nozzle of screw conveyors (Fig. 5c), after insertion into the bulk material, the tip of the nozzle rests on the casing, and its petals open and allow the bulk material to penetrate the casing.

Figure 5d demonstrates a nozzle that can adjust the size of the material passage holes, which can ensure rational loading and compliance with the established standards for the transport process.

If foreign objects get into the nozzle presented in Figure 5e, which can cause damage to the working body, the western screw 5 of the nozzle stops and disconnects it from the screw of the retracting line using the balls 2 exiting the holes made on the line shaft 1 due to their axial displacement and deformation of the springs 3.

When foreign objects enter the nozzle presented in Figure 5f through the technological holes, which can cause damage to the screw working body, the 3-way screw of the safety nozzle stops and disconnects it from the working body of the transport line due to the axial displacement of the nozzle shaft and compression of the spring.

It has been established that to ensure the technological process of transporting by screw conveyors with retracting lines, it is necessary to determine the rational values of the dimensions of the holes for the passage of bulk material of nozzles. The capacity of a screw conveyor can be calculated using the formula:

$$Q=0{,}25 \cdot \pi \cdot \varphi \cdot V_n \cdot (D^2-d), \tag{1}$$

where D – diameter of the casing; d – diameter of the shaft of the working body; V_n – axial speed of movement of the load in the casing; φ – coefficient of filling the inter-turn space.

The reloading capacity must be equal to the bulk material loading capacity. If the bulk material is loaded through the nozzle, the capacity of the screw conveyor can be determined by the following equation:

$$Q=k \cdot F \cdot n \cdot V_z, \tag{2}$$

where F – area of one hole; n – number of holes; V_z – the material filling rate; k – loading factor of the screw conveyor, k=0.7...0.5.

The rate of cargo spillage through the hole is determined by the formula [26]:

$$V=\lambda \cdot \sqrt{3.2 \cdot g \cdot RR}, \tag{3}$$

where λ – the coefficient of the passage of bulk material; R – the reduced radius of the conveyor outlet (the ratio of the outlet area to the perimeter of the outlet); g – the acceleration of free fall.

If the appropriate transformations are made, the following dependence is used to determine the size of the radius of the loading hole:

$$R=\sqrt[5]{\frac{\varphi^2 \cdot V_n^2 \cdot (D^2-d^2)}{25{,}6 \cdot k^2 \cdot n^2 \cdot \lambda^2 \cdot g}}. \tag{4}$$

In addition, the width of the rectangular loading opening can be determined from the dependency:

$$l=\frac{\pi}{a}\left[\frac{\varphi^2 \cdot V_n^2 \cdot (D^2-d^2)}{25{,}6 \cdot k^2 \cdot n^2 \cdot \lambda^2 \cdot g}\right]^{\frac{1}{5}}. \tag{5}$$

Using these dependencies, it is possible to determine the required design dimensions of the loading holes of the screw conveyor nozzles and obtain the maximum productivity of screw conveyors for the transport of bulk materials.

When developing progressive designs of screw conveyors with flexible working bodies, it is advisable to use the method of morphological analysis [27], which allows for obtaining a solution to the problem: obtaining the most rational and economical design solutions for establishing new mechanisms and their working bodies. Using the method of structural and schematic synthesis and morphological analysis [24], the constituent elements and the links between them were identified and a morphological matrix was compiled in the form of Table 1.

Table 1. Morphological table of features of structural elements of a flexible screw conveyor

Conveyor drive			Screw working body						Loading mechanism	
			Screw construction							
1. View	2. Type of movement	3. Quantity	4. Spiral profile	5. Partial	6. Solid	7. Spiral combination	8. Connection design	9. Gutter construction	10. Process	11. Type
1.1. Electric drive 1.2. Pneumatic drive 1.3. Internal combustion engine 1.4. Hydraulic drive	2.1. Continuous 2.2. Cyclic 2.3. With accelerations and decelerations	3.1. One 3.2. Two 3.3. Several	4.1. Narrowband 4.2. Wideband 4.3. Corrugated 4.4. L-shaped or inclined 4.5. Blade 4.6. With cut-outs or openings 4.7. Spring	5.1. Gimbal 5.2. Hinged 5.3. Sectional	6.1. Bulkhead 6.2. With flexible simple shaft 6.3. With flexible folding shaft	7.1. Single-type 7.2. Combined	8.1. Toothed 8.2. Riveting 8.3. Welded 8.4. Bolted 8.5. Finger 8.6. With internal section connection 8.7. With external section connection 8.8. With internal and external section connection 8.9. Elliptic 8.10. Ball	9.1. Solid 9.2. Sectional	10.1. Gravitational 10.2. orced 10.3. Separate 10.4. With calibration 10.5. With shredding 10.5. With additional technical operations 10.6. Multilink	11.1. Hopper 11.2. Nozzle 11.3. Loading device

Source: developed by the authors based on [24]

The main morphological features of screw conveyors have presented: types of drive, types of screw working bodies, designs of loading mechanisms, types of screw conveyor arrangement, and types of unloading mechanisms. The morphological model of spiral conveyors, which is presented in Table 1 [24], can be recorded by a morphological matrix, which was established by the method of designating the numbers of codes of the corresponding alternative designs, which are placed in the columns of the developed morphological table:

$$N = K_1 \cdot K_2 \cdot K_3 \cdot \ldots \cdot K_j = \prod_{j=1}^{n} K_j, \tag{6}$$

$$N_{\Gamma\Gamma K} = \begin{vmatrix} 1.1 & 2.1 & 3.1 \\ 1.2 & 2.2 & 3.2 \\ 1.3 & 2.3 & 3.3 \\ 1.4 & & \end{vmatrix} \cap \begin{vmatrix} 4.1 & & & \\ 4.2 & & & \\ 4.3 & 5.1 & 6.1 & 7.1 \\ 4.4 & 5.2 & 6.2 & 7.2 \\ 4.5 & 5.3 & 6.3 & \\ 4.6 & & & \\ 4.7 & & & \end{vmatrix} \cap \begin{vmatrix} 8.1 \\ 8.2 \\ 8.3 \\ 8.4 \\ 8.5 \\ 8.6 \\ 8.7 \\ 8.8 \\ 8.9 \\ 8.10 \end{vmatrix} \cap \begin{vmatrix} 9.1 \\ 9.2 \end{vmatrix} \cap \begin{vmatrix} 10.1 & \\ 10.2 & 11.1 \\ 10.3 & 11.2 \\ 10.4 & 11.3 \\ 10.5 & \\ 10.6 & \end{vmatrix}. \tag{7}$$

The total number of design variants of flexible screw conveyors that make up the morphological matrix (7) is very significant, and therefore it is necessary to spend a lot of time selecting productive solutions, and therefore it is necessary to use the established variants by combinations of the presented method to synthesise hierarchical groups using the method of morphological analysis, which establishes conditions for dividing this system into a specific number of established hierarchical levels with their decomposition in each of the various established designs of this system [25].

For the presented variant, the combination of the first hierarchical level and the model of the established system “Flexible Screw Conveyor”, presented in Figure 6, [24], can be divided into two subgroups.

The first presented subgroup includes designs of elements that demonstrate special morphological features of the design of the working body (5) and (7), and special morphological features of the design of the screw working body connection (8), and the second includes structural elements of screw working bodies (6). When using this method, the number of synthesised variants is determined by the formula:

$$N_{I\Gamma}=\sum_{z=1}^{l}\sum_{x=1}^{q}\prod_{i=1}^{m}K_i, \tag{8}$$

where z – designation of the hierarchical level; l – number of levels; x – subgroup of a certain hierarchical level; q – number of subgroups of a certain hierarchical level; K_i – selection of a design feature of the mechanism of a subgroup of a certain hierarchical level; m – number of selections of design features of mechanisms of a particular subgroup of a specific hierarchical level.

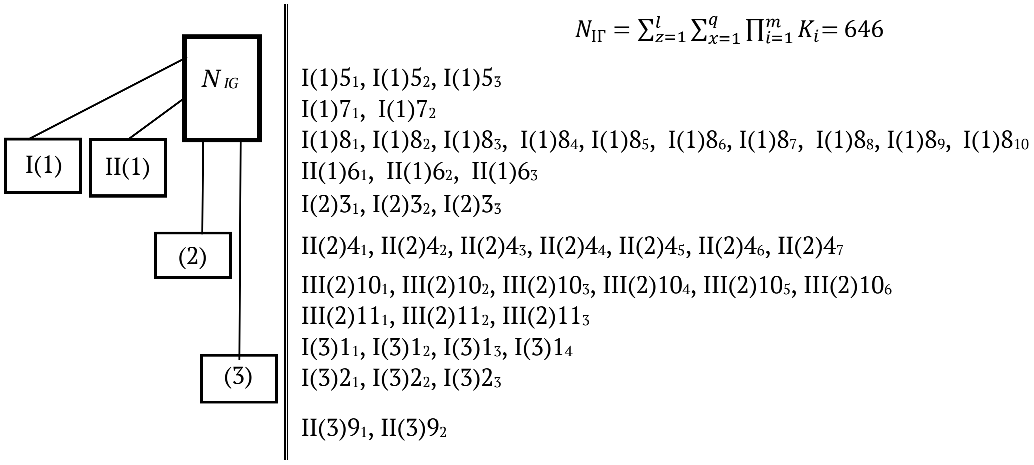

Figure 6. Diagram of the model of the mechanical system "Screw loader":
I – the first subgroup of the hierarchical level; II – the second subgroup of the hierarchical level;
III – the third subgroup of the hierarchical level; (2) – the second hierarchical level; (3) – the third hierarchical level

If the method of morphological analysis is used to calculate the number of alternative designs, the total number of generated variants of flexible spiral conveyors will be 1632960 variants, and if the method of synthesis of hierarchical groups with subsequent decomposition into separate subgroups is used, using the method of morphological analysis, the number of variants will be only 102, which is much less than using the conventional method of synthesis.

The choice of the established design variant of the screw working bodies of the reloader will depend on the transportation process and the amount of force load on the screw working body. If the main parameters in the design of working bodies are productivity and geometric dimensions and the quality indicators of the technological process are neglected, then in such a model of a mechanical system the number of coefficients will be reduced to two values, and the selection task will be to find designs that would ensure optimal strength and cost of screw working bodies. It will result in the search for rational solutions to establish equally strong structures of rigid and flexible screw working bodies, considering their technical and economic indicators. It will result in the search for rational solutions to establish equally strong structures of stiff and flexible screw working bodies, considering their technical and economic indicators.

As a result of the analysis of the design solutions of the generated variants, workable designs of flexible screw conveyors were obtained (Fig. 7) [27].

Since the design and kinematic parameters of these devices are interrelated, it is necessary to set a specific value of the loader's capacity Q, i.e. a value that would reflect the amount of material that will be periodically loaded into the device. This parameter is the initial value for setting the diameter of the spiral and its rotation frequency. According to the methodology for determining the performance of screw conveyors:

$$Q_p=Q_v\rho,\ \text{t/h}, \tag{9}$$

where Q_v – volumetric capacity, m³/hour; ρ – bulk density of the transported material, t/m³.

The volumetric capacity is determined by the formula:

$$Q_v=47D_C^2\xi n_C\psi c_\beta, \tag{10}$$

where D_C – outer diameter of the working body, m; ξ – pitch ratio of the working body; n_C – rotational speed of the working body, rpm; ψ – conveyor filling rate; c_β – coefficient that considers the angle of inclination of the working body.

The estimated capacity is determined by the formula:

$$Q_p=47D_C^2\xi n_C\psi c_\beta\rho, \tag{11}$$

whence the calculated value of the outer diameter of the spiral is equal:

$$D_C \approx \sqrt{\frac{Q_p}{47\xi n_C\psi c_\beta\rho}}. \tag{12}$$

The final value of the outer diameter of the helix is determined according to DSTU 2763-94 [28], with the closest value to the calculated one being the largest.

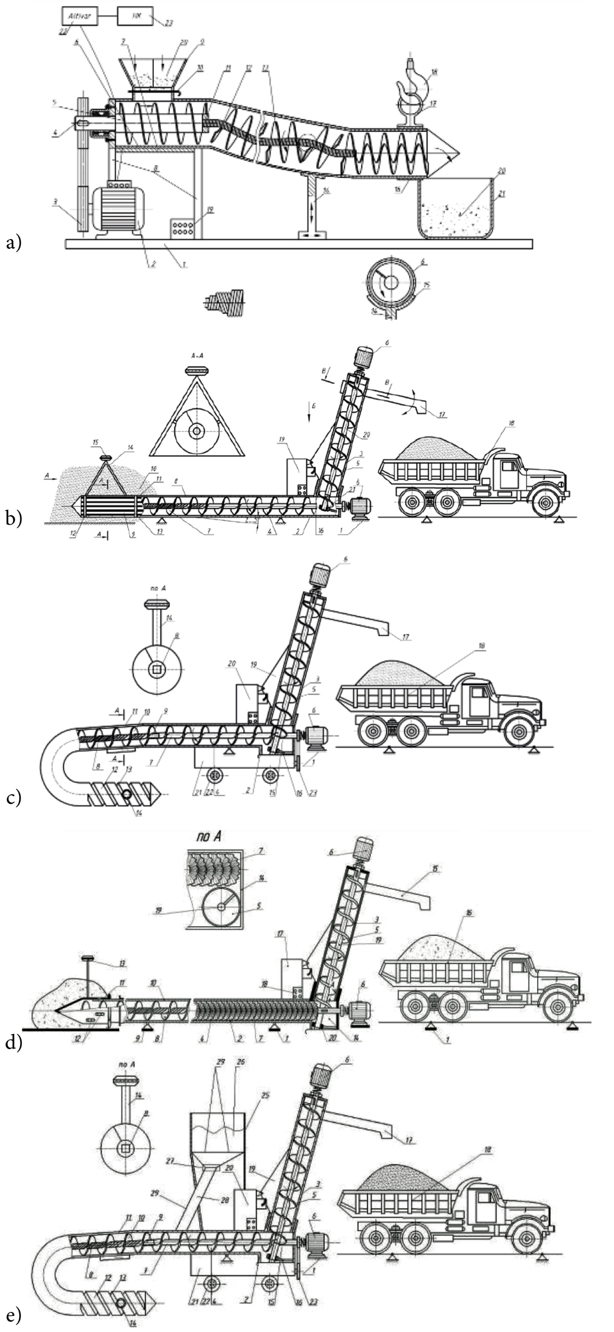

Figure 7. Synthesised models of screw conveyors and loaders

The drive power can be calculated based on the following considerations. The power of the drive motor is used to overcome the frictional resistance when the material is moved in the respective hose, for bearing losses and to lift the material to a specific height (vertical conveying section).

The total drag force W caused by the friction of the bulk material against the pipe walls and the inclination of the device at an angle β to the horizon (Fig. 8) [27] is equal:

$$W=qgf_pL_C\cdot cos\alpha+qgf_pL_C\cdot sin\alpha=qg(Lf_p+h), \tag{13}$$

where q – the distributed mass of the material, kg; g – free fall acceleration; f_p – coefficient of friction of the material against the walls of the hopper pipe; L_C, L, h – length of the spiral and its projections, m; α – the angle of inclination of the highway to the horizon.

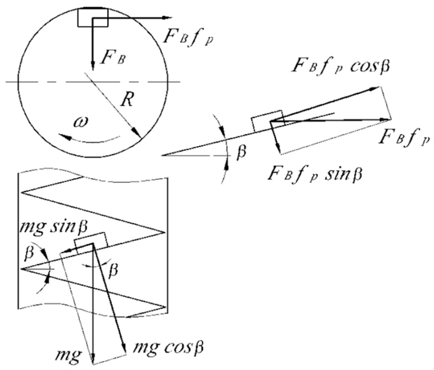

Figure 8. Calculation scheme for determining the critical speed of the helix

Note: m – mass of the material particle; f_p – coefficient of friction of the material against the walls of the hopper; R – radius of the spiral; β – angle of rise of the spiral; F_B – reaction force of the hopper

If the speed of material movement is expressed as:

$$\upsilon=t_Cn_C/60, \tag{14}$$

where t_C – the spiral pitch, and the distributed mass of material q through the productivity Q:

$$Q=3{,}6qt_Cn_C/60, \tag{15}$$

the necessary power N_1 is obtained, which is required to overcome the resistance force W:

$$N_1=\frac{W\upsilon}{1000}=\frac{Qg(Lf_p+\mathrm{h})}{3600}. \tag{16}$$

If the drag force is considered to be the normal pressure on the surface of the propeller blade, without considering the angle of elevation, the friction force of the material against the helix can be calculated:

$$F_C=qgf_C(Lf_p+h), \tag{17}$$

where f_C – the coefficient of friction of the material to the helix.

Since the force acts in a cross-section approximately equal to 0.25 D_C, the power N_2 consumed by friction against the spiral is equal:

$$N_2=F_C\upsilon=\frac{qgf_C(Lf_p+h)}{1000}\cdot\frac{\pi dn_C}{60}, \tag{18}$$

where d – diameter of the spiral shaft, m. After the appropriate transformations, the following will be obtained:

$$N_2=\frac{Qf_C(Lf_p+h)}{367}\cdot\frac{\pi d}{t_C}. \tag{19}$$

However, in production conditions, it is difficult to determine all the forces that oppose the movement of the working body, thus a well-known dependence is used to determine the drive power [2]:

$$N = \frac{Q_p L_C}{367\eta_П} \cdot (k \pm sin\,\alpha), \quad (20)$$

where η_p – actuator efficiency; k – material resistance coefficient.

Accordingly, the "+" ign is used when lifting the material, and the "-" sign when lowering it. For horizontal positioning of the hopper section:

$$N = \frac{Q_p L_C k}{367\eta_П}. \quad (21)$$

In addition to the appropriate diameter and shape of the spiral blades, a certain spiral speed is required to lift material with the vertical section. To determine the minimum required helix rotation frequency, consider the kinematics of the material movement using the example of the scheme presented in Figure 8.

A particle of mass m on a helical surface is subject to two forces, one of which is downward $mg\,\sin\beta$, and the other – the frictional force of the particle against the surface of the spiral $mgf_C\cos\beta$. During the rotational movement of the particle along with the spiral at a certain speed υ along the radius R, a centrifugal force $m\upsilon^2/R$ arises, which presses the material particle against the fixed wall of the spiral sleeve, where the friction force of the particle against the sleeve $m\upsilon^2 f_p/R$ arises, which generates additional pressure on the helical surface of the spiral blade. The vertical component of this pressure is $m\upsilon^2 f_p\cos\beta/R$, and the normal pressure on the helical surface is $m\upsilon^2 f_p \sin\beta/R$.

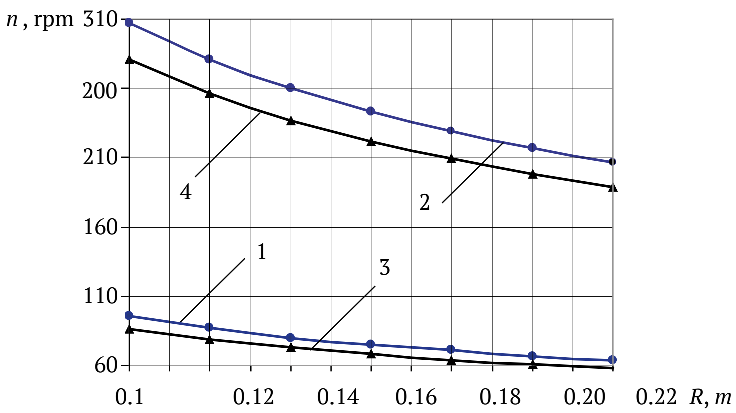

Figure 9. Dependence of the change in the critical rotation frequency of the working body of the loader on its radius $n=f(R)$ at different values of the process line elevation angle and the coefficient of friction of the material against the pipe walls: 1 – (β=16°, f_p=0.15); 2 – (β=20°, f_p=0,15); 3 – (β=16°, f_p=0,18); 4 – (β=20°, f_p=0.18)

The critical velocity, i.e. the velocity on the circumferential surface of the spiral at which the material fraction is in equilibrium, is found from the following condition:

$$mg\,sin\,\beta + mgf_C\,cos\,\beta + \frac{m\upsilon_{кр}^2 f_p f_C\,sin\,\beta}{R} - \frac{m\upsilon_{кр}^2 f_p\,cos\,\beta}{R} = 0, \quad (22)$$

where the critical velocity is equal:

$$\upsilon_{кр} = \sqrt{\frac{gR\,sin\,\beta + f_C\,cos\,\beta}{f_p\,cos\,\beta - f_C\,sin\,\beta}} = \sqrt{\frac{gR}{f_p}tg(\beta + \rho_C)}, \quad (23)$$

where ρ_C – the angle of friction of the material particle to the surface of the spiral.

Considering that the critical speed is equal:

$$\upsilon_{kp} = \frac{\rho R n_{kp}}{30}, \quad (24)$$

the critical speed of the working body is equal:

$$n_{кр} = \frac{30}{\pi R}\sqrt{\frac{gR}{f_p}tg(\beta + \rho_C)}. \quad (25)$$

To determine the influence of the screw radius R, the angle of the rise of the process line β, and the coefficient of friction of the material against the pipe walls f_p on the value of the working body rotation frequency, we determined the dependence (25). According to the results obtained, which are presented in Figure 9, it was found that the frequency of rotation of the working body decreases with the growth of the screw radius, and, accordingly, the greater the value of the angle of the rise of the technological line and the smaller the value of its radius, the lower the value of the coefficient of friction of the material against the pipe walls.

The monograph [22] discusses new designs of mechanisms with screw working bodies for the mechanisation of labour-intensive processes of bulk materials handling. Progressive designs are presented, their technical characteristics are defined, but the designs with the best technical and economic indicators are not identified.

Work [24] is devoted to the design, manufacturing technology and experimental studies of flexible screw conveyors, the main characteristics of which are mobility and the possibility of reloading bulk materials along curved routes. The research provides a theoretical justification for the design of flexible screw conveyors, explores the processes of their manufacture, presents the results of experimental studies and optimises the design parameters of screw working bodies, but it is necessary to improve the methodology for designing the structures of working bodies of screw conveyors.

Research [25] describes the main methods of transporting bulk agricultural materials along curved routes in the closed elastic casing using nozzles. A theoretical substantiation of the structural and kinematic parameters of the proposed schemes of flexible screw conveyor nozzles has been performed, but it is necessary to determine the optimal parameters of these mechanisms.

Work [29] states that to ensure the growth of productivity and quality of technological processes using screw transport and technological mechanisms of machines, it is necessary to use progressive and efficient designs of screw working bodies in their designs. In addition, the research synthesises mechanisms with structures of screw working bodies using morphological analysis and selects several competitive designs. However, no designs with improved technical and economic characteristics have been identified.

In addition, work [30] presents the design of screw conveyors with hopper loading and screw conveyors with loading through nozzles. In addition, a classification of loaders for screw transport and technological mechanisms is presented. However, there are no analytical dependencies for determining the design parameters of screw loaders.

Work [31] presents the calculation of the structural and power parameters of screw loaders, but the proposed methodology does not fully provide opportunities to carry out engineering and technological calculations of the structural and energy parameters of screw loaders.

Thus, the research deals with the establishment of structures of screw conveyors using structural and schematic synthesis by using hierarchical groups and morphological analysis. The research analyses the influence of many factors on the processes of moving bulk cargo by flexible conveyors with screw working bodies and establishes the structural elements of these conveyors that determine the design features of these means of transport.

CONCLUSIONS

The designs of screw conveyors with hopper loading and screw conveyors with nozzle loading are presented. In addition, a classification of loaders for screw transport and technological mechanisms is presented. The mathematical dependencies for determining the geometric and design parameters of loaders with screw working bodies are presented.

Using the method of structural analysis, the synthesis of screw loaders and mixers with screw working bodies was performed, establishing designs with the best technical-economic characteristics and selecting competitive designs.

The research presents a system for coding and synthesis of structures of screw mechanisms, which allowed consistently conducting engineering and technological calculations to establish some relevant constraints and using computer software to develop and select competitive structures of screw working bodies that would ensure high-quality and productive implementation of technological processes.

It has been established that the choice of design solutions for screw implements will depend on the type of technological process and the magnitude and nature of the load on the screw implements. For this purpose, based on the necessity to ensure the strength of the screw working bodies in the design, it is necessary to limit the number of variants of mechanism designs and develop workable designs of the sections of flexible screw mechanisms of screw conveyors for the transport of bulk materials.

Engineering and technological calculations of the structural and energy parameters of the presented screw loader have been performed, which can be of practical use in the design of similar mechanism designs.

The prospect for these studies will be to determine the kinematic parameters of screw conveyors based on ensuring maximum conveyor performance, damage to bulk materials, the size of curved routes and the rheological properties of bulk materials.

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Обґрунтування та розрахунок конструктивно-силових параметрів гвинтових завантажувачів

Анотація. Існуючі конструкції гвинтових робочих органів транспортно-технологічних машин не завжди можуть забезпечити необхідну продуктивність та уникнення перевантаження, що веде до деформацій і пошкоджень деталей механізмів. Тому необхідно створювати нові ефективні гвинтові робочі органи, які б забезпечували виконання технологічного процесу. Метою роботи було обґрунтування і дослідження конструкції та методики розрахунку основних конструктивно-силових параметрів розробленого гвинтового завантажувача, проведення синтезу гвинтових завантажувачів з використанням методу морфологічного аналізу для того, щоб одержати конструкції механізмів з кращими технічними і економічними характеристиками. Для проведення досліджень використано методи теорії поверхонь, аналітичної та диференціальної геометрії, систем комп'ютерної графіки і математики. В результаті проведених теоретичних та експериментальних досліджень приведено конструкції гвинтових конвеєрів з бункерним завантаженням та гвинтових конвеєрів із завантаженням через насадки. Також приведена класифікація завантажувачів гвинтових транспортно-технологічних механізмів. Визначено залежності для розрахунку конструкцій завантажувачів гвинтових конвеєрів. Здійснено синтез завантажувачів та змішувачів методом морфологічного аналізу для одержання конструкцій механізмів з кращими технічними і економічними характеристиками та створено конкурентоздатні конструкції механізмів. Запропоновано систему кодування та синтезу елементів конструкцій і механізмів гвинтових робочих органів із покращеними технологічними властивостями та відібрано конкурентоздатні конструкції шнекових робочих органів, які якісно та продуктивно виконують технологічні процеси. Розроблено методику розрахунку основних конструктивно-силових параметрів гвинтового завантажувача, за допомогою якої можливо визначити параметри гвинтового завантажувача. Матеріали статті можуть бути використані при подальших дослідженнях гвинтових конвеєрів і зокрема гвинтових завантажувачів з визначення їх конструктивних, технологічних, енергетичних та силових параметрів

Ключові слова: шнековий конвеєр; насадка; транспортно-технологічний механізм; конструктивні елементи; структурний синтез; морфологічний аналіз; методика розрахунку