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DESIGN ENGINEERING AND SUBSTANTIATION OF THE PARAMETERS OF SECTIONAL TOOLS OF FLEXIBLE SCREW CONVEYERS

R. HEVKO[1]   A. VITROVYI[1]
O. KLENDII[2]   I. LIUBEZNA[1]

Abstract: *Based on the conducted analysis, the main drawbacks of flexible screw conveyers have been determined and new designs of a multifunction conveyer and its tools configuration have been suggested. Calculations of surface stress value in hinged joint elements have been made in order to choose rational design and power parameters of tools aimed at providing the improvement of their reliability and operating life. Experimental investigations for determining load capacity of a tool bearing shaft have been conducted. The obtained results can be used for improving screw conveyers.*

Key words: *sectional tool, hinged joint, screw conveyer.*

1. Introduction

Transportation of loose agricultural materials in closed casings of flexible screw conveyers reduces energy consumption when compared to pneumatic conveyers in 6…8 times [5]. Besides, material transportation by screw tools provides ecological performance of this technological process without causing a dust layer in an unloading area as compared with pneumatic conveyer operation.

The first developments in this field were made by a German scientist Kh. Herman, whose investigation results are published in paper [1]. However, investigation data is concerned with flexible screw tools that are made of circular bars, which does not provide high efficiency when material is transported.

The conducted theoretical and experimental investigations in the area of loose material transfer for two-line screw conveyers [3], as well as, material intake by active loading spouts [4], made it possible to choose rational design and kinematic parameters of tools as well as their operation modes.

Papers [6, 7] consider determination of parameters and operation modes of loose material transportation processes by vertical and inclined screw conveyers including the determination of rational parameters of tools. Results of investigating the kinematics of grain material in a screw conveyer with a rotary casing are represented in paper [8].

[1] Ternopil National Economical University, Ternopil, Ukraine.
[2] Separated Subdivision of National University of Life and Environmental Sciences of Ukraine Berezhany Agrotechnical Institute, Berezhany, Ukraine.

In order to improve the efficiency of flexible screw conveyers, continuous strapped helixes arranged in elastic casings were used. However, the conducted experimental research shows that they break down quickly when transporting materials at small radii of curvature due to regular cyclic variations that arise.

That is why the main aim of this paper is the development and the substantiation of the parameters of screw tools that are made of separate sections, which are hinged to each other, in order to provide high efficiency when transporting loose materials.

2. Materials and Methods

An overall schematic of a flexible screw conveyer [2], which includes a loading trunk line 1 and an unloading one 2, is presented in Figure 1. They are made in the form of circular cross-section closed casings 3 and 4, in which there are helical spirals 5 and 6 connected to drive shafts 7 and 8 of electric motors 9 and 10.

In the area of drive shafts, trunk lines are connected to each other by means of two sections 11 and 12 of a transfer pipe, which are attached in the ports of closed casings 3 and 4 at one end and connected to each other at another end. Helical spirals are arranged in such a way that their central axes coincide with the axes of electric motor drive shafts. In the area of their connection by means of the sections of a transfer pipe, trunk lines may be arranged both in horizontal (Figure 1b) and in vertical (Figure 1c) planes.

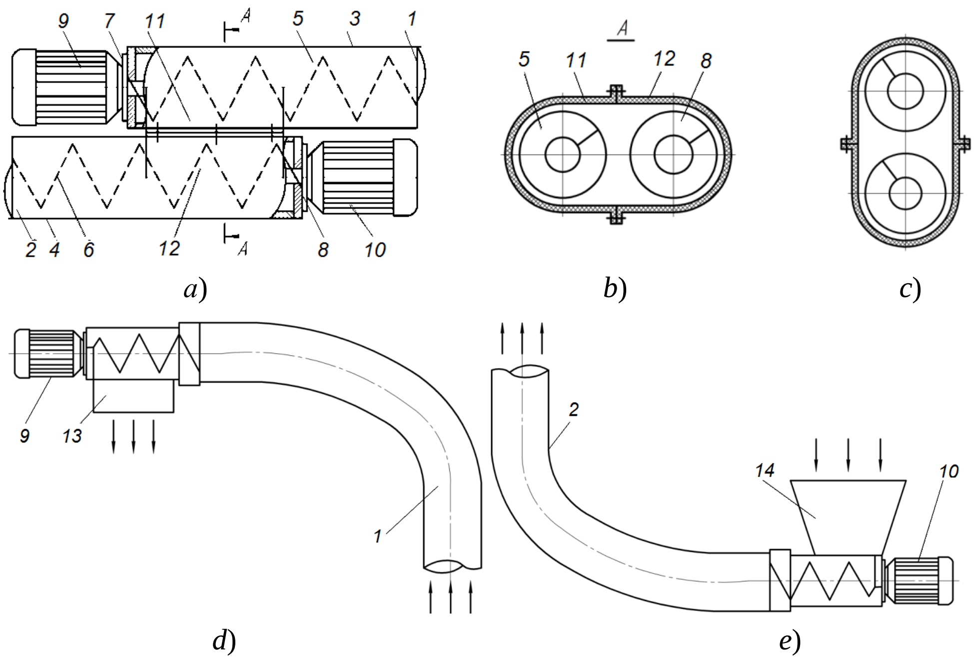


Fig. 1. *Design of a flexible screw conveyer: a - general view; b - horizontal arrangement of trunk lines; c - vertical arrangement of trunk lines; d - one line loading conveyer version; e - one line unloading conveyer version*

While in operation, loose material is delivered to an intake area of a loading trunk line and is transported by a spiral 5 in a casing in the direction towards a transfer pipe. Then material in a pipe is transferred to a spiral 6 and is transported to an unloading area.

Technological trunk lines can be used in the form of one line conveyers. Thus, an unloading opening 13 can be attached to a section of a transfer pipe, namely to a loading trunk line, and a hopper 14 can be attached to an unloading trunk line. A conveyer can be used in three ways, both as a two line one (horizontal and vertical arrangement of a transfer pipe), and as a one line conveyer in a pulling and loading mode (Figure 1d) and in a delivering and unloading mode (Figure 1e). In order to solve the set problem, a screw tool has been designed and it is represented in Figure 2.

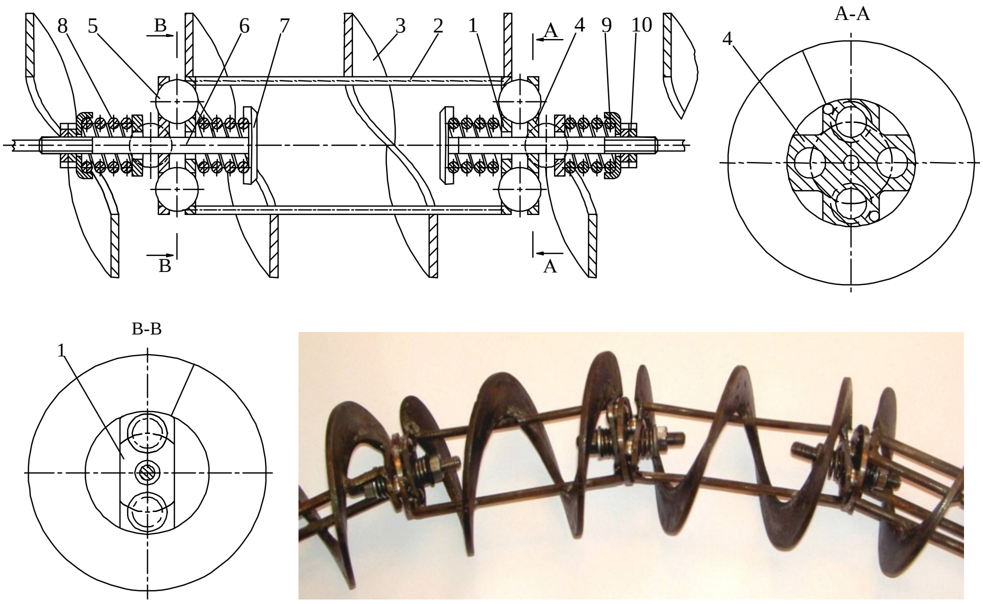


Fig. 2. *Construction arrangement and general view of a hinged tool of a screw conveyer*

It is made of hinged sections with an autonomic spring ball-type joint. Every section is made in the form of a pair of end washers 2 connected by rods 2, to which a spiral rib 3 is attached. Between the adjacent sections there is an intermediate washer 4, in which there are four openings that are equispaced in circular direction. In end washers there are two diametrically opposite openings, in which there are balls 5 that in the other end are fixed in a pair of intermediate washers, here, the lines that connect the centres of the adjacent end washers are arranged mutually perpendicular to one another. Spiral sections are tightened against each other by a spring mechanism, which is made in the form of a core rod 6 with a flange 7. The rod is fixed in the opening of an intermediate washer and on the inside of adjacent end washers there are springs 8, which deflection value is regulated by a pressure washer 9 and by nuts 10.

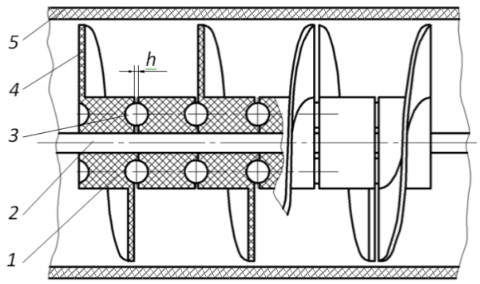
While in operation, a tool, which is located in an elastic casing, is rotating and transporting loose material to the area of unloading. Since pairs of balls that connect end washers to an intermediate washer are arranged mutually perpendicular to one another, this provides relative rotation of screw sections when transporting loose materials along curvilinear routes.

Another version of a sectional tool of a screw conveyer and a general view of its separate elements are represented in Figure 3. It consists of screw sections in the form of an integral plastic central bushing 1 with sockets for balls 3 and a double-helical section of a spiral 4. Location of sockets on various end surfaces of every central bushing is displaced for 90º in circular direction. Bushings are located on a rope 2 and are tightened against each other by a tensioning mechanism. A tool is located in a casing 5.

While in operation along curvilinear routes, ball pairs rotate relative to sockets in the direction that is perpendicular to the line, which connects their centers.

Since socket pairs, which are located on the opposite end surfaces, are displaced relative to valleys in circular direction for 90º, a tool is freely deformed and follows the operation mode of hinge couplings. The main aim of the investigation is determination of contact stress values in hinged joint elements of screw sections, which is the key factor that influences contact surface wear [9].

On the basis of Hertz contact problem, theoretical investigations determining contact stress levels on socket surfaces depending on design and power parameters of coupling elements have been conducted.



a) *b*)

Fig. 3. *A sectional tool of a screw conveyer: a - construction arrangement; b - general view of separate screw sections*

Generally speaking, in case of the interaction pattern of the two bodies presented in Figure 4, a contact plane is of the form of an ellipse with semi-axes:

$$a = \alpha_\kappa \cdot \sqrt[3]{\frac{3PR_y r(1-\mu^2)}{E(2R_y - r)}}; \quad b = \beta_\kappa \cdot \sqrt[3]{\frac{3PR_y r(1-\mu^2)}{E(2R_y - r)}}, \tag{1}$$

where P - normal force in the contact area of interacting bodies; R_y - radius of a socket in the plane of normal force action; μ - Poisson ratio; r - radius of a ball; E - modulus of elasticity.

The value of coefficients α_κ and β_κ are determined from the tables of strength of materials [10] as functions of angle ψ, which is calculated by means of the following formula:

$$\psi = \arccos\left(\frac{r}{2R_y - r}\right). \tag{2}$$

In order to determine the value of radius R_y, let us previously determine the value of the gapΔ, which occurs between the surface of a ball and the edge of a socket in the zone of transition from a cone surface to an end one.

The deduced dependence for obtaining value s, which determines the distance from the point of contact of a ball with a socket to an operating end surface of a screw section, is the following:

$$s = r\sin\alpha - \delta\ . \tag{3}$$

In order to calculate the value of l, the dependence for determining parameter k has been previously deduced. Taking into consideration that cosα = s/k and (3), we obtain:

$$k = \frac{r\sin\alpha - \delta}{\cos\alpha}. \tag{4}$$

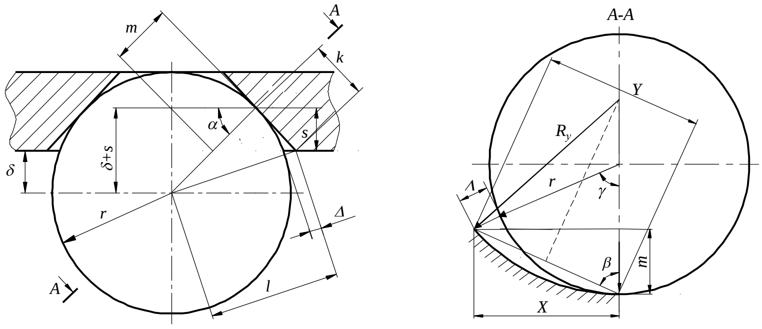


Fig. 4. *Schematic representation for determining the radius of a socket R_y in the plane of normal force P*

Then:

$$l = \sqrt{r^2 + k^2} = \sqrt{r^2 + \left(\frac{r\sin\alpha - \delta}{\cos\alpha}\right)^2}. \tag{5}$$

Value Δ is determined from the condition:

$$\Delta = l - r = \sqrt{r^2 + \left(\frac{r\sin\alpha - \delta}{\cos\alpha}\right)^2} - r. \tag{6}$$

The next step of calculation is the determination of functional dependence of angle γ, which plots an arc from the contact point of a ball with a socket to the line, which connects the centre of a ball with a socket edge in plane A-A. Previously, value m was determined:

$$m = \frac{s}{\sin\alpha} = \frac{r\sin\alpha - \delta}{\sin\alpha}. \tag{7}$$

Then:

$$\cos\gamma = \frac{r - m}{r}; \quad \gamma = \arccos\left(\frac{\delta}{(r+\Delta)\sin\alpha}\right). \tag{8}$$

Taking into consideration (8), we determine value x:

$$x = (r+\Delta)\sin\left(\arccos\left(\frac{\delta}{(r+\Delta)\sin\alpha}\right)\right). \tag{9}$$

In order to calculate R_y, dependences have been deduced for determining Y and angle β:

$$Y = \sqrt{x^2 + m^2}, \quad Y = \sqrt{\left\{(r+\Delta)\sin\left(\arccos\left(\frac{\delta}{(r+\Delta)\sin\alpha}\right)\right)\right\}^2 + \left\{\frac{r\sin\alpha - \delta}{\sin\alpha}\right\}^2}. \tag{10}$$

Taking into consideration (7) and (9), the value of β is determined from the condition tgβ = *x*/*m*:

$$\beta = \text{arctg}\left(\frac{(r+\Delta)\sin\left(\arccos\left(\frac{\delta}{(r+\Delta)\sin\alpha}\right)\right)\sin\alpha}{r\sin\alpha-\delta}\right). \tag{11}$$

In a general case, the value of R_y is calculated using the following formula:

$$\cos\beta = \frac{Y}{2R_y}; \quad R_y = \frac{Y}{2\cos\beta}. \tag{12}$$

In order to reduce the awkwardness of the final formula when determining R_y, its calculation is performed from the system of equations taking into consideration (12); (10); (11) and (6):

$$\begin{cases} R_y = \dfrac{\sqrt{\left\{(r+\Delta)\sin\left(\arccos\left(\dfrac{\delta}{(r+\Delta)\sin\alpha}\right)\right)\right\}^2 + \left\{\dfrac{r\sin\alpha-\delta}{\sin\alpha}\right\}^2}}{2\cos\beta}; \\ \beta = \text{arctg}\left(\dfrac{(r+\Delta)\sin\left(\arccos\left(\dfrac{\delta}{(r+\Delta)\sin\alpha}\right)\right)\sin\alpha}{r\sin\alpha-\delta}\right); \\ \Delta = \sqrt{r^2+\left(\dfrac{r\sin\alpha-\delta}{\cos\alpha}\right)^2} - r. \end{cases} \tag{13}$$

Applying formula (2), the tabulated values for determining $\alpha_к$ and $\beta_к$, dependences (1) and a system of Equation (13), at the set value of force *P* maximum stresses in the centre of a contact plane are determined:

$$\sigma_{\max} = 1.5\frac{P}{\pi ab}. \tag{14}$$

Thus, the formulated system of Equations (14) with the help of a variable method allows selecting such geometrical parameters of end surfaces of sections, which, at the set forces and proper materials, provide a proper condition at which maximum stresses do not exceed a standard rate $\sigma_{\max} \leq [\sigma]$.

In order to conduct an experimental research, screw sections with two and four longitudinal rods respectively have been made (Figure 5ab), as well as two sections, which are connected with each other by means of a hinged spring element (Figure 5c).

As a basic experimental plant, a tension testing machine P5 (Figure 5c) was used in order to investigate force parameters both for separate sections and for their joints. When conducting experimental research, section ends were fixed in the pivots of the machine and then they were loaded in circular direction. The sections had the following design parameters: outer diameter of the spiral D = 96 mm; width of the spiral B = 25 mm; thickness of the spiral t = 5 mm; length of a section L = 120 mm; diameter of a longitudinal rod d = 6 mm; center-to-center distance between the pairs of diametrically located balls W = 30 mm.

3. Results and Discussion

Based on the results of theoretical calculations, it has been determined that the most significant increase of R_y relative to the radius of a ball r can be observed when the absolute value of α increases. Thus, at r = 7 mm the increase of angle α from 30^0 to 40^0 results in the increase of the absolute value of R_y for 1.47 mm, which influences the value of contact stresses significantly.

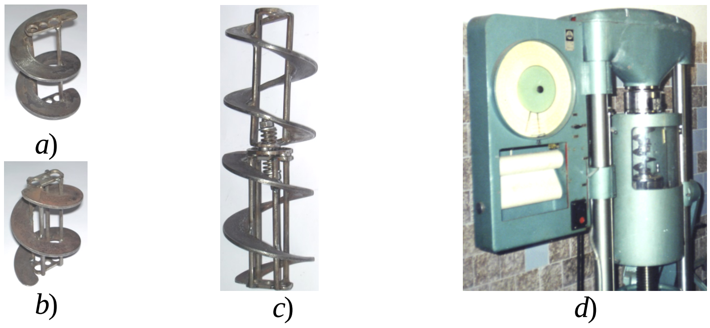


Fig. 5. *An overall view of the sections of a screw tool and an experimental plant: a - a section with two longitudinal rods; b - a section with four longitudinal rods; c - two sections connected with each other by means of a hinged spring element; d - overall view of an experimental stand*

The increase of value R_y results in the increase of σ_{max}, and if force P increases in 10 times, σ_{max} increases in 2.15 times. This can be explained by the fact that at greater interaction force, a contact plane increases and this, in its turn, restrains the intensity of the increase of σ_{max}. Based on the results of our experimental research, graphical dependences of torque for one section and coupled sections on a torque angle of end elements have been built and they are represented in Figure 6.

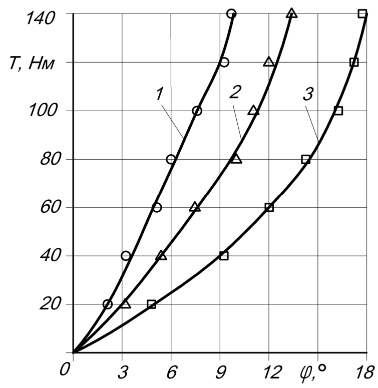


Fig. 6. *Torque-T-vs-torque-angle-φ curves: 1 - a section with two longitudinal rods; 2 - a section with four longitudinal rods; 3 - two sections connected with each other by a hinged spring element*

Curvilinear nature of graph 3 within the limits of 40...50 Nm for the two sections, which are connected with each other, can be explained by the fact that the appearance of additional hinge links causes more intensive increase of angle φ at the increase of T because of inaccuracies of the design and the appearance of local gaps. If there is further increase of $T > 80$ Nm, the curve $T = f(\varphi)$ changes to a pronounced linear dependence.

4. Conclusions

In order to eliminate the identified problems in the operation of flexible screw conveyers, new types of hinged sectional tools have been designed. Due to unloading spiral ribs, when there is torque transfer that is performed by a jointed shaft, they provide the improvement of reliability and operating life of conveyers. Analytical dependences have been deduced in order to estimate contact stresses, which occur in joint elements, and in order to choose such design and power parameters of hinged ball-type joints that meet strength conditions. Methodology has been offered and experimental research has been conducted in order to investigate separate screw sections and their joints and determine functional dependence of a torque angle on the value of circular load of tool elements. This allows choosing the necessary parameters of spring elements for section pressurizing depending on the conditions and on the transport length of loose materials.

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