EXPERIMENTAL STUDIES OF FLEXIBLE SECTIONAL SCREW CONVEYOR TORQUE VALUE

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Abstract. Despite the presence of a wide variety of designs for the transportation of bulk materials in closed technological highways, the problem of their improvement and the search for optimal parameters remains relevant. High productivity and mobility of the loading and unloading technological operations with a minimum degree of damage to the material on complex curved routes can be achieved using flexible screw conveyors. As an object of study there was used a new flexible screw conveyor of an experimental design. To determine the dependence of the torque upon the change in the rotational speed of the screw, the height of the lifted material and the bending radius of the flexible screw-type hinged-sectional working body, the method of a full-factorial experiment was used. It was established that the dominant factor that affects the magnitude of the torque is the frequency of rotation of the working body, but the least influential factor is the bending radius of the flexible screw hinged sectional working body. When changing the frequency of rotation of the working body within the range of 300...800 rpm, the torque increases by 17% for barley and by 18% for technical salt. When the height of lifting the material changes within 1...3 m, the torque increases by 14% for barley and by 16% for technical salt.

Keywords: bulk materials, transportation, optimisation, screw conveyor.

Introduction

In many branches of agriculture large volumes of bulk materials (grain, mineral fertilisers, etc.) have to be transferred. Transportation of bulk agricultural materials through closed technological highways is one of the important ways of their transfer in the processes of production [1-3]. In practice various technological systems are widely used for transportation of agricultural materials; however, as a rule, all of them, in addition to advantages, have a number of disadvantages that limit their scope of application or do not allow achieving the desired performance.

Many scientists have been engaged in the research and search for more advanced designs [4-7]. Screw conveyors are widely used in agriculture. However, when complex spatial schemes are used for transportation, the rectilinear screw conveyors have a number of obvious disadvantages [8-10]. High efficiency and mobility of the loading and unloading technological operations with a minimum degree of damage to the material on complex curved routes can be achieved by using flexible screw conveyors [11-13]. However, the specific of operation of such conveyors has not yet been fully studied, which hinders the creation of reliable, high-performance and energy-saving designs. The widespread flexible screw conveyors have a number of disadvantages, and they cannot fully meet the requirements of practice [11; 14]. Thus, the use of flexible screw spirals, when conveyors operate on curved routes, leads to their rapid destruction due to the occurrence of alternating cyclic loads.

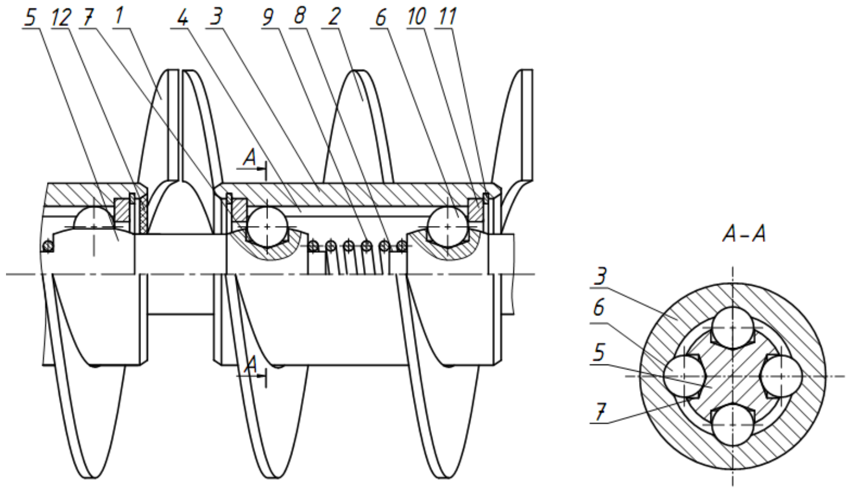
The problem of research of the process of operation, and improvement of the flexible screw conveyors is topical, and it requires further, more optimal solutions. The principal design of the new flexible screw conveyor, developed with the participation of the authors, also requires research in the direction of optimising the parameters. Compared to the rectilinear screw conveyors, when using flexible screw conveyors, there is a significant difference in the dynamics of the starting and the working loads. The lack of research on this issue does not allow a reasonable choice of the optimal values of the power of the electric motor, the moments of operation of the protective devices (couplings), etc.

The purpose of this work: to experimentally investigate the effect of the screw rotation frequency, the lifting height of the transported material and the bending radius of the flexible screw hinged sectional working body upon the magnitude of the torque.

Materials and methods

In the process of searching for more optimal technical solutions, an experimental design of a flexible sectional screw working body was used (Fig. 1) [15].

a)



b)

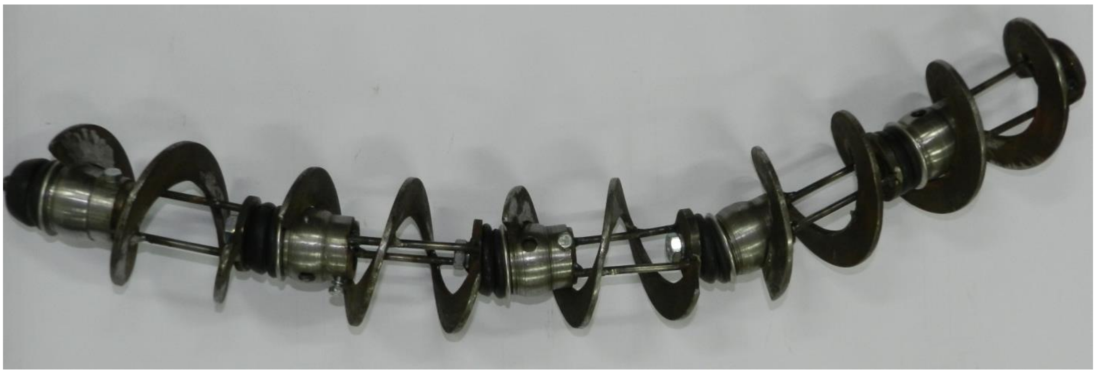


Fig. 1. **Drawing (a) and a general view (b) of the flexible screw sectional working body**

It is implemented in the form of two identical adjacent spirals, the left one 1 and the right one 2, the ends of which are rigidly connected with their internal diameters to separate splined bushings 3, in the internal diameters of which there are made semicircular axial splines 4, which are evenly spaced around the circumference and are in interaction with cylindrical hinges 5 through balls 6, which are rolled in sockets 7 at the ends of cylindrical hinges with the possibility of free twisting, like a cardan gear. But the ends of the cylindrical hinges 5 of a smaller diameter 8 are in interaction with the inner diameters of the expansion springs 9. In addition, the balls 6 at the ends of the cylindrical hinges 4 are in interaction with the restrictive rings 10, which are at the edges of the sections in interaction with the retaining rings 11. To protect the internal holes of the splined bushings 3, if necessary, from two ends, they are closed with sleeves 12. The work of the screw working body is as follows. During the rotation of the spiral section 1 the rotational movement is transmitted through the rolling elements 6 to the cylindrical hinges 5 and adjacent sections of the working screw body. The advantages of the proposed flexible screw working body include an increase in the loading capacity and expansion of technological capabilities. In order to estimate the maximum loads that develop in the elements of the flexible screw conveyor during the transitional starting and braking processes, we will create its dynamic model and analyse the resulting solution.

To determine the impact of the parameters of transportation of the bulk medium and the design parameters of the conveyor upon the torque (optimisation parameter T), a full-factorial experiment FFE – 3^3 was carried out [16-18], that is, determination of the dependence of the torque upon the change in three main factors: the screw rotation frequency n and the bending radius of the flexible screw hinge – the sectional working body R_k, m, i.e. . $T = f(n, h, R_k)$. The encoded values of the factors are presented in Table 1.

Investigations in order to determine the torque of the working body of the conveyor were carried out during the transportation of materials with a corresponding bulk density: barley – 710 kg m^{-3}; technical salt – 2150 kg m^{-3}, which made it possible to construct analytical regression equations.

Table 1

Results of coding the factors and the levels of their variation in the research of the torque

Factors	Designation	Interval of variation, s	Levels of variation, natural/coded		
Auger rotation frequency *n*, rpm	x_1	250	300/–1	550/0	800/ + 1
Bulk material lifting height *h*, m	x_2	1.0	1/–1	2/0	3/ + 1
Bending radius of the flexible screw articulated sectional working body R_k, m	x_3	0.6	0.3/–1	0.9/0	1.5/ + 1

After coding the factors, a plan-matrix of the corresponding multi-factorial experiment of the PFE 3^3 type was compiled for the total number of experiments $N = 3^3$, which was implemented by the method of extracting the serial numbers of the experiments. The rotation frequency of the working body was changed using an Altivar frequency converter, the lifting height of the bulk material was changed by changing the angle of inclination of the line, the bending radius of the flexible screw articulated sectional working body by changing the curvature of the technological line.

The response function (optimisation parameter), the torque $T = f(n,h,R_k)$, determined experimentally, is represented as a mathematical model of a full quadratic polynomial:

$$T = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + \\ + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2, \quad (1)$$

where b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22}, b_{33} – coefficients of the corresponding values x_i; x_1, x_2, x_3 – corresponding encoded factors.

The general form of the regression equation of the maximum torque, based on the results of the conducted FFE 3^3 in the coded values, is:

$$T_b = 28.234 + 0.0143n + 4.125h - 0.15R_k, \quad (2)$$

$$T_s = 39.298 + 0.01845n + 4.796h - 0.175R_k. \quad (3)$$

Results and discussion

Graphic values of dependencies for determining the torque of transportation, when using material (barley, technical salt), are shown in Fig. 2 and Fig. 3. For this, the software “Statistica-6.0” for Windows was used, with the help of which a graphical reproduction of regression models was built in the form of quadratic responses and their two-dimensional sections.

Figures 2 and 3 show graphic dependences of the torque of a flexible screw conveyor with a sectional working body upon the screw rotation frequency *n* = 300…800 rpm, the lifting height of the bulk material *h* = 1.0…3.0 m and the bending radius of the flexible screw hinged sectional working body $R_к$ = 0.3… 1.5 m.

From the analysis of the obtained graphic dependences, it can be established that the dominant factor affecting the magnitude of the torque is the rotational frequency *n* of the working body, but the least affecting factor is the bending radius R_k, of the flexible screw sectional working body. However, the lifting height of the material *h* also has a significant effect upon the power parameters of the transportation process.

When changing the frequency of rotation *n* of the working body within 300...800 rpm, the torque *T* increases by 17% for barley and 18% for technical salt. When the lifting height of the material *h* changes within 1...3 m, the torque *T* increases by 14% for barley and 16% for technical salt. And in the range of changes in the bending radius of the flexible screw sectional working body R_k from 0.9 m to 1.5 m, the torque *T* decreases by 0.5% for barley and by 0.6% for technical salt.

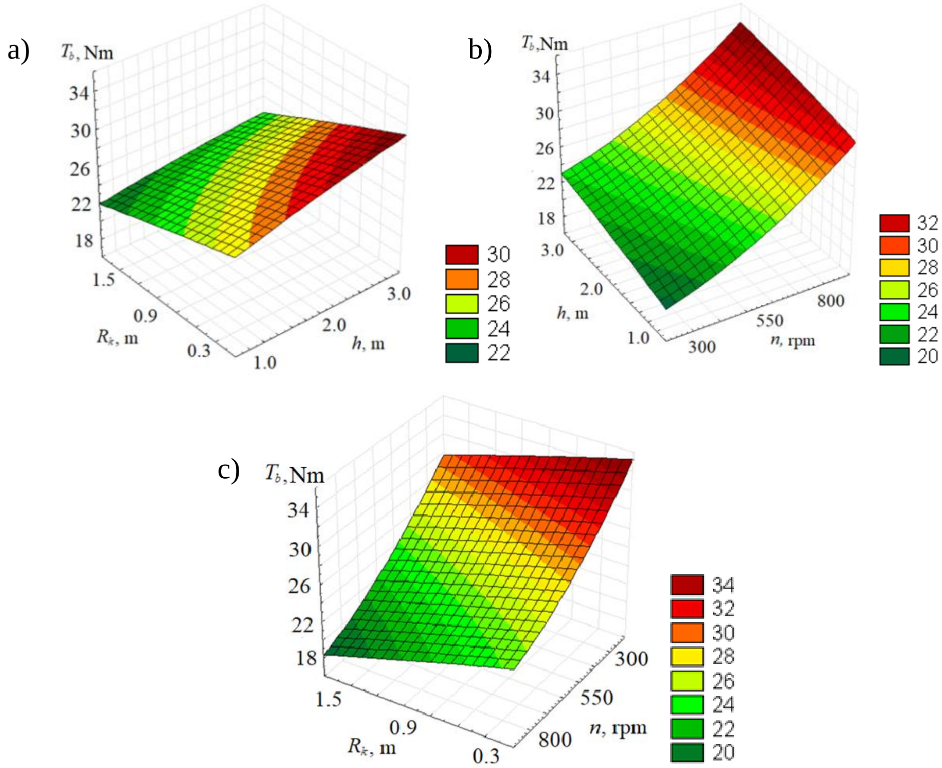


Fig. 2. **Response surfaces of the torque change on the drive shaft from variable factors during transportation of barley:** a – $T_b = (R_κ, h)$; b – $T_b = (h, n)$; c – $T_b = (R_κ, n)$

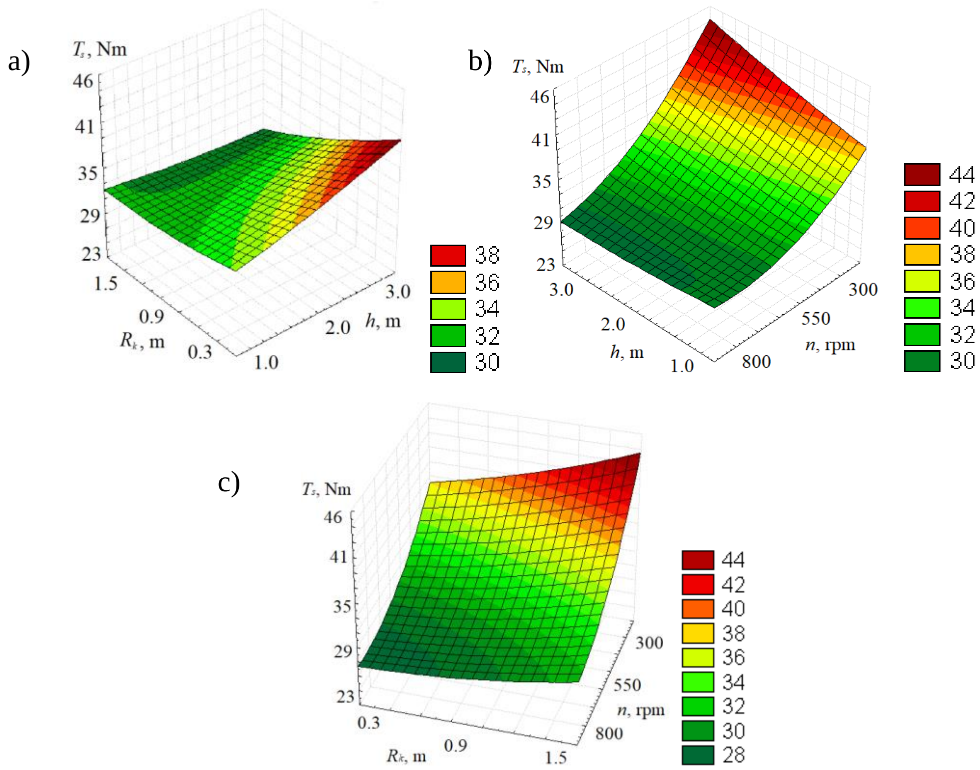


Fig. 3. **Response surfaces and their two-dimensional cross-section of the change in the torque on the drive shaft from variable factors during transportation of technical salt:**

a) – $T_s = (R_κ, h)$; b) – $T_s = (h, n)$; c) – $T_s = (R_κ, n)$

Conclusions

On the basis of the performed multi-factorial experiment a regression dependence was obtained to determine the impact of the number of revolutions *n*, the height of lifting the material *h* and the radius of curvature of the flexible screw hinged sectional working body R_k upon the value of the torque *T* during the transportation of bulk materials; by analysis of which it was established that the dominant factor affecting the magnitude of the torque is the rotational frequency of the working body; and the least impact is made by the bending radius of the flexible screw hinged sectional working body R_k. However, the lifting height *h* of the material also has a significant impact upon the power parameters of the transportation process. The factor field was determined by the following range of parameters: $300 < n < 800$ (rpm); $1 < h < 3$ (m); $0.3 < R_k < 1.5$ (m).

Author contributions

Conceptualization, V.B., O.T. and S.I.; methodology, S.I. and V.B.; software, O.T. and J.O.; validation, O.T., V.A. and V.B; formal analysis, V.B and O.T.; investigation V.B., S.I. and J.O.; data curation, O.T., V.B. and V.A.; writing – original draft preparation, V.B.; writing – review and editing, S.I. and V.B.; visualization, J.O.; project administration, V.B.; funding acquisition, S.I. All authors have read and agreed to the published version of the manuscript.

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