EXPERIMENTAL RESEARCH ON PERFORMANCE OF FLEXIBLE SCREW CONVEYOR WHEN TRANSPORTING AGRICULTURAL MATERIALS

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Abstract. The paper presents the design of a flexible screw conveyor working body and a laboratory setup for experimental studies of determining its performance in transporting agricultural materials. Studies of conveying capacity have allowed to determine its dependence on many factors that characterize the process, namely: screw rotation frequency *n*, coefficient ψ of line filling, inner diameter of the pipeline shell *D*. To determine the effect of these parameters on the performance of the screw conveyor, a full-factor experiment was conducted, the results of which showed that the dominant factor influencing the performance value is the rotation frequency of the working body *n*, and the least influential is the diameter of the housing *D*, but the value of the cooefficient ψ of the main also has a significant effect on the performance of the transportation process. So, when changing the rotation frequency of the working body within the range of 300...800 rpm, the productivity increases by 50% for barley and 48% for industrial salt, when changing the line filling ratio within the range of 0.3...0.5, the productivity increases by 16% for barley and 18% for industrial salt, and when changing the pipeline diameter *D* from 0.08 m to 0.1 the productivity increases by 0.7% for barley and 0.2% for industrial salt.

Keywords: transportation, grain material, flexible screw conveyor, capacity, full-factor experiment.

Introduction

In agricultural and industrial production, a complex of machines for loading and unloading of bulk agricultural materials (grains, feed, mineral fertilizer, sand, technical salt, etc.) is used. However, most of them refer to stationary or limited-mobility vehicles, while mobile equipment is underutilized. [1-3].

Screw conveyors with a rigid working body can be attributed to the limited moving vehicles. Their small overall dimensions and metal capacity allow to move the conveyor from one loading zone to another [4]. However, the limitation of their mobility is that it is impossible to manoeuvre the transport line when performing the technological process, which reduces the functional characteristics of these means of mechanization [5].

The diameter and pitch of the auger are chosen depending on the planned productivity and physical and mechanical properties of the material. High mobility of execution of technological processes of moving bulk and lump agricultural materials is carried out by means of flexible screw conveyors [6].

Recently, an active search for optimal designs of flexible screw conveyors, the functional and operational performance of which would meet the established requirements, has been conducted [7]. On the basis of the studies, design, kinematic and technological parameters of working bodies have been justified in terms of their functional purpose [8, 9]. The conducted theoretical and experimental investigations in the area of loose material transfer for two-line screw conveyers [10], as well as material intake by active loading spouts [11], made it possible to choose rational design and kinematic parameters of tools as well as their operation modes. At the same time, there are a number of unresolved issues related to the operational and resource performance of such work tools.

Thus, among the urgent tasks of agricultural production it is important to improve the design of flexible screw conveyors.

The aim of the work is to determine the effect of the screw speed *n*, the trunk filling ratio ψ, and the inner diameter of the trunk shell D on the performance of a flexible screw conveyor.

Materials and methods

To carry out experimental studies, a pilot plant was designed and manufactured, shown in Fig. 1. The reloading pipe of the experimental installation of the screw conveyor (Fig. 1,a) contains a loading and an unloading line, made in the form of housings 5 and 2 and installed in parallel loading 6 and discharging 3 working spiral augers. The latter, respectively, are attached to the drive shafts 7 and 4, which are located in the reloading spigot 1. In order to improve the operational characteristics of screw conveyors, consisting in a guaranteed transportation of bulk materials along curved routes, increasing the conveying capacity, as well as improving their maintainability, a new working body with an articulated connection of sections is designed. The general view of this working body is shown in Fig. 1,b. Fig. 1,c shows a general view of the experimental setup for determining the performance of a screw conveyor with a flexible auger.

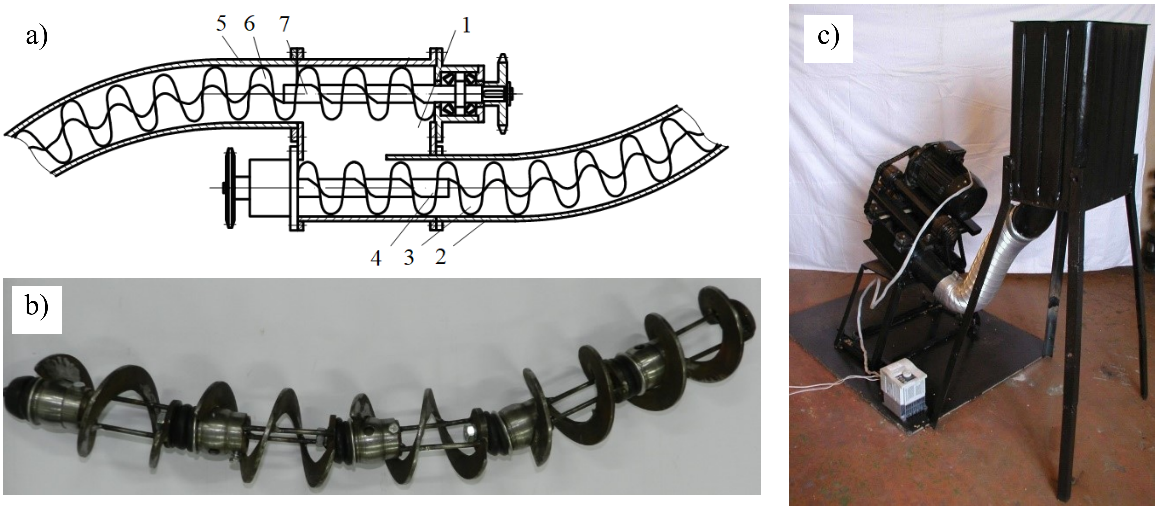

Fig. 1. **Design diagram of the flexible screw conveyor (a), general views of the flexible working body with articulated connection of sections (b) and experimental installation (c)**

The working body parameters were as follows: auger spiral outside diameter – 96 mm; auger spiral inside diameter – 46 mm; spiral pitch – 65 mm; casing inside diameter – 100 mm;

To study the performance of the working body developed, the following agricultural materials with the appropriate volume weight were used: barley – 710 kg·m^{-3}; wheat – 720 kg·m^{-3}; industrial salt – 2150 kg·m^{-3}.

The methodology of the experimental studies in determining the performance of the working body of the flexible screw conveyor was as follows. Beforehand, suitable material was poured into the hopper of the unit and during the established stable transportation process (filling of the overload pipe and lines with material along the entire length) the material was taken into the measuring container, fixing the time of its filling. Then the selected material was weighed on electronic scales and the volume measured, using a measuring vessel. The studies were carried out with fivefold repeatability.

To determine the effect of transportation parameters of the bulk agricultural material and the design parameters of the conveyor to move it (independent factors x_i) a full-factor PFE experiment was conducted on the performance (optimization parameter Q) – 3^3. Studies of the conveying process have determined the dependence of productivity on many factors that characterize the process, namely: auger rotation speed, n, rpm, line fill factor ψ, inside diameter of the trunk shell D, m, i.e. $Q = f(n, \psi, D)$. Since in experiments the variables independent factors are heterogeneous and have different units, and the numbers expressing the value of these factors are of different orders, they were reduced to a single system of calculations by switching from actual values to coded ones. The coded values of the factors are presented in Table 1. After coding the factors, a plan-matrix of the corresponding full-factor experiment of the PFE type was made 3^3 for the total number of experiments $N = 3^3$, which was realized by the method of random variables.

The rotational frequency n of the working body was measured with an Altivar 71 frequency converter, the fill factor ψ – by changing the amount of the bulk material, the diameter D of the shell – by changing the geometric dimensions of the shell.

The response function (optimization parameter), i.e. $Q = f(n, \psi, D)$ determined experimentally is presented in the form of a mathematical model of a full quadratic polynomial:

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

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

The general view of the productivity regression equations based on the results of the conducted PFE 3^3 in coded values is equal for different agricultural materials:

- for transporting barley:

$$Q_b = 3.6425 - 0.002145n + 14.5\psi + 0.00002n^2 + 17.81D^2, \quad (2)$$

- for transporting industrial salt:

$$Q_s = 4.4074 - 0.002553n + 17.8\psi + 0.000024n^2 + 21.73D^2. \quad (3)$$

Table 1

Results of coding factors and their levels of variation in the study of transportation performance

Factors	Identification		Variants on interval	Levels of variation, natural/coded		
	Coded	Natural				
Auger rotation speed, *n*, rpm	X_1	x_1	250	300/–1	550/0	800/ + 1
Trunk fill factor, ψ	X_2	x_2	0.1	0.3/–1	0.4/0	0.5/ + 1
Diameter of the trunk shell, *D*, m	X_3	x_3	0.02	0.06/–1	0.08/0	0.1/ + 1

Thus, it is possible to carry out calculations with PC and establish the relationship between the design and kinematic parameters of this new transporting tool.

Results and discussion

According to the results of the studies, the graphical dependences of changes in productivity (by volume and mass) of the flexible screw conveyor on the frequency of its rotation *n* were plotted, which are shown in Fig. 2.

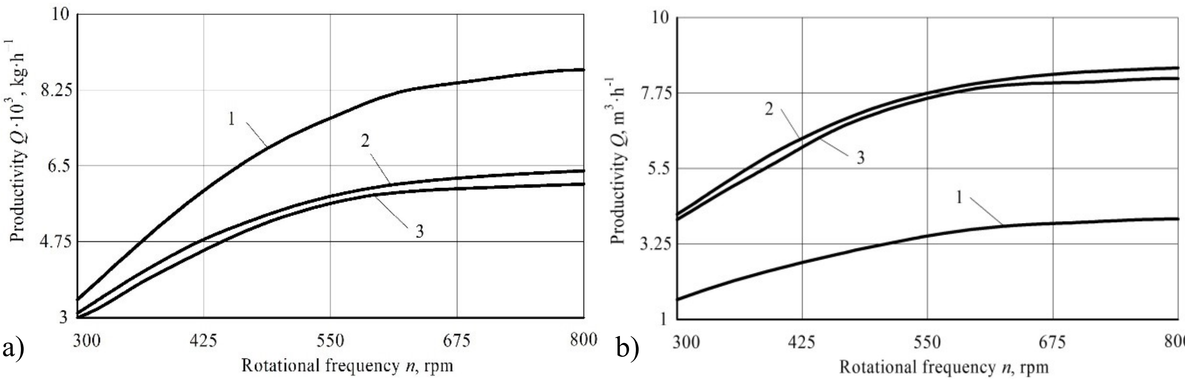

Fig. 2. **Dependences of changes in the mass (a) and volume (b) of the transported material per unit time on the rotation speed of the flexible screw conveyor:**
1 – industrial salt; 2 – wheat; 3 – barley

Analyzing these graphical relationships, we can state that the maximum capacity of this conveyor when transporting materials with a higher volume mass (industrial salt) is within *n* = 570...620 rpm, while *Q* = 8100...8200 kg·h^{-1}. A further increase in the rotation frequency of the flexible screw conveyor leads to a drop in the growth of its productivity, explained by the smaller intake volume of the bulk material, which at higher mass has greater inertia and is partially directed back. For lighter bulk materials (barley, wheat) in this range of variation *n* there is a decrease in productivity growth to *Q* = 5600…5800 kg·h^{-1}, and their character is approximated by linear dependences.

Fig. 3 and Fig. 4 show the response surfaces and their two-dimensional cross-section of the variation of productivity from the rotation speed n of the given working body, the coefficient ψ of the line filling, and the diameter D of the casing. For this purpose, we used the software Statistica-6.0 for Windows, with the help of which we built a graphical reproduction of regression models in the form of quadratic responses and their two-dimensional sections.

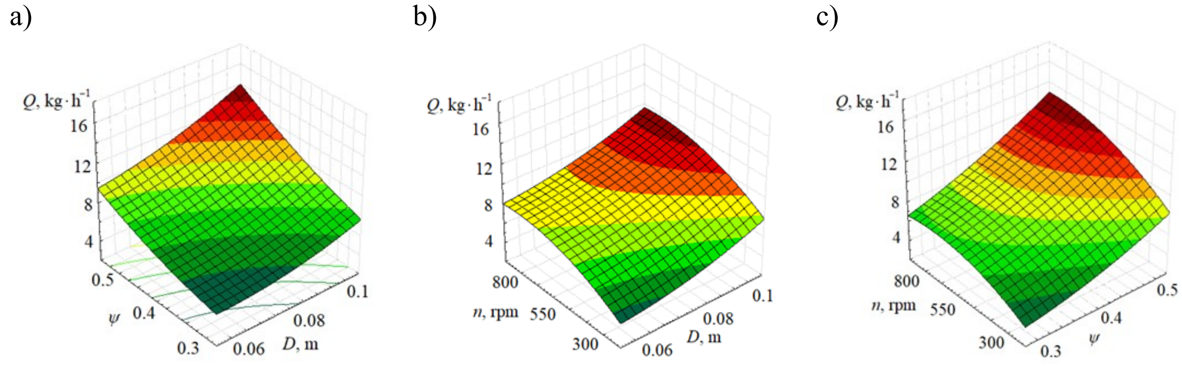

Fig. 3. **Response surfaces of productivity changes from barley transportation variables:** a – $Q = f(\psi, D)$; b – $Q = f(n, D)$; c – $Q = f(n, \psi)$

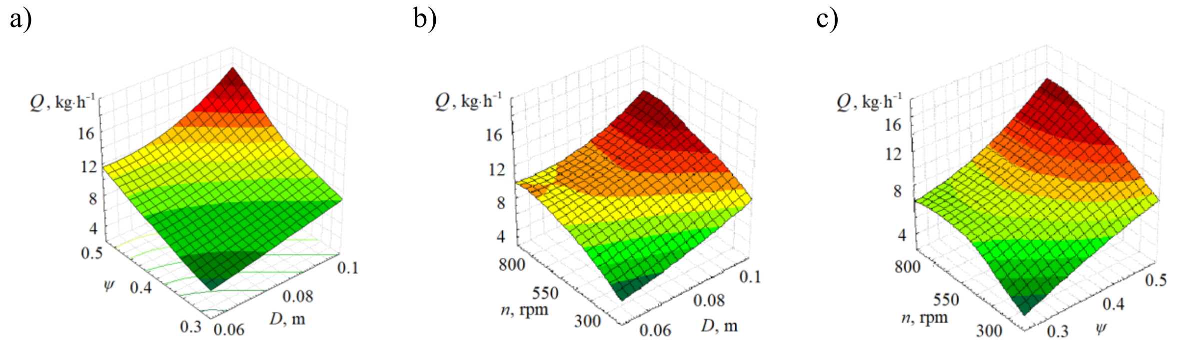

Fig. 4. **Response surfaces of productivity changes from variables in transportation of technical salt:** a – $Q = f(\psi, D)$; b – $Q = f(n, D)$; c – $Q = f(n, \psi)$

From the analysis of these graphical dependences, it can be established that the dominant factor influencing the productivity value is the rotation frequency n of the working body, and the least influential is the diameter D of the shell, but the value of the coefficient ψ of the pipeline filling also has a significant influence on the productivity of the transportation process. So, changing the speed of the working body within 300...800 rpm, productivity increases by 50% for barley and 48% for technical salt, changing the coefficient ψ of pipeline filling in the range of 0.3...0.5, the productivity grows by 16% for barley and 18% for industrial salt, and in the range of changing of the diameter D of the trunk shell from 0.08 m to 0.1 the productivity grows by 0.7% for barley and 0.2% for industrial salt.

Conclusions

1. Based on the analysis of literature sources and patent search, the design of a flexible screw conveyor working body and the laboratory setup for experimental studies to determine the performance in transporting agricultural materials have been developed.
2. According to the results of the research, graphical dependences of productivity changes are built, from which it is established that the maximum productivity of the conveyor when transporting materials with a higher volume mass (technical salt) is in the range of $n = 570...620$ rpm, $Q = 8100...8200$ kg·h^{-1}.
3. A further increase in the rotation speed of the working body leads to a fall in the growth of the conveyor performance, explained by the smaller volume of material intake, which at higher mass has greater inertia and is partially directed back, for lighter materials (barley, wheat) in this range of variation n there is a decrease in the productivity growth to $Q = 5600...5800$ kg·h^{-1}, and the character is approximated by linear dependences.

4. To determine the effect of these parameters on the performance of the screw conveyor a full-factor experiment was conducted, the results of which established that the dominant factor affecting the performance value is the rotation frequency n of the working body, and the least influential is the diameter D of the shell, but the value of the pipeline filling factor ψ also has a significant impact on the performance of the transportation process.
5. So, when changing the rotation frequency of the working body within the range of 300...800 rpm, the productivity increases by 50% for barley and 48% for industrial salt, when changing the line filling ratio within the range of 0.3...0.5, the productivity increases by 16% for barley and 18% for industrial salt, and when changing the pipeline diameter D from 0.08 m to 0.1 the productivity increases by 0.7% for barley and 0.2% for industrial salt.

Author contributions

All the authors have contributed equally to creation of this article.

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