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OPTIMIZING SCREW CONVEYOR PERFORMANCE FOR CONSISTENT GRAIN MATERIAL LOADING

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Abstract: This study investigates the performance of screw conveyors in grain material transportation, with a focus on achieving uniform distribution of the grain mass during loading. A methodology for calculating the parameters of a screw conveyor to ensure consistent unloading along its entire length is proposed. A schematic diagram of the proposed conveyor design is provided, illustrating its functionality and operational advantages. The findings contribute to improving the efficiency of agricultural transport systems by minimizing grain distribution inconsistencies and enhancing loading productivity.

Keywords: transportation, loading, screw conveyor, discharge opening, calculation, distribution.

Introduction. Reducing transportation costs in agricultural operations is a critical challenge, often addressed by improving the efficiency of transport units. Continuous conveying machines, such as screw conveyors, are widely used for transporting bulk materials, including grain.

However, ensuring uniform distribution of grain across truck bodies and trailers remains a significant issue. Previous studies [1, 2, 3] have highlighted the widespread use of screw conveyors in agriculture but have not fully addressed the challenge of uniform grain distribution.

This study aims to enhance the design of screw conveyors to achieve consistent grain distribution during loading, thereby improving the efficiency and productivity of transport units.

Research methods. The research methodology employed a combination of analytical and experimental approaches to evaluate the performance of screw conveyors in grain transportation. Standard techniques, measuring equipment, and numerical methods were utilized to substantiate the uniformity of grain distribution across the vehicle body during loading. Experimental data were analysed using mathematical statistics, theoretical and empirical approaches, and graphical methods to validate the proposed design.

Statement of the problem. Advancements in agricultural machinery necessitate the development of improved designs for transporting grain materials. A key challenge is ensuring uniform grain distribution across vehicle bodies during loading. This study addresses this issue by proposing a screw conveyor design that enhances distribution uniformity while maintaining high technical and economic performance.

Research results. Screw conveyors are extensively used in agricultural production, with numerous studies examining their interaction with grain materials. Researchers such as V.V. Adamchuk, S.F. Babaryka, and others have established fundamental principles for screw conveyor design and application. For instance, V. V. Konovalov proposed a formula for calculating the minimum capacity of a screw conveyor (Equation 1), while A.M. Grigoriev and F.K. Ivanchenko contributed additional formulas for determining screw diameter and axial speed (Equations 2–4). These studies provide a foundation for the proposed design, which incorporates discharge openings along the conveyor casing to ensure uniform grain distribution. The dimensions of these openings vary to achieve consistent loading across the vehicle body, as illustrated in Fig. 1.

For instance, V.V. Konovalov proposed a formula for calculating the minimum capacity of a screw conveyor:

Minimum capacity, kg/s:

$$Q_{\min} = 0{,}25 \cdot 3{,}14 \cdot (D^2 - d^2) \cdot w \cdot r_c \cdot \rho \cdot k_1 \cdot \beta \cdot \phi \cdot \sin(\alpha) \cdot (\cos(\alpha) - f \cdot \sin(\alpha)), \quad (1)$$

where ρ – average grain density, kg/m3;

f – coefficient that takes into account the friction of the mixture on the screw;

k_1 – coefficient that takes into account the filling of the auger;

β – angle of inclination of the auger to the horizon, degrees;

ϕ – coefficient that takes into account the inclination of the auger.

The author proposes to determine the diameter of the working body using the following formula:

$$D = D_b \cdot s_1, \quad (2)$$

where D_b – auger diameter, m;

s_1 – ratio of the diameter of the container and the screw.

A.M. Grigoriev proposes to determine the diameter of the screw from the following relationship:

$$D = \sqrt{Q/(Tc\varphi\rho)} \quad (3)$$

where T – actual screw pitch;

φ – conveyor fill factor;

ρ – bulk grain density;

c – coefficient indicating the effect of the conveyor inclination angle on performance.

In the work of F.K. Ivanchenko, the axial speed of grain movement by the auger is determined by the formula:

$$v = p \cdot n_в / 60, \quad (4)$$

where p – pitch of the helix, mm;

$n_в$ – screw rotation speed, min^{-1}.

Currently, in both agricultural production and other economic sectors, loading devices designed to distribute grain mass evenly in truck beds predominantly rely on gravity. These devices feed grain into spreaders of predefined shapes, ensuring uniform distribution around the container perimeter. However, a significant limitation of such systems is their suitability for cylindrical containers only.

Conversely, screw conveyors are widely employed for simultaneous unloading at multiple points along their length. After analysing existing devices, we propose a novel screw conveyor configuration that enables continuous product discharge along its entire length. A schematic representation of this design is presented in Fig. 1.

The proposed screw conveyor functions as follows: grain material descends under gravitational force from the loading hopper into the central section of the conveyor casing. Simultaneously, it is engaged by the screw and transported along the casing by rotational motion. Upon reaching the perforations along the casing's underside, the material is discharged under gravity. The uniformity of this discharge is achieved through the strategic shaping of the outlet openings, ensuring even distribution of the grain material across the vehicle bed.

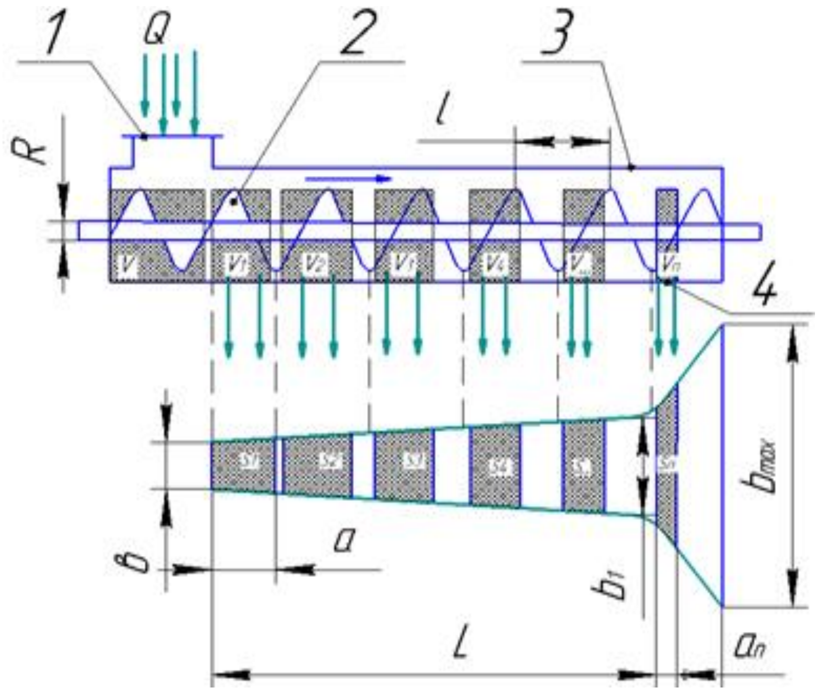

Fig. 1. Schematic of a screw conveyor with multiple product discharge points: 1 – inlet; 2 – screw; 3 – casing; 4 – discharge openings

The screw conveyor shown in Fig. 1 differs from typical screw conveyors in that it has discharge openings along most of the casing length, which differ in size at each discharge section.

The screw conveyor depicted in Fig. 1 distinguishes itself from conventional screw conveyors by incorporating discharge openings along the majority of the casing length, with variations in size at each discharge point.

The dimensions of the discharge openings in the discharge section of the hood vary, ensuring an even distribution of grain material within the vehicle body. Adjusting these dimensions facilitates uniform loading across the entire container.

A fundamental requirement for the proper function of the screw conveyor is that the volume of grain material entering the screw casing from the feed hopper must correspond to the volume discharged. In the case of a driven screw conveyor, the grain layer transported by the screw flights along the casing must be entirely emptied by the final discharge opening.

One of the critical parameters influencing the efficiency of screw conveyors is the angular velocity of the screw, denoted as n. This parameter is of particular importance due to its direct effect on the potential damage to the transported grain material. Hence, careful selection of the angular velocity is necessary to maintain the integrity of the grain or minimize damage during transit.

When designing these conveyors, it is essential to ensure an even discharge of grain material along the entire length of the discharge openings.

The outflow rate of the grain material is influenced by the width of the discharge opening, defined by the following relationship:

$$v_{вит} = b\, c_1 + c_2,\ \text{m/s} \qquad (5)$$

where c_1, c_2 – constants that are determined empirically.

To determine the dependence of the unloading opening b on the length, let us determine the specific mass unloading of the grain mass $Q_{зм}$:

$$Q_{зм} = \rho_{зм} Q/L,\ \text{kg/m·s}, \qquad (6)$$

where $\rho_{зм}$ – bulk density of grain material (wheat), kg/m^3.

Determine the performance of the screw conveyor:

$$Q = S_o\, n_в\, v_{вит} \qquad (7)$$

where $n_в$ – number of segments between screw turns along the length of the unloading screw.

The specific mass leakage rate of the grain material is then expressed as:

$Q_{мас} = \rho_{зм}\, S_o\, n_в\, v_{вит}/L$;

$Q_{мас} = \rho_{зма}\ b\ v_{вит} / L.$ (8)

Since the specific value of the discharged grain mass is constant, we derive the dependence of the discharge opening width, b, on the conveyor length from equation (7):

$$b = Q_{мас}\ L/(\rho_{зма}\ v_{вит}) \quad (9)$$

or:

$$b = Q_{мас}\ L/\ \rho_{зма}(b\ c_1+c_2) \quad (10)$$

will be obtained after the transformation:

$$b\ (b\ c_1+c_2) - Q_{мас}\ L/\ \rho_{зма} = 0 \quad (11)$$

The width of the hole from Equation (11):

$$b = \frac{-c_2 + \sqrt{c_2^2 + 4c_1 Q_{мас} L/\ \rho_{зма}}}{2\ c_1} \quad (12)$$

Taking into account the design characteristics, the specific weight of the discharged grain material can be determined as:

$$Q_{мас} = \rho_{зм} f\pi R_2\ L_2 n/(60\ L_2) \quad (13)$$

Applying transformations, we derive:

$$b = \frac{-c_2 + \sqrt{c_2^2 + 4c_1 f\pi\ R^2 L^2 n/(60\ L^2)}}{2\ c_1} \quad (14)$$

Since the length of the discharge opening depends on the conveyor screw pitch and the minimum grain size, the dependence of the discharge opening width on the length of grain transport is illustrated in Fig. 2.

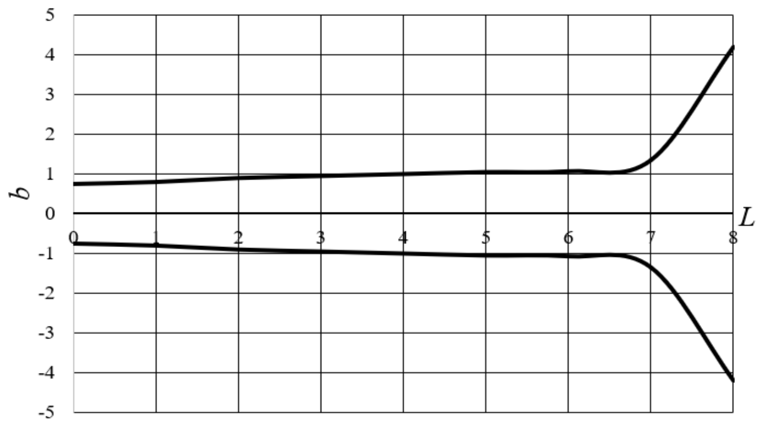

Fig. 2. Relationship between the width of the discharge opening and the length of grain transport

Conclusion. This study substantiates the design of a screw conveyor for uniform grain distribution, establishing a relationship between the width of the discharge opening and the conveyor length. The proposed design addresses the limitations of existing grain loaders by enabling continuous discharge along the conveyor's length. These findings contribute to improving the efficiency of agricultural transport systems and reducing grain distribution inconsistencies.

LIST OF REFERENCES

1. Boyko, A.I. Analysis of the structures of screw conveyors and feeders of grain cleaning machines. Bulletin of Kharkiv Petro Vasylenko National Technical University of Agriculture. Kharkiv: KhNTUA, 2011. Issue 93. VOL. 1. PP. 199-205.

2. Rohatynskyi R. M., Gevko B. M., Dyachun A. E. Scientific and applied bases of creation of screw transport and technological mechanisms. Ternopil: Izd.- in TNTU named after Ivan Puluj, 2014. 280 c.

3. Analysis of theoretical studies of the mixing process. Bulletin of Sumy National Agrarian University. Mechanisation and automation of production processes. 2016. Issue 10/2(30). C. 102-106.