STUDY ON POWER PARAMETERS OF MOVING GRAIN MATERIALS WITH PNEUMATIC SCREW CONVEYOR

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Abstract. The article presents the design of a pneumatic screw conveyor used to move (transport) grain materials. On the basis of this design, an experimental setup was created, enabling the performance of the new conveyor belt to be investigated in the laboratory, including the power parameters. The Altivar-71 frequency converter was used in experimental studies to determine the power parameters of the pneumatic screw conveyor for the transport of grain materials. Based on the results of the experimental studies, graphs of the power characteristics of the pneumatic screw conveyor drive over the time of the transport of grain materials were obtained. By analysing the graphs obtained, it is established that the smooth operation of the conveyor belt depends on the properties of the transported material. In particular, it affects the switching frequency of the pneumatic drive, which prevents it from overloading and, therefore, premature breakdown. In addition, activation of the pneumatic actuator destroys the resulting thickening of the transport granular material. Experimental studies have also been conducted on changes in performance Q of the pneumatic screw conveyor depending on the initial values of the high-pressure air supply P.

Key words: transport, grain material, pneumatic screw conveyor, power characteristics.

Introduction

One of the most important causes of poor quality grain material is damage during handling operations. High-pressure blower-type pneumatic conveying equipment is used to transport grain, with a capacity of 5...30 $t \cdot h^{-1}$, feed length up to 100 m, air velocity 15...40 $m \cdot s^{-1}$ with overpressure up to $(0.6...0.8) \cdot 10^6$ Pa. However, in a number of cases it has proven to be inefficient, as it is expensive to maintain, structurally complex, and requires the use of cyclones to capture material particles from the dust cloud flow.

Auger screw conveyors as a separate technical element of transport mechanisms have found widespread use in the layout of machines for handling or movement of bulk materials due to their simple construction, maintenance and the ability to load and unload material at any point in the process line [1-4].

A common disadvantage of screw mechanisms is that the helical coils do not only provide translational axial movement of the material, but also rotational movement, resulting in damage to the material and reduced performance of such mechanisms. For transporting agricultural bulk solids and grain materials with minimal damage, combinations of mechanical feeding by a screw feeder with compressed air feeding are also used [5-7]. The (Buteler M. et.al., 2020) study presents the design and the evaluation of a laboratory device, which combines mechanical motion of wheat grain and turbulent air streaming inside a positive pneumatic conveyor system [8]. The experimental results, which were conducted under laboratory conditions, show that the recovery efficiency of the prototype was equal to 98.0% (± 1.4) on average. The work [9] presents the experimental characterization of the industrial bulk solid feeder, named Batchpump, and validates the performance in terms of transport capacity and compressed gas consumption of an unconventional compact pressure vessel, used as a feeding device for dense phase pneumatic conveying. The developed device was shown to have similar performance parameters (transport rate and gas consumption) when compared to conventional versions of blow tanks operating at 4 bar pressure and conveying powder material at about 9 $t \cdot h^{-1}$ rate, albeit the smaller dimensions and simplification in operation, resulting in significate advantages in retrofits and in the implement a new conveyor line. The paper [10] covers critical speed of pneumatic transport for conveying materials and measuring the angle of friction and the coefficient of restitution of materials on a variety of material surfaces. With the help of a machine verification test it was proved that the optimal parameters for pneumatic transportation of Baisha peanut pods with a moisture content of 7.24% was a fan speed of 2700 r·min^{-1} and a cushioning/anti-obstruction layer thickness of 6 mm.

Thus, among the current challenges of agricultural production, it is important to develop and justify the rational parameters of pneumatic auger conveyors that ensure efficient movement of grain materials.

The aim of the work is to determine the power parameters of the pneumatic screw conveyor, which will ensure efficient movement of grain materials along the technological routes of different spatial configuration under permissible damage to the grain.

Materials and methods

To achieve this, we have designed and manufactured a prototype of a newly designed pneumatic auger conveyor (Fig. 1). It consists of supports 1 and 2 on which the drive 3, conveyor body 4 with a hopper 5 and auger shaft 6, pneumatic system 7 and the pneumatic valve 8 are installed. The conveyor line consists of consecutively interconnected sections 9 with the length of *l*, each section 9 containing an elastic sleeve 10 which is secured on the right-hand side to a cylindrical connector sleeve 11 by means of a ring 12 adjustable by tightening a bolt 13.

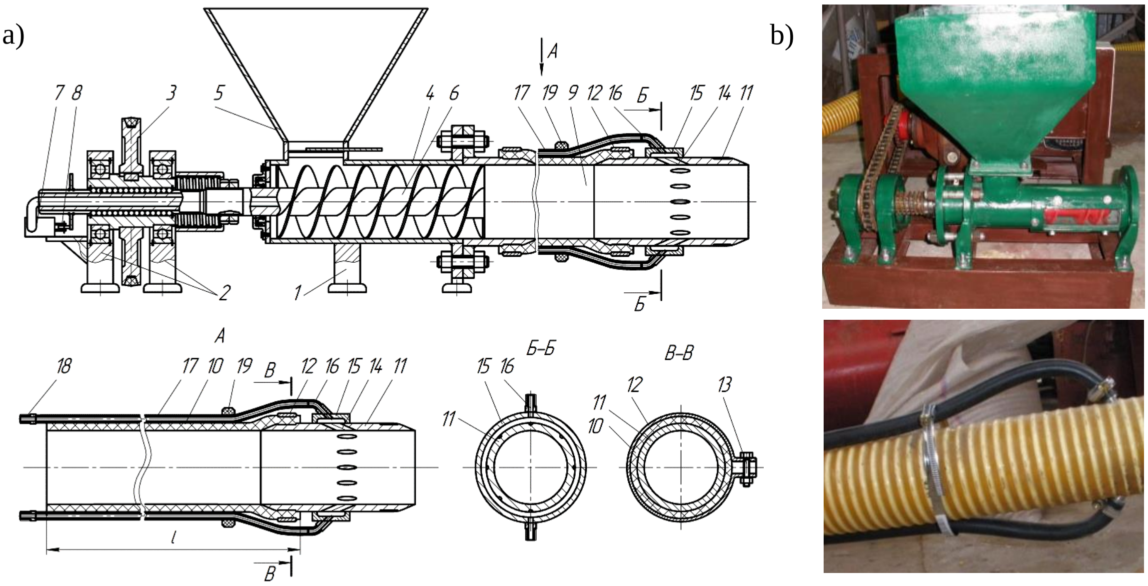

Fig. 1. **Construction diagram (a) and general view (b) of the pneumatic auger conveyor with supply hoses connected to the flexible cover**

In the central part of the cylindrical sleeve 11 there are holes 14 bent in the direction of bulk material transport, which are covered by U-shaped bushes 15, with sockets 16 angled in the direction of material transport on the outer diameters, to which the compressed air hoses 17 are connected. On the left side of the elastic casing, air hoses 17 are fitted with inlet nozzles 18, which are connected to the conveyor's common pneumatic system, whereby the length of the air hoses 17 in each subsequent section is twice as long as in the preceding one. The hoses 17 of each section 9 are offset in relation to each other by 90º on the forming cylindrical surface of section 9. Along the length of each section 9, pneumatic hoses 17 are attached to them with clamps 19.

During operation the loose material enters the conveyor housing 4 through the hopper 5 into the screw feeder 6. If overloading occurs due to a build-up of a certain amount of bulk material in the working chamber of the conveyor housing 4, the screw feeder 6 shifts axially in the opposite direction to the direction of transport of the material. Hoses 17 feed air into each section 9 through openings 14 and liquefy the bulk material which has accumulated in them.

The Altivar-71 frequency converter with Power Suite v.2.5.0 software was used to determine the power parameters of the bulk material handling process during the experimental studies. The Altivar-71 frequency converter is connected to the mains and a computer and allows soft-starting and frequency control of the air screw conveyor motor.

The bulk materials used in the experiments were wheat, bran and sawdust.

The motor voltage was 380 V; the current frequency varied from 0 to 40 Hz, corresponding to 0…450 rpm of the conveyor screw.

Results and discussion

Based on the results of the experimental studies, graphical dependencies of the energy-power characteristics of the pneumatic screw conveyor drive in time during transportation of the specified agricultural materials are plotted.

Fig. 2 shows plots of the power consumption of the conveyor drive over time for the transport of 2.5 mm wheat.

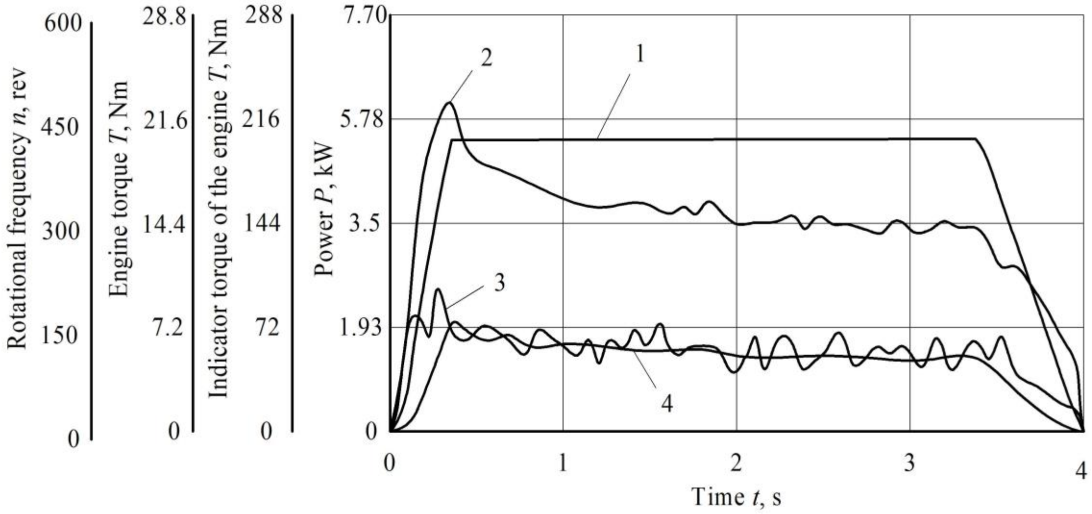

Fig. 2. **Diagrams of changes in energy-power characteristics of the pneumatic screw conveyor drive in time when conveying wheat of 2.5 mm fraction:** 1 – current output frequency; 2 – motor torque; 3 – motor indication torque; 4 – motor power

By analysing the resulting graphs (Fig. 2) three stages can be identified for the pneumatic auger conveyor. The first stage is characterised by an increase in load on the drive, which is explained by its acceleration from 0 to 450 rpm.

The second stage of the conveyor is characterised by an even operating mode. Cyclic growth of the torque on the drive and its subsequent decrease is explained by accumulation of the bulk material in the feeder housing, which leads to an increase in load on the drive and release of air flow from the air distributor, which leads to a decrease in load on the drive.

The third stage of the conveyor belt operation is the shutdown, which is characterised by a decrease in all of the drive energy-power characteristics from the set value to 0.

Fig. 3 shows graphs of the energy and power performance of the conveyor drive over time when conveying sawdust with a fraction of 1.5 mm.

Analyzing the graph (Fig. 3) of the change of power characteristics of the conveyor drive during the time at transportation of sawdust with fraction 1.5 mm, we see that the first stage of the conveyor drive operation is characterized by growth of all power parameters, that is a consequence of the growth of the drive frequency.

The second stage of the drive is characterised by a more intensive engagement of the reflected pneumatic spreader than for wheat transport in Fig. 3 (curve 3).

The third stage of the conveyor belt operation is the shutdown, which is characterised by a reduction in all of the drive energy-power characteristics from the set value to 0. However, the reduction in the torque on the drive is gradual.

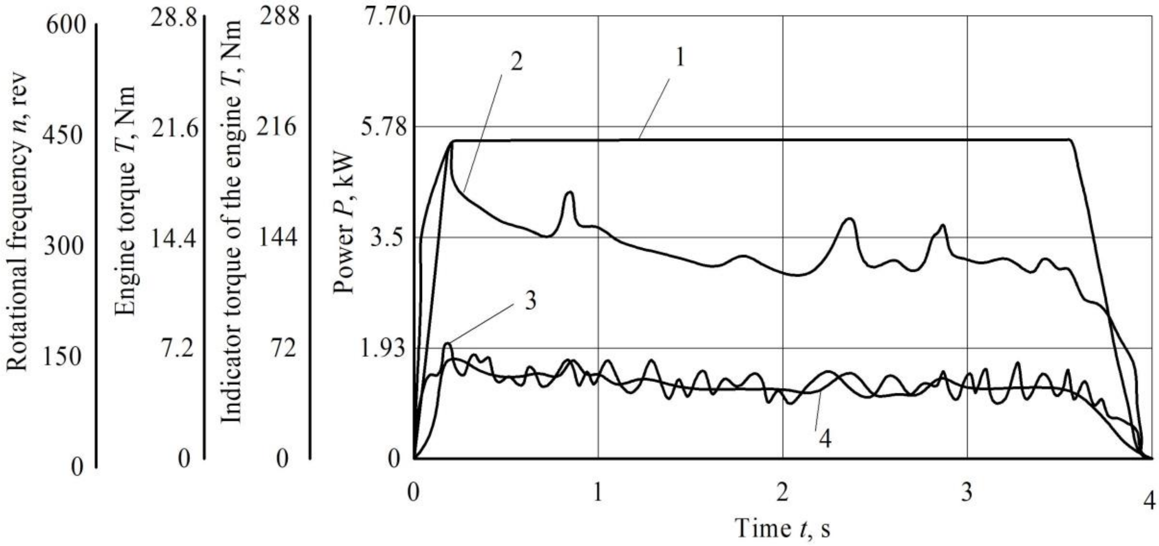

Fig. 3. **Diagrams of changing energy and force characteristics of the pneumatic screw conveyor drivein time when conveying sawdust with 1.5 mm fraction:** 1 – current output frequency; 2 – motor torque; 3 – motor indication torque; 4 – motor power

Fig. 4. shows graphs of the energy and power performance of the conveyor drive over time when transporting bran with 1 mm fraction.

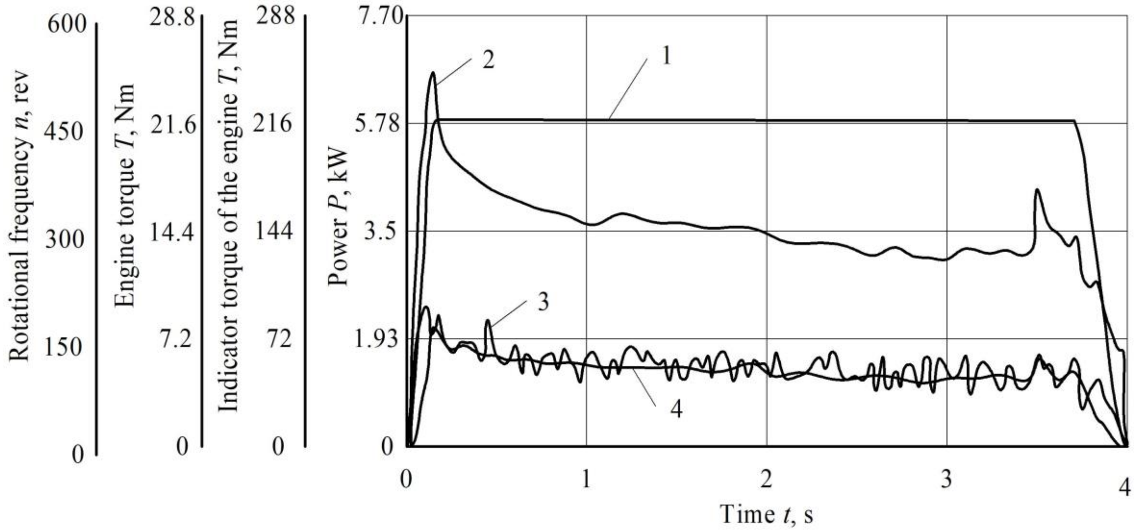

Fig. 4. **Diagrams of energy and power performance of the pneumatic screw conveyor drive in time when conveying bran with a fraction of 1 mm:** 1 – current output frequency; 2 – motor torque; 3 – motor indication torque; 4 – motor power

Analyzing the graphs (Fig. 4) of power characteristics of the conveyor drive during transportation of bran with a fraction of 1 mm, we see that the first stage of the conveyor drive is characterized by growth of all power parameters, which is the consequence of growth of the drive frequency.

The second stage is characterised by a uniform operating mode. However, the torque cycling is much higher due to the more frequent accumulation of bulk material in the feeder housing.

The third stage of the conveyor belt operation is the shutdown, which is characterised by a decrease in all power characteristics of the drive from the set value to 0. However, the decrease in the power characteristics, in particular the torque on the drive, did not occur smoothly.

When analysing all three graphs, we can note that the smoothness of the conveyor belt depends on the properties of the material to be conveyed, in particular the frequency with which the pneumatic drive is activated to prevent it from overloading and consequently breaking down. In addition, the activation of the pneumatic drive breaks up the resulting compaction of the bulk agricultural material, allowing the efficient movement of grain materials along process routes of different spatial configurations while permitting damage to the grain.

The maximum transportation distance of loose material using one section is: wheat – 1.6 m, bran – 2.5 m, sawdust – 3 m. To determine the maximum range of various loose agricultural materials (wheat, sawdust, bran) the methodology and its implementation method based on the pneumatic screw conveyor (Fig. 1) is shown in Fig. 5. At constant feeder speeds of $n = 450$ rpm and feed within 0.002 to 0.003 $m^3 \cdot s^{-1}$ at pressure values P, of the range of $0.2 \cdot 10^6 \leq P \leq 0.3 \cdot 10^6$ Pa determined the range of the material.

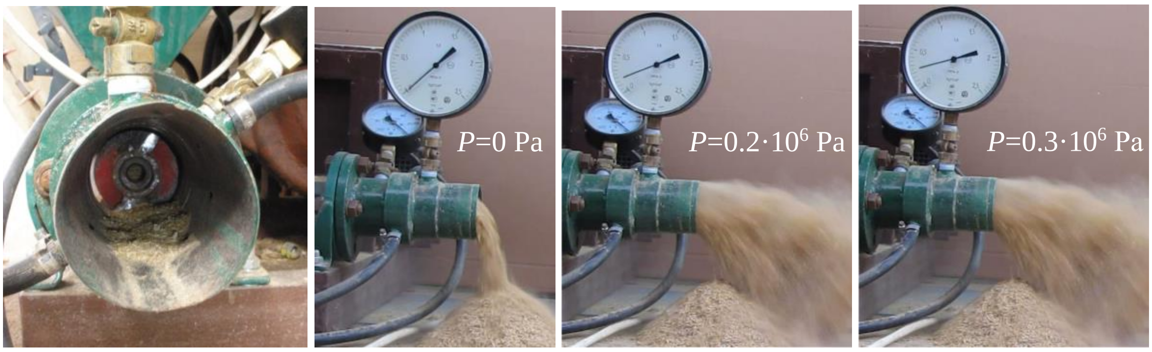

Fig. 5. **General view of bran exit from the nozzle at different values of the air pressure *P***

Experimental studies have also been conducted on changes in performance Q of the pneumatic auger conveyor as a function of the initial values of the high-pressure air supply P, the results of which are shown in the graphical diagram (Fig. 6).

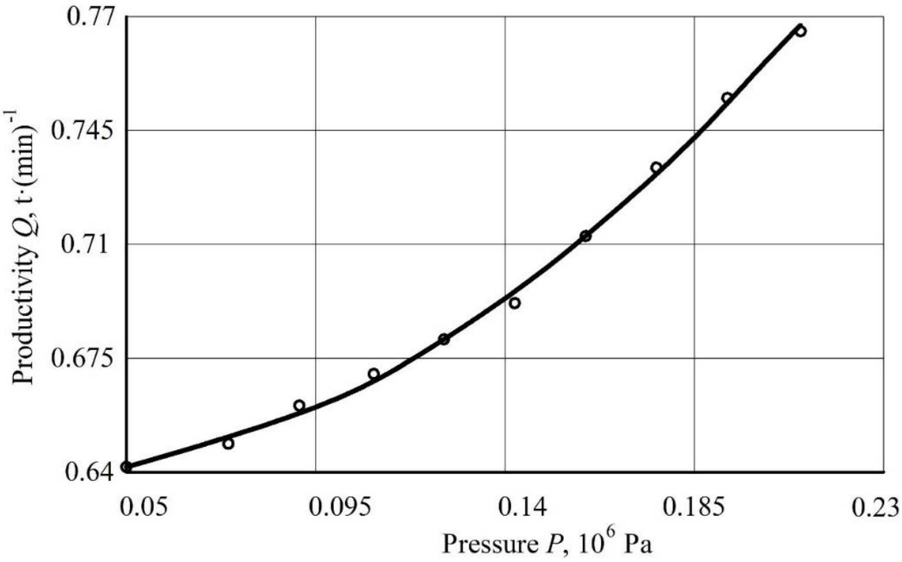

Fig. 6. **Dependence of performance variation as a function of air pressure $P = (0.5…0.21) \cdot 10^6$ Pa**

An analysis of these graphs shows that the change in the operating pressure P in the range of $(0.05…0.2) \cdot 10^6$ Pa has practically no effect on the performance of the pneumatic auger conveyor, and acceleration of material movement is observed at $P_{min} \approx 0.2 \cdot 10^6$ Pa.

The results of the experimental studies can be used to develop industrial designs for pneumatic screw conveyors.

Conclusions

1. Based on the literature analysis and patent search, a pneumatic screw conveyor is designed and manufactured for experimental research. The Altivar-71 frequency converter was used in the experimental studies to determine the energy-power parameters of the conveyor when moving bulk materials. Based on the results of the experimental studies, graphs of the energy-power

characteristics of the pneumatic screw conveyor drive over time during the transport of grain materials were obtained.

2. By analysing these graphs, we have found that the smoothness of the conveyor belt depends on the properties of the material to be conveyed, in particular the frequency with which the pneumatic drive is activated, which prevents overloading and therefore premature breakdowns. In addition, the activation of the pneumatic drive breaks up the resulting compaction of the bulk agricultural material, allowing the efficient movement of grain materials along process routes of different spatial configurations while permitting damage to the grain.
3. Experimental studies have also been conducted on changes in the performance Q of the pneumatic auger conveyor depending on the initial values of the high-pressure air supply P, according to which it was found that the change in the operating pressure P in the range of $(0.05…0.2)\cdot10^6$ Pa has practically no effect on the performance of the pneumatic auger conveyor, and acceleration of material movement is observed at $P_{min} \approx 0.2\cdot10^6$ Pa.

Author contributions

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

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