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RESULTS OF EXPERIMENTAL RESEARCH OF GRANULAR MATERIALS TRANSPORTATION BY TUBULAR SCRAPER CONVEYORS

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A full factor experiment (FFE3³) of transporting bulk materials by a tubular scraper conveyor on a curved track was conducted. There were derived the regression equation dependencies of production and torque on pipe diameter, fill factor and linear velocity. The graphical dependence of production and torque on the above-mentioned factors was constructed, and regression coefficients for different materials were determined.

Keywords: tubular scraper conveyor, transportation, granular medium, conveyor performance

The current level of development of all sectors of the Ukrainian economy requires a significant increase in the technical and economic index of mechanization and automation of technological processes facilities, particularly dealing with increasing their carrying capacity and broadening the technological opportunities. Tubular flexible rope conveyors are implemented in various fields of industry and agriculture for transporting homogeneous bulk materials on curved tracks. They are economically reasonable as they allow an efficient use of production areas and transporting materials in pipes which can be laid on a complex spatial track with a minimal damage, especially for seed materials. The investigation of structural and technological parameters of transport and technological systems of granular materials is conducted in the works of Hrigoriev (1972), Zenkov et al. (1987), Gevko et al. (1993), Gevko and Rogatynsky (1989), and many others. However, the problem of development and study of technological processes of transporting bulk materials by flexible rope conveyors is not paid enough attention and it needs some

further discussions. The main purpose of the work is to study the process of granular medium transporting by tubular scraper conveyors on curved tracks. The use of tubular drag conveyors in some cases is economically feasible for transporting bulk materials because of saving production space and being cheaper than pneumatic systems. Their advantage is that the lying pipe can be in a complex trajectory.

Material and methods

Dynamic systems the main characteristics of which vary along their length (area, volume) according to a specific law are called systems with distributed parameters. Their movement is described by partial differential equations under certain limit conditions. The rope of a conveyor transporting granular medium can be considered as a one-dimensional body the weight of which varies along the length (Fig. 1).

Figure 1 Model of a tubular scraper conveyor (a), and experimental stand for granular medium transportation (b)
1 – drive sprocket, 2 – tool, 3 – coupling, 4 – reducing gear, 5 – electric drive, 6 – frequency converter of Altivar 7.1 series, 7 – personal computer

When the motion of granular medium relatively to the rope may be neglected, this mass is considered as distributed along the rope. All the points of normal cross-sections for the system 'granular medium – rope' have the same kinematic characteristics (except for corner regions). It means that the object may be considered as a one-dimensional mechanical system with distributed parameters.

For these tasks, the determining factors of the process are the main average kinematic characteristics of granular medium dynamics (amplitude and frequency). Therefore, these works have shown that granular medium can be considered in various manufacturing operations as an elastic body with some averaged integral characteristics. In the technological process of granular medium transportation by scrapers using a moving rope, granular medium motion relatively to the rope is not of, in our view, neither theoretical nor practical value. Moreover, the motion of medium's particles relatively to the rope is negligible. Taking into consideration the above-mentioned facts, the motion of granular medium relatively to the rope will be ignored and considered as the one inseparably bound up with the rope. All this allows us to consider the dynamics of the technological process of granular medium transportation as the dynamics of one-dimensional body having the weight unevenly distributed along its length.

Under mass per length unit of the given conditional body (granular medium and rope) we mean the total mass of the rope and granular medium. Thus, the task of granular medium transportation by scrapers using the rope can be attributed to the problem of dynamics of one-dimensional system with distributed parameters. The position of one-dimensional system with distributed parameters for longitudinal vibrations is defined by a function describing the deformation of a conditional elastic material line at a random moment of time. In order to determine the specified function, three sections of rope are considered conventionally: two horizontal (top and bottom) and vertical. The main features (kinematic, physical and mechanical) of the upper and lower branches of the rope are identical, except the force of tension only.

Due to the possibility of a significant replacement of motor 5 in transverse and longitudinal direction, ropes of various lengths and configurations can be tested on the stand. During the investigation, the frequency converter (FC) (Fig. 1 b) was connected to the network, and the PowerSuite software for adjusting the frequency converter of series Altivar 7.1 was used. The electric motor rotation frequency was regulated in automatic mode from 0 to 1,460 rpm. When necessary, also a smooth and abrupt starting and reversing of the drive was used.

A part of the rope between the washers is recommended to cover with a layer (1.5–2.0 mm) of the same material as

scrapers are made. The ends of the rope are connected by a detachable metal washer and spring ring, and the speed of the tool of the tubular rope conveyor ranges from 0.1 to 1.25 m.s⁻¹.

The investigation to find out the conveyor in-use performance was conducted when transporting the following materials with an appropriate bulk density: peas – 700 kg.m⁻³, wheat – 760 kg.m⁻³, corn – 800 kg.m⁻³ and bran – 250 kg.m⁻³ with moisture $W = 12\text{--}15\%$. This allowed constructing the analytical regression equations.

For transporting the granular material in a metal pipe, scrapers made of polyamide PA-6 or PA-12 with surface roughness $R_a \approx 2.5$ microns were used. These scrapers are in direct contact with the seed and do not damage it. Friction coefficient in the pipe is $f = 0.20$, causing lower torque than in case of metal scrapers with friction coefficient $f = 0.60$. Thus, torque reduction for bran is 3–12 %, wheat 7–15 %, peas and corn 3–5 %, for the range of bulk materials filling factor in the pipe 0.3–0.7.

Full factor experiments were performed to determine the effect of geometrical parameters of granular medium transportation and structural parameters of conveyor for moving it (independent factors x) on in-use performance and torque (optimization parameter Q and T), i.e. we determined the dependence of performance and torque on changes in the three major factors: filling factor ψ , pipe internal diameter D , m and linear velocity of transportation v , m.s⁻¹, i. e., $Q = f(D, \psi, v)$ and $T = f(D, \psi, v)$.

To obtain finally the empirical regression equations (Hu, 2010; Hrigoriev, 1972), the processing of experimental data was carried out according to well-known techniques and methods of statistical processing, using well-known techniques of correlation and regression analysis. To obtain an optimization parameter regression model, an appropriate plan of full factor experiment was chosen, the implementation of which was performed in the following sequence.

As during the experiments independent variables factors are heterogeneous with different units of measure and numbers, expressing the values of these factors have different orders, they were reduced to a unified system of calculation by means of transition from actual to coded values that are presented in Table 1.

The full factor experiment was performed at three levels of factors varying. After encoding of input factors, the plan matrix of the full factorial experiment of type FFE 3³ meant the total number of experiments $N = m^k$, where m – number of variation levels, k – number of active input factors in the experiment.

In order to have an accurate assessment of granular material transporting during laboratory experiments, the required number of measurements for monitored indicators (repetition of experiments) was determined according

Table 1 Results of factors encoding and levels of their variation

Factors	Marking		Interval of variation	Levels of variation, natural/code		
	natural numbers	code				
Internal diameter of pipe D in m	X_1	x_1	0.02	0.06/-1	0.08/0	0.1/+1
Filling factor ψ	X_2	x_2	0.2	0.3/-1	0.5/0	0.7/+1
Linear speed of transportation v in m.s ⁻¹	X_3	x_3	0.11	0.12/-1	0.23/0	0.34/+1

to the method described by Zenkov et al. (1987), and the experiments were conducted three times.

The results of calculations are given in the table of experimental results. The processing of results of experiments was conducted using generally known methods and analyses of holding experimental researches.

The response functions (parameter of optimization), i.e. in-use performance $Q^i = f(D, \psi, v)$ and torque $T^i = f(D, \psi, v)$ determined experimentally, are presented in the form of a mathematical model of complete quadratic polynomial:

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

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 – corresponding encoded factors.

Results and discussion

The investigation of transportation effectiveness and determination of torque on the drive sprocket gave us an opportunity to determine the dependence of powers on many factors characterizing the process such as transportation linear speed v , m.s^{-1} , inner pipe diameter D , m, and filling factor ψ . For normalization of action sequences during the experiment and to achieve the required accuracy while varying all the factors, the mathematical method of experimental studies planning was used.

A general view of productiveness regression equations on the results of FFE 3³ in coded values is:

- for transporting maize:

$$Q_{\text{maize}} = 5,484.96 + 0.616D + 0.513\psi + 0.485v + 0.784D\psi + 0.741Dv + 0.722\psi v + 0.618D^2 + 0.488v^2 \quad (2)$$

- for transporting peas:

$$Q_{\text{peas}} = 3,293.23 + 0.597D + 0.498\psi + 0.526v + 0.759D\psi + 0.77Dv + 0.743\psi v + 0.528v^2 \quad (3)$$

- for transporting wheat:

$$Q_{\text{wheat}} = 4,587.97 + 0.591D + 0.507\psi + 0.528v + 0.764D\psi + 0.768Dv + 0.75\psi v + 0.593D^2 \quad (4)$$

- for transporting bran:

$$Q_{\text{bran}} = 4,851.76 + 0.596D + 0.496\psi + 0.529v + 0.759D\psi + 0.771Dv + 0.745\psi v + 0.597D^2 + 0.528v^2 \quad (5)$$

The values of the maximum torque for various bulk materials on the experimental plant:

$$T_{\text{wheat}} = 12.21 + 0.743D + 0.619\psi - 0.037v + 0.947D\psi + 0.308Dv + 0.358\psi v + 0.745D^2 - 0.038v^2 \quad (6)$$

$$T_{\text{bran}} = 11.59 + 0.741D + 0.622\psi + 0.948D\psi + 0.357\psi v + 0.742D^2 - 0.037v^2 \quad (7)$$

$$T_{\text{maize}} = 23.98 + 0.753D + 0.588\psi + 0.926D\psi + 0.303\psi v + 0.758D^2 \quad (8)$$

$$T_{\text{peas}} = 14.11 + 0.744D + 0.619\psi - 0.010v + 0.948D\psi + 0.746D^2 \quad (9)$$

To determine the conveyor in-use performance and transportation torque while using the material (wheat, peas, corn, bran), the graphic values of relationships are presented in Figures 2–8. The Statistica 6.0 software for Windows was used for this purpose, which helped to build a graphical representation of regression models as quadratic response surfaces and their two-dimensional sections.

Figures 2–4 indicate that the performance of tubular scraper conveyor for the bulk material (peas, wheat, corn) depends on inner pipe diameter D and linear velocity and less on filling factor. Consequently, the increase in pipe diameter and speed cause the in-use performance increase of up to 3,975 kg.h^{-1} .

Figure 2 Response surface **a)** and two-dimensional section of response surface **b)** dependences of peas production $Q_{\text{wheat}}(D, \psi)$ on pipe diameter and filling factor at speed $v = 0.23 \text{ m.s}^{-1}$

a

b

Figure 3 Response surface **a**) and two-dimensional section of response surface **b**) dependences of peas production $Q_{peas}(\psi, v)$ on linear velocity and filling factor for pipe diameter $D = 0.08$ m

a

b

Figure 4 Response surface **a**) and two-dimensional section of response surface **b**) dependences of peas production $Q_{maize}(D, v)$ on linear velocity and pipe diameter at filling factor $\psi = 0.5$

Figure 5 Response surface for the dependence of transportation torque using tubular scraper conveyor $M_{\psi, D}^{maize}$ on inner pipe diameter D and filling factor at linear velocity $v = 0.12-0.34$ m.s⁻¹

Figure 6 Response surface for the dependence of transportation torque using tubular scraper conveyor $M_{\psi, D}^{wheat}$ on inner pipe diameter D and filling factor at linear velocity $v = 0.12-0.34$ m.s⁻¹

Figure 7 Response surface for the dependence of transportation torque using tubular scraper conveyor $M_{v,D}^{peas}$ on inner pipe diameter D and linear velocity v at filling factor $\psi = 0.5$

Figure 8 Response surface for the dependence of transportation torque using tubular scraper conveyor $M_{D,\psi}^{bran}$ on inner pipe diameter D and filling factor at linear velocity $v = 0.12\text{--}0.34\text{ m.s}^{-1}$

Figures 5–8 show the graphical dependences of tube scraper conveyor torque on inner pipe diameter $D = 0.06\text{--}0.1\text{ m}$ and filling factor $\psi = 0.3\text{--}0.7$ at linear velocity $v = 0.12\text{--}0.34\text{ m.s}^{-1}$.

Maize grains, because of their large size, much more rarely fall between the scraper surface and pipe surface than bran grains which often fall into the gap between the inner pipe surface and outer scraper surface while transporting, causing transportation process deceleration. Energy consumption for wheat transportation is highest as the ellipsoid wheat shape causes the so-called effect of scraper seizure when part of grains falls into the gap between the scraper and pipe.

Figures 5–8 show that with an increasing inner pipe diameter $D = 0.1\text{ m}$ and at linear velocity $v = 0.34\text{ m.s}^{-1}$ and filling factor $\psi = 0.5$ torque decreases while transporting the bulk materials (corn, peas, wheat, bran).

Conclusion

On the basis of experimental studies, there were derived complex regression relationships to determine the torque and productiveness of transporting by tubular scraper conveyor on curved paths for peas, wheat, corn and bran. The regression coefficients of the equation of performance and torque were determined. It was found that the inner pipe diameter, filling factor and linear velocity of transportation significantly affect the torque and productiveness of transporting.

The relationships for the response surfaces of productiveness of transporting by tube scraper conveyor were prepared using the Statistica 6.0 software, and it was found that the maximum output for corn is $3,975\text{ kg.h}^{-1}$, which is by 10–15 % higher than for wheat.

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