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THEORETICAL BACKGROUNDS OF SCREW LOADERS OPERATION WITH POURING INTO ANOTHER CONTAINER

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Summary. Based on the equation of motion in a screw conveyor-mixer, the kinematics of bulk material is researched. The motion of bulk material in medium speed operation mode of screw conveyor-mixer is analyzed in details. The technique of determining the nature of loading the screw conveyor elements is developed. The analytical dependences for determining the speed change of the given bulk material volume in relation to a casing in medium speed mode of conveyor while mixing the bulk material are developed. This technique can be widely used for designing the screw transport and technological systems

Theoretical backgrounds of screw loaders performance for unloading bulk materials from the horizontal truss on the vertical one are substantiated. The analytical dependences for determining the value of axial force of feeding bulk materials by means of horizontal branch from an inclination angle of the vertical truss are developed. The graphic dependences of the change of minimum axial force of feeding bulk material from the inclination angle of a conveyor vertical branch are developed as well.

Key words: screw feeders, bulk material, feeding force.

INTRODUCTION

Nowadays screw conveyors are widely used for technological transporting and mixing the bulk materials. These conveyors are characterized by simplicity of their design. They are highly reliable, easy to use and easy to adapt when used in automated systems, and they are ecologically friendly as well [2, 4, 7-8, 12-20]. To cut down power consumption and to increase the quality of mixing the bulk materials, a number of screw mixers' original designs are developed. The use of the working body depends on the peculiarities of bulk material loading the auger as well as on the peculiarities of the nature of bulk material motion, and the practicability of using the auger working body.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The advantages of using such augers include the increase of load coefficient in the area of transporting the bulk material from a tanker into auger that leads to the increase of conveyor's productivity.

Analysis of recent research and publications. The works of Grygoryev A.M. [1], Hewko B.M., Rohatynskyi R.M. [3, 10-11], Hewko I.B. [3, 9] and others are dedicated to the issue of transporting and mixing different materials. However, taking into account the diversity of technological processes and structural designs of screw transport and technological mechanisms (STTM), this issue requires further research and refinement of various parameters of theoretical and practical importance.

OBJECTIVES

The objective of this work is to substantiate theoretically the screw loaders performance with two branches of pouring bulk materials.

THE MAIN RESULTS OF THE RESEARCH

A number of original screw conveyor-mixers for cutting down power consumption and minimizing the damage of seeds as well as for increasing the reliability of screw working bodies are designed. To use such conveyors it is necessary to solve issues related to the nature of bulk material motion as well as to the practicability of their use.

To mix the bulk material effectively, the conveyor should work in the medium speed mode. This is the characteristic feature of screw conveyor-mixers Fig. 1. Based on experimental research it is proved that the material in the cross section of conveyor casing is lifted to the upper point and falls on the inner surface of the cylindrical casing under the force of gravity, repeating the cycle by the cycle.

The motion trajectories of the given bulk material volume in the cross section of conveyor casing in the fast- and medium speed modes are compared in Fig. 2.

The angular parameter θ is determined by the nature of bulk material motion during the screw conveyor operation. To determine the nature of bulk material transportation, the motion of the given bulk material volume along the coordinates xyz (Fig. 1.) should be considered.

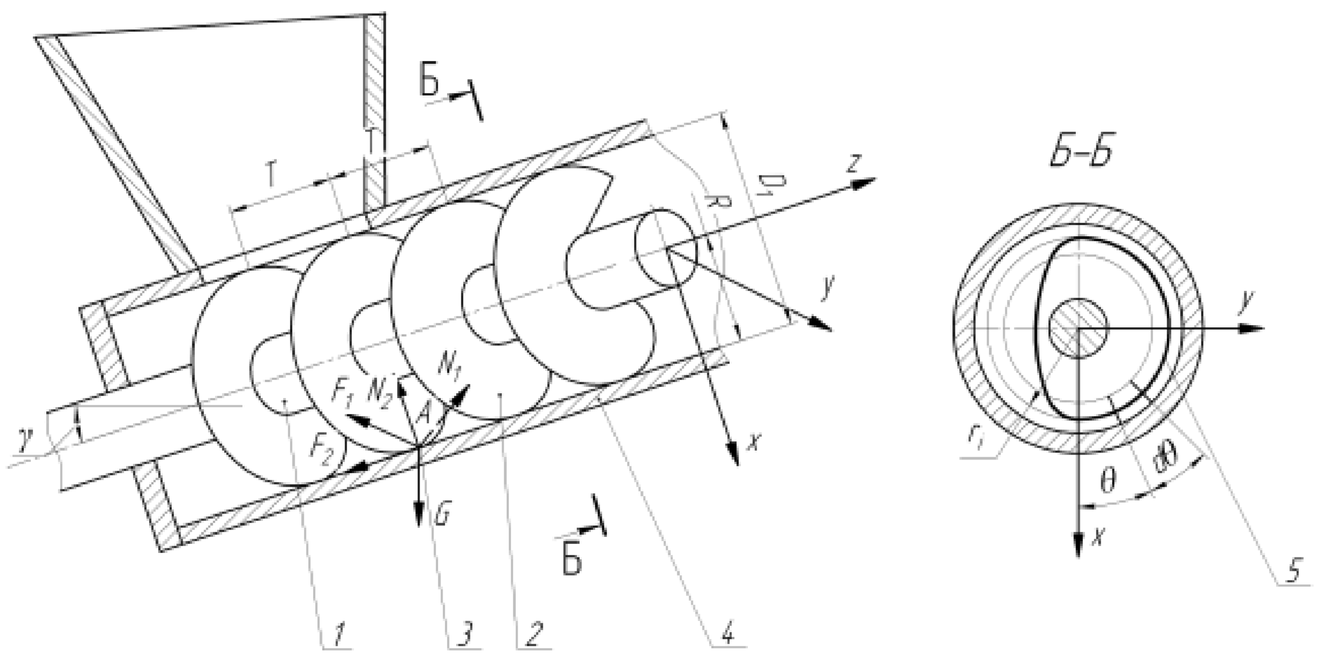

Fig. 1. Computation scheme of transporting the given bulk material volume in the inclined screw conveyor: 1 - drive shaft; 2 – screw working body; 3 – given bulk material volume; 4 – casing; 5 – trajectory of bulk material motion in the medium speed mode (mode of transporting and mixing)

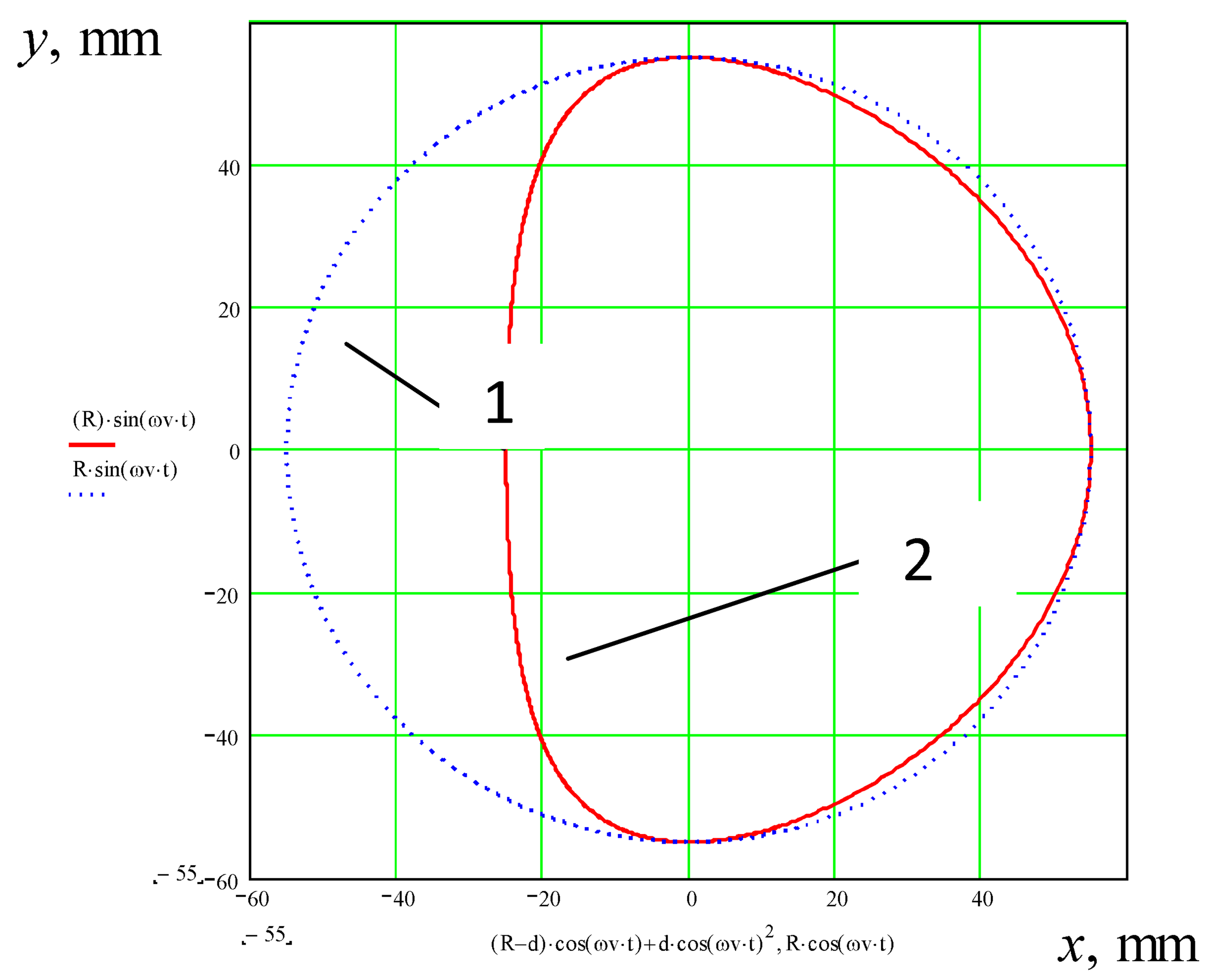

Fig. 2. Motion trajectories of the given bulk material volume in cross section of casing in the fast speed 1 and medium speed 2 modes as compared

When the conveyor operates in the medium speed mode, the bulk material is mixed and transported simultaneously. Taking into account the contact of the given bulk material volume A with the auger's screw surface and the cylindrical surface of the casing, the placement is determined by the radial parameter R and the angular parameter θ.

In parametric form, with sufficient approximation, the coordinates of the given bulk material volume A are determined by the dependences:

$$\begin{aligned} x_A &= (R-d)\cdot\cos\theta + d\cos^2\theta; \\ y_A &= R\cdot\sin\theta; \\ z_A &= \frac{T_0(\omega t-\theta)}{2\pi}, \end{aligned} \tag{1}$$

where: x_A, y_A, z_A, – coordinates of the given bulk material volume, m; R – radial parameter of the given bulk material volume, m; θ – angular parameter of the given bulk material volume, rad; ω – angular speed of working body rotation, rad/s; t – time, s; d – parameter that determines the displacement of motion trajectory of the given bulk material volume in medium speed mode as compared with the fast speed mode, T_0 - step, mm;

Parameter d is the function of angular speed of working body rotation, the inner radius of casing, and the transported material properties. The angular speed of working body rotation increases, the parameter d decreases. The inner radius of casing increases, the parameter d increases as well. In fast speed mode d=0, this parameter can be determined with the use of parametrical dependences based on experimental research.

Motion speeds of the given bulk material volume related to the auger along the axes x, y, z:

$$\begin{cases} \dot{x}_1 = \dot{x}_A - \dot{x}_{1u}; \\ \dot{y}_1 = \dot{y}_A - \dot{y}_{1u}; \\ \dot{z}_1 = \dot{z}_A - \dot{z}_{1u}, \end{cases} \tag{2}$$

where: $\dot{x}_A$, $\dot{y}_A$, $\dot{z}_A$, – projections of motion speed of the given bulk material volume on the axes of coordinates xyz, m/s; $\dot{x}_{1u}$, $\dot{y}_{1u}$, $\dot{z}_{1u}$ – projections of motion speed of the working body on the axes of coordinates xyz, m/s.

As the casing is motionless, the motion speeds of the given bulk material volume related to the casing along the axes x, y, z equal:

$$\begin{cases} \dot{x}_2 = \dot{x}_A; \\ \dot{y}_2 = \dot{y}_A; \\ \dot{z}_2 = \dot{z}_A. \end{cases} \tag{3}$$

The projections of motion speed of the given bulk material volume are defined by differentiating the equation (1) for the general case, when $R \neq const$:

$$\begin{cases} \dot{x}_A = \dfrac{d(R-d)}{dt}\cos\theta - (R-d)\cdot\sin\theta\cdot\dfrac{d\theta}{dt} + \dfrac{d(d)}{dt}\cos^2\theta - 2d\cos\theta\sin\theta\dfrac{d\theta}{dt}; \\ \dot{y}_A = \dfrac{dR}{dt}\sin\theta + R\cdot\cos\theta\cdot\dfrac{d\theta}{dt}; \\ \dot{z}_A = \dfrac{T}{2\pi}\left(\omega - \dfrac{d\theta}{dt}\right). \end{cases} \tag{4}$$

Motion speed of screw working body is determined by dependences:

$$\begin{cases} \dot{x}_{1u} = R\cdot\omega\sin\theta; \\ \dot{y}_{1u} = R\cdot\omega\cos\theta; \\ \dot{z}_{1u} = 0. \end{cases} \tag{5}$$

According to (2) and taking into account the dependences (4) and (5), we develop the formulas:

$$\begin{cases} \dot{x}_1 = \dfrac{d(R-d)}{dt}\cos\theta + R\cdot\sin\theta\cdot\left(\omega - \dfrac{d\theta}{dt}\right) + \\ +d\sin\theta\dfrac{d\theta}{dt} + \dfrac{d(d)}{dt}\cos^2\theta - 2d\cos\theta\sin\theta\dfrac{d\theta}{dt}; \\ \dot{y}_1 = \dfrac{dR}{dt}\sin\theta - R\cdot\cos\theta\cdot\left(\omega - \dfrac{d\theta}{dt}\right); \\ \dot{z}_1 = \dfrac{T_0}{2\pi}\left(\omega - \dfrac{d\theta}{dt}\right). \end{cases} \tag{6}$$

The modules of motion speed of the given bulk material volume are determined by formulas:

$$|\dot{s}_1| = \sqrt{\dot{x}_1^2 + \dot{y}_1^2 + \dot{z}_1^2}\,; \qquad (7)$$

$$|\dot{s}_2| = \sqrt{\dot{x}_A^2 + \dot{y}_A^2 + \dot{z}_A^2}\,. \qquad (8)$$

Inserting the equations (4) and (6) into (7) and (8), and hypothesizing that the casing has a cylindrical shape with R = const, d = const, after the cuts, we get the formulas:

$$|\dot{s}_1| = \sqrt{\left(R^2 + \frac{T_0^2}{4\pi^2}\right)\left(\omega - \frac{d\theta}{dt}\right)^2 + 2Rd\sin^2\theta\left(\omega - \frac{d\theta}{dt}\right)\frac{d\theta}{dt}(1-2\cos\theta) + d^2\sin^2\theta\left(\frac{d\theta}{dt}\right)^2(1-2\cos\theta)^2}\,; \qquad (9)$$

$$|\dot{s}_2| = \sqrt{R^2\left(\frac{d\theta}{dt}\right)^2 + \frac{T_0^2}{4\pi^2}\left(\omega - \frac{d\theta}{dt}\right)^2 + 2Rd\sin^2\theta\left(\frac{d\theta}{dt}\right)^2(1-2\cos\theta) + d^2\sin^2\theta\left(\frac{d\theta}{dt}\right)^2(1-2\cos\theta)^2}\,. \qquad (10)$$

The acceleration of the given bulk material volume is determined by differentiating the equation (6) when R=const; d=const.

$$\ddot{x} = R\cos\theta\frac{d\theta}{dt}\left(\omega - \frac{d\theta}{dt}\right) - R\sin\theta\frac{d^2\theta}{dt^2} + d\cos\theta\frac{d^2\theta}{dt^2} + d\sin\theta\frac{d^2\theta}{dt^2} + 2d\left(\sin^2(\theta)\frac{d^2\theta}{dt^2} - \cos^2(\theta)\frac{d^2\theta}{dt^2} - 2\cos\theta\sin\theta\frac{d^2\theta}{dt^2}\right);$$
$$\ddot{y} = R\sin\theta\frac{d\theta}{dt}\left(\omega - \frac{d\theta}{dt}\right) + R\cos\theta\frac{d^2\theta}{dt^2};$$
$$\ddot{z} = -\frac{T_0}{2\pi}\frac{d^2\theta}{dt^2}. \qquad (11)$$

The numerical and experimental research as well as the research presented in the work [5-6] prove that the stable mode of transportation is set regardless of the initial conditions of transportation after the passage of transitional mode zone.

The minimum force of material feed in a loading zone of a vertical conveyor should be defined; the rational location of a loading conveyor should be specified. To achieve these goals, the analytical model shown in Fig. 3 should be considered.

A particle of the material located on a screw surface of a vertical conveyor in a loading zone is exposed to a horizontal conveyor's action. In the general case of inclined position of screw conveyors axes, the motion of this particle is described by the equations of equilibrium:

$$\begin{cases} \sum X = N_{1x} + F_{1x} + P_{1x} + G_x + F_{ix} = 0; \\ \sum Y = N_{1y} + N_{2y} + F_{1y} + P_{1y} + G_y = 0; \\ \sum Z = N_{1z} + F_{1z} + P_{1z} + G_z = 0, \end{cases} \qquad (12)$$

where: N_{1x}, N_{1y}, N_{1z} – projections of a normal reaction from a vertical auger surface to the axes x, y, z, H; F_{1x}, F_{1y}, F_{1z} – projections of frictional forces between a particle and a surface of a screw working body to the axes x, y, z, H; G_x, G_y, G_z –- projections of a weight force to the axes x, y, z, H; P_{1x}, P_{1y}, P_{1z} – projections of a force of feeding the material into a loading zone by a horizontal conveyor to the axes x, y, z, H; F_{ix} – projection of a centrifugal force to the axis x; N_{2y} – projection of a normal reaction from a casing surface to the axis y, H.

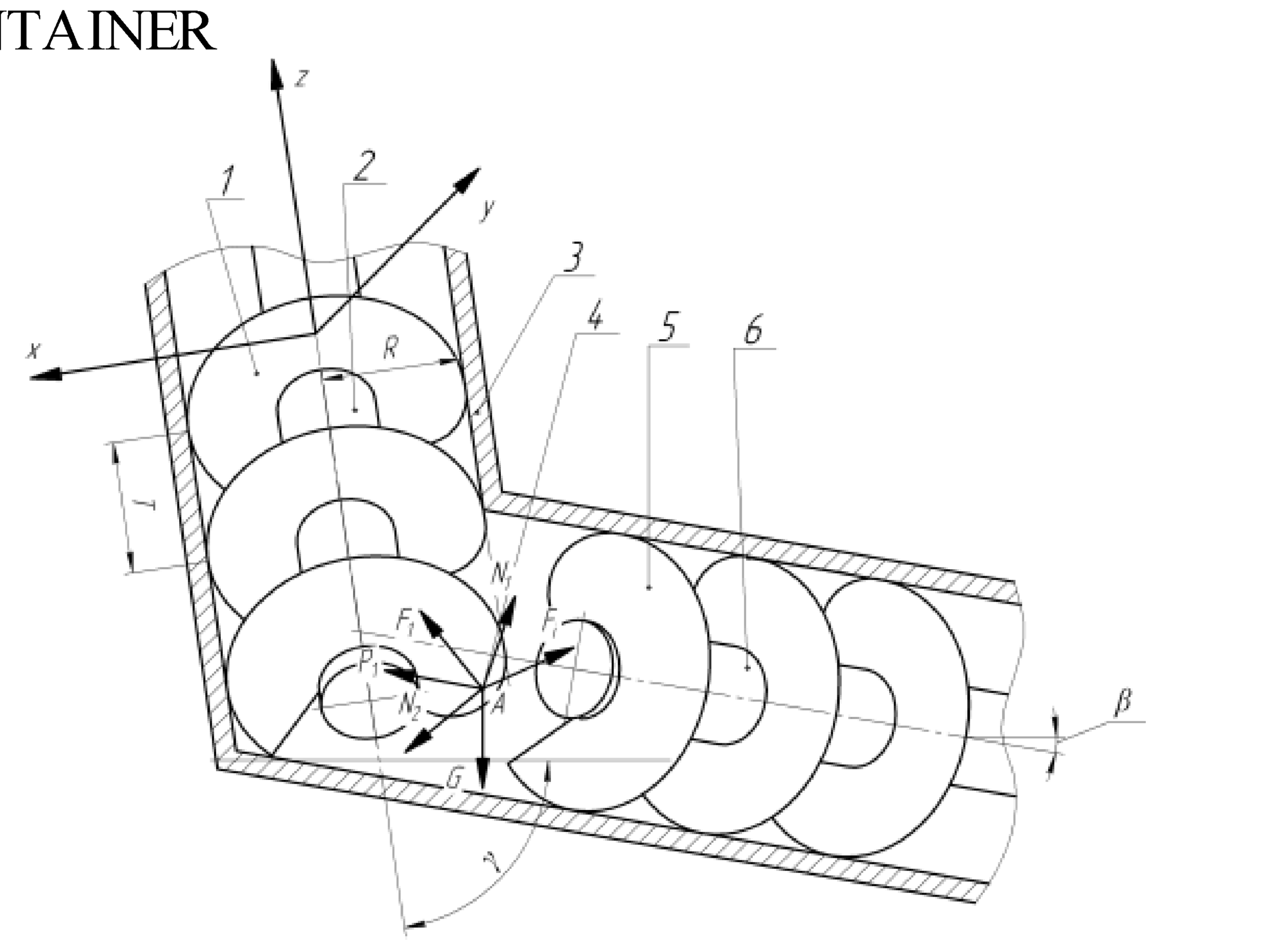

Fig. 3. Analytical model to determine the minimum force of material feed in a loading zone of a vertical conveyor: 1 – screw working body of a vertical conveyor; 2 – shaft of a vertical conveyor; 3 – casing; 4 – a piece of material; 5 – screw working body of a horizontal conveyor; 6 – shaft of a horizontal conveyor

Projections of a normal reaction to the axes are deduced by the formulae:

$$\begin{cases} N_{1x} = -N_1 \cdot \sin\alpha; \\ N_{1y} = -N_1 \cdot \sin\alpha; \\ N_{1z} = N_1 \cdot \cos\alpha, \end{cases} \qquad (13)$$

where: α – an angle of helix ascent of a screw working body, rad; N_1 – normal reaction from the screw surface, H.

Projections of a weight force to the axes:

$$\begin{cases} G_x = mg \cdot \cos\gamma; \\ G_y = 0; \\ G_z = -mg \cdot \sin\gamma, \end{cases} \qquad (14)$$

where: m – a particle mass, kg; γ – axis inclination angle of a vertical screw working body to the horizontal, rad; g – acceleration of gravity, м/с^2.

The projection of a centrifugal force:

$$F_{ix} = -mR\omega_2^2, \qquad (15)$$

where: R – outer radius of a vertical auger, m; ω_2 – angular rate of auger rotation, c^{-1}.

Friction F_1 acts oppositely to the vector of a particle absolute rate, and its projections are:

$$\begin{cases} F_{1x} = -f_1 N_1 \cdot \cos\alpha; \\ F_{1y} = -f_1 N_1 \cdot \cos\alpha; \\ F_{1z} = -f_1 N_1 \cdot \sin\alpha, \end{cases} \qquad (16)$$

where: f_1 – coefficient of friction between the particle and auger surface.

Projections of a force of material feed into the loading zone by a horizontal conveyor:

$$\begin{cases} P_{1x} = P_1 \cdot \sin(\gamma - \beta); \\ P_{1y} = 0; \\ P_{1z} = P_1 \cdot \cos(\gamma - \beta), \end{cases} \qquad (17)$$

Where:β – axis inclination angle of a horizontal screw working body to the horizontal, rad.

The numerical and experimental research as well as the research presented in the work [3, 6] prove that the stable mode of transportation is set regardless of the initial conditions of transportation after the passage of transitional mode zone.

Based on (13-17), the system of equations (12) can be developed:

$$\begin{cases} \sum X = -N_1 \sin\alpha - f_1 N_1 \cos\alpha + P_1 \sin(\gamma-\beta) + mg\cos\gamma - mR\omega_2^2 = 0; \\ \sum Y = -N_1 \sin\alpha - f_1 N_1 \cos\alpha + f_2 N_2 = 0; \\ \sum Z = N_1 \cos\alpha - f_1 N_1 \sin\alpha - mg\sin\gamma + P_1 \cos(\gamma-\beta) = 0. \end{cases} \quad (18)$$

where: N_2 – normal reaction of a casing surface, H.

Based on the third equation, the normal reactions of a casing surface can be deduced:

$$N_1 = \frac{mg\sin\gamma - P_1\cos(\gamma-\beta)}{\cos\alpha - f_1\sin\alpha}. \quad (19)$$

Substituting the equation (19) into the first equation of the equations system (18), the following formulae are deduced:

$$\frac{(-mg\sin\gamma + P_1\cos\ \gamma-\beta\ \ \sin\alpha + f_1\cos\alpha}{\cos\alpha - f_1\sin\alpha} + \\ +P_1\sin\ \gamma-\beta\ + mg\cos\gamma - mR\omega_2^2 = 0. \quad (20)$$

$$(-mg\sin\gamma + P_1\cos\ \gamma-\beta\ \mathrm{tg}(\alpha+\varphi) + \\ +P_1\sin\ \gamma-\beta\ + mg\cos\gamma - mR\omega_2^2 = 0;$$

$$-mg\sin\gamma\,\mathrm{tg}(\alpha+\varphi) + P_1(\cos\ \gamma-\beta\ \mathrm{tg}(\alpha+\varphi) + \\ +\sin\ \gamma-\beta\ ) + mg\cos\gamma - mR\omega_2^2 = 0;$$

$$P_1 = \frac{mg(\sin\gamma\,\mathrm{tg}(\alpha+\varphi) - \cos\gamma) + mR\omega_2^2}{\cos\ \gamma-\beta\ \mathrm{tg}(\alpha+\varphi) + \sin\ \gamma-\beta}, \quad (21)$$

where: φ – friction angle between the material and auger surface, $\varphi = \mathrm{arctg}\, f_1$.

The force of feeding material into a loading zone by a horizontal conveyor can be deduced from the formula:

$$P_1 = P_0 - mg(\sin\beta + f_2\cos\beta), \quad (21)$$

where: P_0 – axial force of material feed, H; f_2 – coefficient of friction between the particle and the surface of a horizontal auger casing.

Substituting the equation (21) into the equation (20), the minimum axial force of material feed can be deduced:

During the study of the technological process of loading a SW, the analytical dependence for determining the value of axial force of a horizontal branch was developed, where:

$$P_o = \frac{mg(\sin\gamma\,\mathrm{tg}(\alpha+\varphi) - \cos\gamma) + mR\omega_2^2}{\cos\ \gamma-\beta\ \mathrm{tg}(\alpha+\varphi) + \sin\ \gamma-\beta} + \\ +mg(\sin\beta + f_2\cos\beta), \quad (22)$$

Based on the formula 22, the graphs of dependences of minimum axial force of material feed on inclination angles of the vertical conveyor (Fig. 4) and the horizontal conveyor (Fig. 5) are developed.

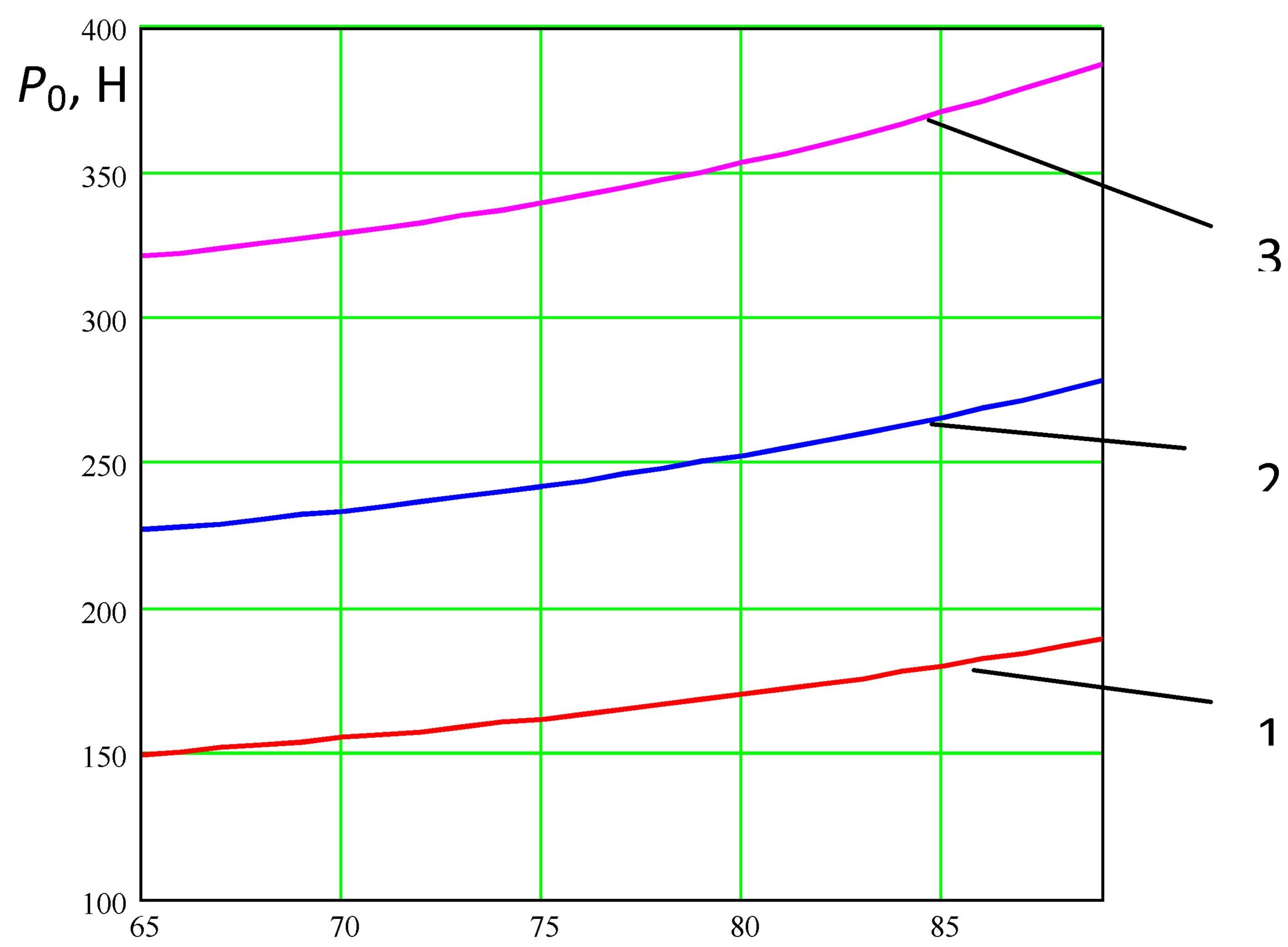

Fig. 4. Graph of the dependence of minimum axial force of material feed on the inclination angle of a conveyor horizontal branch R=0.1м, T=0.2м; β=0grad: 1 – ω_2=20c^{-1}; 2 – ω_2=25c^{-1}; 3 – ω_2=30c^{-1}

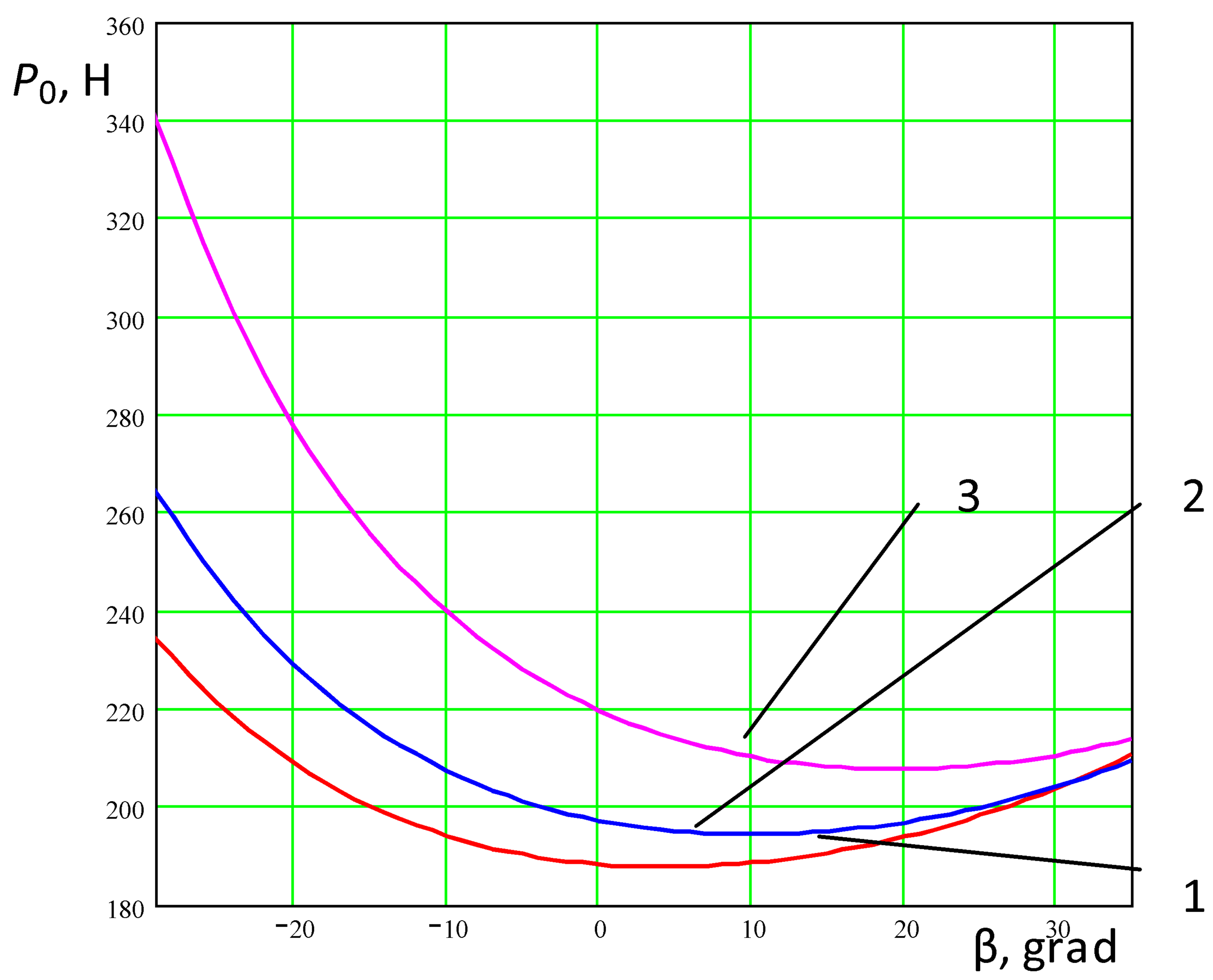

Fig. 5. Graph of the dependence of minimum axial force of material feed on the inclination angle of a horizontal conveyor R = 0.075m, T = 0.15m; = 25s-1 1 – γ = 75grad; 2 – γ = 80grad; 3 –- γ = 90grad

In addition, the graphs in Fig. 3 prove the existence of an optimum inclination angle of a horizontal auger, due to which the axial force of material feed takes the smallest value.

To find the optimum angle β, the equation (23) is differentiated:

$$\frac{dP_0}{d\beta} = \frac{-\left(mg\sin\gamma\,\mathrm{tg}(arctg\frac{T}{2\pi R}+\varphi) - \cos\gamma) + mR\frac{\pi^2 n_2^2}{900}\right)}{\left(\cos\ -\gamma+\beta\ \mathrm{tg}(\mathrm{arctg}\frac{T}{2\pi R}+\varphi) - \sin\ -\gamma+\beta\ \right)^2} \times \\ \times\left(-\sin\ -\gamma+\beta\ \mathrm{tg}(\mathrm{arctg}\frac{T}{2\pi R}+\varphi) - \cos\ -\gamma+\beta\ \right) + \\ +mg(\cos\beta - f_2\sin\beta) \quad (23)$$

Considering the equation (23) equivalent to zero, the optimum angle β can be defined. Nevertheless, this equation has no analytical solution. Therefore, to define the optimum angle β, the graphical method shown in Fig. 3 should be applied.

CONCLUSIONS

1. The engineering technique of determining the nature of loading on the elements in medium speed mode of screw conveyor, on the casing and the screw working body in particular is developed. The speeds of bulk material transportation periodically change when the augers with axis motion are used. This fact improves the process of mixing the bulk materials.

2. The analytical dependences to determine the parameters during transportation of the given bulk material are developed. These dependences can be widely used in designing the screw transport and technological systems.

3. Analysing the graphs in 2 and 3, the following conclusions should be made. First, if the inclination angle of a vertical screw conveyor increases, the minimum axial force of material feed increases as well. Second, to reduce the minimum axial force of material feed by 5-7%, the horizontal auger should be set with a positive inclination angle β of the axis of a horizontal screw working body to the horizontal. The positive inclination angle β ranges within 3-20 degrees. Third, the greater the inclination angle of a vertical auger is, the greater should be the inclination angle of a horizontal auger.

REFERENCES

1. **Grygoryev A.M. 1972.** Screw conveyors / A.M. Grygoryev. – M.: Mechanical Engineering, 184.
2. **Zenkov R.M. 1987.** Continuous transport machines / R.M.Zenkov, I.I.Ivankov, L.N.Kolobov. – M.: Mechanical Engineering, 320.
3. **Rohatynskyi R.M., Hevko I.B., Diachun A.Y. 2014.** The scientific and applied fundamentals of screw transport and technological mechanisms. Ternopil, TNTU, 280.
4. **Pavlyshche V.T. 1993.** The basis of design and machine parts calculation. – K.: "Vyshcha shkola", 555.
5. **Ivanchenko F.K. 1993.** Lifting-and-transport machines. – K.: Vyshcha shkola, 412.
6. **Aleksandrov M. P. 1974.** Lifting and transport machines Mechanical engineering, 503.
7. **All Union State Standards Screw conveyors for feedstuff. Main parameters. 1980.** AUSS 23976 – 80 – M.: Standards publisher, 19. (National standards of Ukraine);
8. **All Union State Standards Augers for agricultural machinery. 1973.** AUSS 2705 - 73. – Standards publisher, 16. (National standards of Ukraine).
9. **Hewko I. 2011**. Model of loading on the screw working bodies (Моделювання характеру навантаження на гвинтові робочі органи) Bulletin TNTU. –V. 16. № 1. 69-77.
10. **Hewko B.M. 1989**. Screw falling mechanisms of agricultural machinery. Higher school, 176.
11. **Rohatynskyi R.M. 1997.** Mechanical and technological backgrounds of interaction of screw working bodies with agricultural raw materials: the thesis of Doctor of Sciences (Engineering) 05.20.01, 05.05.05 / Rohatynskyi Roman Mykhailovych, 502.
12. **Volkov R .A., Gnutov A. N., Diachkov V. K. and others. 1984.** Conveyors: Guide – under the editionship of Y.A. Perten. – Mechanical engineering, 367
13. **Gevko R.B. 2011.** Obgruntuvannya parametriv konstruktsiyi robochogo organu shaybovogo transportera. Visnik Kharkivskogo natsionalnogo tehnichnogo universitetu Imeni Petra Vasilenka. – Vipusk 114. 241-246.
14. **Aleksey Popov 2010.** Новая теория контактной прочности упруго сжатых тел // MOTROL. Commission of Motorization and Power Industry in Agriculture Polish Academy of Sciences Branch of Lublin Ropczyce School of Engineering and Management. – Lublin, – Tom 12A. 223-232.
15. **Loveykin V.S. 2011.** Bagatomasova model dinamiki ruhu kormozmishuvacha gvintovogo tipu zi zminnim oporom // MOTROL. Commis-sion of Motorization and Energetics in Agriculture – Lublin, Vol. 13B. 124-129.
16. **Loveykin V., Javorska A. 2012.** Screw feeder: optimization of motion modes considering that the moments of resistance forces change under linear law Motrol. Motoryzacja i Energetyka Vol. 14/3. 40-46.
17. **Adigamov K.A., Baibara S.N., Chernenko G.V.** 2009. Critical frequency of the vertical screw rotation. Digest of the East-Ukrainian National University named after Volodymyr Dal. – №2 (132). 9-10.
18. **Nilsson L.G. 1971.** On the vertical serew conveyor for non- cohesive bulk materials. Acta polytechnica Scandinavica. 4 Stokholm, 96.
19. **Fernandez J.W, Cleary P.W., Mcbride W., 2009.** Effect of screw design on hopper draw dawn to a horizontal screw feeder, Seventh International Conference on CFD in the Minerals and Process Industries CSIRO, Melbourne, Australia 9-11 Decem.
20. **Lytvynov O., Tana W. 2006.** Towards the dynamic calculation of machines. Motrol. Tom 8A, - pg. 210-223.