DEVELOPMENT OF DESIGN AND INVESTIGATION OF OPERATION PROCESSES OF LOADING PIPES OF SCREW CONVEYORS
/
РОЗРОБКА КОНСТРУКЦІЙ ТА ДОСЛІДЖЕННЯ ПРОЦЕСІВ РОБОТИ ЗАВАНТАЖУВАЛЬНИХ ПАТРУБКІВ ГВИНТОВИХ КОНВЕЄРІВ

Prof. Ph.D. Eng Hevko R.B.[1)], Ph.D. Eng. Rozum R.I.[1)], Ph.D. Eng. Klendii O.M.[2)]
[1)]Ternopil National Economic University / Ukraine; [2)]Separated Subdivision of National University of Life and Environmental Sciences of Ukraine Berezhany Agrotechnical Institute / Ukraine
E-mail: alex_ks@mail.ru

Keywords: *flexible screw conveyer, loading pipe, conveying loose materials*

ABSTRACT
Having analyzed the designs and the quality indices of process performance for loading loose materials by screw conveyors, new ways and engineering solutions for loading materials into an input flow pipe-line have been suggested. Load analysis has been conducted and analytic dependences of the operation process of cam and link-leverage slewing mechanisms of loading pipe activator have been deduced. Movement patterns of a flow pipe-line in the process of loading pipe operation have been investigated. Experimental studies have been conducted and rational operational parameters and modes for the designed pipes have been determined.

РЕЗЮМЕ
На основі проведеного аналізу конструкцій та показників якості виконання технологічних процесів завантаження сипких матеріалів гвинтовими конвеєрами, запропоновано нові способи та технічні рішення завантаження матеріалом вхідної технологічної магістралі. Проведений силовий аналіз та виведено аналітичні залежності процесу роботи кулачкового та шарнірно-важільного механізмів повороту активатора завантажувального патрубка. Досліджено закономірності траєкторії переміщення технологічної магістралі під час роботи завантажувального патрубка. Проведені експериментальні дослідження та встановлено раціональні параметри і режими роботи розроблених патрубків.

INTRODUCTION
A review of scientific and patent literature, technical and economic performance of flexible screw conveyors and processes of conveying loose materials in flow pipe-lines *(Boyko A.I. et al., 2011; Vitrovyi A.O., et al., 2012; Klendiy M.B., 2006,2007; Hevko I.B., 2008; Hu G. et al., 2010; Loveikin V. et al., 2012 Pylypets M.I. 2002 and Rohatynskyi P.M., 2014)* shows that they satisfy most of the requirements to a certain extend, but most of these mechanisms require constant operator intervention. That is why, in order to improve the operation of conveyors it is necessary to pay more attention to the development of loading devices of screw conveyors. In addition to that, an important factor is minimization of material capacity of screw conveyors, which, on the one hand, allows reducing their cost and on the other hand, decreasing power inputs in order to convey loose materials. Moreover, it is necessary to provide maximum possible limits for regulating design and kinematic parameters of operating elements as well as to provide fast replacement of technological units for the adjustment of the machines to specific production conditions.

MATERIAL AND METHOD
The aim of this research work was designing, constructing and testing loading pipes of screw conveyors and the determining the effect of the design and kinematic parameters of operating elements on technological process performance.

The effectiveness of the operation of flexible screw conveyors, which depends greatly on the value of the operating efficiency of pipe-lines, is determined by the design concept of a loading pipe. The existing designs of loading pipes require constant conveying of loose materials in a flow pipe-line, which is mostly done by an operator.

The given researches are a continuation of previously conducted ones*(Hevko R.B. et. al., 2014; Hevko R.B., et.al., 2015; Hevko R.B., et.al., 2016; Klendii M.B. and Klendii O.M., 2016).*

In order to solve the given tasks, structural and mechanical diagram of a flexible screw conveyor with a loading pipe has been developed and its experimental sample has been designed, which is shown in Figure 1. It is designed in the form of a base 4, where there is a loading pipe 5 fixed, which provides the transfer of loose materials from a loading flow pipe-line 3 to an unloading one 6 and also the drive of the operating elements located in a cantilever. At the free end of a loading flow pipe-line the developed designs of loading pipes 2 are arranged *(Hevko R.B. and Rozum R.I., 2003; Danylchenko M.H. et. al., 2004)*, which interact directly with the heap of loose materials 1.

Figure 2 presents the design concept of an self-loading pipe with a cam (Fig.2a) and link-leverage (Fig.2b) slewing mechanisms of activators. A pipe includes a helical spiral 2, which is arranged in a cylindrical catcher 3 with separation ports and transfers to an elastic casing 1. An output shaft 4 of a helical spiral is connected to active driving elements 5 through a slewing mechanism 6.

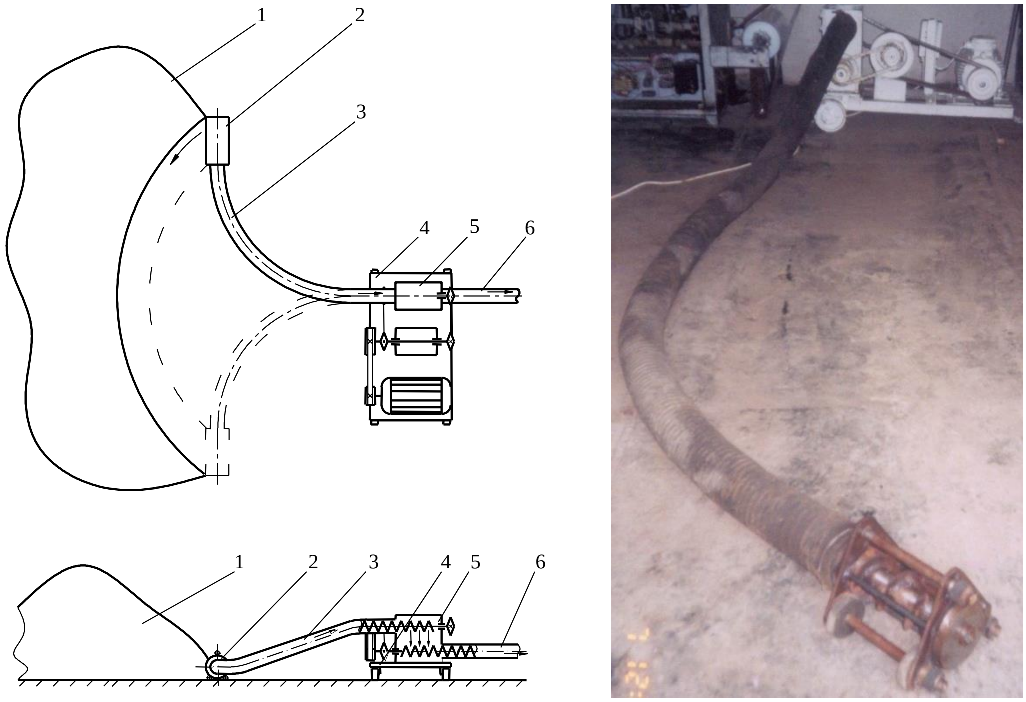

Fig. 1 - Structural and mechanical diagram of a screw conveyor with a loading pipe

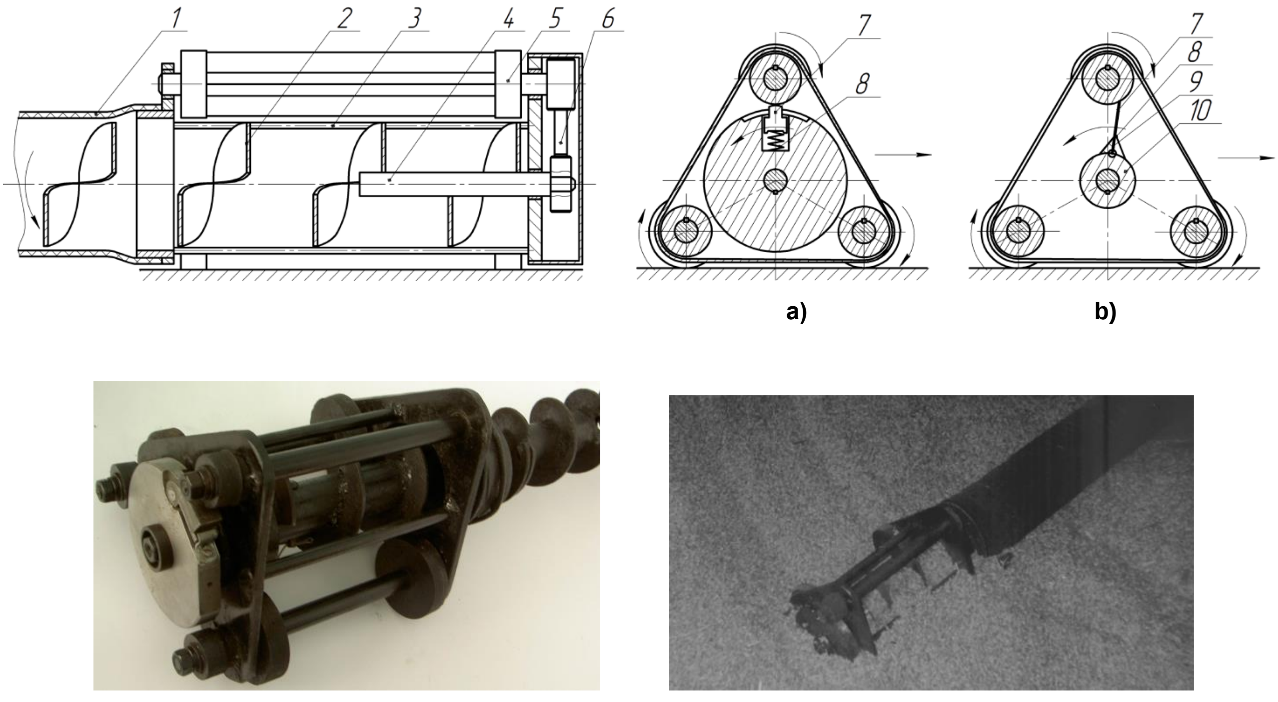

Fig. 2 - Design concept and overview of self-loading pipes

In the first case, a slewing mechanism of activators is made in the form of a radial placed cam *7*, which is spring-loaded *8* toward active driving elements. In the second case, it is made in the form of a disc *10*, which is arranged on an output shaft of a helical spiral, where there is a lever *7* hinged to it, which periodically interacts with activators and is spring-loaded *8* toward a damping catcher *9* of a turning angle of a lever.

In the operation process torque from an output shaft of a helical spiral is imposed through a slewing mechanism on activators, which, when rotating, excite loose materials and, at the same time, transfer self-loading pipe toward the heap of materials as the intake proceeds.

When substantiating rational design and load parameters of a slewing mechanism of activators, two variants of their construction have been considered in order to choose the optimum diagram of a loading pipe, which should be able to provide the intensification of the process of material feed as the intake proceeds.

A design diagram used for the determination of the interrelation between constructive and load parameters of the elements linking a loading pipe and a cam slewing mechanism of activators is shown in Figure 3.

In the diagram *h* denotes the distance between the centre of an activator and a disc centre; r_a denotes the radius of an activator; *r* is written for the radius of a cam; *δ* denotes the clearance between an activator surface and a disc surface; *m* is written for the decentralisation of a cam hemisphere relative to a disc surface; *k* denotes the distance from the centre of a cam hemisphere to the centre of a disc; *l* denotes the arm of action *N*; *z* denotes the arm of action of friction force $F^{з}_{fr}$; *φ* is written for an angle of disc rotation; F_{sp} denotes spring pressure; F^{n}_{fr} denotes friction force in the cam – groove pair of a disc; $F^{з}_{fr}$ denotes friction force in a cam – activator pair; *N* denotes reaction force from the interaction of a cam surface and an activator surface.

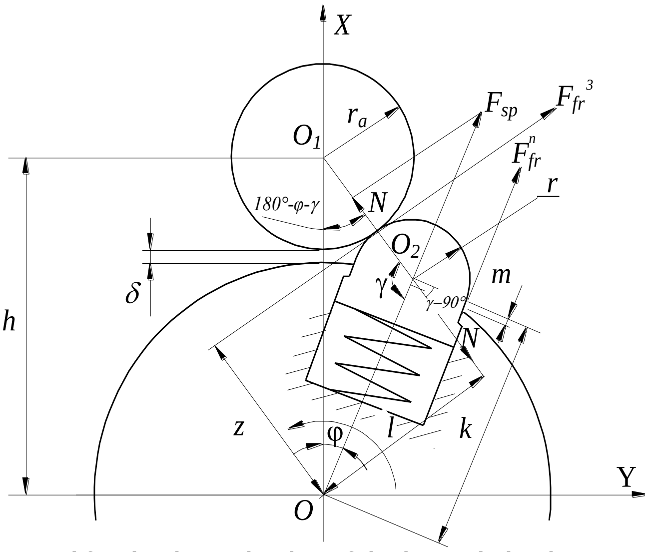

Fig. 3 - A design diagram used for the determination of the interrelation between constructive and load parameters of the elements linking a loading pipe and a cam slewing mechanism of activators

On the basis of the conducted theoretical investigation, equation systems for the determination of torque from the design parameters of the elements of linkage and also a pattern angle *φ* of rotation of a cam relative to an end disc activator have been produced.

Activator torque is determined by the following equation system:

$$\begin{cases} T_a = NfR; \\ N = -C(\Delta_0 + \Delta)\left[1 - 0{,}5 f \sin 2\gamma\right]\cos\gamma; \\ \Delta = h - R - \delta - m - k; \\ k = h\cos\varphi - \sqrt{(R+r)^2 - h^2\sin^2\varphi}; \\ \gamma = \left[180° - \arcsin\left(\dfrac{h\sin\varphi}{R+r}\right)\right]. \end{cases} \tag{1}$$

where *C* – spring stiffness; Δ_0 – value of spring pretension; Δ – travelling value of spring deflection.

Since peak torques arise at the first stage of the interaction of a cam with an activator, limits of angle φ change is chosen to be from φ_{max} (cam engagement into the contact with an activator) to $\varphi = 0$ (vertical installation of their central axis).

Value φ_{max} is determined by the following dependence:

$$\varphi_{\max} = \arccos\left(\frac{h^2 + k_n^2 - (R+r)^2}{2hk_n}\right) \tag{2}$$

where $k_n = h - R - \delta - m$.

A design diagram used for the determination of the interrelation between constructive and load parameters of the elements linking a loading pipe and a link-leverage slewing mechanism of activators is shown in Figure 4.

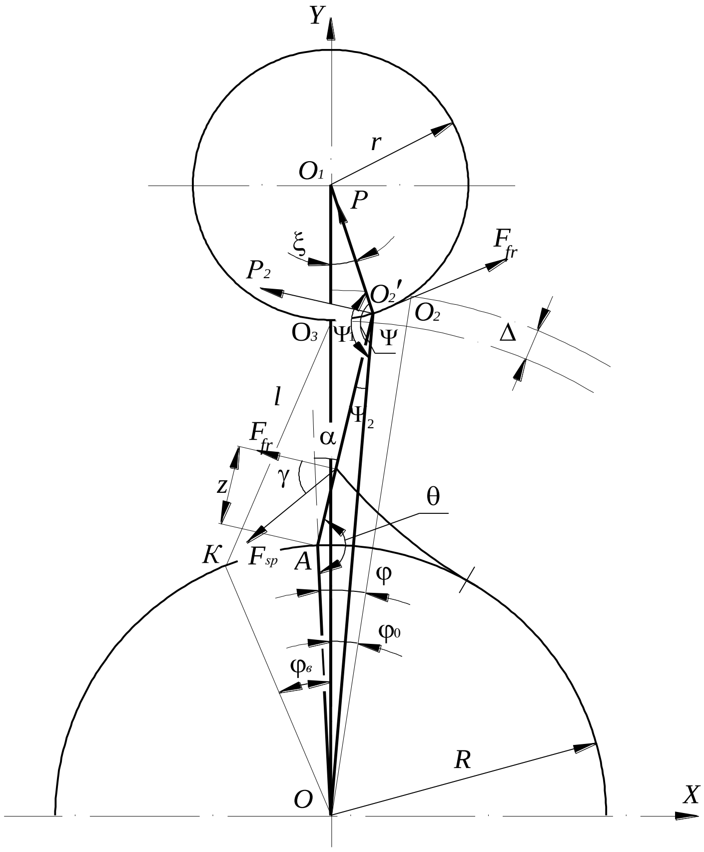

Fig. 4 - Diagram used for determination of constructive and load parameters of a loading pipe with link-leverage slewing mechanism of activators

Activator torque is defined as the function of an angle of cage rotation ($T_a = f(\varphi)$) and takes the following form:

$$\begin{cases} T_a = \dfrac{EIz^2 f\pi}{l \cdot l_{sp}^3 \cdot 60^\circ} l_n(\alpha)\cos\gamma\sin\Psi; \\ \Psi = \arcsin\left(\dfrac{(R+l-\Delta+r)\sin\xi}{\sqrt{R^2+l^2-2Rl\cos\theta}}\right) - \arcsin\left(\dfrac{R\sin\theta}{\sqrt{R^2+l^2-2Rl\cos\theta}}\right); \\ l_n = (R+l-\Delta+r)\sin\xi; \\ \xi = \arccos\left(\dfrac{r^2+(R+l-\Delta+r)^2-R^2-l^2-2Rl\cos\alpha}{2r(R+l-\Delta+r)}\right). \end{cases} \tag{3}$$

Where: *I* denotes the inertia moment of a flat spring; *E* denotes the modulus of elasticity of a flat spring; *R* denotes the radius of a disc; l denotes the length of a hinged lever; l_{sp} denotes the length of a spring beam;

$l_n^з$ denotes the arm of action of friction force; *Δ* denotes lever and activator overlapping $\Theta = 180^0 - \alpha$.

The deduced equation system gives the opportunity to evaluate the influence of the design elements of a loading pipe on the value of activator torque needed for its self-movement in the process of the material intake with the turning angle of a lever *α*.

In order to take into consideration load factors, which arise when there is a change in the radius of curvature *ρ* of an elastic casing with a loading pipe and according to its movement pattern, a diagram of a flow pipe-line load has been considered (Fig.5).

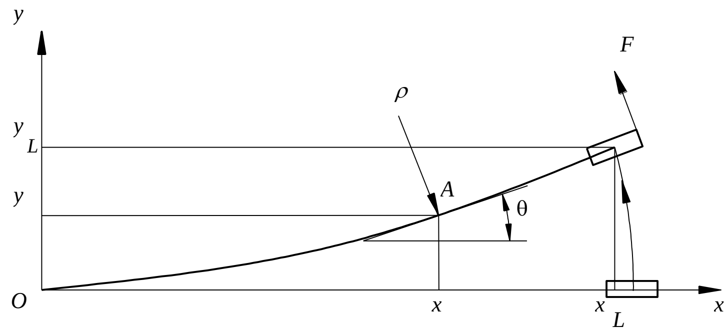

Fig. 5 - A design diagram of a flow pipe-line load

A travelling moment, which causes a change in the curvature of routing by independent variables, namely a bend angle θ and a travelling length *S*, has been determined from the following formula:

$$M(x) = M(\theta) = F\left[\sin\theta_L \int_l^L \sin\theta \cdot dS + \cos\theta_L \int_l^L \cos\theta \cdot dS\right] \quad (4)$$

where *F* denotes equal driving force applied to a pipe, taking into account clamp resistance.

Based on the results of the investigations, the flow routing of a flexible screw conveyor has been simulated using a chain curve, the parametric equation of which, depending on the parameter *S,* takes the following form:

$$x = \frac{C_\varphi}{M} \cdot \ln\left(\frac{S \cdot M}{C_\varphi} + \sqrt{\frac{S^2 \cdot M^2}{C_\varphi^2} + 1}\right) \quad (5)$$

$$y = \sqrt{\frac{C_\varphi^2}{M^2} + S^2} - \frac{C_\varphi}{M} \quad (6)$$

Movement increase of a pipe with coordinates x_L, y_L at variable moment *M*:

$$du_L = u'_y y'_M dM = \frac{C_\varphi}{M^2}\left(L\sqrt{1 + \frac{C_\varphi^2}{M^2 L^2}} - \frac{C_\varphi}{M}\right) dM \; . \quad (7)$$

RESULTS

In order to analyze equation system (1), namely functional relationships, $T_a = f(\varphi)$ the following parameter values were taken: *h* = 74 mm ; *R* = 22 mm; *δ* = 2 mm; *m* = 2 mm; *C* = 10 N/m; Δ_0 = 5 mm; *f* = 0.17. Value φ_{max} = 12.37°.

Using the obtained results it has been determined, that the maximum cam torque corresponds to the moments of its engagement with an end disk and corresponds to the angles of rotation *φ* = 8°-12°.

When an activator becomes jammed, torque increases by 28% compared to the unrestricted turning of an activator.

Activator torque has reverse absolute value trend and its maximum value is *α=0°*. It can be explained by the fact, that an activator arm is permanent.

Graphical dependencies presented here must be used in order to determine rational design parameters of a loading pipe and also their operating modes.

In order to analyze equation system (3), the following parameter values were taken: h=0.074 m; R=0.025 m; Δ=0.003 m; r_a=0.022 m; l=0.03 m; f=0.17; l_{sp}=0.03 m; γ=60^0; z= 0.02 m, I=5.63·10^{-12} m^4.

Using the obtained results it has been determined, that regarding a link-leverage slewing mechanism of activators, the most essential influence on the value of activator torque T_a is exerted by the length of a hinged lever l and the inertia moment of a flat spring I. The limits of rational parameters have been determined: the radius of a disc 0.02...0.03 m, the length of a hinged lever 0.025...0.035 m, the diameter of an activator 0.02...0.024 m, lever and activator overlapping value 0.002...0.004 m.

Using the investigation results of the mechanical trajectory of a loading flow pipe-line (equations 4-7) and the movement of a loading pipe depending on bending moment M, the corresponding motion trajectories have been defined (Fig.6). The following parameter values were taken: unit stiffness C_φ = 500 Nm^2; the length of a flow pipe-line L = 6 m.

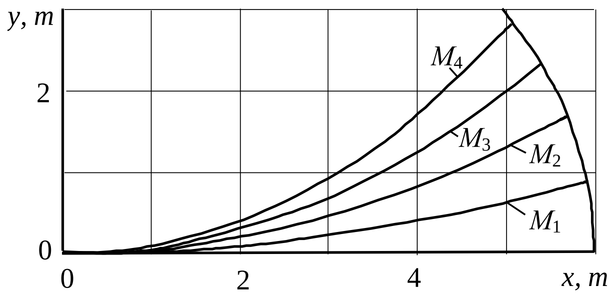

Fig. 6 - Motion trajectories of a loading flow pipe-line and movement of a loading pipe depending on bending moment M: M_1 = 25 Nm; M_2 = 50 Nm; M_3 = 75 Nm; M_4 = 100 Nm

In order to examine the developed designs of loading pipes under actual operating conditions, a pilot plant of a flexible screw conveyor has been constructed. It has been made in the form of a base, where there is a loading pipe fixed, which provides the transfer of loose materials from a loading flow pipe-line to an unloading one and also the drive of the operating elements located in cantilever. At the free end of a loading flow pipe-line the developed designs of loading pipes are arranged, which interact directly with loose materials.

A complex experiment using the pilot plant of a flexible screw conveyor has been conducted and, as a result, a regressive dependence, showing its efficiency characteristic $У$ from the rotation frequency of a conveyor helix n, the clearance between an activator surface and a disc surface δ and spring force F_{sp}, has been obtained

$$У = -5.69 + 0.0163n + 430\delta + 0.031F_{sp}. \quad (8)$$

It has been stated that in the operation process of a flexible screw conveyor, equipped with the developed self-loading pipe with a cam slewing mechanism of activators, with the following range of parameter variations: 400 < n < 600 (r/m), 0,002 < δ < 0,004 (m), 10 < F_{sp} < 50 (N), the greatest influence on the process of material intake and the productivity of a conveyor respectively is exerted by the rotation frequency of an operating helix. In addition to that, the increase of values δ and F_{sp} leads to the increase in the process efficiency of loading loose materials into a flexible casing, but their influence in this range of parameter variations is halved.

The determination of a functional dependence between tractive force P on a loading pipe and the value of its cross travel l is needed for defining the value of activator torque, which would provide the movement of a flow pipe-line.

In the process of investigation, force at the beginning of a loading pipe movement together with a flexible casing (that is to say, their transition from a static position into a moving position) have been determined first and, in addition, movement force at the specified values of lateral position (l = 1, 2, 3 m) has been defined as well.

The results of the experimental studies show, that break-down force of a pipe-line from its static position, when a pipe is placed in certain positions, is twice as much as the travel force in these positions. Movement force of a pipe-line without stopping from its initial position to the position, that corresponds to l = 3 m, exceeds movement force of a pipe-line, needed to reach the same position with discrete stops by 13 %.

Taking into consideration the obtained values of tractive force, torque of moving a loading pipe of a flow pipe-line for various standard sizes of supporting rollers with radius r_o has been determined. In case of emergency with a curved four meter pipe-line: $P \approx 100$ N; $r_o = 0.03$m. Then $T_a = Pr_o = 3$ Nm.

Methodology has been developed and experimental studies have been conducted in order to determine the value of the maximum torque for the turning of activators in various loose mediums. Here the width and the height of loose material column were the same.

It has been stated, that for activator turning in loose medium the maximum torque at which the material is shifted by a beater blade, is the following: for bran – 0.31Nm; barley – 0.58Nm; wheat – 0.96Nm.

Having analyzed the results of the experimental studies for certain specified concrete design and process parameters, it can be stated, that torque, which is to provide the appropriate tractive force of a flow pipe-line far exceeds the torque needed for activator turning in loose medium. That is why, design and load parameters of the elements of a loading pipe must be selected based on the tractive force, which is needed for pipe-line movement.

Unit design moment, which provides maximum deflection of a flexible screw, can be determined from the following formula:

$$M_{P\,max} = \frac{mgf}{2} L \tag{9}$$

Accordingly, the length of a flexible screw L, which services operating area with width B, must be chosen using the following statement:

$$L = \sqrt[3]{\frac{B^3}{4} + \frac{2BC_\varphi}{mgf}} \tag{10}$$

where unit stiffness of a conveyor C is specified experimentally in accordance with the following ration:

$$C_\varphi = \frac{F_e L_e^2}{2\theta_e} \tag{11}$$

Where: F_e, L_e and θ_e denote the experimental values of tractive force, the length of a flow pipe-line and the angle of deflection of a loading pipe respectively.

In process testing of a flexible screw conveyor, equipped with the developed self-loading pipe, the transporting grain material has shown the following results: if rotation frequency of a helical spiral is $n = 560$ r/m and the diameter is 96 mm, productivity of a conveyor is about 4600 kg/h.

CONCLUSIONS

Based on the analysis of the state and the development trends of the movement of loose materials in flexible screw conveyors, a new way of loading flow pipe-lines, which envisages the active use of a loading pipe, has been suggested. On the basis of this principle a flexible screw conveyor equipped with a loading pipe has been developed and made; in addition to this, its theoretical and experimental studies have been conducted.

Equation systems in order to determine interrelation between design and load parameters of cam and link-leverage slewing mechanism of activators have been deduced.

The analysis of the movement pattern of a flow pipe-line has given the opportunity to determine, that routing trajectory of a flexible screw can be approximated to the accuracy, sufficient for practical use, by a catenary line, the parameters of which are unit stiffness of a flow pipe-line and a bending moment, which is formed by a pipe drive. It has been determined, that at the stiffness of a flow pipe-line being $C_\varphi = 450...500$ Nm^2 and the length being $l = 4...6$ m the operating area is $B = 3.2...8$ m.

Methodology of conducting experimental studies of the elements and samples of self-loading pipes of flexible screw conveyors has been developed. It allows studying the influence that design and loading parameters of slewing mechanism of activators have on the performance of a loading pipe and the value of a flow pipe-line movement.

The conducted experimental studies of a cam slewing mechanism of activators gave the opportunity to determine the dependence of the maximum torque on the design parameters of the elements of linkage. As for link-leverage slewing mechanism, the change in the value of central plate torque depending on the turning angle of an activator has been determined. The difference between theoretical and experimental studies does not exceed 17%.

Based on the conducted complex experiment, regressive dependencies showing that the efficiency of the performance of a flexible screw conveyor equipped with the developed self-loading pipe is influenced by rotation frequency, the clearance between an activator and a disc and spring pretension, have been obtained.

Based on the investigation results, a design technique of the developed designs of screw self-loading pipes has been developed. The conducted process testing is indicative of the desirability for the application of such types of loading pipes in flexible screw conveyors when operating with loose materials of agricultural production.

REFERENCES

[1] Boyko A.I., Kulikiskiy V.L., (2011), Investigation of contact grain interaction in gap "coil-jacket" of screw feeders grain cleaning machines (Дослідження контактної взаємодії зерна в зазорі "виток-кожук" шнекових живильників зерноочисних машин). *Scientific Bulletin of NUBiP-K.: Red species. Department NUBiP 201*, Vol.166, Engineering and Energy AIC, P.1, pp.267-274;

[2] Danylchenko M.H., Rozum R.I., Hevko R.B., (2004), Pipe of a Screw Conveyor (Патрубок гвинтового конвеєра), Patent. 4003 Ukraine (2004), МРК 7 B65G33/16, 33/24. (Пат. 4003 Україна);

[3] Hevko I.B., (2008), Screw transporting-technological mechanisms. Calculation and designing (Гвинтові транспортно-технологічні механізми. Розрахунок і конструювання), *Bulletin of Ternopil Ivan Puliui State Technical University (Вісник Тернопільського державного технічного університету імені Івана Пулюя)*, p.307, Ternopil;

[4] Hevko R.B., Rozum R.I., (2003), A Loading Pipe of a Screw Conveyor (Завантажувальний патрубок гвинтового конвеєра), Patent. 61435 A Ukraine МРК 7 B65G33/16, B65G33/24;

[6] Hevko R.B., Dzyura V.O., Romanovsky R.M. (2014), Mathematical model of the pneumatic-screw conveyor screw mechanism operation, *INMATEH-Agricultural engineering Journal*, vol.44, no.3, pp.103-110, Bucharest / Romania;

[7] Hevko R.B., Zalutskyi S.Z., Tkachenko I.G., Klendii O.M., (2015), Development and investigation of reciprocating screw with flexible helical surface, *INMATEH-Agricultural engineering Journal*, vol. 46, no.2, pp.133-138, Bucharest / Romania;

[8] Hevko R.B., Klendiy M.B., Klendii O.M., (2016), Investigation of a transfer branch of a flexible screw conveyer, *INMATEH-Agricultural engineering Journal*, vol.48, no.1, pp.29-34, Bucharest / Romania;

[9] Hu G., Chen J., Jian B., Wan H., Liu L., (2010). Modelling and simulation of transportation system of screw conveyors by the discrete element method, *International Conference on Mechanic Automation and Control Engineering*, *MACE2010*, Article number 5536244, pp.927-930;

[10] Klendiy M.B., (2006). Investigation of transfer process of bilk load by screw operating devices (Дослідження процесу перевантаження сипкого вантажу гвинтовими робочими органами), Bulletin *of Ternopil Ivan Puliui State Technical University (Вісник Тернопільського державного технічного університету імені Івана Пулюя*), Vol.3, pp.92-100, Ternopil;

[11] Klendiy M.B., Klendii O.M., (2016), Interrelation between incidence angle and roll angle of concave disks of soil tillage implements, *INMATEH-Agricultural engineering Journal*, vol.49, no.2, pp.13-20, Bucharest / Romania;

[12] Klendiy M.B., (2007), Development and parameters validation of paddle conveyor-mixer design (Розробка конструкції та обґрунтування параметрів лопатевого транспортера-змішувача), *Scientific Bulletin of National Agricultural University*, Vol.92, P.2, pp.533-540;

[13] Loveikin V., Chovniuk Yu., Kulyk V., (2012), Optimizatsii a rezhimov kolebanii zernovykh smesei pri nalichii sukhogo treniia, *Motrol – Motoryzacja I energetyka rolnictva*, Vol.14, v3, pp.140-149, Lublin;

[14] Pylypets M.I., (2002), Scientifical and technological bases of production coiling machine parts billet (Науково-технологічні основи виробництва навивних заготовок деталей машин): PhD.Thesis *Engineering Sciences specials (автореф. дис. на здобуття наук. ступеня доктора техн. наук)*., pp.35, Lviv;

[15] Rohatynskyi R.M. and others, (2014), Scientific and applied backgrounds of creating the screw transport and technological mechanisms (Науково-прикладні основи створення гвинтових транспортно-технологічних механізмів), *Bulletin of Ternopil Ivan Puliui Nationai Technical University (Вісник Тернопільського yfwsjyfktного технічного університету імені Івана Пулюя)*, pp.278, Ternopil;

[16] Vitrovyi A.O., Pik A.I., Hevko R.B., (2012), Advance in technology of flexible screw conveyers: monograph (Підвищення технічного рівня гнучких гвинтових конвеєрів: монографія), Aston, p.204.