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THE DYNAMIC PROCESSES DURING THE TELESCOPIC SCREW TRANSPORTERS' WORK

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Summary. *The article analyzes the problem of using telescopic screw conveyors, determines the factors that negatively influence the process of moving bulk cargo by this type of transport. In order to confirm the results of theoretical research, the existing module of the conveyor was designed and manufactured and a series of experiments were conducted.*

Key words*: telescopic ginger transportation, screw, bending fluctuations, torsional oscillations, rotation.*

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Problem statement. Telescopic screw conveyors designed to move bulk media can rotate at significant angular speeds (up to 800 rpm and above). Actual non-uniform inclusions in the environment, asymmetries of the telescopic screw and external disturbances lead in many cases to its oscillations, and then to significant dynamic loads in it [1]. Their magnitude increases in so-called resonance cases. In addition, the conveyor screw performs usually complex vibrations: a combination of bending and torsional. Examining such complex processes even if the conveyor screw can be considered a one-dimensional resilient body is a difficult task. At the same time, as the results of the tests show, in some cases even without environment movement and external periodic disturbances, the intensity of bending oscillations increases significantly [1–3]. This can be explained only by the interaction of some forms of oscillation with others. It is the research of the above phenomena in the telescopic screw – loose environment system when moving the loose environment that will make it possible to select in advance the mode of operation of the conveyor, which makes the above processes impossible, and then increase the service life of the telescopic screw conveyor.

Analysis of recent research and publications. Issues of telescopic screw conveyors, dynamic processes in the process of their work are devoted to the work of R. M. Rogatynskyi [1], I. B. Hevko [2], A. L. Lyashuk [3], I. B. Sokil [4–7], etc. Special attention was paid by the researchers to the issues of selection of parameters of working bodies and study of cargo transportation processes. However, the problem of increasing productivity by improving the transportation process always remains relevant and requires further research.

The goal of the work. To build a mathematical model of dynamics telescopic screw – loose environment.

Implementation of the work. In many cases, in universal agricultural cargo transfer units, in order to achieve the required overloading distance, the screw conveyor is complicated and decomposed-compiled by means of a hydro- or pnemo equipment, making its design too complex and expensive. Therefore, the use of the telescope principle in screw conveyors has wide application in various designs of agricultural and other machinery.

Studies have been carried out to analyse the functioning of telescopic screw conveyors. In a number of works [4–7], the effect of the motion of the solid flow of the loose environment on the longitudinal or bending oscillations of the elastic bodies has been studied. On their basis, it can be argued that even the speed of movement of the loose environment changes the main

Corresponding author: Viktor Hud; e-mail: vic_g@ukr.net dynamic characteristics of single-mold (bending or longitudinal) oscillations. The amount of environment exposure increases significantly with the relative amount of its motion. As for the telescopic screw system – loose environment, then:

- first, the telescopic screw rotates at a considerable angular speed, which means that even slight lateral deformations at some point in time (the nature of which may vary) cause significant stresses;
- second, the relative movement of the loose environment along the screw provides its mathematical model of bending oscillations of a qualitatively new kind – the appearance in it of a mixed derivative of linear and time variables. It is with the help of said composition that the influence relative to the screw of the loose environment is partially taken into account;
- third, the working telescopic screw is an elastic body, which rotates, so that due to partial wedging, non-uniformity of the medium and other reasons it additionally performs even torsional oscillations.

By the amplitude of torsional oscillations, as the results of studies [1] show in most cases, the maximum relative linear movements of the external points of the screw due to torsional oscillations are much less than the linear movements due to its bending oscillations. The above can serve as a basis for some simplification of the mathematical model of the dynamics of the screw – loose environment system. Its essence consists in the following: in the mathematical model of bending oscillations of the investigated system it is assumed that torsional oscillations cause a small amount of periodic action on bending. The main parameters of this action (first of all frequency) can be determined on the basis of the main characteristics of the screw: its linear mass, moment of inertia, elastic characteristics of the material [8] or by partial processing of experimental data [9].

It is known [10] that a mathematical model of bending oscillations of an elastic body, which rotates along a fixed axis Ω at a constant angular velocity provided that a continuous flow of a uniform zero stiffness environment moves along it at a constant relative linear velocity V is a system of differential equations:

$$\begin{gathered}
(\rho_1+\rho_2)\frac{\partial^2 u}{\partial t^2}+2\rho_2 V\frac{\partial^2 u}{\partial t\partial z}-2(\rho_1+\rho_2)\Omega\frac{\partial w}{\partial t}+\rho_2 V^2\frac{\partial^2 u}{\partial z^2}-\\
-2(\rho_1+\rho_2)I\Omega\frac{\partial^3 w}{\partial t\partial x^2}+EI\frac{\partial^4 u}{\partial z^4}-(\rho_1+\rho_2)\Omega^2 u==\varepsilon f\left(u,w,\frac{\partial u}{\partial t},\frac{\partial w}{\partial t},\frac{\partial u}{\partial z},\frac{\partial w}{\partial z},\ldots,\frac{\partial^3 u}{\partial z^3},\frac{\partial^3 w}{\partial z^3},\gamma\right)\\
(\rho_1+\rho_2)\frac{\partial^2 w}{\partial t^2}+2\rho_2 V\frac{\partial^2 w}{\partial t\partial z}+2(\rho_1+\rho_2)\Omega\frac{\partial u}{\partial t}+\rho_2 V^2\frac{\partial^2 w}{\partial z^2}+\\
+2(\rho_1+\rho_2)I\Omega\frac{\partial^3 u}{\partial t\partial x^2}+EI\frac{\partial^4 w}{\partial z^4}-(\rho_1+\rho_2)\Omega^2 w=\varepsilon g\left(u,w,\frac{\partial u}{\partial t},\frac{\partial w}{\partial t},\frac{\partial u}{\partial z},\frac{\partial w}{\partial z},\ldots,\frac{\partial^3 u}{\partial z^3},\frac{\partial^3 w}{\partial z^3},\gamma\right)
\end{gathered}\tag{1}$$

In (1) $u(t,z), w(t,z)$ – projections of the displacement vector of the point of the central axis with the coordinate z of the telescopic screw at an arbitrary moment of time t in projections on the axis of the fixed coordinate system $OXYZ$. Here OZ of the said reference system coincides with the unformed straight position of the screw, Ω – an angular speed of screw rotation around the specified axis, ρ_1, ρ_2 – weight of body and moving medium unit of length respectively, EI – its bending stiffness of the screw, $f\left(u,w,\frac{\partial u}{\partial t},\frac{\partial w}{\partial t},\frac{\partial u}{\partial z},\frac{\partial w}{\partial z},\ldots,\frac{\partial^3 u}{\partial z^3},\frac{\partial^3 w}{\partial z^3},\gamma\right)$ and $g\left(u,w,\frac{\partial u}{\partial t},\frac{\partial w}{\partial t},\frac{\partial u}{\partial z},\frac{\partial w}{\partial z},\ldots,\frac{\partial^3 u}{\partial z^3},\frac{\partial^3 w}{\partial z^3},\gamma\right)$ – 2π – periodic for $\gamma=\nu t+\gamma_0$ functions describing nonlinear components of reducing force, resistance forces and other forces, the maximum value of which is considerably less than the value of reducing force, as indicated by a small parameter ε.

Below, for the sake of simplicity, we will assume that these functions are polynomial in terms of the set of variables, and that their physical content implies that they must be related by a relationship $f\left(u,w,\frac{\partial u}{\partial t},\frac{\partial w}{\partial t},\frac{\partial u}{\partial z},\frac{\partial w}{\partial z},\dots,\frac{\partial^3 u}{\partial z^3},\frac{\partial^3 w}{\partial z^3},\gamma\right)=g\left(w,u,\frac{\partial w}{\partial t},\frac{\partial u}{\partial t},\frac{\partial w}{\partial z},\frac{\partial u}{\partial z},\dots,\frac{\partial^3 w}{\partial z^3},\frac{\partial^3 u}{\partial z^3},\gamma\right)$.

As for the complex vibrations of the screw (combination of bending and torsional), provided that the latter are described by known law $\vartheta(z,t)$ (hereinafter considered torsional to correspond to their simple mathematical models) the system of equations (1) is transformed to the form:

$$
\begin{gathered}
(\rho_1+\rho_2)\frac{\partial^2 u}{\partial t^2}+2\rho_2 V\frac{\partial^2 u}{\partial t\partial z}-2(\rho_1+\rho_2)\left(\Omega+\frac{\partial\vartheta(z,t)}{\partial t}\right)\frac{\partial w}{\partial t}+\rho_2 V^2\frac{\partial^2 u}{\partial z^2}-\\
-2(\rho_1+\rho_2)I\left(\Omega+\frac{\partial\vartheta(z,t)}{\partial t}\right)\frac{\partial^3 w}{\partial t\partial x^2}+EI\frac{\partial^4 u}{\partial z^4}-(\rho_1+\rho_2)\left(\Omega+\frac{\partial\vartheta(z,t)}{\partial t}\right)^2 u-(\rho_1+\rho_2)\frac{\partial^2\vartheta(z,t)}{\partial t^2}w=\\
=\varepsilon f_1\left(u,w,\frac{\partial u}{\partial t},\dots,\frac{\partial^3 w}{\partial z^3},\gamma\right),\\
(\rho_1+\rho_2)\frac{\partial^2 w}{\partial t^2}+2\rho_2 V\frac{\partial^2 w}{\partial t\partial z}+2(\rho_1+\rho_2)\left(\Omega+\frac{\partial\vartheta(z,t)}{\partial t}\right)\frac{\partial u}{\partial t}+\rho_2 V^2\frac{\partial^2 w}{\partial z^2}+\\
+2(\rho_1+\rho_2)I\left(\Omega+\frac{\partial\vartheta(z,t)}{\partial t}\right)\frac{\partial^3 u}{\partial t\partial x^2}+EI\frac{\partial^4 w}{\partial z^4}-(\rho_1+\rho_2)\left(\Omega+\frac{\partial\vartheta(z,t)}{\partial t}\right)^2 w+\\
+(\rho_1+\rho_2)\frac{\partial^2\vartheta(z,t)}{\partial t^2}u=\varepsilon f_2\left(u,w,\frac{\partial u}{\partial t},\dots,\frac{\partial^3 w}{\partial z^3},\gamma\right)
\end{gathered}
\tag{2}
$$

The last two components in the left-hand part of equations (2) express the components of inertia forces of the conventionally separated element of the telescopic screw and they are caused by the non-uniform deformed rotation thereof (relative torsional oscillations).

The dynamic process of the screw depends not only on power and kinematic ($\frac{\partial\vartheta(z,t)}{\partial t},\frac{\partial^2\vartheta(z,t)}{\partial t^2},\Omega,V$) factors, but on the method of fastening. In the case of its slowly adjustable length, the latter take the form:

$$
\begin{aligned}
&u(t,z)\big|_{z=0}=\left.\frac{\partial^2 u}{\partial z^2}\right|_{z=0}=0, \qquad w(t,z)\big|_{z=0}=\left.\frac{\partial^2 w}{\partial z^2}\right|_{z=0}=0,\\
&u(t,z)\big|_{z=l(\tau)}=\left.\frac{\partial^2 u}{\partial z^2}\right|_{z=l(\tau)}=0 \quad w(t,z)\big|_{z=l(\tau)}=\left.\frac{\partial^2 w}{\partial z^2}\right|_{z=l(\tau)}=0.
\end{aligned}
\tag{3}
$$

and correspond to the movement of the elastic screw in the bearings the distance between which is $l(\tau)$. It is in this way that the variable length of the screw is taken into account in the mathematical model and is $l(\tau)=l_0+\varepsilon k_1 t$, k_1 constant. The object is to describe the main parameters of bending oscillations of the screw provided that torsional oscillations are described by dependence:

$$\vartheta(x,t)=h\sin\frac{k\pi}{l(\tau)}z\cos\vartheta,\ \vartheta=(\Theta t+\vartheta_0), \tag{4}$$

in which a – their amplitude, $\Theta=\frac{k\pi}{l(\tau)}\sqrt{\frac{GJ_0}{I_0}}$ – frequency, ϑ_0 – initial phase, I_0 – linear moment of inertia relative to neutral axis of elastic body together with environment, J_0 – its equatorial moment of inertia, G – shear modulus.

In order to investigate the principle of telescoping in screw conveyors on the basis of the patent search and analysis of scientific literary sources and synthesis [11] was carried out, developed, designed and manufactured an experimental installation which is shown in Figures 1–3.

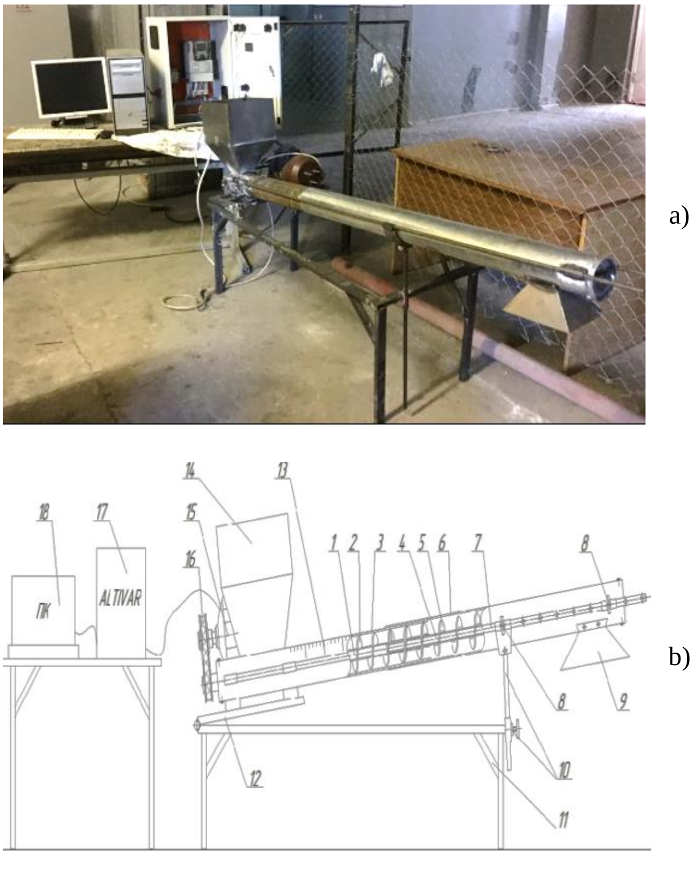

Figure 1. Stand to study the characteristics of telescopic screw conveyors: a) general view; b) structural scheme; 1 – axial motion of the screw section; 2 – a screw axial motion in the axial direction of the screw section; 3 – part of the casing is fixed in the axial direction; 4 – axial movement of the screw section; 5 – a screw moving in the axial direction of the screw section; 6 – is a part of the casing moving in the axial direction; 7 – guides; 8 – catches of guides; 9 – discharge nozzle; 10 – support for adjusting the height of the material; 11 – frame; 12 – mobile table; 13 – Scale of overlapping screws; 14 – bunker; 15 – electric drive of the conveyor; 16 – belt drive; 17 – converter of frequency of rotation of the drive; 18 – personal computer

Figure 2. Scale of the overhang of the stand screw to study the characteristics of telescopic screw conveyors

Figure 3. A stand for the study of telescopic screw conveyors in a disassembled state

In a research installation, the outer diameter of the screw is 97 mm; internal diameter of immovable branch pipe – 100 mm; external – 107 mm; internal diameter of movable branch pipe – 109 mm. Movable branch pipe is made of galvanized sheet and therefore it contains connecting seam and ovality and irregularities along the whole length, which affected speed of twisting and unwinding of telescopic part of screw conveyor.

As a result of the studies carried out, it has been found that the biggest problem in telescopic screw conveyors is maintaining the same gap between the casing and the spiral in the different sections of the telescope, which significantly affects the time of rolling out and rolling of the axially movable part of the screw to the stationary one and the occurrence and magnitude of the torsional and bending oscillations. It has also been found that the overloading capacity of agricultural cargoes by a telescopic screw conveyor does not differ from the overloading capacity of these materials by conventional screw conveyors.

Conclusions. It has been found that the greatest problem in telescopic screw conveyors is the maintenance of the same gap between the casing and the spiral in different sections of the telescope, which significantly affects the time of rolling out and rolling of the axially movable part of the screw to the stationary one and the occurrence and magnitude of bending and torsional oscillations during the movement of loose weights. It has been found that the capacity of overloading agricultural cargoes by a telescopic screw conveyor is similar to that of overloading these cargoes by conventional screw conveyors and does not vary from the value of rolling out and extending the telescopic part of the screw conveyor.

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ДИНАМІЧНІ ПРОЦЕСИ В ТЕЛЕСКОПІЧНИХ ГВИНТОВИХ ТРАНСПОРТЕРАХ

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Резюме. *Проведено аналіз проблеми використання телескопічних гвинтових конвеєрів, визначено фактори, які негативно впливають на процес переміщення сипких вантажів даним видом транспорту. Для підтвердження результатів теоретичних досліджень спроектовано й виготовлено діючу модуль конвеєра та проведено ряд дослідів. Як показують результати досліджень, для більшості випадків максимальні відносні лінійні переміщення зовнішніх точок гвинта, що зумовлені крутильними коливаннями, є набагато меншими за лінійні переміщення, які зумовлені його згинальними коливаннями. Це може служити підставою для деякого спрощення математичної моделі динаміки системи гвинт – сипке середовище. Його суть полягає у наступному: у математичній моделі згинальних коливань досліджуваної системи приймається, що крутильні коливання спричиняють малої величини періодичну дію на згинальні. Саме дослідження вказаних явищ у системі телескопічний гвинт – сипке середовище під час переміщення сипкого середовища дасть можливість наперед вибирати такі режим роботи транспортера, які роблять неможливими вказані процеси, а відтак збільшують ресурс експлуатації телескопічного гвинтового конвеєра. Встановлено, що найбільшою проблемою в телескопічних гвинтових транспортерах є збереження однакового зазору між кожухом та спіраллю в різних секціях телескопа, що значно впливає на час викочування та закочування рухомої в осьовому напрямку частини шнека на нерухому та на появу і величину згинальних і крутильних коливань під час переміщення сипких вантажів. А також те, що продуктивність перевантаження сільськогосподарських вантажів телескопічним гвинтовим транспортером є аналогічною продуктивності перевантаження цих вантажів традиційними гвинтовими конвеєрами і не змінюється від величини викочування та видовження телескопічної частини гвинтового конвеєра.*

Ключові слова: *телескопічний гвинтовий транспортер, гвинт, згинальні коливання, крутильні коливання, обертання.*

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