RESEARCH ON THE DYNAMICS OF SAPROPEL UNLOADING FROM A CABLE INSTALLATION BUCKET
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ДОСЛІДЖЕННЯ ДИНАМІКИ РОЗВАНТАЖЕННЯ САПРОПЕЛЮ ІЗ КОВША КАНАТНОЇ УСТАНОВКИ

Prof. Ph.D. Eng. Hevko B.M., Lect. Ph.D. Eng. Diachun A.Y., Lect. Ph.D. Eng. Dzyura V.O., Lect. Ph.D. Eng. Skyba O.P., Mel'nychuk S.L.
Ternopil Ivan Pul'uj National Technical University, Ruska Str., 56, Ternopil, Ukraine
E-mail: volodymyrdzyura@gmail.com

Keywords: *sapropel extraction, cable installation, dynamic model, buff load.*

ABSTRACT
The new design of an installation for extracting sapropel is proposed. The theoretical background of sapropel extraction is developed. Based on the second order Lagrange equations and the standard program of numerical method Kunna-Tucker, the differential equation of bucket oscillation is derived. The graphic dependences of changing the angle of bucket deformation are developed as well as the linear horizontal and vertical deformation during unloading the bucket.

РЕЗЮМЕ
Запропоновано нову конструкцію установки для добування сапропелю. Теоретично обґрунтувано видобутку сапропелю на основі рівнянь Лагранжа другого роду і стандартної програми чисельного методу Кунна-Таккера, відтворені диференціальне рівняння коливань ковша. Представлені графічні залежності зміни кута деформації ковша, а також лінійної горизонтальної та вертикальної деформації при розвантаженні ковша.

INTRODUCTION
Agriculture of Ukraine plays a major role in providing people with food products and the industry with raw materials. The soil fertility, which is the foundation of agriculture, essentially contributes to obtaining high yields of crops with appropriate quality indicators.

Derno-podzolic soils dominate in Polissia of Ukraine, namely in Volyn and Rivne regions. They are characterized by low natural fertility; that is why fertilizers application, especially organic ones, is the determining factor in obtaining high yields. The use of sapropel as an organic fertilizer improves soil fertility in the mentioned regions. (*Shymchuk M.Y., 1966; Smyrnov A.V. 1973; Diduh V.F., Taraymovych I.V., and others, 2011; Tsyz' I.Y., Khomych S.M., 2009, 2013*) and others studied the issues of sapropel application for improving yields capacity. (*Tarasiuk V.V., 2012; Khomych S.M., 2014; Hlopetskyi R.A., 2014, 2016; Shymchuck O. 2014; Vanags R., 2015*) and others substantiated the production technologies of sapropel granules. (*Loveykin V.S., Nesterov A.P., 2002; Oleg Lyashuk, Zdenko Tkáč, and others, 2013; Lyubachivskij R. and others, 2013; Holubentsev A.N., 1959; Komarov M.S., 1989; Pavlovs'kyi M.A. 2002)*, and many others studied the parameters of transportation machinery used for sapropel extraction.

MATERIAL AND METHODS
Based on experimental studies, significant dynamic oscillation was found to occur during sapropel transportation. Besides, the oscillation amplitude decreases during the unloading process. Oscillations occur both in vertical and horizontal planes. Since the mechanical motion of the bucket affects the speed of its unloading and the performance of a cable installation, there is a need to study the dynamic loads on the cable installation elements and the nature of its components movement.

This movement can be calculated by solving differential equations of motion. To simplify calculations, some idealization of the system should be performed with rejection of minor factors.

The analytical model of unloading the bucket is shown in Fig. 1. This model is represented as the lumped masses connected by elastic ties. Elastic ties are considered permissible weightless and characterized by a constant stiffness coefficient.

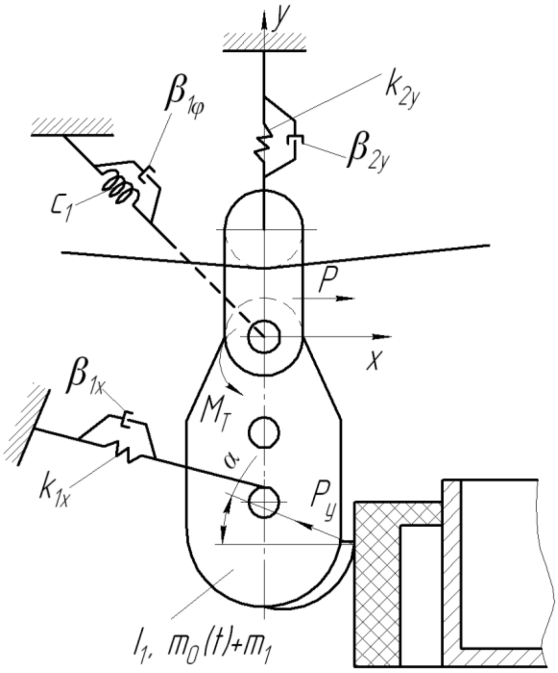

Fig. 1 - Analytical model of unloading the bucket of cable installation

Local stresses and strains in the joints of individual elements will be neglected. The lumped masses are: $m_0(t)$ - sapropel mass, m_1 - bucket mass, I_1 - moment of bucket inertia with sapropel. In addition, the figure shows stiffness coefficients: k_{1x} –given stiffness coefficient of unloading cable, k_{2y} –given stiffness coefficient of bearing cable, C_1 - given stiffness in torsion of the bucket. Besides, the damping coefficients are marked: $\beta_{1\varphi}$ – damping coefficient of torque oscillations of the bucket; β_{1x} – damping coefficient of linear oscillations of unloading cable in the direction of the axis x; β_{2y} – damping coefficient of linear oscillations of bearing cable in the direction of the axis y. The feed force of the bucket P and the impact force P_y are applied to a plate conveyor. The impact force P_y occurs during the unloading of sapropel. In addition, the frictional moment M_T, which prevents rotation of the bucket, is applied to it.

When unloading, the sapropel mass in the bucket is reduced. This process is defined by the dependence:

$$m_0(t) = m_p - \frac{t}{t_v} \cdot V_k \cdot \rho \,, \tag{1}$$

where: m_p – mass of loaded sapropel;

t – time;

t_v – time of unloading sapropel from the bucket;

V_b – volume of loaded sapropel in the bucket;

ρ – sapropel density.

Similarly, the moment of bucket inertia with sapropel I_1 is changed. Having avoided negative values, the changes of sapropel mass into the dynamic model were implemented correctly with the aid of the auxiliary algebraic function:

$$m'_0(t) = \frac{m_0(t) + P_C - |m_0(t) - P_C| + \big|m_0(t) + P_C - |m_0(t) - P_C|\big|}{4} \,, \tag{2}$$

where: P_c - auxiliary constant.

An example of the function application (2) is presented graphically in Fig. 2.

Our system has three degrees of freedom. Let us choose as generalized coordinates φ - angle of the bucket (it is considered positive in the counter-clockwise direction); x_1 – movement of the bucket mass centre in the direction of the axis x; y_1 - movement of the bucket mass centre in the direction of the axis y. Positive movement directions are shown in Fig. 1.

Differential equations of oscillations without taking into account the environmental resistance were deduced with the aid of second order Lagrange equations:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_j}\right)-\frac{\partial T}{\partial q_j}=-\frac{\partial \Pi}{\partial q_j}+Q_j \quad (j=1,3). \tag{3}$$

Then the kinetic energy of the system:

$$T=\frac{1}{2}I_1\dot{\varphi}^2+\frac{m_1+m_0(t)}{2}\left(\dot{x}_1^2+\dot{y}_1^2\right). \tag{4}$$

Potential energy of the system:

$$\Pi=\frac{1}{2}C_1\varphi^2+\frac{1}{2}k_{1x}\left(x_1-R\varphi\right)^2+\frac{1}{2}k_{2y}y_1^2\ , \tag{5}$$

where :R – distance from the bucket mass centre to the axis of rotation.

$$\frac{\partial T}{\partial \dot{\varphi}}=I_1\dot{\varphi};\quad \frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}}\right)=I_1\ddot{\varphi};\quad \frac{\partial T}{\partial \varphi}=0;\quad -\frac{\partial \Pi}{\partial \varphi}=-C_1\varphi+k_{1x}R\left(x_1-R\varphi\right).$$

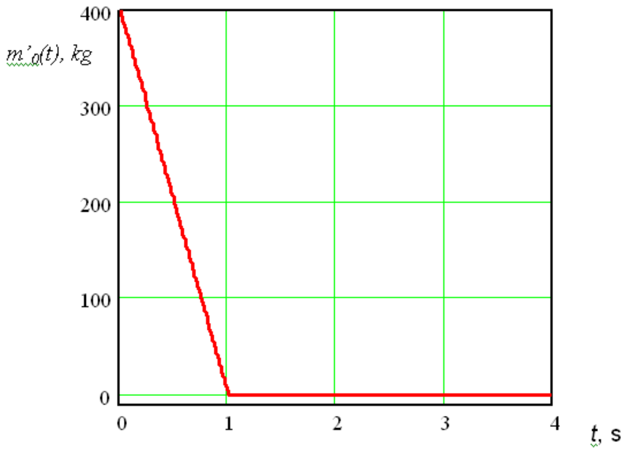

Fig. 2 - Graph of sapropel mass changes in the bucket in time

So, the first equation is

$$I_1\ddot{\varphi}+\left[C_1+R^2k_{1x}\right]\varphi-k_{1x}Rx_1=P_yR_1\cos\alpha-M_T\ ,$$

where: R_1 - distance from the point of the bucket and support interaction to the axis of bucket rotation;
α - angle of the bucket and support interaction.

$$\frac{d}{dt}\ \frac{\partial T}{\partial \dot{x}_1}=\left(m_1+m_0(t)\right)\ddot{x}_1;\quad -\frac{\partial \Pi}{\partial x_1}=-k_{1x}\left(x_1-R\varphi\right);\quad \mathrm{Q}_{x_1}=\mathrm{P}_{x_1}\ .$$

$$\left(m_1+m_0(t)\right)\ddot{x}_1+k_{1x}\left(x_1-R\varphi\right)=P_y\cos\alpha-P$$

Similarly, the third equation is deduced. The final complete system of equations of the problem is:

$$\begin{gathered}I_1\ddot{\varphi}+\left[C_1+R^2k_{x1}\right]\varphi-k_{1x}Rx_1=P_yR_1\cos\alpha-M_T\\ \left(m_1+m_0(t)\right)\ddot{x}_1+k_{1x}\left(x_1-R\varphi\right)=P_y\cos\alpha-P\\ \left(m_1+m_0(t)\right)\ddot{y}_1+k_{2y}y_1=P_y\sin\alpha-\left(m_1+m_0(t)\right)g\end{gathered} \tag{6}$$

where: g – gravitational acceleration.

Taking into account the energy degradation, the following equations are deduced:

$$\begin{gathered}I_1\ddot{\varphi}+\left[\beta_{1\varphi}+R^2\beta_{1x}\right]\dot{\varphi}-\beta_{1x}R\dot{x}_1+\left[C_1+R^2k_{x1}\right]\varphi-k_{1x}Rx_1=P_yR_1\cos\alpha-M_T\ ,\\ \left(m_1+m_0(t)\right)\ddot{x}_1+\beta_{1x}\dot{x}_1-\beta_{1x}R\dot{\varphi}+k_{1x}\left(x_1-R\varphi\right)=P_y\cos\alpha-P\ ,\\ \left(m_1+m_0(t)\right)\ddot{y}_1+\beta_{2y}\dot{y}_1+k_{2y}y_1=P_y\sin\alpha-\left(m_1+m_0(t)\right)g\ .\end{gathered} \tag{7}$$

While studying the impact interaction of the bucket and support, the only immediate impact force P_y is considered. This force is strong enough to create a pulse of finite size:

$$\vec{S}_1 = \int_{t_0}^{t_0+t_{K2}} \vec{P}_y dt \,, \tag{8}$$

where : t_0 - initial time, s;

t_{K2} - duration of impact, s.

During the collision of solids, the order of t_{K2} is 10^{-4}s.

As we know from theoretical mechanics:

$$\vec{S}_1 = m_1 \cdot \vec{V}_f - m_1 \cdot \vec{V}_i \,, \tag{9}$$

where : V_f - final relative velocity of the bucket, m/s;

V_i - initial relative velocity of the bucket, m/s.

RESULTS

For the case $t_0 = 0$, $V_{\Pi} = 0$, the final relative velocity of the bucket V_K equals the velocity of movement. As the impact is not absolutely elastic, the coefficient of renewal K_B should be considered. It defines physical and mechanical properties of materials and lies in the interval 0 K_B <1. The force of impact P_1 is assumed constant in the interval from t_0 to t_{K2} Therefore, equating equations (8) and (9), and considering the coefficient of renewal, after appropriate transformations the following formula is deduced:

$$P_1 = K_B \cdot \frac{m_1 \cdot V_K}{t_{K2}} \,. \tag{10}$$

To implement the force of impact P_y into the dynamic model taking into account its short action, the auxiliary non-dimensional coefficient should be used:

$$F_9 = b \cdot \left(1 - \frac{t}{t_{K2}}\right), \tag{11}$$

where : b - coefficient in the order of magnitude higher than the value of impact force.

Then the force of impact can be explained by algebraic function:

$$P_y = \frac{F_9 + P_1 - |F_9 - P_1| + \left|F_9 + P_1 - |F_9 - P_1|\right|}{4} \,. \tag{12}$$

The change of impact force in time t is shown in Fig. 3.

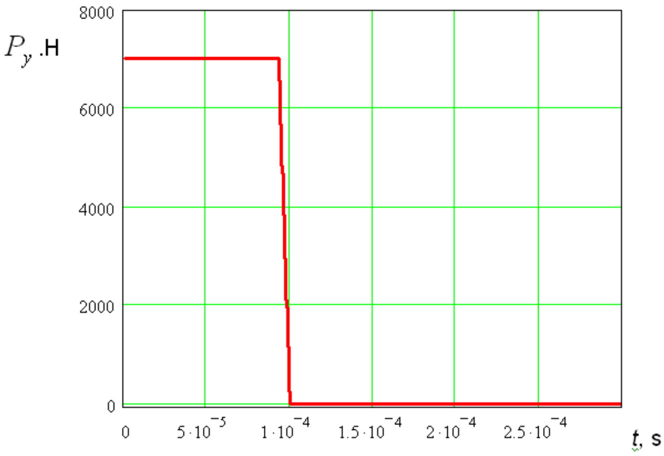

Fig. 3 - Graph of changing the force of bucket impact on the support $P_б$ in time t

The reasons to set down initial conditions for the system of equations are as follows. The time is counted from the moment of the bucket and support collision. During the movement of sapropel to that moment, the elastic elements of the system are not subjected to deformation. Therefore, the initial relative coordinates and velocities are assumed equal to zero. Further deformation occurs due to external forces. Therefore, if $t = 0$, the following formulae are deduced:

$$\varphi(0)=0\,,\;\; x_1(0)=0\,,\;\; y_1(0)=0\,,$$
$$\dot{\varphi}(0)=0\,,\;\; \dot{x}_1(0)=0\,,\;\; \dot{y}_1(0)=0\,. \qquad (13)$$

The differential equations (7) with initial conditions (13) should be solved on the computer using a standard subprogram of numerical method Kunna-Tucker.

According to the research results, the graphic dependences of changing the angle of bucket deformation in time (Fig. 4) are developed, as well as the dependences of linear horizontal deformation of the bucket in time (Fig. 5) and linear vertical deformation of the bucket in time (Fig. 6) during unloading sapropel.

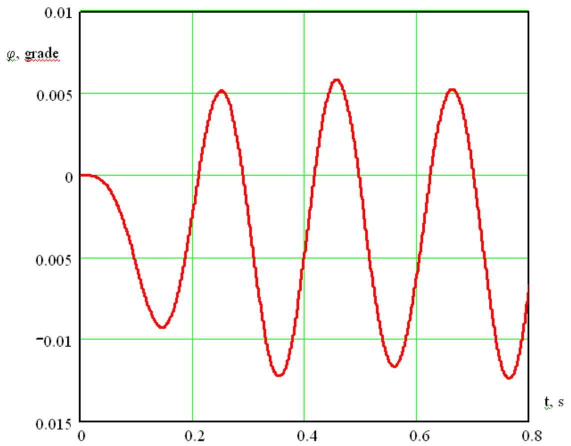

Fig. 4 - Graph of changing the angle of bucket deformation in time

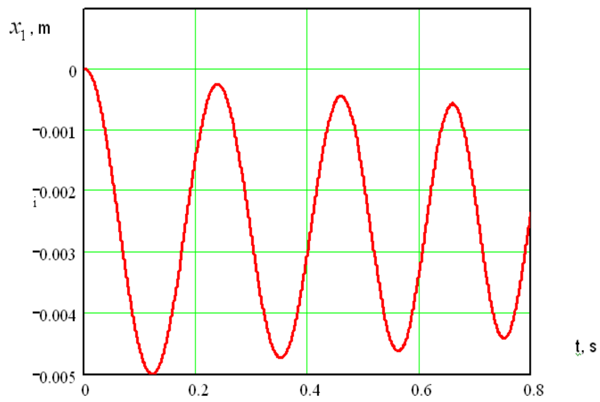

Fig. 5 - Graph of changing the linear horizontal deformation of bucket in time

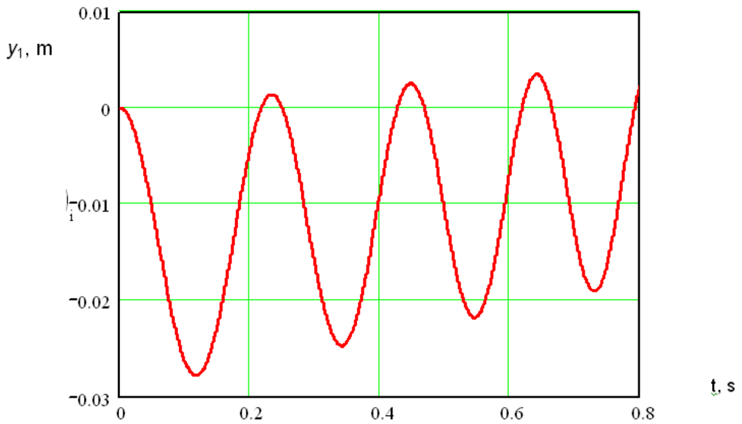

Fig. 6 - Graph of changing the linear vertical deformation of bucket in time

To test the adequacy of the proposed system of differential equations, all its components were determined experimentally. According to the presented graphic dependences, the change of vertical linear deformation of the bucket in time is greater than the change of horizontal linear deformation of the bucket in time and reaches 0.028m due to the smaller given stiffness coefficient of bearing cable as compared to the given stiffness coefficient of unloading cable.

The use of local organic raw materials will reduce the cost of the final product and will increase the amount of humus-forming plants. Sapropel from freshwater lakes as organic component should be appropriately used in the production of granular OMF (organic mineral fertilizer) in the areas of its significant resources. Sapropel is a universal substance that contains a set of elements necessary for plant nutrition. As experience shows, the use of sapropel instead of traditional organics can reduce the production cost. In addition, the development of sapropel recreational fields contributes much to the restoration of natural environment.

Thus, the impact of sapropel on soil fertility is multifaceted and complex. The effectiveness of sapropel on sandy soils is much higher than on heavy soils.

CONCLUSIONS

The new design of installation for extracting sapropel is proposed. The theoretical background of sapropel extraction is developed. Differential equations of oscillations, without taking into account the environmental resistance, were deduced with the aid of second order Lagrange equations and the standard program of numerical method Kunna-Tucker. The graphic dependences for changing the angle of bucket deformation are developed as well as the linear horizontal and vertical deformation during unloading the bucket.

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