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DYNAMIC COMPUTER MODELING OF ARABLE WALKING TRACTOR WITH PLOW[1]

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Abstract: *The subject of the study is a motocultivator whose construction is designed for soil cultivation on small-scale private farms. Magnitudes - variables and constants that characterize the statics and dynamics of the motocultivator are identified. The motion equations are derived based on the corresponding body simplifications that move in the vertical-longitudinal plane with two degrees of freedom. The computerized simulation model of the dynamic system was developed using the Vemsim software. The numerical solution has been obtained. After analysis the relevant conclusions are made to improve the sustainability of the motocultivator movement within the required controllability.*

Keywords: *dynamics, model, motocultivator, sustainability, controllability*

INTRODUCTION

The problem of the dynamic sustainability of the movement of soil cultivation machinery is of paramount importance and is subject to the attention of many researchers (Bozhkov, S., at all 2011) (Daskalov, A., 1989) and others. These literary sources deal with different classes of four-wheel tractors that have a production economic purpose. In the articles of (Ovsyannikov, S., & Grib V., 2016) and (Ovsyannikov, S., 2015) the main mass-geometrical characteristics of the moto cultivator were determined and the emerging forces were analyzed in his work. It is concluded that the addition of a supporting wheel is a useful solution to ensure the performance of the moto cultivator. The dynamic state of the moto cultivator is determined by the balance of forces applied to it during the work process. There are examples published on Internet clips that show that under certain conditions this balance can be ascertained that the moto cultivator moves making a furrow without any external intervention by the operator, but observation on his part, of course, is very important, since even the smallest change in working conditions leads to a breach of the established balance of the forces.

The subject of the study in this article is the sustanbility of the movement of a moto cultivator with the task of formulating recommendations and introducing relevant improvements in its construction in order to ease the work of the person who works with it.

EXPOSITION

The calculation scheme and determination of the variables and constant parameters of the moto cultivator

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The moto cultivator is studied as shown in Fig 1. To the original construction a supporting wheel pos. 9. is added. Two power sensors are mounted pos. 6 and 8, with which the forces occurring in the vertical longitudinal plane are measured when the moto cultivator is operating. The movement in the direction of axis **X** is realized by the working wheel pos. 1. Keeping the horizontal movement in the horizontal plane is done by the operator with the rods, pos. 5.

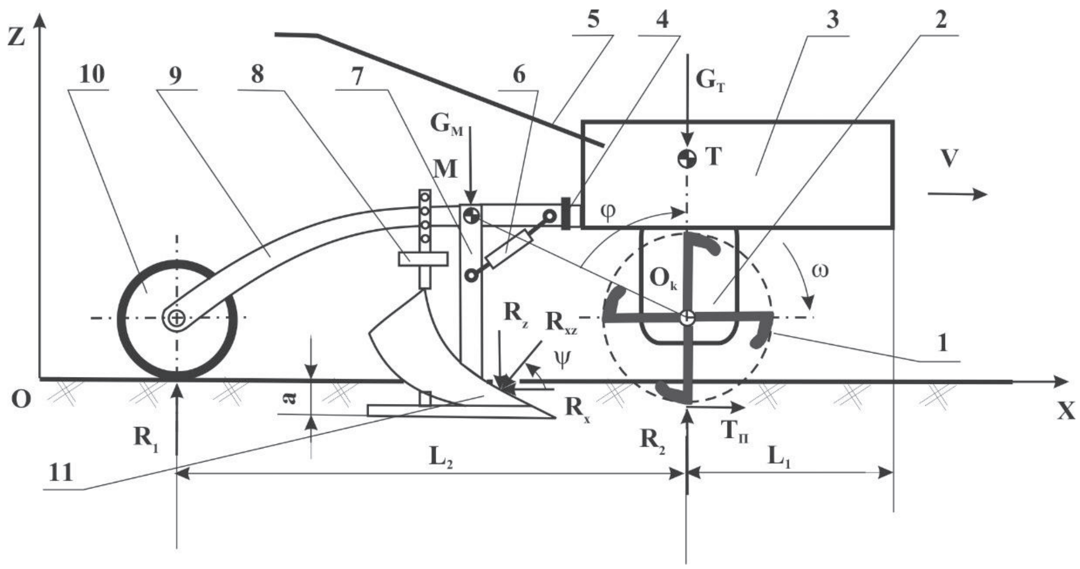

Fig. 1. The calculation scheme of the motocultivator

In a static position on the moto cultivator are exerted the forces from the engine block pos. 1, 2 and 3, the attached plow pos. 11 with pedal wheel pos. 10, shoulder pos. 9 and postal pos. 7. These are forces: $\mathbf{G_M}$, $\mathbf{G_T}$, $\mathbf{R_1}$ and $\mathbf{R_2}$, (Fig. 1). These forces and the linear dimensions shown in the figure are the constant magnitudes characterizing the moto cultivator. In a dynamic mode, with a plow in the soil at depth **a = 20 cm**, when the moto cultivator moves with a velocity **V = 0.6 m/s**, occurs pressure distributed over the surface of the plow, which can be represented as a concentrated force $\mathbf{R_{xz}}$, from contact with the soil. This force forms an angle $\psi = 120^0$ according to literature data (Demirev & Bratoev, 2012) with axis **X** and can be decomposed into two components: $\mathbf{R_z}$ and $\mathbf{R_x}$, which are registered by the force sensors pos. 6 and 8. The $\mathbf{T_П}$ force occurs and causes the torque of resist as a result of the contact of the engine wheel with the soil.

The speed of motion of the moto cultivator and the magnitude of these forces are variable in time according to the operating conditions.

The equations of movement of the moto cultivator

We assume that the object of the survey consists of two concentrated mass points at point **M** and point **T,** (Fig. 1). There are two degrees of freedom. The moto block pos. 1, 2 and 3 mades a rectilinear translational movement in the **X** axis direction, and the attachment itemes, pos. from 6 to 10 - rotary motion at an angle **φ** around a point $\mathbf{O_k}$ and **Y** axis, that is not shown in the scheme given in Figure 1. The movement is performed in the vertical-longitudinal plane defined by the **OZX** coordinate system with the origin point **O**. It is assumed that the model is a type of elliptical pendulum (Pisarev, A., etc. 1975).

The summarized coordinates $\mathbf{q_{1,2}}$ of the model are the cartesian coordinates **x** and **z**, and the effect of the rotation of point **M** on angle **φ** can be expressed as:

$$\varphi \rightarrow \left| \begin{aligned} x_\varphi &= \overline{\mathrm{O_к M}}\, sin\,\varphi \\ z_\varphi &= \overline{O_k M} cos\varphi \end{aligned} \right. \tag{1}$$

Then for $\mathbf{q_{1,2}}$ of the point mass M we have:

$$q_{1,2} \rightarrow \left| \begin{array}{l} x_M = x(t) + \overline{O_k M}\ \sin\varphi(t) \\ z_M = \overline{O_k M}\cos\varphi \end{array} \right. \tag{2}$$

The common kinetic energy of the translational and rotational movement is:

$$\mathrm{T} = \mathrm{T_T} + \mathrm{T_M} \tag{3}$$

where $\mathbf{T_T}$ is the kinetic energy of the engine block, and $\mathbf{T_M}$ is the kinetic energy of the working machine. They have the following form:

$$\mathrm{T_T} = \frac{m_T \dot{x}^2}{2}\ \mathrm{T}_M = \frac{m_M(\dot{x}_M^2 + \dot{z}_M^2)}{2} \tag{4}$$

After differentiating $\mathbf{x_M}$ and $\mathbf{z_M}$, see eq. (2) and performing an adaptation for $\mathbf{T_M}$ the following is obtained:

$$T_M = \frac{m_M}{2}(\dot{x}^2 + 2\overline{O_k M}\dot{x}\dot{\varphi}\cos\varphi + \overline{O_k M}^2\dot{\varphi}^2\cos^2\varphi + \overline{O_k M}^2\dot{\varphi}^2\sin^2)\,\varphi \tag{(5}$$

The overall kinetic energy of the model is:

$$\mathrm{T} = \frac{1}{2}(m_T + m_M)\dot{x}^2 + m_M\overline{O_k M}\dot{x}\dot{\varphi}\cos\varphi + \frac{1}{2}m_M\overline{O_k M}^2\dot{\varphi}^2 \tag{(6}$$

The potential energy of the body with the concentrated of mass is:

$$\Pi = -m_M g(\overline{O_k M}\cos\varphi + r_k) \tag{7}$$

where **g** is the acceleration of the Earth.

The Lagrange's function of the two bodies is:

$$L = \mathrm{T} - \Pi = \frac{1}{2}(m_T + m_M)\dot{x}^2 + m_M\overline{O_k M}\dot{x}\dot{\varphi}\cos\varphi + \frac{1}{2}m_M\overline{O_k M}^2\dot{\varphi}^2 + m_M g(\overline{O_k M}\cos\varphi + r_k) \tag{(8}$$

The movement is expressed by two Lagrange equations of the type:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) - \frac{\partial L}{\partial x} = Q_x\ \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\varphi}}\right) - \frac{\partial L}{\partial \varphi} = Q_z \tag{(9}$$

The summarized active forces at the respective degrees of freedom are:

- along the axis **X**:

$$Q_x = T_\Pi - R_x \tag{10}$$

where the force of the engine wheel friction with the soil is: T_P = μR_2, (Figure 1);

- and along the axis **Z**:

$$Q_z = -R_z - G_T - G_M \tag{11}$$

The system of equations of motion acquires the type:

$$(m_T + m_M)\ddot{x} + m_M\overline{O_k M}\ddot{\varphi}\cos\varphi - m_M\overline{O_k M}\dot{\varphi}\sin\varphi = T_\Pi - R_x \tag{12}$$

$$m_M\overline{O_k M}\ddot{x}\cos\varphi + m_M\overline{O_k M}\ddot{\varphi} + g m_M\overline{O_k M}\sin\varphi = -G_M - G_T - R_z \tag{13}$$

In order to simplify the expressions we put: $\mathbf{D = m_M\, O_k M}$. And since the angle $\boldsymbol{\varphi}$ varies very narrowly, it can be assumed that $\sin\varphi \cong \varphi$ and $\cos\varphi \cong 1$, then the system is:

$$(m_T + m_M)\ddot{x} + D\ddot{\varphi} - D\dot{\varphi}\varphi = T_\Pi - R_x \tag{14}$$

$$D\ddot{x} + D\ddot{\varphi} + gD\varphi = -G_M - G_T - R_z \tag{15}$$

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The system of equations presented in a matrix form is:

$$\begin{vmatrix} m_T + m_M & D \\ D & D \end{vmatrix} \begin{vmatrix} \ddot{x} \\ \ddot{\varphi} \end{vmatrix} + \begin{vmatrix} 0 & D\varphi \\ 0 & 0 \end{vmatrix} \begin{vmatrix} \dot{x} \\ \dot{\varphi} \end{vmatrix} + \begin{vmatrix} 0 \\ gD \end{vmatrix} \begin{vmatrix} x \\ \varphi \end{vmatrix} = \begin{vmatrix} T_{II} - R_x \\ -G_M - G_T - R_z \end{vmatrix} \tag{16}$$

The abbreviated entry is:

$$A\ddot{q} + B\dot{q} + Fq = C \tag{17}$$

Matrix **A** has the opposite matrix because it contains positive and constant magnitudes. The matrix equation (17) can be represented as a second-order linear differential equation:

$$\ddot{q} = -A^{-1}B - A^{-1}F + A^{-1}C \tag{18}$$

The computer simulation of the movement of the motocultivator. Numerical decision.

We substitute with the magnitudes of the equations (17) and after the transformations we reach the following system of differential equations:

$$\begin{vmatrix} a\ddot{x} + d\ddot{\varphi} - d\varphi\dot{\varphi} = b \\ d\ddot{x} + d\ddot{\varphi} + f\varphi = c \end{vmatrix} \tag{19}$$

where: **a = 4,1; b = 12,5; c = 46,18; d = 30,6; f = 300.**

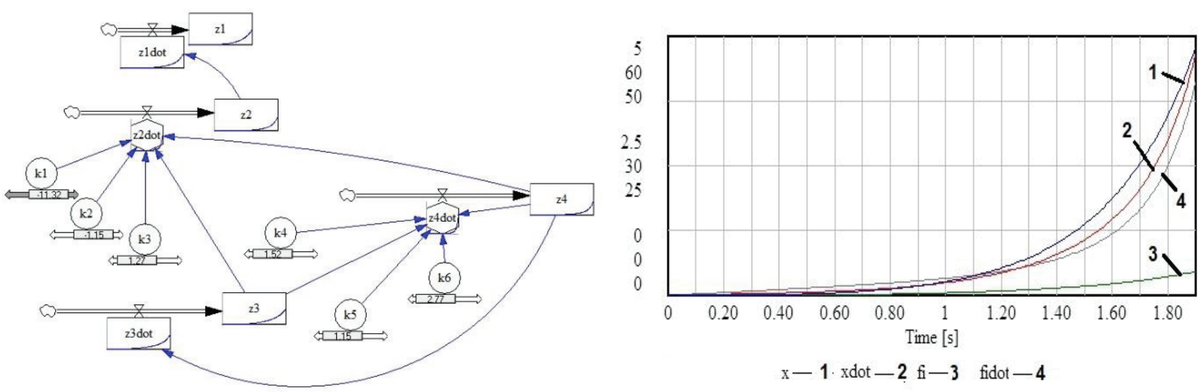
The resulting fourth-order system (19) is brought to a system of four differential equations of the first order by changing the variables.

$$x = z_1; \quad \dot{x} = z_2; \quad \varphi = z_3; \quad \dot{\varphi} = z_4 \tag{20}$$

and acquires the following appearance:

$$\begin{vmatrix} \dot{z}_1 = z_2 \\ \dot{z}_2 = \dfrac{f}{a-d} z_3 + \dfrac{d}{a-d} z_3 z_4 - \dfrac{c-b}{a-d} \\ \dot{z}_3 = z_4 \\ \dot{z}_4 = -(\dfrac{f}{a-d} + \dfrac{f}{d}) z_3 - \dfrac{d}{a-d} z_3 z_4 + \dfrac{c-b}{a-d} + \dfrac{c}{d} \end{vmatrix} \tag{21}$$

A simulation model (Fig. 2) is drawn using the symbol's of "Vensim" - a simulator for graphical simulation, and simulation of dynamic systems described with ordinary differential equations (Mitrev, P., 2016).



a) б)

Fig. 2. Graphical model - a) and simulation results - b)

The analysis of the sustainability of the linear system

The system's differential motion equations (19) are linear, which means that the matrix **A** own values fully determine the stability of the equilibrium point and the type of the phase portrait. In this case the solutions of its characteristic equation are:

$$\lambda_1 = 34{,}7 + 44{,}3j \quad u \quad \lambda_1 = 34{,}7 - 44{,}3j \tag{22}$$

These are two complex conjugate numbers with a positive real part, which means that the phase trajectories represent a family of logarithmic spirals which move away from the equilibrium point, i.e. we have an unsustainable focus.

CONCLUSION

The dynamic modeling of the moto cultivator has shown that it is an unsustainable system that demands to be continuously regulated with external impact in order to function according to its purpose, namely to pass a rectilinear furrow in the pole.

The insertion of a support wheel does not ultimately solve the issue of sustainability. The additional measures are also required, which, according to the results of the study, are change in the values of the parameters in the matrix **A**. When the real part of the roots eq. (21) becomes negative, the phase trajectories become a family of logarithmic spirals that are approaching the equilibrium point called sustained focus. And if the values of the matrix **A** are purely imaginary numbers, then in this case the phase trajectories will be invested in each other ellipses (or in particular circles) including the equilibrium point that is neutral stable and is called the center. And if the values of the matrix **A** are purely imaginary numbers, then in this case the phase trajectories will be merged in each other's ellipses (or in particular circles) including the equilibrium point that is neutral stable and is called the center.

This can be achieved by changing the values of the elements of the matrix A, which represent the masses of the two bodies involved in the dynamic model. In other words, it is necessary to introduce reasonable changes in the construction of the moto block by changing some dimensions and materials from which its details are made.

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