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The Determination of the Parameters of a Ploughshare-Rotor Potato Digger

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Annotation. The results of this research on the technological process of potato-digging are based on plots of land where the crop has been dug up and sorted using a ploughshare-rotor potato digger. The ideal parameters for the working components of the machine have been determined.

Keywords: tubers(potatoes), technological process, sorting, ploughshare-rotor potato digger, structural technical parameters, plots, potato conveyer belt.

INTRODUCTION

The mechanization of potato harvesting is widespread in Ukraine, in both farm and village economies. Thus, this is a very up-to-date question, and it is important to provide new, simple, effective and reliable machines for this purpose.

Although there now exists the possibility, in large fields, to mechanize the process and lower the expense of labor to 0.2-0.5 man hours per 0.01 hectares, on smaller garden plots the existing mechanized methods require 12-15 man hours per 0.01 hectares, that is, 25-75 times more than in large fields.

The most promising direction for research is to develop machines that have active components that dislodge and separate the potatoes are all stages of the technological process. This problem can be solved by developing apparatuses that provide intensified technological processes, that is, a special composition of the working surface of the ploughshare, which has a special form and has a special potato-digging rotor set in above it.

Those who have previously done research on the technological process and the working parts of machines for the digging and separation of potatoes, and consequently determined the parameters of such machines, include P.M. Vasilenk. V.P. Goryachkin, L.B. Pogoriliy, P.M. Nastenko, and G.D. Petrov.

An analysis of the existing technological processes and working parts of potato-digging and separation machines has revealed a poor level of separation and mechanical damage done to the potatoes, which is caused by an imperfect clod-breaking apparatus and a faulty composition of machine parts.

By analyzing the literature concerning this problem, we determined the weaknesses in the construction of existing potato harvesting machines and also determined how we can improve the technological process of potato digging by improving the efficiency of the digger ploughshare and putting in a spade rotor above it that provides an active breaking up of the soil layer.

The results of our research and development of the components of a new potato digger and separation machine can now provide villagers with small plots of land and adequate, efficient mechanical means for performing this task.

RESEARCH METHODS

For the theoretical research of optimized parameters for potato digging machines we used the methods of theoretical mechanics, higher mathematics and mathematical statistics to develop a mechanical, mathematical model of the technological process. The experimental, practical research was done in a laboratory setting, planning multivariable experiments for testing and then analyzing the results of these experiments. Theoretical calculations and the statistical processing of experimental data were conducted using processing programs on a personal computer.

RESEARCH RESULTS

In the proposed construction of a potato digger (Fig. 1) the layer of soil and potatoes that is to be dug encounters blade 4, and undergoes a matching rotating movement along with the blade and a simultaneous lateral movement. After the blade and its “contents” have turned a certain number of degrees a mass is thrown out on the surface of the field. As the blade strikes the field, this blow being concentrated at the end portion of ploughshare 3, the process of clod-breaking is improved and the level of separation is thus improved as well. The working parts of the digging apparatus are shown in diagram 1.

We conducted theoretical research on the mutual interaction of the ploughshare and the soil layer the characteristics of the movement of the dug-up mass along its surface(both above and below).

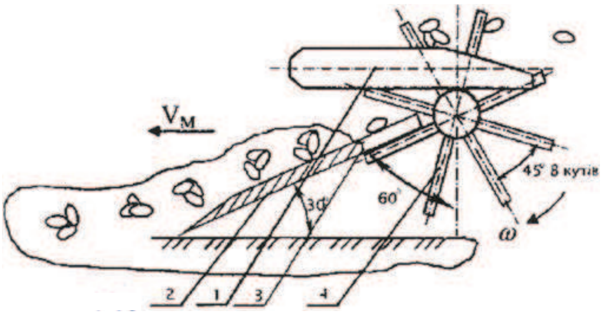

Fig. 1. Technological potato digger plan

In Fig. 2 we show the forces which act upon the ploughshare. at point A the soil layer is cut; at point E at the curvature the lower part of the layer is deformed; at point H the layer is deformed from the top side. On the surface, from point H cuts are made that begin the process of separation.

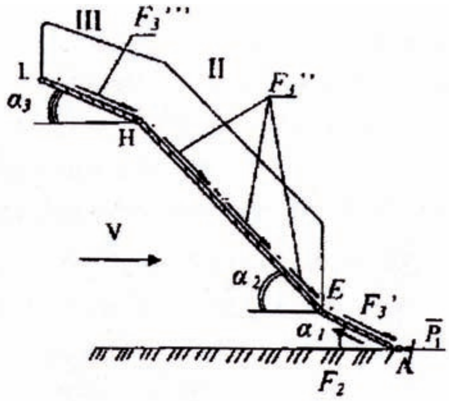

Fig. 2. Forces that act on the ploughshare

Force of resistance *of P*, which operates on the ploughshare, is represented as a vector sum:

$$\overline{P} = \overline{P}_1 + \overline{F}_2 + \overline{F}_3, \tag{1}$$

where: P_1 is the force of cutting resistance, F_2 is the force of friction between the ground and the underside of the ploughshare and F_3 is the sum of the forces of resistance between the soil and the upper surface of the ploughshare.

After determining its component parts, the force of resistance P which the ploughshare encounters when in operation is equal to:

$$\overline{P} = \overline{K}_p l_3 + f_1 \overline{Q}_л + f_2 \overline{Q}_B, \tag{2}$$

Where KR is the specific cutting resistance, f_1 is the length of the blade; mcode Q_1, is the coefficient of friction between the blade and the soil, Q_L is the force of pressure of the blade on the soil, f_2 is the coefficient of friction at the surface of the ploughshare, and Q_B is the force of pressure between of the soil on the surface of the ploughshare.

In choosing the form of the surface of the ploughshare it is important to maximize the effectiveness of breaking up the surface without damaging the tubers themselves. For this reason, the surface of the ploughshare is designed with a variable transversal cut area, which diminishes the direction of the cutting edge, thus causing a layer to go up, being loosened from below with motion upward. This increased efficiency of the loosening process is arrived at by rounding off the form of the lateral walls of the ploughshare. The curved surface of the ploughshare reduces sticking, which is the chief complication in the process itself

In the cutting area of the ploughshare the monolith of soil is broken up at the same time when the mixture of soil and potatoes enters the machine. When soil is worked up by the ploughshare, forces are exert on the areas of contact of the transversal cut S and the cut A-An (Fig. 3).

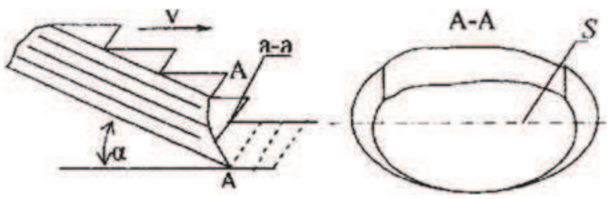

Fig. 3. Characteristics of soil output when the ploughshare of the potato digger is in motion.

It is a known fact that the soil becomes disrupted and rises up when it is pressed upon. The distribution of forces at the intersection of disruption A-An is not the same for all heights.

By experiment it was determined that total frictional force F for the movement of the soil/potato mixture along the surface of the plowshare is:

$$F = \frac{fP'L \sin 2\alpha}{S_1} \tag{3}$$

where: f is the coefficient of friction of the soil on a ploughshare, P' is the force of pressure of the ploughshare in pounds, L *is* the perimeter of the cross-section of the ploughshare in meters; α is the tilt angle of the ploughshare (out of the horizontal position) in degrees; S_1 is the area of the cross-section of soil through the line a-a in m^2.

As a result of analyzing the dependence of the speed of the mixture V as it moves along the surface of the ploughshare on the speed at the potato-digger *V*, it was determined that the maximum allowable speed for the motion of the soil/potato mixture is 0,4 m/sec, with a tilt angle of $\alpha = 12°$ for the ploughshare. As *V is* increased, and the angle *α* increases, there is a danger of soil accumulating ahead of the plough surface.

Thus, on the basis of the experiments we did, an optimal form of the surface of the ploughshare has been determined (Fig. 4), its geometric parameters being: the width of the front part of the ploughshare *a=415 mm*, the width of the back part of the ploughshare *b=361 mm*; the length of the ploughshare *1=475 mm*; the height of the ploughshare *h=150 mm*.

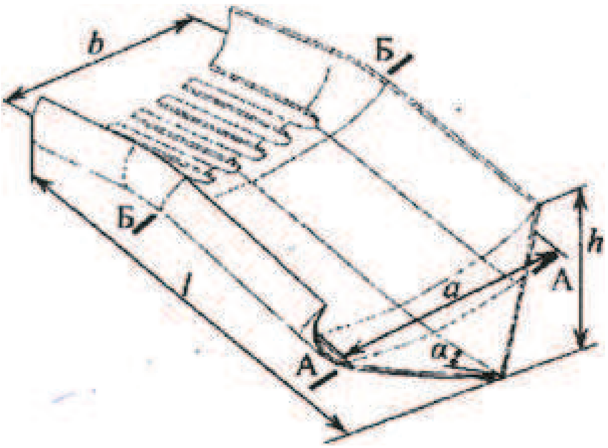

Fig. 4. The plougshshare structure

In order to determine the parameters for the rotor blade, we examined the relative motion of the tubers C (Fig. 5) on the surface of the rotor blade. At a certain moment the position of the rotor blade O1 K is give as the angle $\psi = \psi_0 + \omega t$, where ψ_0 is the initial position of the rotor at time t=0; *ω* is the angular speed of rotation of the rotor in radians/second, and t is the interval of time in seconds.

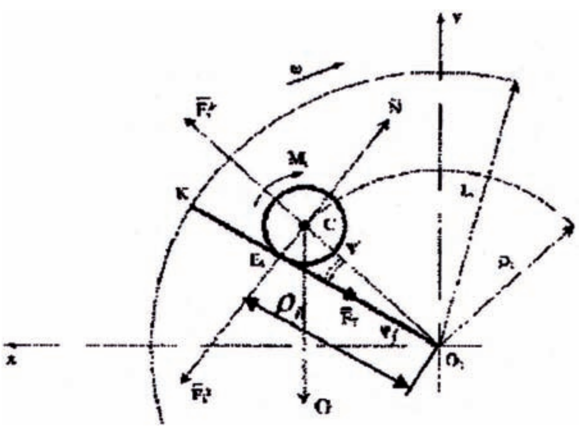

Fig. 5. The motion of the tubers on the surface of the blade

The vector equation of the motion of the potatoes at the surface of the blade is as follows:

$$m\bar{a} = \bar{G} + \bar{N} + \bar{F}_T + \bar{F}_i^{\text{в}} + \bar{F}_i^{\kappa}, \qquad (4)$$

where: m in is the mass of the potatoes in kg., $\bar{a}$ is the acceleration of the potatoes at the blade surface in m/s^2, $\bar{G}$ is the gravitational force on the potatoes in newtons, $\bar{N}$ is the normal reaction at the surface of the blade, in newtons, $\bar{F}_T$ is the force of friction exerted when the potatoes rub the blade in newtons, $\bar{F}_i^{\text{в}}$ is the centrifugal force of inertia of the potatoes with respect to the axis of rotation $\bar{F}_i^{\kappa}$ in newtons, and is the force of Koriolis inertia in newtons.

The equation for the motion of the potatoes on the blade projected unto the fixed coordinate system O_1XYZ is:

$$\left.\begin{aligned} m\ddot{x} &= -N\sin\psi - F_T\cos\psi + F_i^k\sin\psi + F_i^{\text{в}}\cos(\bar{F}_i^{\text{в}}, x) \\ m\ddot{y} &= -G + N\cos\psi - F_0\sin\psi + F_i^k\cos\psi + F_i^{\text{в}}\cos(\bar{F}_i^{\text{в}}, y) \end{aligned}\right\}, \qquad (5)$$

where: *ψ* is the angle of rubbing friction in degrees, and $\cos(\bar{F}_i^{\text{в}}, x)$ $\cos(\bar{F}_i^{\text{в}}, y)$ are the cosines of the angles of motion, where:

$$\cos(\bar{F}_i^{\text{в}}, x) = \cos\psi\frac{\sqrt{\rho_c^2 - R_б^2}}{\rho_c} - \sin\psi\frac{R_б}{\rho_c} = \frac{1}{\rho_c}\left[\cos\psi\sqrt{\rho_c^2 - R_б^2} - \sin\psi R_б\right]; \qquad (6)$$

$$\cos(\bar{F}_i^{\text{в}}, y) = \sin\psi\frac{\sqrt{\rho_c^2 - R_б^2}}{\rho_c} + \cos\psi\frac{R_б}{\rho_c} = \frac{1}{\rho_c}\left[\sin\psi\sqrt{\rho_c^2 - R_б^2} + \cos\psi R_б\right], \qquad (7)$$

where: Rб is the radius of the tuber in meters, mcode; cc is the radius in meters of the position of the center C of the potatoes with respect to the O_1 axis.

Solving (5), (6) and (7) we find that:

$$\left.\begin{aligned} m\ddot{x} &= -N\sin\psi - fN\cos\psi + 2m\omega V\sin\psi + \\ &\quad + m\omega^2(\cos\psi\sqrt{\rho_c^2 - R_б^2} - \sin\psi R_б) \\ m\ddot{y} &= -mg + N\cos\psi - fN\sin\psi - 2m\omega V\cos\psi + \\ &\quad + m\omega^2(\sin\psi\sqrt{\rho_c^2 - R_б^2}\cos\psi R_б) \end{aligned}\right\} \qquad (8)$$

As the potatoes perform constant motion the projected acceleration of point C will be $\ddot{X} = 0$, $\ddot{Y} = 0$. Calculating we find that:

$$\left.\begin{aligned} &-N\sin\psi - fN\cos\psi + 2m\omega V\sin\psi + \\ &\quad + m\omega^2(\cos\psi\sqrt{\rho_c^2 - R_б^2} - \sin\psi R_б) = 0 \\ &-mg + N\cos\psi - fN\sin\psi - 2m\omega V\cos\psi + \\ &\quad + m\omega^2(\sin\psi\sqrt{\rho_c^2 - R_б^2}\cos\psi R_б) = 0 \end{aligned}\right\}. \qquad (9)$$

Reducing system (9) we find the value of the normal reaction at the surface of the blade:

$$N = \frac{mg}{\sin\psi(tg\psi + ctg\psi)} + 2m\omega V - m\omega^2 R_б \qquad (10)$$

The equation for the moments of rotation of the potatoes around its axis is:

$$I_б \ddot{\xi} = Mr - FTR_б, \text{ or } \frac{2}{3} mR_б^2 \ddot{\xi} = NR_б tgV - fNR_б, \quad (11)$$

where: I_b is the moment of inertia of the potatoes with respect to their center in kg-m; $\ddot{\xi}$ the angular acceleration of the rotational motion of the potatoes in rad/s[2], and Mr is the moment of rubbing friction of the potatoes in newton-m.

From equation (11) we determine that:

$$\ddot{\xi} = \frac{2}{3}(tgV - f)\left[\frac{g}{R_б \sin\psi(tg\psi + ctg\psi)} + \frac{2\omega V}{R_б} - \omega^2\right]. (12)$$

Taking into account that $\psi = \psi_0 + \omega t$, and $V = R_б\dot{\xi}$, making the corresponding transformation we find that:

$$\frac{d^2\xi}{d\psi^2} - \frac{A_1}{\omega} \cdot \frac{d\xi}{d\psi} = \frac{A_2}{\omega^2}\cos\psi - \frac{A_3}{\omega^2}, \quad (13)$$

where: $3\omega(tgV - f) = A_1$; $\frac{3}{2}(tgV - f)\frac{g}{R_б} = A_2$; $\frac{3}{2}(tgV - f)\omega^2 = A_3$.

The solution of equation (13) is performed by numerical methods, initially setting the condition for the initial entrance of the potatoes into the blade mechanism:

$$N = F_i^k - G\cos\psi + F_i^в \sin\psi' > 0. \quad (14)$$

Taking into account that when the potatoes are first taken in, the normal for N=0, $\omega^2 R_б - g\cos\psi - 2\boldsymbol{m}\omega V > 0$, ***a*** $\dot{\xi} = d\xi/dt$, the dependence of the angle of entrance of the potatoes when cut off by the blade can be written as the condition:

$$\psi > ar\cos\left(\frac{\omega^2 R_б - 2\omega\dot{\xi}R_б}{g}\right). \quad (15)$$

The solution of equation (13) then takes the form:

$$\xi = \frac{\omega t}{2} + \frac{3g(tg\upsilon - f)\cdot\sin\frac{\omega t}{2}}{2\omega^2 R_б} \frac{\left[\sin(\frac{\omega t}{2}) - 3(tg\upsilon - f)\cdot\cos(\frac{\omega t}{2})\right]}{\left[9\cdot(tg\upsilon - f)^2 + 1\right]}. \quad (16)$$

Differentiating equation (13) with MathCadi for ξ, we obtain the following value for the angular velocity of the tubers:

$$\dot{\xi}(t) = \frac{\omega}{2}\left(1 + \frac{3\cdot g\cdot(tg\theta - t)}{g\omega^2 R_б\sqrt{9\cdot(tg\theta - f)^2 + 1}}\cdot \sin\omega t + arctg(3(f - tg\theta))\right) \quad (17)$$

In Fig. 6 we see the dependencies of the angle of introduction on the angular velocity and the radius of the potatoes (going from the equality $\psi_в$=arccoS($\omega^2 R_б - 2\omega\dot{\xi}R_б$)/g).

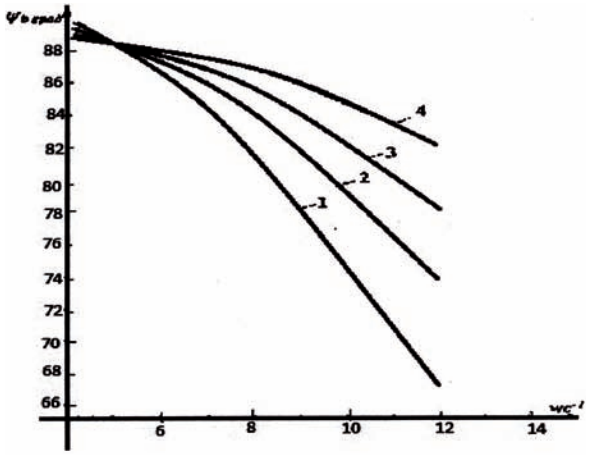

Fig. 6. The depencdencies of the angle of introduction on angular velocity $\psi_в$, for the angular velocites ω: 1, 2, 3, 4 corresponding to R_b= 0,06; 0,04; 0,25; 0,01 m

It was determined that with a radius for the potatoes R_b= 0.06 m, and an angular velocity of rotation of the blade ω=9, ..., 11 rad/s, the potatoes are thrown out at an angle of $\psi_в$=70,...,75[0].

CONCLUSIONS

1. Existing technologies for digging potatoes, using traditional means do not properly break up the potato bearing soil to its full extent, especially when the soil is moist (soil sticks to the moving parts, thus greatly reducing the efficiency of the separation process. The way to improve the efficiency of this process is use a ploughshare- rotor blade system.
2. Examining the motion of the soil/potatoes mixture on the surface of the ploughshare we determine its optimal form and parameters. The optimal angle for the set of the plough is α=12[0] with at machine speed of V_H=0,4 m/s. Increasing the machine speed and the ploughshare angle, α, lead to a dangerous accumulation of soil in front of the surface of the plough.
3. By mathematically modelling the motion of the potato producing soil, we have obtained the theoretical dependency of its motion as it is lifted up on the surface of the ploughshare.
4. We made a mathematical model that characterizes the relative, reciprocal motion of the processed mixture on the surface of the rotor blade. As a result of the analysis, we determined that the necessary distance for the thrown potatoes is between 0,8 and 1,1 m. and that the optimal values are obtained for an angular velocity for the blade of V_0=3 m/s and a blade length l_1=0,44 m.

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