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ANALYSIS OF THE BEHAVIOR OF POTATO BEARING LAYER PARTICLES ON THE OSCILLATING PLANE OF THE POTATO PLANT PLOUGHSHARE

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Abstract. *New design of the vibrating undermining operating body of potato harvesting machine where the specificity is that the plane of such ploughshare performs oscillating movements according to a certain law was proposed in this paper. Therefore, each point of the plane has different transporting and separating ability. The design and description of this operating body is presented in this paper. On the basis of its kinematic scheme the calculated dependencies which determine the conditions of movement of the individual particle by its plane are given. The above mentioned technique made it possible to determine for a separate kinematic mode of operation of the potato digger the value of accelerations that the oscillating plane transmits to the particle for the occurrence of directional motion. The values of the acting and minimum required accelerations acting on the particle located on the oscillating plane of the ploughshare have been analyzed, and conclusions about the possibility of its directed motion have been made.*

Key words: *fluctuation, kinematic scheme, acceleration, inertia force, directed motion, ploughshare, plane, separation, angle of friction, vibrating movement, potato digger, technological process, potato production.*

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1. INTRODUCTION

Mechanisation of agricultural production in Ukraine is one of the top priorities for mechanical engineers in this field. The quality and cost of manufactured products depend on the level of technological processes equipped with efficient technical means. This problem is getting worse due to the fact that the market in our country has a large share of expensive agricultural machines of foreign production. The development of Ukrainian agricultural engineering is somewhat slow, which prevents the industry from realising its potential. In order to strengthen the position of Ukrainian manufacturers of agricultural machines, there is a need to develop new designs of machines, units or operating bodies that would ensure high technological efficiency and be competitive on the market.

Therefore, analyzing the problems that are observed in the production of potatoes in small auxiliary farms in the technological operation of harvesting, the scientific search is directed to find solutions to improve the designs of single-row potato diggers. Such machines should be combined with low-powered energy resources and efficiently perform the technological harvesting operation.

The peculiarity of potato production in Ternopil region is that it has mainly heavy black soil, which complicates the process of digging up the potato bearing layer and separation of its components. Therefore, it is important for potato diggers, especially those

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aggregated with low-powered energy resources, that the digging ploughshare is active and provides partial separation.

This idea was implemented by the development of the new design of vibrating ploughshare [15], which has the system of suspensions enabling it to make oscillatory movements according to different laws and with different amplitudes.

Before implementing this design solution in practice, it is necessary, as a special case, to model and test the behaviour of the potato bearing layer particle on the plane of the ploughshare. This is necessary to ensure that the particles can move in the directional manner along the oscillating plane. In addition, this will provide certain transport capacity of the ploughshare, and relative movement of such particles on its plane intensifies the separation process.

2. ANALYSIS OF AVAILABLE INVESTIGATION RESULTS AND PUBLICATIONS

Analysing the sources of information, the researchers offer many options for the design of the digging operating bodies of potato diggers and methods of digging in general [1–6, 18]. Each of these solutions has its own specific application. However, not many researchers emphasise that this operating body should work in complicated conditions: when harvesting fruit we can observe sodden soil, increased lumpiness, the presence of plant remains, etc. The above mentioned conditions of operation of the digging operating body encourage us to find solutions to reduce traction resistance when machines are moving, to ensure good soil cover during digging for easier subsequent separation of particles, and to obtain directed movement of the potato bearing layer under certain kinematic mode of the ploughshare drive operation [8–14]. The problem of the kinematic operation mode influence on the possibility of the occurrence of directional movement of particles located on its plane is not yet sufficiently developed for this type of the operating body. This is especially true for the effect of inertial forces on the potato bearing layer particle in each position of the rotation angle of the drive mechanism crank when the plane of the ploughshare does not make plane-parallel oscillations.

Therefore, it is necessary to develop the model which determines certain conditions concerning the possibility of directional motion of the particle at each point of the oscillating plane.

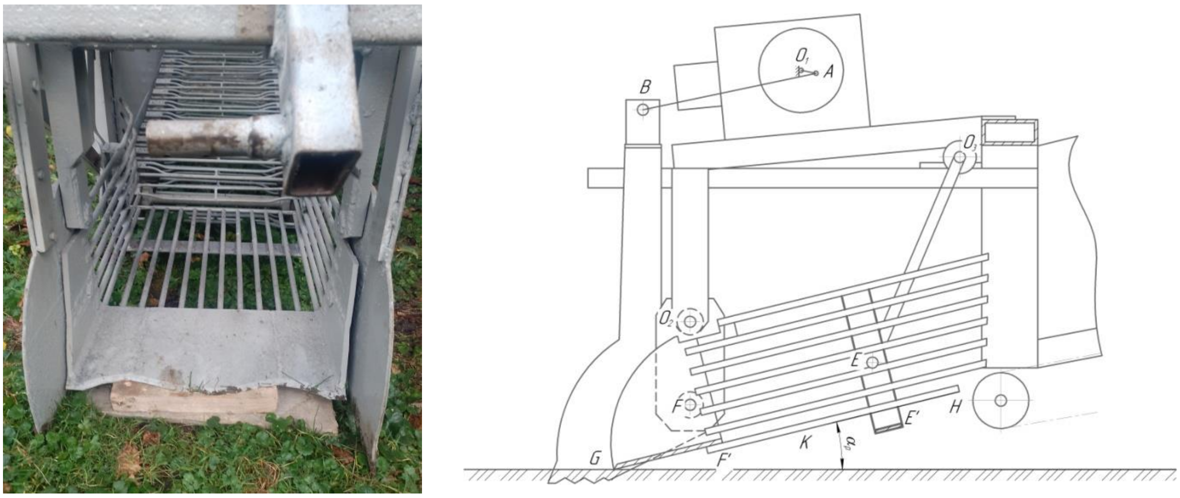
3. OBJECTIVE OF THE PAPER

The objective of the paper is to develop the methodology in order to identify the conditions under which we can analyse the possible behaviour of particles of the potato bearing layer on the oscillating plane of the vibrating ploughshare of the single-row potato digger during technological process.

4. PRESENTATION OF THE MAIN MATERIAL

The ploughshare operation in terms of its ability to move the particle in directed manner can be modelled as the operation of oscillating plane.

In theoretical terms, ploughshare is a wedge that cuts the potato bearing layer and moves it along its plane while separating the particles that pass through the cracks on the bar part of the ploughshare, Fig. 1.



a b

Figure 1. General view of the ploughshare of popato digger – a; its scheme – b

The described process includes conditionally independent three tasks: cutting the potato bearing layer by the ploughshare cutting blade; generation of the directed movement of potato bearing layer by the ploughshare plane; assessment of the separation capacity of the ploughshare bar [17].

At the initial stage, it is very interesting to investigate the influence of ploughshare kinematic parameters, which affect its ability to transport particles of the potato bearing layer. Or, in other words, to study the behaviour of the particle on the ploughshare plane at different positions of the crank drive mechanism.

Let's move on to the modelling of this process. So, ploughshare is an oscillating plane that is at angle α_p to the horizon (Fig. 1) and makes oscillatory movements according to a certain law. The ploughshare plane (cross section, line GH) is pivoted by two suspensions: the rear suspension EO_3 (pivot E is located at distance EE' (Fig. 1) from the ploughshare plane); the front suspension FO_2 (distance FF' from the ploughshare plane).

The front suspension is the part of the drive mechanism. It is a double-armed lever FO_2B . The pivot B is connected to the connecting rod AB, which transmits the force to oscillate the ploughshare from the crank AO_1. Dependencies describing the kinematics of the ploughshare drive are given in paper [16].

First, let's consider the simplest partial case, when one single particle with m_{par} mass is located on the ploughshare plane and its motion is carried out as a plane particle. In addition, at this stage, we assume that air resistance and the interaction of other particles do not have a significant impact. And another condition is that the friction coefficient f is constant, it does not depend on the thickness of the potato bearing layer, as well as the kinematic parameters during the ploughshare operation.

At this stage of the investigation, it is important to determine what ranges of kinematic parameters are to be ensured in order for the operating body to be functional. Later, we will impose additional restrictions in order to make the model adequate to the actual conditions of the ploughshare operation.

Let us distinguish three possible movements of the particle on the ploughshare plane [7]:

- movement downwards in the plane;
- upward movement;
- movement off the plane.

It should be understood that there is a case when the particle moves with the plane, i.e. no relative displacement occurs.

Let's define the fragment of the plane and the particle on it to show the action of forces when the particle moves downward, Fig. 2 a.

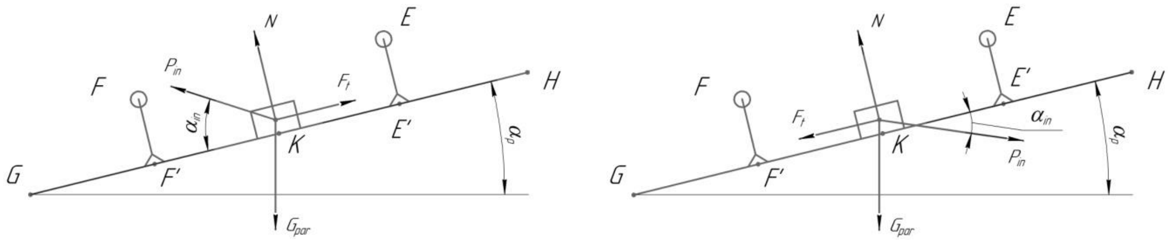


Figure 2. Schemes of the action of forces on the particle when it moves downward – a and upward – b

Under such conditions, the particle can move downwards if the acting forces are projected onto the axis parallel to the plane of the ploughshare, and the resulting force that moves the particle downwards will be greater than the corresponding resulting force that is opposite in direction.

Let's write this condition in the following way

$$P_{in} \cdot \cos\alpha_{in} + G_{par} \sin\alpha_p > F_t \,, \tag{1}$$

where P_{in} is the inertia force acting on the particle;

α_{in} is the angle of direction of the inertia force vector;

G_{par} is the particle weight force;

α_p is the angle of inclination of the ploughshare plane to the horizon;

F_t is the friction force.

Here

$$P_{in} = m_{par} a_i \cdot \cos\alpha_{in} \,, \tag{2}$$

where a_i is the acceleration of the particle at the *i*-th time moment.

The force of particle weight is expressed by the known dependence

$$G_{par} = m_{par} \cdot g \,, \tag{3}$$

where g is the acceleration of free fall, $g = 9{,}81\ m/s^2$.

According to the diagram (Fig. 2), the friction force is $F_t = fN$, where f is friction coefficient; N is the normal force.

Or in the expanded form

$$F_t = tg\varphi_t \left(G_{par} \cdot \cos\alpha_p - P_{in} \cdot \sin\alpha_{in}\right), \tag{4}$$

where φ_t is friction angle.

Next, it is necessary to choose the parameter that can be used to influence the described process. This parameter is the acceleration, which determines the oppositely directed inertia forces acting on the particle [19]. According to previous investigations [16], the following distribution of inertia forces with respect to the unit mass at three characteristic points of the track line produced by the intersection of the longitudinal-vertical plane with the ploughshare plane (G – point belonging to the ploughshare blade, K – middle and H – extreme point of the ploughshare on the conveyor side) was determined, Fig. 3.

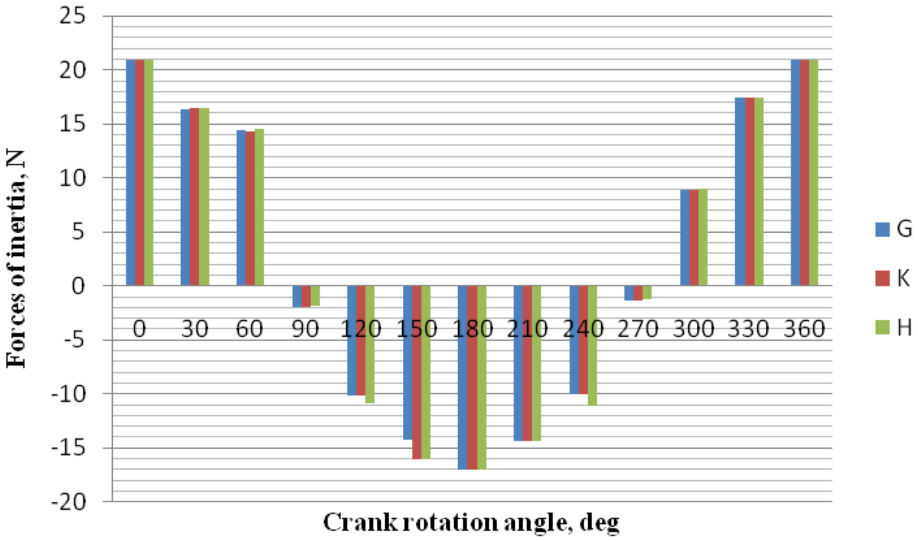


Figure 3. Inertia forces affecting the unit mass at points G, K, H

This makes it possible to see the probable directions of the particle movement on the ploughshare plane. The question can be answered more affirmatively when we analyse each of the conditions (for example, condition (1)) that determines the possibility of directional motion of the particle.

In order to implement this approach, let us identify acceleration a_i, from expression (1) by carrying out several transformations.

Let's write expression (1) in expanded form

$$m_{par} a_i \cos\alpha_{in} + m_{par} g \sin\alpha_p > tg\varphi_t \left(m_{par} g \cos\alpha_p - m_{par} a_i \sin\alpha_{in} \right), \tag{5}$$

let's reduce the left and right sides of inequality (5) by m_{par} and group

$$a_i \cos\alpha_{in} + tg\varphi_t \cdot a_i \sin\alpha_{in} > tg\varphi_t \, g \cos\alpha_p - g \sin\alpha_p ,$$

or

$$a_i > \frac{g\left(tg\varphi_t \cos\alpha_p - \sin\alpha_p \right)}{\cos\alpha_{in} + tg\varphi_t \sin\alpha_{in}},$$

After transformations and simplifications of the right-hand side of the inequality, we finally get the expression for acceleration value a_i, which will move the part downwards. Let us assign the acceleration index «d»

$$a_{i(d)} > \frac{g\sin(\alpha_p - \varphi_t)}{\cos(\alpha_{in} - \varphi_t)}, \tag{6}$$

Thus, the first condition under which the part should move down the ploughshare plane is obtained. The given condition (6) determines the value and direction of the acceleration transmitted by the ploughshare plane to the particle and causes directional movement.

Similarly, we consider the approach for determining the acceleration that will cause the particle to move up the ploughshare plane. Let us present the diagram of the acting forces according to the specified condition, Fig. 2 b.

The main condition for the upward movement will be that the resultant of the acting forces moving the particle upward is greater than the resultant of the forces holding the particle or trying to move it down by the ploughshare plane.

The actions of the forces are written mathematically through their projections on the axis parallel to the ploughshare plane

$$F_t + G_{par} \cdot \sin\alpha_p < P_{in} \cdot \cos\alpha_{in}. \tag{7}$$

We make transformations similar to the previous ones:

$$tg\varphi_t \left(m_{par} g \cdot \cos\alpha_p + m_{par} a_i \sin\alpha_{in}\right) + m_{par} g \cdot \sin\alpha_p < m_{par} a_i \cos\alpha_{in};$$
$$a_i \cos\alpha_{in} + tg\varphi_t \cdot a_i \sin\alpha_{in} > tg\varphi_t\, g\cos\alpha_p - g\sin\alpha_p,$$
$$a_i > \frac{g\left(tg\varphi_t \cos\alpha_p - \sin\alpha_p\right)}{\cos\alpha_{in} + tg\varphi_t \sin\alpha_{in}}.$$

Finally, we get, assigning acceleration a_i index "u"

$$a_{i(u)} > \frac{g(\sin\alpha_p + \varphi_t)}{\cos(\alpha_{in} + \varphi_t)}. \tag{8}$$

As it was noted above, the particle movement along the ploughshare plane is possible with the particle detachment from its surface. If such kinematic mode of ploughshare operation is ensured, then the contact of the particle with the plane should be broken. To understand this process, it is possible to imagine that the particle is «attached» to the ploughshare plane by he weightless elastic bond. In this case, the normal force N would have a negative value. However, since the particle has one-way connection with the ploughshare plane, then it is sufficient to consider the boundary condition when $N = 0$ (the moment of particle «detachment»), Fig. 2.

$$N = G_{par} \cdot \cos\alpha_p - P_{in} \cdot \sin\alpha_{in} = 0 \tag{9}$$

or in the expanded form

$$m_{par} g \cdot \cos\alpha_p - a_i \cdot m_{par} \cdot \sin\alpha_{in} = 0,$$

finally we have, assigning the acceleration index «0»

$$a_{i(0)} > \frac{g \cdot \cos\alpha_p}{\sin\alpha_{in}}. \tag{10}$$

Thus, all the main options for the behaviour of the particle on the ploughshare plane which makes it possible to assess the possibility of directional movement of the dug up potato bearing layer in the first approximation have been worked out.

Since the ploughshare plane does not make plane-parallel movements, the transport capacity of the ploughshare plane will vary For visual representation, we present the histogram of ploughshare position (α_p) relatively to the horizon at the corresponding value of the crank angle φ, Fig. 4.

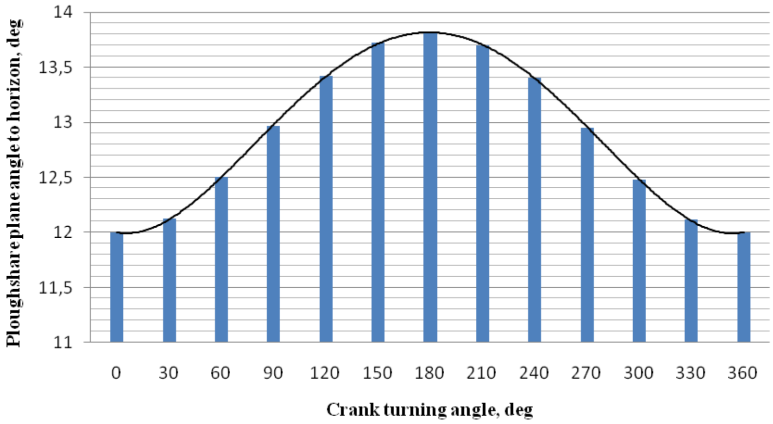


Figure 4. Position of ploughshare plane from crank turning angle

The points of maximum angles α_p are approximated by the curve – polynomial of the fourth degree ($R^2 = 0{,}999$) to estimate the intermediate values of the ploughshare position

$$\alpha_p(\varphi) = 0{,}001\varphi^4 - 0{,}045\varphi^3 + 0{,}363\varphi^2 - 0{,}681\varphi + 12{,}36. \tag{11}$$

Now, having conditions (6), (8) and (10), we can check the possible directional motion of the particle on the ploughshare plane.

Let us carry out such analysis for point G, which belongs to the cutting blade of the ploughshare, i.e., we consider the behaviour of the particle located in the initial part of the ploughshare plane.

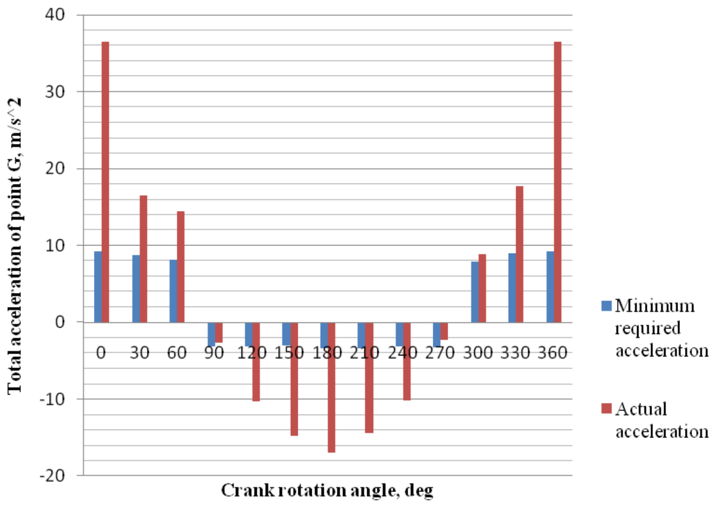


Figure 5. Histogram for comparative analysis of behavior particles at point G

The values of actual accelerations (red) at point G are shown in Fig. 5 in the form of a bar graph.They are compared with the minimum accelerations (blue), which determine the possibility of fulfilling conditions (6) and (8) of the corresponding particle motions.

Similar histograms (Figures 6 and 7) are shown for the characteristic points K and H.

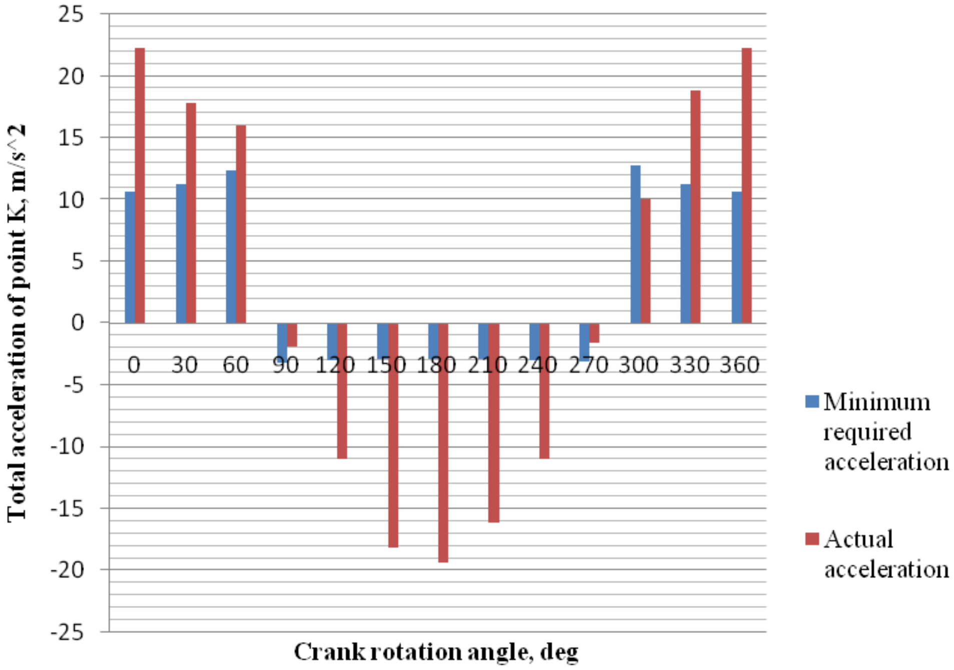


Figure 6. Histogram for comparative analysis of behavior particles at point K

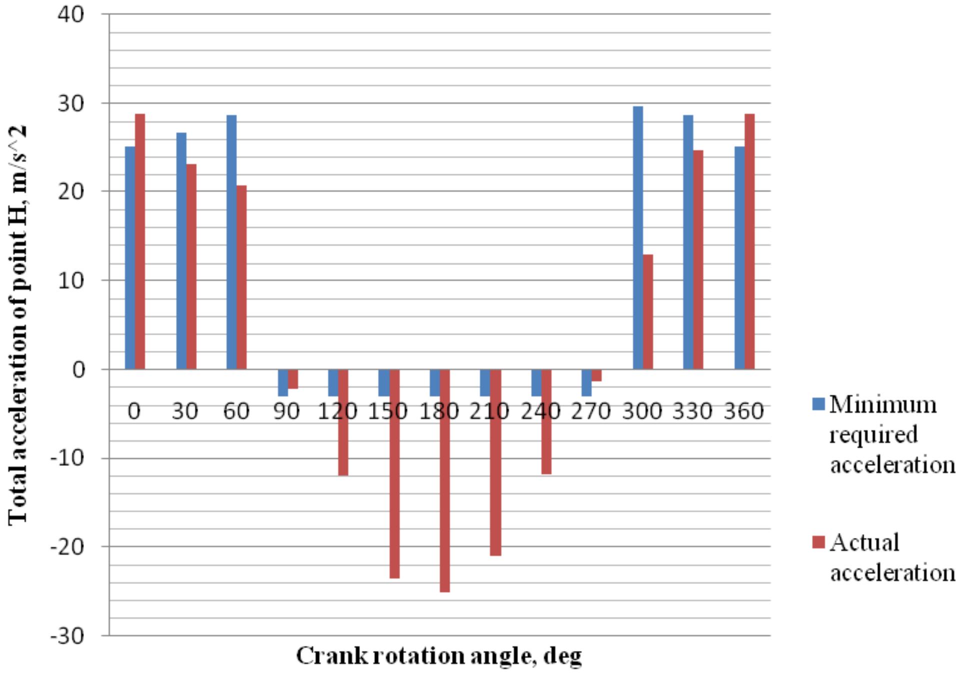


Figure 7. Histogram for comparative analysis of behavior particles at point H

Separate histogram (Fig. 8) shows the results of comparison of the corresponding accelerations at point H where the effect of particle detachment from the ploughshare plane occurs during its directional movement.

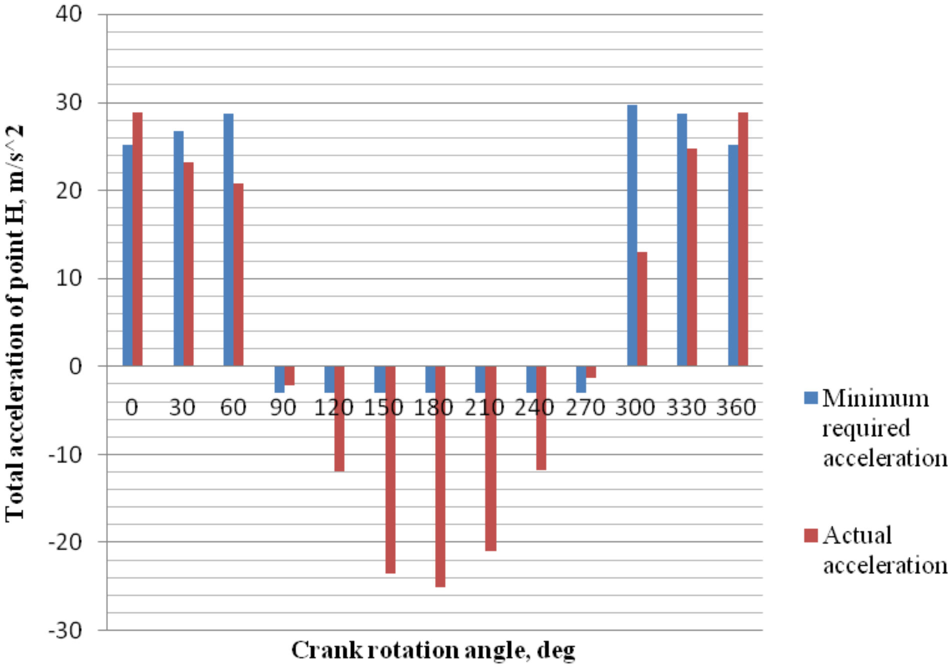


Figure 8. Histogram for comparative analysis of the particle behavior at point H, provided that it is detached from the plane of the ploughshare

Thus, according to the above mentioned model of the behaviour of potato bearing layer particle on the oscillating ploughshare plane, it is possible to analyse the possibility of its directional movement and model it in the first approximation. For this purpose, it is necessary to use the built-in design adjustments of the entire system and to select the required kinematic parameters of the drive.

5. CONCLUSIONS

A number of results have been obtained by means of newly developed design of vibrating ploughshare which is used as separating and transporting operating body of potato digger. These results describe special case of the behaviour of potato bearing layer particle on its plane. Based on the developed simplified mathematical model of the particle behaviour on the vibrating plane, the conditions under which this particle can have directional motion are obtained. On this basis, mathematical dependencies which due to the comparison of the minimum required values and acting accelerations, and hence inertial forces were written down. They make it possible to judge the directional movement of the particle (potato, soil clod, etc.) along the ploughshare plane.

The particles located at the beginning of the ploughshare (point G) during the working stroke at crank rotation speed 432 rpm and within the rotation angle φ from 0 to $\frac{\pi}{3}$, will be moved upwards. The effective accelerations here are as follows: at $\varphi = 0; \frac{\pi}{6}; \frac{\pi}{3}$, respectively, 36.5 $\frac{m}{s^2}$; 16.47 $\frac{m}{s^2}$; 14.38 $\frac{m}{s^2}$, and the required accelerations according to condition (8) are 9.19 $\frac{m}{s^2}$; 8.76 $\frac{m}{s^2}$; 8.14 $\frac{m}{s^2}$. This means that the condition is met and the particles will move upwards in the ploughshare plane. At the crank $\varphi = \frac{\pi}{2}$ position, the inertial force is directed downwards, which should cause the particle to move downwards. The acceleration here is 2.69 $\frac{m}{s^2}$, and the minimum required acceleration according to condition (6) is 3.14 $\frac{m}{s^2}$; while comparing the values, it is clear that the condition of moving the particle down the ploughshare plane is not met, which means that the friction force is greater and the particle will move with the plane, and there is no relative movement of the particle. With further rotation of the crank to $\varphi = \pi$ (until the end of the working stroke), the particle will move downwards with low intensity, as well as at the beginning of the reverse stroke of the ploughshare (to $\varphi = \frac{3}{2}\pi$). Then the direction of the particle movement will change to its upward shift until the ploughshare stroke is completed ($\varphi = 2\pi$).There is no movement of the ploughshare with the particle detaching from its plane in this area. The upward and downward movement of the particle, movement with the ploughshare plane, make it possible to intensify the separation of small soil particles that pass through the gaps in the bar part of the ploughshare. Similar approaches are used to analyse the directional movement of the particle in the ploughshare points K and H, guided by the histograms presented in Figs. 6 and 7. According to the analysis of the presented results, the movement of the particle with detachment from the ploughshare plane is detected in point H, which is located in the rear part of the ploughshare and is the closest to the bar conveyor. Such effect plays a positive role here, as it helps to clean the ploughshare plane from the potato bearing layer particles and makes it easier for them to pass to the next operating body - the conveyor belt.

Thus, the presented model of the behaviour of a potato bearing layer particle on the ploughshare plane in the form of the written conditions (6), (8) and (10) and the availability of values of kinematic parameters during its operation makes it possible to carry out the preliminary analysis of the possibility of directed movement of such particles by the oscillating plane.

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АНАЛІЗ ПОВЕДІНКИ ЧАСТИНОК БУЛЬБОНОСНОГО ПЛАСТА НА КОЛИВНІЙ ПЛОЩИНІ ЛЕМЕША КАРТОПЛЕКОПАЧА

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Резюме. *Підвищення рівня механізації виробничих процесів при вирощуванні сільськогосподарської продукції залишається актуальним напрямком досліджень науковців галузевого машинобудування. За аналізом проблематики, яка прослідковується при виробництві картоплі в малих підсобних господарствах на технологічній операції збирання, у роботі наведено рішення щодо покращення конструкцій однорядних картоплекопачів. Запропоновано нову конструкцію вібраційного підкопуючого робочого органу картоплезбиральної машини, де специфікою є те, що коливна площина такого лемеша переміщається за визначеним законом руху, а тому кожна її точка має різну можливість до транспортуючої та сепарувальної здатності. Представлено конструкцію та опис даного робочого органу й на основі його кінематичної схеми наведено розрахункові залежності, які визначають умови переміщення окремої частинки його площиною.*

Наведена методика обґрунтовує можливість направленого руху частинки вгору площиною лемеша, вниз та з відривом. При невиконанні умови, за порівнянням прискорень, частинка не матиме відносного переміщення та буде рухатися разом з площиною. На основі такого підходу для окремого кінематичного режиму роботи картоплекопача визначено значення прискорень, що коливна площина передає частинці для виникнення направленого руху. Проаналізовано значення діючих та мінімально необхідних прискорень, які діють на частинку, що знаходиться на коливній площині лемеша, та зроблено висновки про можливість її направленого руху. Встановлено, що на передній та середній частинах лемеша при різних кутах повороту кривошипа можливі рухи частинки вгору-вниз та разом з площиною, а задня частина лемеша може ще й забезпечувати рух частинки з відривом від площини лемеша. Такий ефект підкидання відіграє позитивну роль, оскільки допомагає очистити площину лемеша від частинок бульбоносного пласта та полегшено перейти на наступний робочий орган – транспортер. Виникнення описаних відносних рухів частинки на площині лемеша сприяють підвищенню інтенсифікації процесу сепарації. Подальші теоретичні описи процесу сепарації будуть базуватися на основних підходах наведеної методики щодо визначення можливості направленого руху частинки на коливній площині лемеша.

Ключові слова: *коливання, кінематична схема, прискорення, сила інерції, направлений рух, леміш, площина, сепарація, кут тертя, вібраційний рух, картоплекопач, технологічний процес, виробництво картоплі.*

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