UDC 621.8:631.356.4 DOI: https://doi.org/10.32515/2664-262X.2024.10(41).1.200-212

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Engineering method of studying the kinematic parameters of the working body of the potato harvesting machine

The work provides an engineering methodology for studying the kinematic parameters of the drive mechanism of the ploughshare of a single-row potato harvesting machine. The development of a new design of the potato harvesting machine led to a special approach to studying its kinematic parameters. The essence of the engineering methodology is that it is based on the graphical-analytical method of plans in the study of kinematic mechanisms. For the physical design of the drive mechanism of the potato harvesting machine, theoretical descriptions were made and plans of velocities and accelerations were built, which allows the researcher to obtain the specified kinematic parameters for any points of the links of this mechanism. The paper obtained a number of values of kinematic parameters that characterize the operation of this mechanism and on the basis of which the technological efficiency of the ploughshare of the potato harvesting machine is analyzed.
potatoes, potato harvesting machine, kinematic parameters, velocity, acceleration, ploughshare, crank, drive mechanism, working body, engineering methodology

Problem statement. The cost of production of crop products directly depends on the level of mechanization of technological processes. One of the most labor-intensive operations is the harvesting operation in the production of potatoes. This is a particularly acute issue for small farms or farms where there is a lack of equipment [13, 15]. There are many offers of mini potato harvesting machines on the market, but few of them come from Ukrainian manufacturers of such equipment. In addition, most of this equipment is not designed for regional specifics - heavy soils. Therefore, during operation, potato harvesting machines often break down, their technological efficiency decreases, or they are generally unable to perform this technological operation under such conditions [16].

From this follows the need to carry out research work to find new solutions for obtaining optimal designs of potato harvesters [18]. However, the problem is complicated by the fact that we are talking about small, low-energy machines that are operated with tractors of a traction class of 0.6 tons and less. Therefore, decisions made must be well-considered and made on the basis of proven engineering analysis techniques and basic approaches to designing agricultural machinery [2].

Analysis of recent research and publications. Many scientists focus on the study of mini potato machines [5-10]. This is especially well developed in those countries that most export such equipment to the world market. However, there is very limited information that covers engineering methods of research, for example, kinematic parameters of the main working bodies of potato diggers. The accuracy of the final result depends on the application and implementation of a particular theory that describes the desired process [3, 4, 14]. The problem is exacerbated if there are new constructive solutions that are different from the typical ones. Then it is difficult for the designer to simulate the work of the proposed design. Therefore, it is worth developing theoretical approaches for analyzing certain parameters of machines in the form of engineering techniques that have the necessary sequence and completeness for the implementation of the study, as well as simple mathematical calculations.

Statement of the task. The purpose of the study is to develop an engineering technique for studying the kinematic parameters of the driving mechanism of the ploughshare of a potato harvesting machine as the main working body.

Presentation of the main material. According to the development of our own design of the potato harvesting machine (Fig. 1), the biggest interest in the research is the system of ploughshare with its drive mechanism [11]. Energy intensity of machine, the degree of separated particles of the tuberous layer, etc., depends on the efficiency of this working body.

We will build the engineering method of researching the kinematic parameters of the working body based on the principle from the energy input into the system to the interaction of the working body with the environment that creates working resistance.

The ploughshare is driven from the tractor power takeoff shaft, the frequency of which is $n = 540$ rpm. The selection shaft is connected to the angular conical reducer with a gear ratio $i = 1{,}25$, Fig. 1.

Figure 1 – General appearance of the potato harvesting aggregate

Source: developed by the authors

Based on this, the frequency of the leading link of the drive will be

$$n_1 = \frac{n}{i}. \tag{1}$$

If we go to the angular speed of the driving link (crank), then

$$\omega_1 = \frac{\pi n_1}{30}. \tag{2}$$

Based on considerations of the necessary amplitude of movement of the cutting edge (17 mm), we accept the radius of the crank $l_1 = l_{AO_1} = 0{,}0273$ *m*.

For constructive reasons and the implementation of the physical design of the ploughshare of the potato harvesting machine, the lengths of the links and the distance between their supports are accepted according to the following kinematic scheme of the ploughshare drive, Fig. 2.

For the kinematic analysis of such a mechanism, the simplest is the graphic-analytical method of plans, which gives an idea of the values of velocities and accelerations [17]. This method forms the basis of the proposed engineering methodology.

An important aspect in such a study is to identify the value of the links acting at any point of the ploughshare or other points. For example, in addition to the magnitude of velocities or accelerations, their directions as well. In the future, this will be of crucial importance for determining the "behavior" of soil particles and tubers on the ploughshare plane, that is, it will determine the possibility of directional movement of such a mass and its separation.

Therefore, using this method, we will establish the necessary kinematic parameters of the studied quantities at characteristic points of the ploughshare plane [12]. In order to obtain a general picture of changes in the velocities and accelerations of the links at certain points of the ploughshare and its drive, now we will take a research step - this is a multiple rotation of the crank is a multiple of 30 and ranges from 0 to 360^0. Under these conditions, the ploughshare will perform one complete cycle: forward (working) and reverse (idle) moving.

Now we will move on to determining the kinematic parameters.

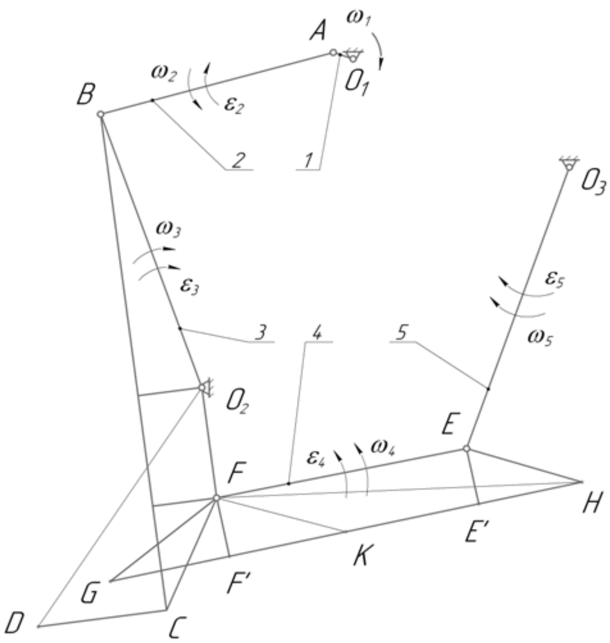


Figure 2 – Kinematic scheme of the ploughshare drive
Source: developed by the authors

For the initial position of the crank, we assume that it corresponds to the extreme posterior deviation of the ploughshare towards the conveyor, that is, after which the ploughshare blade (working course) will move towards the uncopied tuberous formation. This position is determined by the geometric construction on its kinematic scheme, made to scale. We check the correctness of the positions of the links of such a mechanism on the physical design of the ploughshare drive.

We assume that the tractor power takeoff shaft rotates at a constant angular velocity and $\omega_1 = const$.

Then the linear (circular) speed of the p. A of the crank will be

$$\vartheta_A = \omega_1 \cdot l_1 . \quad (3)$$

To find the velocities and accelerations for characteristic points belonging to the ploughshare or connecting links of the drive mechanism, vector systems of equations are written, which we will use to solve:

$$\begin{cases} \vec{\vartheta}_B = \vec{\vartheta}_A + \vec{\vartheta}_{BA}; \\ \vec{\vartheta}_B = \vec{\vartheta}_{O_2} + \vec{\vartheta}_{BO_2}. \end{cases} \quad (4)$$

$$\begin{cases} \vec{\vartheta}_E = \vec{\vartheta}_F + \vec{\vartheta}_{EF}; \\ \vec{\vartheta}_E = \vec{\vartheta}_{O_3} + \vec{\vartheta}_{EO_3}. \end{cases} \quad (5)$$

The following notations are used here: $\vec{\vartheta}_B$ – vector of absolute (within the drive mechanism) velocity p. B ; $\vec{\vartheta}_{BA}$ – vector of relative velocity p. B relative to p. A . The notation for the remaining points is in accordance with the kinematic diagram, Fig. 2.

The main idea of the proposed graphic-analytical method of plans is that unknown velocities can be found by having some of the values of the velocities and for others only their directions. The methodology of the method of plans is known [17] and therefore we will not give its sequence.

Describing the drive mechanism of the ploughshare, we present the dependencies and main results of determining the kinematic parameters of this mechanism. Solutions of systems (4) and (5) are obtained by sequentially calculating the numerical values of the desired velocities of the points and constructing their vectors on the velocity plane in the accepted scale. An example of a velocity plan (Fig. 3) will be given below after describing the procedure for determining all the velocities of the characteristic points of the links.

The angular velocity of the connecting rod ω_2 (link 2) is found by the value of the relative velocity p. B relative to p. A, the expression will have the form

$$\omega_2 = \frac{\vartheta_{BA}}{l_{BA}}. \tag{6}$$

Similarly, we find the angular velocity of link 3 ω_3, through the obtained value of the relative velocity p. B relative to the support O_2

$$\omega_3 = \frac{\vartheta_{BO_2}}{l_{BO_2}}. \tag{7}$$

Next, solving the problem, we see that p. F also belongs to link 3, which means that its angular velocity is equal to ω_3.

It is known that circular velocities are proportional to the length of the links, so to determine the velocity, the following ratio will be valid $\vartheta_{FO_2} = \vartheta_F$

$$\vartheta_{FO_2} = \frac{l_{FO_2}}{l_{BO_2}} \cdot \vartheta_{BO_2}. \tag{8}$$

The obtained relative velocities of the points allow us to determine the angular velocities of the corresponding links.

The angular velocity ω_4 of the plane of the ploughshare will be determined by the expression

$$\omega_4 = \frac{\vartheta_{EF}}{l_{EF}}. \tag{9}$$

The angular velocity of the rear suspension of the ploughshare (link 5) will be

$$\omega_5 = \frac{\vartheta_{EO_3}}{l_{EO_3}}. \tag{10}$$

As it can be seen from Fig. 2, the fourth link FE is not in the plane of the base of the ploughshare, but only conditionally connects the points of the hinge joints with the suspensions. The ploughshare design itself is trough-shaped and therefore its actual working plane is lower. In Fig. 2 it is conventionally marked by the line GH, which belongs to this plane. Thus, it is necessary to determine the velocity in p. G – this is the point of the ploughshare blade, p. K – the middle of its base, p. H – the point of the rear edge of the ploughshare.

Since the formed figure $GFEH$ is a solid body described by the characteristic points of the ploughshare, such a figure has the same angular velocity as link 4 FE.

It follows that the relative velocity of p. G with relative to p. F will be

$$\vartheta_{GF} = \vartheta_{EF} \frac{l_{GF}}{l_{EF}} = \omega_4 \cdot l_{GF} . \tag{11}$$

In a similar way, we determine the relative velocity of p. H and p. K

$$\vartheta_{HF} = \vartheta_{EF} \frac{l_{HF}}{l_{EF}} = \omega_4 \cdot l_{HF} , \tag{12}$$

$$\vartheta_{KF} = \vartheta_{EF} \frac{l_{KF}}{l_{EF}} = \omega_4 \cdot l_{HF} . \tag{13}$$

Absolute velocities p. H and p. K are determined from the velocity plan, Fig. 3.

And another characteristic point of the ploughshare drive mechanism is the extreme p. D of the active sidewall. The role of such a link in the ploughshare mechanism is to separate the tuberous layer from the main mass of soil for further facilitated digging.

In the same way we approach the determination of this velocity. Since p. D belongs to link 3, which has a complex configuration, its angular velocity will be equal to ω_3. The expression of the velocity for p. D will have the form

$$\vartheta_D = \vartheta_{DO_2} = \omega_3 l_{DO_2} = \vartheta_{FO_2} \cdot \frac{l_{DO_2}}{l_{FO_2}}. \tag{14}$$

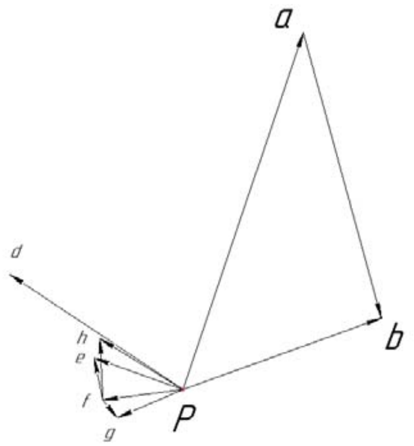


Figure 3 – Velocity plan of the ploughshare drive mechanism ($\varphi_1 = 30^0$)

Source: developed by the authors

Hence, the method of determining the speeds for all characteristic points of the links of the vibrating ploughshare drive mechanism was described. All key relationships are recorded here, which allow a simple way to establish the value and direction of the velocity of any points of interest to the researcher.

For example, we will show the velocity plan at the crank position $\varphi_1 = 30^0$, Fig. 3.

Such a velocity plan can be obtained for any position of the drive crank as a leading link and determine the velocity of an arbitrary point belonging to the ploughshare drive mechanism.

According to the results of the study, a number of values of linear and angular velocities were obtained. Fig. 4 shows the graphical dependences of the obtained angular velocities of the drive mechanism links.

All the necessary linear velocities of the points of the links were also found, which is convenient for implementing the task of studying the processes performed by the ploughshare as a working body.

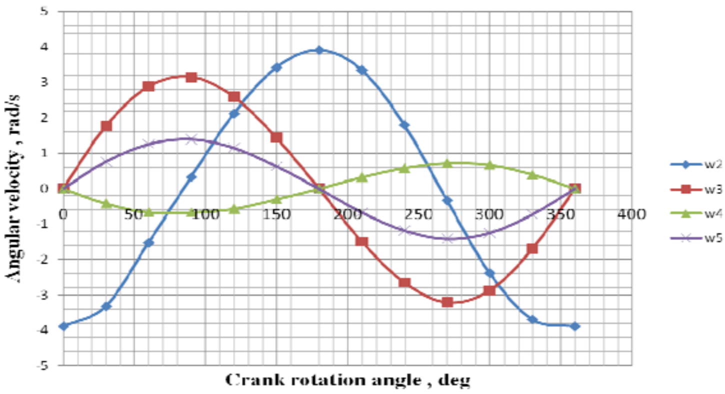


Figure 4 – Graphical dependences of changes in angular velocities of links

Source: developed by the authors

Determining the velocities of the points as a prerequisite for determining accelerations, parameters that we will operate directly to analyze the efficiency of such a mechanism. Let us move on to determining the values and directions of the accelerations of the same characteristic points.

To find the accelerations of points belonging to this mechanism, we first need to compose vector systems of equations, which we will use to solve:

$$\begin{cases} \vec{a}_B = \vec{a}_A + \vec{a}^n_{BA} + \vec{a}^\tau_{BA}; \\ \vec{a}_B = \vec{a}_{O_2} + \vec{a}^n_{BO_2} + \vec{a}^\tau_{BO_2}. \end{cases} \quad (15)$$

$$\begin{cases} \vec{a}_E = \vec{a}_F + \vec{a}^n_{EF} + \vec{a}^\tau_{EF}; \\ \vec{a}_E = \vec{a}_{O_3} + \vec{a}^n_{EO_3} + \vec{a}^\tau_{EO_3}. \end{cases} \quad (16)$$

Here are denoted: $\vec{a}_B$ – the vector of absolute (within the drive mechanism) acceleration of p. B, $\vec{a}^n_{BA}$, $\vec{a}^\tau_{BA}$ – in accordance, the normal and tangential components of the total (modulus) acceleration of p. B in obedience to p. A. The remaining notations are similar and assigned to the corresponding points, Fig. 2.

To solve system (15), it is first necessary to determine the normal components of the total accelerations:

$$a^n_{BA} = \frac{\vartheta^2_{BA}}{l_{BA}}, \quad (17)$$

$$a^n_{BO_2} = \frac{\vartheta^2_{BO_2}}{l_{BO_2}}. \quad (18)$$

The tangential components of these accelerations will be found from the acceleration plan (Fig. 5), which will also be given after the description of the entire procedure for finding accelerations for characteristic points of the drive mechanism.

Then the total (modulus) accelerations:

$$a_{BA} = \sqrt{\left(a^n_{BA}\right)^2 + \left(a^\tau_{BA}\right)^2}, \quad (19)$$

$$a_{BO_2} = \sqrt{\left(a^n_{BO_2}\right)^2 + \left(a^\tau_{BO_2}\right)^2}. \quad (20)$$

Having the tangential components of the accelerations, we determine the angular accelerations of the links:

– for link 2

$$\varepsilon_2 = \frac{a^\tau_{BA}}{l_{BA}}; \quad (21)$$

– for link 3

$$\varepsilon_3 = \frac{a^\tau_{BO_2}}{l_{BO_2}}. \quad (22)$$

It is worth noting that $\varepsilon_1 = 0$, because $\omega_1 = const.$

Now we will solve the second system of vector equations (16).

We determine the acceleration p. F, which belongs to link 3.

Now we will write an expression for determining the normal component of the acceleration $a^n_{FO_2}$ through the previously determined velocities of the corresponding points.

$$a^n_{FO_2} = \frac{\vartheta^2_{FO_2}}{l_{FO_2}}. \quad (23)$$

Its tangential component will be determined by

$$a^\tau_{FO_2} = \varepsilon_3 \cdot l_{FO_2}. \quad (24)$$

Then the total acceleration is p. F

$$a_F = a_{FO_2} = \sqrt{\left(a^n_{FO_2}\right)^2 + \left(a^\tau_{FO_2}\right)^2}. \quad (25)$$

Next, it is needed to determine the normal components of the remaining accelerations:

$$a^n_{EF} = \frac{\vartheta^2_{EF}}{l_{EF}}, \quad (26)$$

$$a^n_{EO_3} = \frac{\vartheta^2_{EO_3}}{l_{EO_3}}. \quad (27)$$

The tangential components of the considered accelerations are determined from the acceleration plan, for instance Fig. 5

The total accelerations will be:

$$a_{EF} = \sqrt{\left(a^n_{EF}\right)^2 + \left(a^\tau_{EF}\right)^2}, \quad (28)$$

$$a_{EO_2} = \sqrt{\left(a^n_{EO_2}\right)^2 + \left(a^\tau_{EO_2}\right)^2}. \quad (29)$$

Based on the obtained tangential acceleration components, we determine the angular accelerations of links 4 and 5:

$$\varepsilon_4 = \frac{a^{\tau}_{EF}}{l_{EF}}, \tag{30}$$

$$\varepsilon_5 = \frac{a^{\tau}_{EO_3}}{l_{EO_3}}. \tag{31}$$

The acceleration of p. G relative to p. F we will write in this form

$$\vec{a}_{GF} = \vec{a}^{\,n}_{GF} + \vec{a}^{\,\tau}_{GF}. \tag{32}$$

where a^n_{GF} is a normal component of acceleration a_{GF},

$$a^n_{GF} = \frac{\vartheta^2_{GF}}{l_{GF}}; \tag{33}$$

a^{τ}_{GF} is a tangential component.

We will define this component through the angular acceleration of link 4, because p. G belongs to it

$$a^{\tau}_{GF} = \varepsilon_4 \cdot l_{GF}. \tag{34}$$

Then the total acceleration is suitably (32)

$$a_{GF} = \sqrt{\left(a^n_{GF}\right)^2 + \left(a^{\tau}_{GF}\right)^2}. \tag{35}$$

Similarly, we find the acceleration a_{HF}.

$$a_{HF} = \sqrt{\left(a^n_{HF}\right)^2 + \left(a^{\tau}_{HF}\right)^2}, \tag{36}$$

where a^n_{HF} is a normal component of acceleration a_{HF}

$$a^n_{HF} = \frac{\vartheta^2_{HF}}{l_{HF}}; \tag{37}$$

a^{τ}_{HF} is a tangential component

$$a^{\tau}_{HF} = \varepsilon_4 \cdot l_{HF}. \tag{38}$$

Another characteristic point of the mechanism under consideration is p. D, it belongs to the cutting edge of the active side of the ploughshare, its acceleration will be

$$a_{DO_2} = a_D = \sqrt{\left(a^n_{DO_2}\right)^2 + \left(a^{\tau}_{DO_2}\right)^2}, \tag{39}$$

where $a^n_{DO_2}$ is a normal component of acceleration a_{DO_2},

$$a^n_{DO_2} = \frac{\vartheta^2_{DO_2}}{l_{DO_2}}. \tag{40}$$

The tangential component of this acceleration is determined through the angular acceleration ε_3 of link 3

$$a^\tau_{DO_2} = \varepsilon_3 \cdot l_{DO_2}. \tag{41}$$

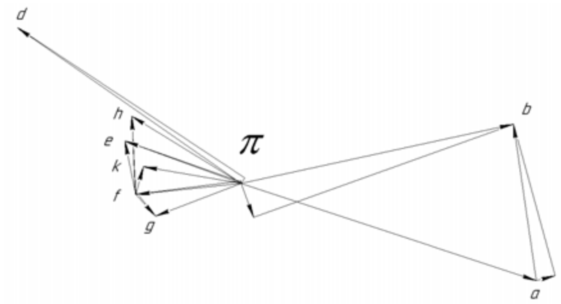
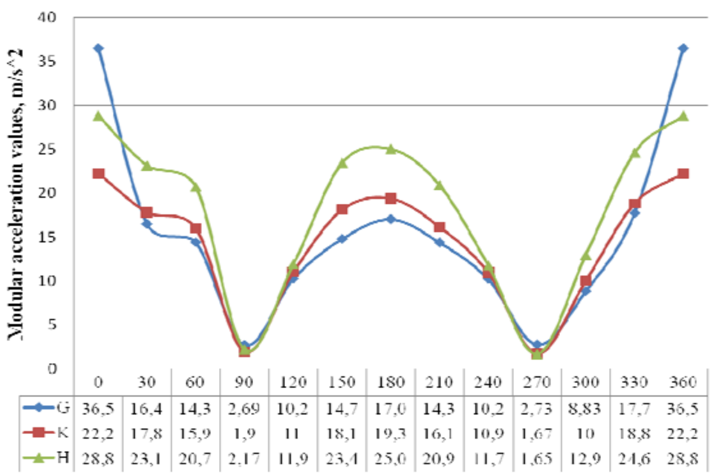


Figure 5 – Plan of accelerations of the ploughshare drive mechanism ($\varphi_1 = 30^0$)
Source: developed by the authors

Thus, the velocities and accelerations for the characteristic points of the ploughshare drive mechanism were found.

Now an important aspect will be to observe how the determined kinematic parameters will change during the working cycle of the ploughshare. For example, the nature of the change in accelerations will determine the directional movement of the particle along its plane, Fig. 6.



	0	30	60	90	120	150	180	210	240	270	300	330	360
G	36,5	16,4	14,3	2,69	10,2	14,7	17,0	14,3	10,2	2,73	8,83	17,7	36,5
K	22,2	17,8	15,9	1,9	11	18,1	19,3	16,1	10,9	1,67	10	18,8	22,2
H	28,8	23,1	20,7	2,17	11,9	23,4	25,0	20,9	11,7	1,65	12,9	24,6	28,8

Figure 6 – Change in accelerations at characteristic points of the ploughshare plane
Source: developed by the authors

In addition, it is worth monitoring the change in accelerations that occur in the p. G belonging to the ploughshare blade, and the p. D of the active sidewall, the work of which will cause the effect of separating the tuberous layer when digging it, Fig. 7.

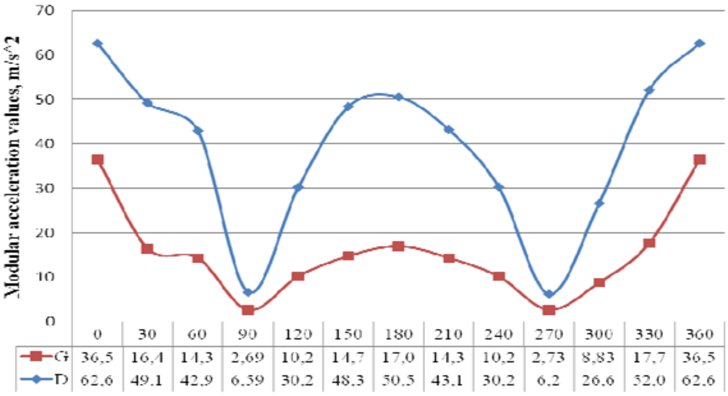


Figure 7 – Acceleration p. D and p. G

Source: developed by the authors

To identify the moments of inertia of the links and determine the tangential components of any points belonging to the links of the ploughshare drive mechanism, it is advisable to indicate the values of the angular accelerations of the links, Fig. 8.

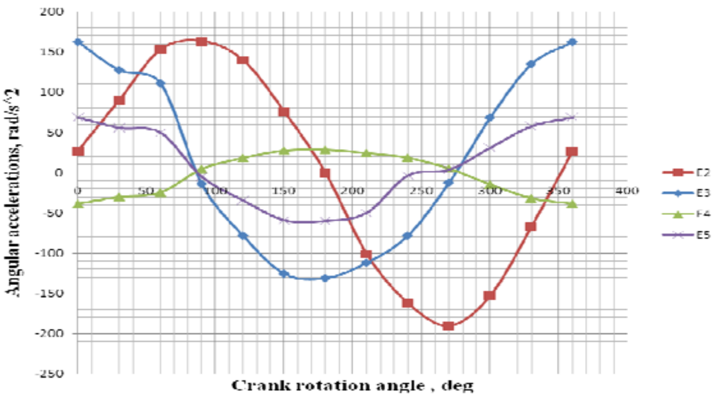


Figure 8 –Angular accelerations of drive mechanism links

Source: developed by the authors

Thus, the presented engineering methodology for studying the kinematic parameters of the ploughshare drive mechanism allows us to describe the patterns of interaction of the links of such a mechanism and characterize the linear, angular velocities and accelerations of any points or links of the mechanism under study. The obtained kinematic parameters have scalar values and directions, which allow the researcher to more fully understand their influence on the process under study.

Conclusions The developed engineering methodology for studying the kinematic parameters of the ploughshare drive mechanism is based on the graph analytic method of plans. The advantage of this method is that velocities or accelerations can be determined for any point belonging to the links of the mechanism without using complex analytical descriptions.

Based on the above method, the linear velocities of the characteristic points of the mechanism in all its positions with the crankshaft rotation step were determined $\varphi_1 = 30^0$.

Here are the ranges of velocity values for characteristic points of the working plane of the ploughshare: p. G – $\vartheta_G = 0...0{,}42$ m/s; p. H – $\vartheta_H = 0...0{,}58$ m/s.

Here are the ranges of velocity values for characteristic points of the working plane of the ploughshare: p. G – $\vartheta_G = 0...0{,}42$ m/s; p. H – $\vartheta_H = 0...0{,}58$ m/s.

Angular velocities of the mechanism links:

link 2 – $\omega_2 = 0{,}32...3{,}9$ rad/s; link 3 – $\omega_3 = 0...3{,}21$ rad/s, link 4 – $\omega_4 = 0...0{,}72$ rad/s; link 5 – $\omega_5 = 0...1{,}42$ rad/s.

Acceleration of characteristic points: p. G – $a_G = 2{,}69...36{,}5$ m/s^2; p. K – $a_K = 1{,}9...22{,}2$ m/s^2; p. H – $a_H = 1{,}65...28{,}8$ m/s^2; p. D – $a_D = 6{,}2...62{,}6$ m/s^2.

Angular accelerations of links:

link 2 – $\varepsilon_2 = 0...190{,}5$ rad/s^2; link 3 – $\varepsilon_3 = 12{,}4...162{,}5$ rad/s^2; link 4 – $\varepsilon_4 = 4{,}84...38{,}5$ rad/s^2; link 5 – $\varepsilon_5 = 3{,}55...68{,}8$ rad/s^2.

The obtained values will be used as the basis for further research into the behavior of a tuberous layer particle on the plane of the ploughshare in order to determine the parameters to ensure its directional movement and separation intensity

List of References

1. Bulgakov V., Nikolaenko S., Adamchuk V., Z. & Olt J. Theory of impact interaction between potato bodies and rebounding conveyor. Agronomy Research. 2018. 16(1). pp. 52-63. DOI: 10.15159/AR.18.037.
2. Fu, Y.;& Wang, C. Experiment and study of the vibration of type 4SW-170 potato digger. *Journal of Agricultural Mechanization Research,* v.35. P.147-151, 2013. https://doi.org/10.13427/j.cnki.njyi.2013.01.052.
3. Hevko R.B., Tkachenko I.G., & Synii S.V., Development of design and investigation of operation processes of small-scale root crop and potato harvesters, *INMATEH Agricultural Engineering*. 49 (2), pp. 53-60, Romania (2016).
4. Hrushetsky S.M., Yaropud V.M., Duganets V.I., Duganets V.I., Pryshliak, V.L. & Kurylo V.M. Research of constructive and regulatory parameters of the assembly working organs for the potato's harvesting machines. *INMATEH-Agricultural Engineering.* 2019. Vol. 59. № 3. pp. 101-110. DOI: 10.35633/INMATEH-59-11.
5. Huali Yu, Xiaoshun Zhao, Yongying Sang & Tao Wu. Parametric Modeling and Moving Simulation of Vibrating Screen and Tubers on Potato Harvester. *Advance Journal of Food Science and Technology* 7(6): 474-478, 2015.
6. Li, J.; Lv, Y.; Sun, Y.; & Lin, Y. Design and experiment of separating and lifting device of potato harvester. *Journal of Agricultural Mechanization Research,* v.44. P.1-263, 2022. https://doi.org/10.13427/j.cnki.njyi.2022.12.020.
7. Lü Jinqing, Tian Zhongen, Wu Jin'e, Yang Ying, Shang Qinqin, Wang Yingbo, et al. Design and experiment on 4U1Z vibrating potato digger. *Transactions of the Chinese Society of Agricultural Engineering*. Vol.31 No.12. Jun. 2015. P. 39-47.
8. Shengshi Xie , Kai L. Lu , Wei G. Deng , Fang Wang , Peng Li & Guangyu Liu. Improved design and experiment of separating sieve for potato digger. *Brazilian Journal of Agricultural and Environmental Engineering.* v.27, n.12, 2023. P. 966-972. DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n12p966-972.
9. Shengshi Xie, Chunguang Wang, & Weigang Deng. Experiment of a swing separating sieve on a potato digger Engenharia Agrícola, Jaboticabal, v.39, n.4, p.548-554, jul./aug. 2019.
10. Xie, S.; Wang, C.; & Deng, W. Displacement analysis of potato relative to separation sieve and separation sieve performance test. *Journal of Agricultural Science and Technology*, v.21, p.71-81. 2019. https://doi.org/10.13304/j.nykjdb.2018.0492.
11. Бабій А.В. Вібраційний леміш картоплекопача / Бабій, А.В., Головецький, І.В., Гладьо, Ю.Б., Андрейків О.Є., Гамрач В.О / Деклараційний патент на корисну модель ua 156320 u A01D 21/00 (2024.01). Заявлено 09.01.2024, u 2024 00129, опубліковано 05.06.2024, Бюл. №23.
12. Бабій А.В., Головецький І.В. Визначення конструктивних параметрів елементів машин при нестаціонарних процесах навантаження. *Матеріали І-ї Міжнародної науково-технічної конференції «ПРИКЛАДНА МЕХАНІКА» присвяченої 80-ти річчю з дня народження професора Ч.В. Пульки. ТНТУ, Тернопіль*, 2024. С.149-151.
13. Бабій А.В., Головецький І.В., Герасимович П.В. Проблеми та перспективи розвитку картоплярства в Україні. *Збірник тез доповідей X-ої Міжнародної науково-практичної конференції молодих учених та студентів „Актуальні задачі сучасних технологій". Тернопіль, 2021.* ФОП Паляниця

В.А. Т.1. С. 25-26.
14. Бабій А.В., Головецький І.В., Гладьо Ю.Б. Дослідження кінематичних параметрів вібраційного лемеша картоплекопача з використанням комп'ютерної програми. *Загальнодержавний міжвідомчий науково-технічний збірник. "Конструювання, виробництво та експлуатація сільськогосподарських машин",* 2023. Вип. 53. С. 227-236.
15. Головецький І.В., Бабій А.В. Конструктивні особливості та ефективність роботи міні картоплекопачів. *Центральноукраїнський науковий вісник. Технічні науки*. 2023. Вип. 8(39), ч.II. С. 134-143.
16. Грушецький С.М. Інноваційна картопляна техніка – комплексне рішення задач. *Конструювання, виробництво та експлуатація сільськогосподарських машин : Загальнодержавний міжвід. наук.-техн. зб*. Під заг. ред. І.М. Черновола. Кіровоград : КНТУ, 2009. Вип. 39. С. 68-81.
17. Кіницький Я.Т. Короткий курс теорії механізмів і машин: Підручник для інж.-тех. спец. вищих закл. України. – 2-е вид., переобл. і скор. Львів: Афіша., 2004.272 с.
18. Ляшук В. М., Дідух В. Ф., Герасимик-Чернова Т. П., Бартошик І. С. Особливості формування врожаю картоплі. *Сільськогосподарські машини : зб. наук. ст.* Луцьк, 2019. Вип. 42. С. 49–55.

References

1. Bulgakov V., Nikolaenko S., Adamchuk V., Z. & Olt J. (2018). Theory of impact interaction between potato bodies and rebounding conveyor. Agronomy Research. 16(1). P. 52-63. DOI: 10.15159/AR.18.037.
2. Fu, Y.;& Wang, C. (2013). Experiment and study of the vibration of type 4SW-170 potato digger. *Journal of Agricultural Mechanization Research*. v.35, P. 147-151 https://doi.org/10.13427/j.cnki.njyi.2013.01.052.
3. Hevko R.B., Tkachenko I.G., & Synii S.V., (2016). Development of design and investigation of operation processes of small-scale root crop and potato harvesters, *INMATEH Agricultural Engineering*. 49 (2), P. 53-60. [in Romania].
4. Hrushetsky S.M., Yaropud V.M., Duganets V.I., Duganets V.I., Pryshliak, V.L. & Kurylo V.M. (2019) Research of constructive and regulatory parameters of the assembly working organs for the potato's harvesting machines. *INMATEH-Agricultural Engineering*. Vol. 59. № 3. pp. 101-110. DOI: 10.35633/INMATEH-59-11.
5. Huali Yu, Xiaoshun Zhao, Yongying Sang & Tao Wu. (2015). Parametric Modeling and Moving Simulation of Vibrating Screen and Tubers on Potato Harvester. *Advance Journal of Food Science and Technology* 7(6): 474-478.
6. Li, J.; Lv, Y.; Sun, Y.; & Lin, Y. (2022). Design and experiment of separating and lifting device of potato harvester. *Journal of Agricultural Mechanization Research,* v.44, p.1-263, https://doi.org/10.13427/j.cnki.njyi.2022.12.020.
7. Lü Jinqing, Tian Zhongen, Wu Jin'e, Yang Ying, Shang Qinqin, Wang Yingbo, et al. (2015). Design and experiment on 4U1Z vibrating potato digger. *Transactions of the Chinese Society of Agricultural Engineering.* Vol.31 No.12. Jun. P. 39-47.
8. Shengshi Xie , Kai L. Lu , Wei G. Deng , Fang Wang , Peng Li & Guangyu Liu. (2023). Improved design and experiment of separating sieve for potato digger. *Brazilian Journal of Agricultural and Environmental Engineering.* v.27, n.12. P. 966-972. DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n12p966-972.
9. Shengshi Xie, Chunguang Wang, & Weigang Deng. Experiment of a swing separating sieve on a potato digger *Engenharia Agrícola, Jaboticabal,* v.39, n.4. P. 548-554, jul./aug. 2019.
10. Xie, S.; Wang, C.; Deng, W. (2019). Displacement analysis of potato relative to separation sieve and separation sieve performance test. *Journal of Agricultural Science and Technology,* v.21. P.71-81. https://doi.org/10.13304/j.nykjdb.2018.0492.
11. Babii A.V. Vibratsiinyi lemish kartoplekopacha [Vibrating ploughshare of a potato harvesting machine]/ Babii, A.V., Holovetskyi, I.V., Hlado, Yu.B., Andreikiv O.Ie., Hamrach V.O / Deklaratsiinyi patent na korysnu model ua 156320 u A01D 21/00 (2024.01). Zaiavleno 09.01.2024, u 2024 00129, opublikovano 05.06.2024, Biul. №23 [in Ukrainian].
12. Babii A.V., & Holovetskyi I.V. (2024). Vyznachennia konstruktyvnykh parametriv elementiv mashyn pry nestatsionarnykh protsesakh navantazhennia [Determination of structural parameters of machine elements during non-stationary load processes]. *Materialy I-yi Mizhnarodnoi naukovo-tekhnichnoi konferentsii «PRYKLADNA MEKhANIKA» prysviachenoi 80-ty richchiu z dnia narodzhennia profesora Ch.V. Pulky. TNTU,* Ternopil. P.149-151 [in Ukrainian].
13. Babii A.V., Holovetskyi I.V.,& Herasymovych P.V. (2021). Problemy ta perspektyvy rozvytku

kartopliarstva v Ukraini [Problems and prospects of the development of potato growing in Ukraine]. *Zbirnyk tez dopovidei Kh-oi Mizhnarodnoi naukovo-praktychnoi konferentsii molodykh uchenykh ta studentiv „Aktualni zadachi suchasnykh tekhnolohii“.* Ternopil. FOP Palianytsia V.A. T.1. P. 25-26 [in Ukrainian].
14. Babii A.V., Holovetskyi I.V., Hlado & Yu.B. (2023). Doslidzhennia kinematychnykh parametriv vibratsiinoho lemesha kartoplekopacha z vykorystanniam kompiuternoi prohramy [Study of kinematic parameters of the vibrating blade of a potato digger using a computer program]. *Zahalnoderzhavnyi mizhvidomchyi naukovo-tekhnichnyi zbirnyk. "Konstruiuvannia, vyrobnytstvo ta ekspluatatsiia silskohospodarskykh mashyn".* Vyp. 53. P. 227-236 [in Ukrainian].
15. Holovetskyi I.V., & Babii A.V. (2023). Konstruktyvni osoblyvosti ta efektyvnist roboty mini kartoplekopachiv [Design features and efficiency of mini potato harvesting machine]. *Tsentralnoukrainskyi naukovyi visnyk. Tekhnichni nauky.* Vyp. 8(39), ch.II. P. 134-143 [in Ukrainian].
16. Hrushetskyi S.M. (2009). Innovatsiina kartopliana tekhnika – kompleksne rishennia zadach [Innovative potato technology is a comprehensive solution to problems]. Konstruiuvannia, vyrobnytstvo ta ekspluatatsiia silskohospodarskykh mashyn : *Zahalnoderzhavnyi mizhvid. nauk.-tekhn. zb. Pid zah. red. I.M. Chernovola. Kirovohrad : KNTU.* Vyp. 39. P. 68-81 [in Ukrainian].
17. Kinytskyi Ya.T. (2004) Korotkyi kurs teorii mekhanizmiv i mashyn [A short course in the theory of mechanisms and machines]: Pidruchnyk dlia inzh.-tekh. spets. vyshchykh zakl. Ukrainy. 2-e vyd., pereobl. i skor. Lviv: Afisha. 272 p [in Ukrainian].
18. Liashuk V. M., Didukh V. F., Herasymyk-Chernova T. P., & Bartoshyk I. S. (2019). Osoblyvosti formuvannia vrozhaiu kartopli [Features of potato crop formation]. *Silskohospodarski mashyny : zb. nauk. st. Lutsk.* Vyp. 42. P. 49–55 [in Ukrainian].

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Інженерна методика дослідження кінематичних параметрів робочого органу картоплезбиральної машини

Необхідність виконувати дослідницькі роботи з пошуку нових рішень для отримання оптимальних конструкцій картоплезбиральних машин виникла з потребою підвищення рівня забезпеченості збиральною технікою виробників у підсобних чи невеликих фермерських господарствах. Проблема ускладнюється тим, що така машина повинна агрегатуватися з малоенергонасиченими тракторами тягового класу 0,6 т та менше. Тому при обґрунтуванні параметрів запропонованої конструкції картоплекопача рішення мають бути добре зваженими та прийнятими на основі перевірених інженерних методик для аналізу та основних підходів до конструювання сільськогосподарської техніки.

У роботі наведено інженерну методику дослідження кінематичних параметрів приводного механізму лемеша як основного робочого органу однорядної картоплезбиральної машини. Суть інженерної методики полягає в тому, що вона базується на графоаналітичному методі планів при дослідженні кінематичних механізмів. Для фізичної конструкції приводного механізму лемеша картоплекопача зроблено теоретичні описи та побудовано плани швидкостей і прискорень, що дає можливість досліднику отримати вказані кінематичні параметри для будь-яких точок ланок даного механізму. У підсумку отримано ряд значень кінематичних параметрів, що характеризують роботу даного механізму та на основі яких виконується аналіз технологічної ефективності лемеша картоплезбиральної машини.

Таким чином, наведена інженерна методика дослідження кінематичних параметрів механізму приводу лемеша дозволяє описати закономірності взаємодії ланок такого механізму та охарактеризувати лінійні, кутові швидкості та прискорення будь-яких точок чи ланок досліджуваного механізму. Отримані кінематичні параметри мають визначені скалярні значення та напрямки векторів, що дозволяє досліднику більш повно зорієнтуватись про їх вплив на досліджуваний процес. Перевагою такого методу є те, що швидкості чи прискорення можна визначити для будь-якої точки, що належить ланкам механізму, не застосовуючи складних аналітичних описів. На основі наведеної методики були визначені лінійні швидкості характерних точок механізму у всіх його положеннях, кутові швидкості ланок, прискорення точок та кутові прискорення ланок. Отримані значенні є основою подальшого дослідження поведінки частинки бульбоносного пласта на площині лемеша з метою визначення параметрів для забезпечення його направленого руху та інтенсивності сепарації.

картопля, картоплезбиральна машина, кінематичні параметри, швидкість, прискорення, леміш, кривошип, приводний механізм, робочий орган, інженерна методика

Одержано (Received) 10.10.2024 *Прорецензовано (Reviewed) 18.10.2024*
Прийнято до друку (Approved) 28.10.2024