Kinematic mode of operation of potato harvester auger

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Abstract. The digging work parts of modern potato harvesters, when working on loamy soils with low humidity, do not meet the agrotechnical requirements. Modern machines should perform pruning, lifting, and moving the potato bed layer to the separating organs without unloading and collapsing with the least energy consumption, losses, and damage to tubers. The authors proposed combined digging work parts with passive plowshares and active augers. The purpose of the study is to substantiate the operating mode of the potato harvester auger. The basic principles and methods of classical mechanics, mathematical analysis, and statistics were used in this study. Based on theoretical studies, analytical dependences for determining the operating mode of the auger are obtained. To ensure pruning, lifting, and moving of the tuberous, the kinematic mode indicator should be in the range of 4.08 - 4.15.

1 Introduction

Potatoes are one of the most important foods and industrial crops of Uzbekistan. One of the unsolved problems is the lack of harvesting machines that meet the agro technical requirements for digging tubers. Agricultural engineering requires that the potato bed layer's pruning, lifting, and moving to the separating organs be carried out without unloading and collapsing. At the same time, avoid loss and damage to tubers with minimal soil intake from the garden, and also have a steady course of digging organs at any given depth of digging potatoes. The uniformity of the supply of the excavated mass to the separation devices without unloading is also important. Therefore, the task of finding, researching, and improving the digging working bodies, substantiating their rational design and optimal parameters that ensure the requirements mentioned above, is very relevant. R.Norchaev [1], D.Norchev [2-3], F.Mamatov [4-5], and others were engaged in research on the creation and application of crofter diggers with active and passive working bodies, the study of their performance indicators, and the justification of parameters. Research on the study of the process of interaction of a passive working organ with the soil was carried

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out by F.Mamatov [4-5], F.Maiviatov [6-7], Kh.Fayzullaev [7, 9, 10], U.Kodirov [10, 13], Sh.Kurbanov [12]. The process of interaction of the screw working body with the processed mass was studied by F.Mamatov [4-5], E.Eshdavlatov [4-5], K.Devsh [16], R.Farhadi [17], R.Hevko [18].

The purpose of the study is to substantiate the operating mode of the potato harvester auger [19-25].

2 Materials and Methods

The basic principles and methods of classical mechanics, mathematical analysis, and statistics have been used in this study.

We have developed a potato digger with passive and active working bodies (Figure 1). The active working body is made in the form of a screw installed on the outer edges of the plowshares. The combined digging work consists of 2-the main flat digging plowshares 1 and 2, intermediate plowshares 3, 4, and 5, transporting augers 6 and 7, and separating work part 8.

One of the main factors affecting the quality and energy performance of the potato harvester is the mode of operation of the auger. The operating mode of the auger is characterized by an indicator of the kinematic mode λ. To establish a connection between the kinematic parameters of the formation and the kinematic mode of operation of the screw working body, consider the process of transporting the formation under the influence of the screw blade and the plowshare.

3 Result and Discussion

It is known [15] that the movement of soil particles in the auger will occur in cases when the friction force caused by the centrifugal force C_y and gravity G acting on the particle are so large that they slow down the particle in joint rotation with the auger, i.e., force it to slip along the auger, overcoming the friction force on the auger.

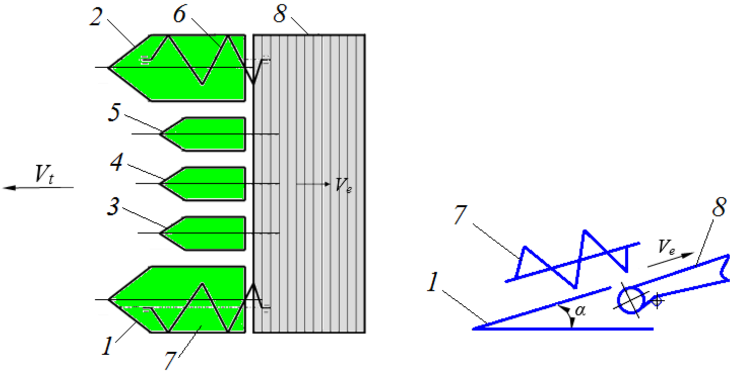

Fig. 1. Technological scheme of the combined digging work part: 1,2 are main flat digging plowshares; 3,4,5 are intermediate plowshares; 6,7 are transporting augers; 8 is separating working body

In this case, the soil will move at an angle ψ to the axis of the auger along a helical line, the direction of which is opposite to the direction of the helical line of the auger blade.

It is known that the angle θ, which characterizes the design parameter of the auger, can be determined from the condition of the steady-state operation of the auger [15]. In this case, a soil particle of mass m will be in equilibrium under the action of forces applied to it. The gravity force G (Fig.2), the normal reaction of the auger blade N_{sn}, the friction force of the particle on the surface of the auger blade $F_{fl,}$ the centrifugal force $C_c=m\omega_n^2R$ (ω_n – angular velocity), the friction force of the particle on the surface of the plowshare $F_c=m\omega_p^2Rf_{2,}$ the normal reaction from the plowshare N_d.

The centrifugal force does not affect the direction of movement of the soil particle, as it is balanced by the reaction of the plowshare.

The equilibrium conditions of the particle have the following form:

$$N_{\mathrm{sn}} = G\sin(\theta+\alpha) + F_c\cos(\psi-\theta) \quad (1)$$

$$N_{sn}^{f} = F_c\sin(\psi-\theta) + G\cos(\theta+\alpha) \quad (2)$$

here

$$G = mg$$

$$F_c = \frac{m\upsilon_{op}^2 f_2}{2}$$

where f_1 is the coefficient of soil friction along the auger blade; f_2 is the coefficient of soil friction along the plowshare; ψ is the angle of inclination of the particle trajectory to the auger axis, deg; υ_{op} is the circumferential velocity of the soil at a radius R, m/s.

Solving equations (1) and (2) together, we obtain:

$$mg\sin(\theta+\alpha)f_1 + \frac{m\upsilon_{op}^2}{R}f_1 f_2\cos(\psi-\theta) = \frac{m\upsilon_{op}^2}{R}f_2\sin(\psi-\theta) + mg\cos(\theta+\alpha).$$

By dividing the obtained equality by $\cos\theta$ we have

$$tg\theta = \frac{Rg\cos a - \upsilon_{op}^2 f_2 f_1\cos\psi - Rgf_1\sin a + \upsilon_{op}^2 f_2\sin\psi}{Rgf_1\cos\alpha + \upsilon_{op}^2 f_2 f_1\sin\psi + \upsilon_{op}^2 f_2\cos\psi + Rg\sin\alpha}\ . \quad (3)$$

The resulting expression (3) characterizes the angle $\theta$of the screw working body depending on the kinematic mode ψ and on the conditions of its operation φ_1, f_2, q.

Under the influence of the auger blade, soil particles make a rotational movement relative to the axis of the auger, so the angle of inclination of its trajectory ψ can be determined from the condition that at length L (the length of the plowshare), the soil particle should turn no more than $\pi/2$ rad90°. From here

$$tg\psi = \frac{\pi R}{2L}$$

$$\psi = arctg(\frac{\pi R}{2L}) \quad (4)$$

To determine the circumferential velocity of the soil, consider the vector velocity diagram (Fig.3)

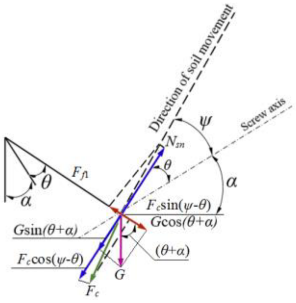

Fig. 2. Scheme of interaction of a soil particle with a screw blade

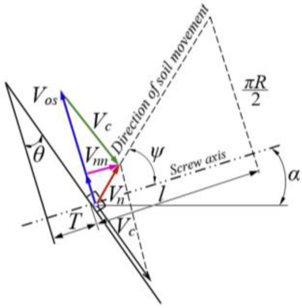

Fig. 3. Vector diagram of the velocities of a soil particle during its movement under the influence of a screw blade

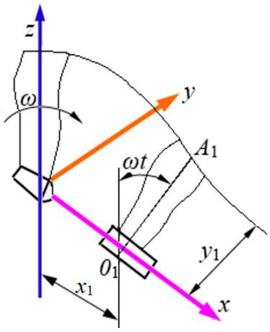

Fig. 4. Kinematics of the screw working body

Under the influence of the auger blade with a pitch of S and the angle of inclination of the helical line θ at a radius of R, the soil particle moves at an angle ψ to the axis of the auger. At the same time, the soil particle makes a complex movement: it slides along the blade at a speed of h_c and simultaneously rotates relative to the axis of the screw with a circumferential speed of υ_{op} [15]

$$\upsilon_{op} = \upsilon_{pp} tg\psi \tag{5}$$

where υ_{pp} – is the velocity of soil movement along the axis of the auger, m/s; $tg\psi=\pi R/2L$ – is the tangent of the angle of inclination of the trajectory of the soil particle to the axis of the auger.

Substituting its value in (5) instead of tgψ, we get:

$$\upsilon_{op} = \upsilon_{pp}\pi R/2L \tag{6}$$

where R is the distance of the soil particle from the auger axis, m; L is the length of the plowshare, m

Taking into account $\upsilon_{pp}=\upsilon_{un}/\cos\alpha$, expression (6) can be written as follows

$$\upsilon_{op} = \upsilon_{un}\pi R/2L\cos a \tag{7}$$

From this expression, it can be seen that the circumferential velocity of the soil is directly proportional to the translational velocity of the digger υ_{un} and inversely proportional to the length of the plowshare L and the angle of the plowshare installation α.

From Fig. 4, we have [15]:

$$tg\theta = \frac{\upsilon_{pp}}{\upsilon_{o.s} - \upsilon_{op}} = \frac{\upsilon_{pp}}{\upsilon_{o.s} - \upsilon_{pp} tg\psi}$$

Therefore, the longitudinal component of the ground velocity of the application is equal to

$$\upsilon_{pp} = \frac{\upsilon_{o.s}}{ctg\theta + tg\psi} \quad (8)$$

It is known that the movement of the screw consists of a relative (rotational) around the axis with a speed of $\upsilon_{o.s}$ and a portable translational with a speed of υ_{un}.

Consider the movement of the extreme point of the screw *A* (Fig.3), which is at the initial moment in position A_0. After a certain period of time t, the auger will move from position *O* to position O_1, passing the path υ^t_{un}, and the axis of the auger will turn by the angle ωt. As a result, the screw point *A* will move from position A_0 to position A_1, and its coordinates are determined by the equations [15]:

$$x_1 = \vartheta_{un} t$$
$$y_1 = R_{aug} \sin \omega t$$
$$z_1 = R_{aug} \cos \omega t \quad (9)$$

where υ_{un} is the translational speed of the potato digger, m/s; R_{aug} is the radius of the auger, m; ω is the angular velocity of the auger, s^{-1}.

The geometric shape of the trajectory of point *A* depends on the indicator of the kinematic mode

$$\lambda = \frac{\upsilon_{o.s.}}{\upsilon_{un}} \quad (10)$$

where $\upsilon_{o.s.}$ is the circumferential velocity of the screw point, m/s.

Substituting the expressions φ and $\varphi R_{ot}/\upsilon_0$ in equations (10) instead of ωt and t, we will have

$$x_1 = \frac{\varphi R_{aug}}{\lambda}$$
$$y_1 = R_{aug} \sin\varphi$$
$$z_1 = R_{aug} \cos\varphi \quad (11)$$

Equation (12) characterizes the trajectory of the absolute motion of point *A* in parametric form. This trajectory is a helical line, the pitch of which depends on the kinematic mode indicator λ. Since the working surface of the screw consists of a solid tape, this imposes its limitations on equation (12). To avoid unloading the soil before the auger, the following conditions must be met

$$\upsilon_{un} = \upsilon_{pp} \cos\alpha.$$

Taking into account the formula (8), we have

$$\upsilon_{un} = \frac{\upsilon_{o.s.}}{(ctg\theta + tg\psi)\cos a} \quad (12)$$

where $\upsilon_{o.s.}$ is the circumferential speed of the auger, m/s; θ is the angle of elevation of the screw line of the auger, deg; ψ is the angle between the trajectory of the soil and the axis of the auger, deg.

From formula (13), we have

$$\lambda = \frac{\upsilon_{o.s.}}{\upsilon_{un}} = (ctg\theta + tg\psi)\cos a; \qquad (13)$$

Three cases of operation are possible when working with a combined digging working body, depending on the ratio λ and $(\mathrm{ctg}\theta+\mathrm{tg}\psi)/\cos a$.

1. $\lambda<(\mathrm{ctg}\theta+\mathrm{tg}\psi)/\cos\alpha$. In this case, the mass will be unloaded in front of the augers, leading to an increase in the traction resistance of the plowshare and an increase in the torque on the auger. Eventually, the plowshare will be clogged with a mass; losses and damage to tubers will increase.
2. $\lambda>(\mathrm{ctg}\theta+\mathrm{tg}\varphi)/\cos a$. Rotating augers will intensively loosen soil layers and throw them back; as a result, energy is spent irrationally, and damage to tubers occurs.

Substituting the value of θ in formula (3) into expression (13), we can obtain the following equation

$$\lambda = \left[\frac{Rgf_1\cos\alpha + \upsilon_{op}^2 f_2 f_1\sin\psi + \upsilon_{op}^2 f_2\cos\psi + Rg\sin\alpha}{\upsilon_{op}^2 f_2\sin\psi - Rgf_1\sin a - \upsilon_{op}^2 f_1 f_2\cos\psi + Rg\cos\alpha} + tg\psi\right]cos\alpha. \qquad (14)$$

The obtained formula shows that λ depends on the design parameters of the screw, its operating conditions, and operating modes.

Calculations carried out using this formula at R=0.15m; $f_1 = f_2$ =0.5; α=30°; ψ=66-68° [15]; g=9.8 m^2/s; υ_{op}=1.25m/s showed that the kinematic parameter λ is in the range of 4.08 - 4.15.

4 Conclusion

A potato harvester with a passive plowshare and an active auger mounted on the outer edge of the plowshare is proposed. The forces acting on the auger from the soil side and the kinematics of the auger working body are considered. Based on theoretical studies, the analytical dependences for determining the operating mode of auger potato harvester have been obtained.

Theoretical research has established that for providing pruning, lifting, and moving of tuberous mass on a plowshare, the kinematic operating mode of an auger must be within 4,08 - 4,15. Prospective is the design of a potato harvester with passive and active working bodies in the form of an auger, which contributes to improving the quality and energy performance.

References

1. D.R.Norchaev Advanced energy-saving potatoes lifting machine. *European Applied Sciences Journal*. – Stuttgart, 2015. – P.45-46.
2. D.R.Norchaev Draught resistance of supporting-soil crumbles destructing device // European Sciences review Scientific journal. – Vena, 2016. – 9-10. – P.199-201.
3. P.I.Bajmetov, D.P.Hopchaev. Jeffektivnoct' ppimenenija opopno-komkopazpyshajushhego yctpojctva ppi ybopke kaptofelja. European Applied Science: modern approaches in scientific researches: 2nd International Scientefic Conference. Stuttgart (2013) pp.171-173.
4. F.Mamatov, E.Eshdavlatov, A.Suyunov. The Shape of the Mixing Chamber of the

Continuous Mixer, *J Adv Research in Dynamical & Control Systems* **12,** 2016-2023 (2020)

5. F.M.Mamato, E.Eshdavlatov, A.Suyuno. Continuous Feed Mixer Performance, *Journal of Advanced Research in Dynamical and Control Systems* **12,** 2195-2200 (2020)
6. F.Maiviatov, F.Karshiev, Sh.Gapparov. Movement of crushed stem particles when they interact with hammers, *IOP Conf. Series: Earth and Environmental Science* **868**, 012060 (2021)
7. F.Maiviatov , K.Ravshanov, S.Mamatov, I.Temirov, D.Kuvvatov, A.Abdullayev, Combined machine for preparing the soil for re-sowing crops, *IOP Conf. Series: Earth and Environmental Science* **868,** 012066 (2021)
8. K.Ravshanov, K.Fayzullaev, I.Ismoilov, D.Irgashev, S.Mamatov and Sh.Mardonov, The machine for the preparation of the soil in sowing of plow crops under film,*IOP Conf. Series: Materials Science and Engineering* **883** (2020)
9. D.Chuyanov, G.Shodmonov, I.Avazov, N. Rashidov, S.Ochilov, Soil preparation machine parameters for the cultivation of cucurbitaceous crops, *IOP Conf. Series: Materials Science and Engineering* **883** (2020)
10. Kh.Fayzullayev, S.Mamatov, M.Radjabov, Sh.Sharipov, R.Tavashov, and M.Nurmanova. The quality of loosening the soil with subsoilers of the combined machine*, IOP Conf. Series: Materials Science and Engineering* **1030** (2021)
11. I.Temirov, Kh.Ravshanov, Kh.Fayzullaev, Sh.Ubaydullaev and U.Kodirov, Development of a machine for preparing the soil for sowing melons under the film, *IOP Conf. Series: Materials Science and Engineering***1030** (2021)
12. U.Kodirov, N.Aldoshin, Sh.Ubaydullayev, E.Sharipov, Z.Muqimov and B.Tulaganov, The soil preparation machine for seeding potatoes on comb, *Conf. series: materials science and engineering* **883,** (2020)
13. H.Ravshanov, L.Babajanov, Sh.Kuziev, N.Rashidov, SH.Kurbanov, Plough hitch parameters for smooth tails, *IOP conf. series: materials science and engineering* **883** (2020)
14. B.Mirzaev, F.Mamatov, U.Kodirov and D.Chuyanov, Study on machine for processing and preparing the soil for sowing potatoes on ridges, *E3S Web of Conferences* **304**, (2021)
15. Kh.Fayzullaev, F.Mamatov, B.Mirzaev, D.Irgashev, S.Mustapakulov and A.Sodikov, Study on mechanisms of tillage for melon cultivation under the film,*E3S Web of Conferences* **304**, (2021)
16. V.V.Sharov Obosnovanie osnovnyh parametrov rotornogo pluga dlja gladkoj vspashki. Moscow (1986), p. 227.
17. K.Devsh , T.Ashok. Performance evaluation of tractor drawn potato digger cum-elevator, International Journal of Agricultural Science and Research, **7** (2), (2017)
18. R. Farhadi, N. Sakenian, P. Azizi, Design and construction of rotary potato grader, Bulgarian, *Journal of Agricultural Science*, **2** (2012)
19. R.B. Hevko, I.G. Tkachenko, S.V. Synii, Development of design and investigation of operation processes of small-scale root crop and potato harvesters, *INMATEH - Agricultural Engineering,* **49** (2), (2016)
20. N. Koga, T. Kajiyama, K. Senda, S. Iketani, S. Tamiya, S. Tsuda, Energy efficiency of potato production practices for bioethanol feedstock in northern Japan, *European Journal of Agronomy*, **44**(1), (2013)

21. D.X. Sun, A.M. Zhang, J.X. Gong, Design and experiment on 1SZL-250A type subsoiling rotary tillage fertilizer combined soil working machine, *Journal of Chinese Agricultural Mechanization*, **37** (4) (2016)
22. M. Tauseef A, A. Ghafoor, A. Munir, M. Iqbal, M. Ahmad, Design modification and field testing of groundnut digger, *Asian Journal of Science and Technology*, **5** (2014)