Analysis of the state of mechanized sowing of rice in seedlings

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Abstract. This article presents a brief analysis of the state of rice cultivation, the main advantages and disadvantages of seedling rice planting, analyzes the prospects for rice cultivation and mechanization of this process in Uzbekistan. Measures are indicated to fully meet the needs of the population in this product and reduce imports in Uzbekistan by giving special attention to the placement of varieties adapted to soil and climatic conditions with high-quality grain and high yields, the development and implementation of highly efficient resource-saving agricultural technologies in their cultivation. The factors influencing the decline in the efficiency of rice growing for the Central Asian region are analyzed. The purpose of the use of technical means for planting rice in seedlings is substantiated. The technical characteristics are presented a comparative analysis of the technological process, the main design advantages and disadvantages of machines for planting rice is made. Data on the physical and mechanical properties of soils used for rice crops, as well as on the main varieties of rice grown in the region are presented. After analyzing the agro-technical requirements for sowing rice in seedlings, a technical solution that improves the technological process of transplanting machines of the PA-600D-R and RF-455 brands (Korea) is proposed. The results of research on the development of the design of a planting device with optimal parameters and the possibility of using it for planting rice in seedlings for the soil and climatic conditions of Uzbekistan are presented. A mathematical model of the machine is built and its optimal values have been determined. Using special programs such as Compass 3D, 3D Max, MS Word, MS Excel and a number of other programs, 3D and 2D models of parts of the rice planter planting device were prepared. The analysis and results of the studies carried out will allow using the obtained data in improving the design of the planting device. The use of a machine equipped with such devices when sowing rice in seedlings will significantly reduce the consumption of seeds, irrigation water, shorten the growing season, reduce crop weeds and, as a result, increase grain yield.

1 Introduction

The annual growth of our country's population leads to an increase in demand for food and agricultural products. This, in turn, makes the use of new technologies, the creation of new varieties, the improvement of soil cultivation processes and the use of water-saving methods one of the topical issues. To meet the needs of the population of the republic for rice in 2022, a total of 111.2 thousand hectares were planted with this crop. Of these, 40.3 thousand hectares were sown with rice as the main crop, and 70.9 thousand hectares as a secondary crop. According to statistics, rice is grown in more than 120 countries around the world. The total area under rice cultivation is 157 million hectares, from which more than 650 million tons of crop are obtained [1].

To obtain a high yield of rice, large amounts of water are used. The growing global water shortage, which is increasing every year, is affecting agriculture as well as the rice sector. Rice farming, like other branches of agriculture, cannot be imagined without modern technologies. In particular, of the total area intended for sowing rice, 38.2 thousand hectares are sown with seedlings, 15.3 thousand hectares with seeds using modern seeders, and water-saving technologies are being introduced [2].

The method of planting rice seedlings has a number of conveniences and advantages compared to the traditional (sowing by seeds) method of planting rice. When planting rice in a seedling style, up to 60-70% of rice seeds, 25-30% of water are saved and productivity increases by 20-25%. By planting rice by seedling method, it is possible to reduce the period of ripening and harvesting from 10 to 20 days. In addition, using this method, it will be possible to plant rice as a repeated crop or harvest up to 3 times from one field, depending on climatic conditions [3]. Taking into account the information given above, in our Republic, which has limited water resources, by using seedling method of planting rice, we will be able to grow crops with relatively little water consumption and increase productivity.

By planting rice seedlings, you can achieve the following benefits:
- growth period – reduced to 25-30 days;
- irrigation water consumption is saved - 7000-8000 m3/ha;
- seed consumption - reduced to 65-70 kg/ha;
- weed control – herbicides may not be used at all;

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- consumption of mineral fertilizers is reduced by 25-30%;
- productivity increases by 30-50%. [4-6].

From this it can be seen that when planting by seedling method, high yields and low water and labor costs can be achieved. The other side of the matter is the mechanization of this process. That is, the planting process requires more labor than planting with seeds.
Comparative main indicators of the economic efficiency of mechanized and manual planting of rice seedlings are presented in Table 1.

Table 1. Comparative indicators of the economic efficiency of planting with seedlings.

№	Indicators	Mechanized planting	Planting by hand
1	planting scheme, cm	30x12 (3-4 seedlings per 1 cluster)	20x20 (2-3 seedlings per 1 cluster)
2	planting depth, cm	2-3	2-3
3	number of seedlings, pcs	840-1120	500-750
4	productivity, m^2/ h	1500	20
5	labour cost per hectare	1 machine 6.6 hours	1 person 500 hours, or 63 people 8 hours

Race plant setters PA-600D-R and RF-455 of the South Korean company Tong Yang Moolsan are used for planting seedlings in the conditions of Uzbekistan, and their productivity is 1-3 hectares per working day. In the world's leading rice-growing countries, rice planting machines with high productivity have been created and are being used [7-10]. However, when using these machines in the conditions of Uzbekistan, a variety of problems arise, which significantly reduces the level of mechanization of the method of sowing rice in the form of seedlings. For example, their high cost, as well as planting patterns that are not suitable for planting rice varieties in Uzbekistan, etc.

2 Material and method

The purpose of the study was to find the possibility of improving the technical and economic parameters of the plant setter, increasing the accuracy of the dimensions and shape of parts, as well as the reliability of the high-quality execution of the technological process. Various methods have been developed to solve such problem as development of the research object control algorithm. One of these methods is Pontryagin's maximum principle, which allows us to observe the relationship between optimization tasks and the evaluation of the maximum possibilities of the necessary conditions for optimality. To achieve the target function in the process of controlling and optimizing the parameters of the object - the plant setter, various algorithms are used. In this case, the target function should be a value that depends on the decision factors according to mathematical models of the work and energy processes occurring in the plant setter. The diagram of mathematical modeling and genealogical structure of planter movement control is shown in Fig.1

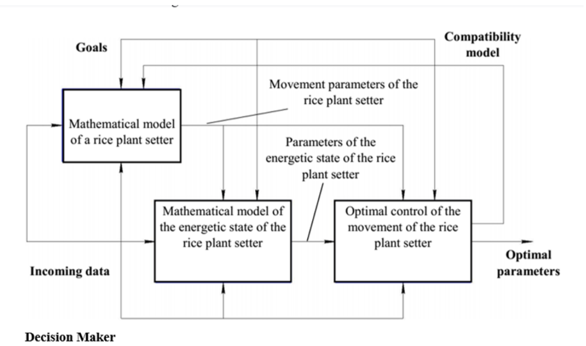

Fig.1. Scheme of mathematical modeling and genealogical structure of plant rice setter motion control.

Fig. 1 shows a strategy for studying the structure of mathematical modeling and technological processes using adequate models and analysis tools that meet accepted criteria. With this approach, the decomposition of the functional block A0 allows for targeted actions that make it more likely to obtain predetermined results of work processes and plant seedlings in conditions of changing external and internal environments. As can be seen from Fig. 1, three areas - “Seedling Machine Mathematical Model”, “Seedling Machine Energy Status Mathematical Model” and “Seedling Machine Movement Optimal Control” are the operating processes of the plant setter characteristic for learning.

The motion equation of plant setter is expressed by the Lagrange equations of the second type, and the power in the moving mechanisms is expressed by the energetic Hamiltonian equations, formulas of Runge-Kutta type from 1st to 4th orders, and among them is the formula Euler and the standard Runge-Kutta formula [11].

3 Results and discussion

3.1 Development of a mathematical model of the object of study

Modeling and control of parameters make it possible to improve technical and economic indicators of the seedling planting machine (plant setter) in the design process using the appropriate mathematical model, increase the accuracy of the dimensions and shapes of the parts, as well as the reliability of the normal operation of the system. Therefore, one of the priorities is to develop a mathematical description of a seedling planting machine that works in dynamic modes (Fig. 2)

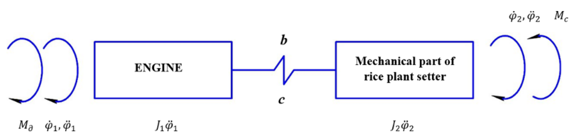

Fig.2. Dynamic model of rice plant setter.

We compile a mathematical model of the movement of the plant setter using the Lagrange equation of the second kind [12].

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}_i}\right) - \frac{\partial T}{\partial \varphi_i} + \frac{\partial F}{\partial \dot{\varphi}_i} + \frac{\partial P}{\partial \varphi_i} = Q_i \quad (1)$$

Where T is the kinetic energy of the mechanisms by which the planting machine rotates; P – potential energy of the rotating mechanisms of the plant setter; F is the dissipative forces of the Relay; φ_i is the generalized coordinates; $\dot{\varphi}_i$ is the generalized velocities; Q_i is the generalized forces.

We define the conditions of the Lagrange equations:

a) partial derivatives on displacements:

$$\frac{\partial T}{\partial \varphi_i} = 0, \quad \frac{\partial P}{\partial \varphi_i} = c_1(\varphi_\partial - \varphi_n)$$

b) partial derivatives on the generalized coordinate velocity:

$$\frac{\partial T}{\partial \dot{\varphi}_i} = j_i \dot{\varphi}_i, \quad \frac{\partial F}{\partial \dot{\varphi}_i} = b_1(\dot{\varphi}_\partial - \dot{\varphi}_n)$$

c) time-differential:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}_i}\right) = j_i \ddot{\varphi}_i$$

d) generalized forces:

$$Q_1 = M_\partial; \quad Q_2 = M_p; \quad Q_3 = M_c,$$

Where M_∂, M_p, M_c are the driving torque and resistance moments in the engine and gearbox.

Replacing certain conditions (1) of the Lagrange equations, we get differential equations of motion of the seedling planting machine.

$$\begin{cases} j_{\ddot{a}}\ddot{\varphi}_{\ddot{a}} = M_{\ddot{a}} - b(\dot{\varphi}_{\ddot{a}} - \dot{\varphi}_\partial) - c(\varphi_{\ddot{a}} - \varphi_\partial) \\ j_\partial \ddot{\varphi}_\partial = b(\dot{\varphi}_{\ddot{a}} - \dot{\varphi}_\partial) + c(\varphi_{\ddot{a}} - \varphi_\partial) - M_c \end{cases} \quad (2)$$

Where - j_1, j_2 are the moments of inertia of the rotating masses of the planting machine, N·m·s^2; $\ddot{\varphi}_\partial$, $\ddot{\varphi}_p$ are the angular acceleration of the rotating masses of the planting machine, s^{-2}; $\dot{\varphi}_\partial$, $\dot{\varphi}_p$ are the angular velocities of rotating masses of seedling planting machine: s^{-1}; $\varphi_д$, φ_p are the angular movements of the rotating masses of the seedling planting machine, rad; b is the viscosity coefficient of elastic coupling, N·m·c/rad; c is the singularity coefficient of the elastic coupling, N·m/rad; M_∂, M_c, – moments of movement and resistance of the seedling planting machine, N·m.

3.2 Calculation of the constructive parameters of the plant setter

Calculation of the singularity and viscosity coefficients of the plant setter elastic coupling.

$$c_1 = \frac{M_{\dot{n}}}{\varphi_i}, \qquad b_1 = \frac{0.64 c_1}{2\pi\omega}$$

where -c_1 is the angular displacement of plant setter shaft, it does not exceed 1°30' [13]; ω is the frequency of the process, c^{-1}.

Table 2. Calculated values of the singularity and viscosity coefficients of the elastic pin bushing [14].

φ_m - angular displacement of the shaft	c_1 - singularity coefficient	b_1- viscosity coefficient
0.5^0=0.008726 rad	4769.23 Nm/rad	1.45 Nms
1^0=0.017452 rad	2384.615 Nm/rad	0.725 Nms

To solve the problem of optimal control of a plant setter, we will use the theory of optimal systems [11-15]. Let the movement of the machine for planting seedlings in the initial state of time look like this:

$$\varphi_i(0) = \varphi_0(0), \quad \dot{\varphi}_i(0) = \dot{\varphi}_0(0) \quad (3)$$

It is necessary to find such a control *u(t)* to transfer the movement of the plant setter from the initial position to the specified one:

$$\varphi_i(t) = \varphi_0(t), \ \dot{\varphi}_i(t) = \dot{\varphi}_0(t), \ (i = 1, \ldots, n), \ 0 \le t \le T \quad (4)$$

This requires that the transition time be short. In this case, the control goal is to minimize the functionality under conditions (3) and (4).

$$J\big(\varphi_0, u(t), \varphi(t)\big) = \int_{t_0}^{T} f^0(\varphi(t), u(t), t)dt \quad (5)$$

Under conditions (3), (4)

$$\varphi(t) = f(\dot{\varphi}(t), u(t), t) \quad (6)$$

$$u \in U, \quad t_0 \le t \le T, \quad (7)$$

Where *f(…)* is a continuous–differentiable function; *u (t)* is a piecewise-continuous function in the range [t_0,T].

We will use maximum principle of Pontryagin to research the necessary condition for optimal control of plant setter movement [16, 17].

To formulate the maximum principle, we introduce the Hamilton-Pontryagin function:

$$H(\varphi, u, t, \psi_i, \psi_0) = -f^0(\varphi, u, t) + \langle \psi, u \rangle \quad (8)$$

and the joint system

$$\begin{cases} \frac{d\psi_1}{dt} = \frac{\partial H_P}{\partial y_1} = -j_P^{-1} c_1 \psi_2 \\ \frac{d\psi_2}{dt} = \frac{\partial H_P}{\partial y_2} = -\psi_1 + j_P^{-1} b_1 \psi_2 \end{cases} \quad (9)$$

We enter $|u| \le 1$. Control limit $|u| \le 1$.

To solve the problem under consideration, the following necessary condition must be met:

$$H(\varphi_i(t), u(t), t, \psi_i, \psi_0) = \max_{u \in U} H(\varphi_i(t), u, t, \psi_i(t), \psi_0) \quad (10)$$

Before moving on to determining the optimal control, we will form a function based on (8).

$$\begin{cases} \varphi_1 = y_1, \ \dot{\varphi}_1 = y_2, \\ \dot{y}_2 = u_\partial - j_1^{-1}[b_1(y_2 - y_4) + c_1(y_1 - y_3)] \\ \varphi_2 = y_3, \ \dot{\varphi}_2 = y_4, \\ \dot{y}_4 = j_2^{-1}[b_1(y_2 - y_4) + c_1(y_1 - y_3)] - u_c \end{cases} \quad (11)$$

and we get a mathematical model describing the $u_\partial = \frac{1}{j_1} M_\partial$ motion control of the plant setter, where

$u_c = \frac{1}{j_2} M_c = u_c + u_0 \sin \omega t$, ($u_0$ is the amplitude of its oscillations relative to the average value).

Similarly, if $f^0 = 1$, then $J(\varphi_0, u(t), \varphi(t)) = T - t_0$ – in this case (3)–(7) issues are called the question of quick action.

The object under consideration is a stationary system, and according to condition (4) f and U do not depend on time, i.e.

$$f(t, y, u) = f(y, u), \quad U(t) = U \quad (12)$$

If stationary problem (5) has optimal control $u(t)$ (12) and optimal trajectory $\varphi_0(t)$, then there is an $(\psi_1(t))$, $\psi(t) \in R^n$ vector of nontrivial joint variables that generates conditions (10) such that the maximum condition (8) is satisfied.

$$\psi_0(t) = const \leq 0 \quad (13)$$

Just as the conjugate system (9) is homogeneous on respect to ψ_i, the change in equation (12) can be chosen voluntarily, so that

$$\psi_0(t) = -1 \qquad 0 \leq t \leq T \quad (14)$$

from the $\max_{|u|<1} H$ condition in $\psi_2 \neq 0$, $u = sign\psi_2$ follows, if $\psi_2 \neq 0$, then the boundary question of the maximal principle is written as:

$$\begin{cases} \varphi_1 = y_1, \ \dot{\varphi}_1 = y_2, \\ \dot{y}_2 = sign\psi_2 - j_1^{-1}[b_1(y_2 - y_4) + c_1(y_1 - y_3)] \\ \varphi_2 = y_3, \ \dot{\varphi}_2 = y_4, \\ \dot{y}_4 = j_2^{-1}[b_1(y_2 - y_4) + c_1(y_1 - y_3)] - sign\psi_2 \end{cases} \quad (15)$$

In these cases, the boundary value problem of the maximum principle (15) consists of boundary conditions (3), (4) and (14) arising from system (10).

We equate the Hamilton-Pontryagin function with the following form:

$$\begin{cases} H_1 = \psi_0 + \psi_1 y_2 + \psi_2 \dot{y}_2 \\ H_2 = \psi_0 + \psi_1 y_4 + \psi_2 \dot{y}_4 \end{cases} \quad (16)$$

It follows that condition (10) $u = sign\psi_2, \psi_2 \neq 0$ separates the function. In this case the boundary issue (11), (15) consists of

$$H_i = -f^0 u + \psi_2(t) u_\partial \quad (17)$$

In it

$$u_k = sign\psi_2(t) = \begin{cases} 1, & \psi_2(t) > 1, \\ -1, & \psi_2(t) < 1, \end{cases} \quad k = 2,4, \dots .2 \quad (18)$$

that is, the control $u_k(t)$ has the ability to connect alternately at a single point.

To study the movement of the plant setter, a computational experiment was carried out using the Runge-Kutta numerical method based on the initial condition $t=0$, the results were obtained in the form of tables and graphs.

Table 2. Results of calculating the movement of a plant setter.

x0	*f(1)*	*f(2)*	*f(3)*	*f(4)*	*md*
0	0	1802.666	0	-13.7778	811.2
0.1	23.7177	851.4497	73.9223	443.7573	383.1524
0.2	60.1334	-304.9864	141.7368	1000.003	-137.2439
0.3	102.0398	-449.4657	206.9103	1069.497	-202.2598
0.4	139.1183	231.7723	274.406	741.8221	104.2975
0.5	169.2167	791.9009	345.2592	472.4008	356.3554
0.6	197.8274	713.2685	416.828	510.2228	320.9708
0.7	230.1317	282.3553	486.6201	717.4917	127.0599
0.8	265.9478	42.6356	554.723	832.7974	13.186
0.9	301.66	170.2113	622.8759	771.4333	76.5951
1	334.9348	418.4312	692.2012	652.0392	188.294
x0	*mp*	*mcc*	*MO*	*pd*	*pp*
0	-6.2	6.2	0.0001	0	0
0.1	199.6908	6.2001	0.0001	9.0875	14.7616
0.2	450.0016	6.1991	0.0001	-8.2529	63.7818
0.3	481.2741	6.2	0.0001	-20.6385	99.5806
0.4	333.82	6.2001	0.0001	14.5097	91.6022
0.5	212.5804	6.1999	0.0001	60.3013	73.3953
0.6	229.6002	6.2	0.0001	63.4968	95.7038
0.7	322.8713	6.2001	0.0001	29.2405	157.1156
0.8	374.7588	6.1999	0.0001	5.1025	207.8873
0.9	347.145	6.2	0.0001	23.1057	216.2283
1	293.4176	6.2001	0.0001	63.0662	203.104

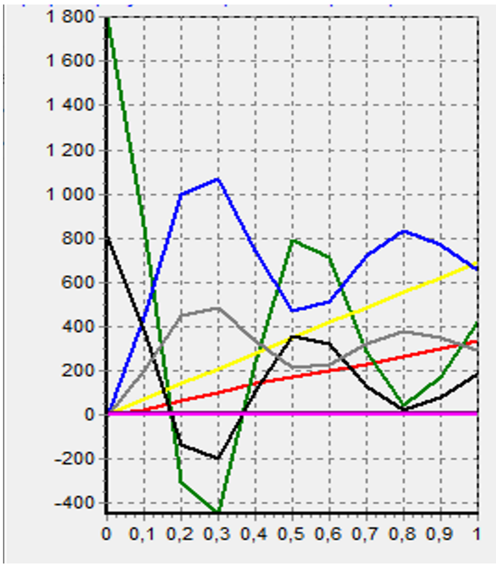

Fig.2. Graphs of the results of calculating parameters of a plant setter movement.

f_1 – angular velocity of the moving part of the object

f_2 - angular acceleration of the moving part of the object

f_3 - angular velocity of the object

f_4 - angular acceleration of the object

md – driving moment

mp – moment of the object

mcc – moment of the resistance

MO – vibration amplitude

4 Conclusion

The experience of the world shows that planting rice by the seedling method allows to increase its productivity, shorten the vegetation period, reduce water consumption and harvest up to 2-3 times a year, depending on the soil and climate conditions. By mechanizing the planting process, it is possible to reduce the demand for labor and increase productivity. However, several problems arise in the use of planting machines in the conditions of Uzbekistan. This greatly reduces the level of mechanization of the method of planting rice in the form of seedlings. Some scientific research is currently being carried out to solve these problems.

The movement of the seedling planting machine was developed using the type 2 Lagrange equations. Based on Pontryagin's principle of maximum, the question of efficiency of actions was raised and the necessary conditions for optimal control were researched based on the criterion of quality of control. By forming the Hamilton-Pontryagin function, joint functions were developed. This joint functions management algorithm made it possible to obtain a U(t) solution.

On the basis of the developed mathematical models, boundary issues of Pontryagin were formulated. In solving boundary issues, the values of object motion in the transition process were determined based on a criterion given using Runge-Kutta methods, and control made it possible to transfer the object from the initial state to the given final state in the shortest possible time when it was u= +1; u= -1.

The coefficients of inertia, viscosity and singularity of the elastic coupling, by solving joint functions and boundary issues determined. It made it possible to obtain results describing the movement of the seedling planting machine by solving the movement equation.

Using Hamilton's canonical equations to assess the energy state of the plant setter expressive equations of the mechanical energy of the plant setter were compiled. This made it possible to determine the power consumption.

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