To determine the equation of motion of a tuber in the drum of the planting apparatus of a potato planting machine

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Abstract. The article presents the results of theoretical research on the improvement of planting devices for potato planting machines. The question of the movement of potato tubers relative to the planting apparatus of the potato planting machine is considered. A new design scheme of the planting apparatus is proposed. The obtained research results are the basis for research on ensuring the uniformity of the layout of potato tubers relative to the row and serve as a recommendation for agricultural producers.

1. Introduction
The uniformity of the layout, ensuring the possibility of planting potato tubers of various weight characteristics is possible by improving the planting technology and design parameters of the planting devices. The task of creating new and modernizing the existing working bodies of machines for planting potatoes in order to improve the quality of technological operations, reduce energy consumption and manual labor costs is urgent.

2. Materials and methods
In the theoretical part of the research, the analysis of research in the field of improving the design parameters of planting devices of potato planting machines [1-5]. The dependences of the angular speed of rotation of the planting device disk \( k \) on the speed of the translational movement of the planting device \( V \) to ensure the required distance between the planted tubers (figure 1). The data were processed using the Mathcad software product.

3. Results and Discussion
During one revolution of the planting apparatus drum, \( N \) tubers enter the furrow.

Accordingly, \( N \) is the number of drum sections. If \( k \) is the required distance between two adjacent tubers, then the planting apparatus, when planting \( N \) tubers, will move a distance:

\[
S = N \cdot k \tag{1}
\]

On the other hand:

\[
S = V \cdot T \tag{2}
\]

Where \( V \) is the speed of uniform translational motion of the planting device, \( T \) is the time of one revolution of the disc of the planting device.
Since the disc of the planter rotates uniformly with an angular velocity $\omega$, then:

$$T = \frac{2\pi}{\omega}$$

Substituting (3) in (2) and taking into account (1), we obtain an expression that relates the angular speed of rotation of the disk, the speed of translational motion of the apparatus, the distance between the planted tubers and the number of disk sections of the planting apparatus:

$$N \cdot k = V \cdot \frac{2\pi}{\omega}$$

Or:

$$\omega = V \cdot \frac{2\pi}{N \cdot k}$$

The tuber, having fallen from the hopper into the drum of the planting apparatus, will be fixed between the discs of radius $R$, located opposite to each other (figure 3).

![Figure 1](image1.png)

**Figure 1.** Calculation scheme for determining the dependence of the speed of rotation of the planting device disk apparatus $\omega$ on the speed of the translational movement of the planting device $V$.

**Figure 2.** Dependences between $V$ and $\omega$ at different distances $k$ between tubers in the furrow for a fixed number of sections $N$.

The distance between the discs can be adjusted depending on the size of the planted fraction. Let the position of the tuber, fixed between the discs in the drum, be determined by the coordinate $r_0$, measured from the axis of rotation of the drum to the center of mass of the tuber (figure 3).
Figure 3. Scheme for justifying the equation of motion for a tuber in the drum of the planting apparatus.

The distance $r_0$ is related to the radius of the tuber $r$ and the angle $\alpha$ between the discs by the ratio:

$$r_0 = \frac{r}{\sin \left( \frac{\alpha}{2} \right)}$$  \hspace{1cm} (6)

Let's take a tuber as a material point. Let $V$ be the speed of translational motion of the device (the axis of rotation of the drum of the planting device), $\omega$ - the angular velocity of the drum of the planting device, $R$ is the radius of the disc of the planting device, $r_0$ is the distance from the axis of rotation of the disk to the position of the tuber in the planting device, $h$ is the distance from the axis of rotation the drum of the planting apparatus to the soil surface (figure 4).

Figure 4. Design scheme for describing the equation of motion of the tuber.

Let's introduce a coordinate system: we direct the $X$-axis along the soil surface in the direction of the machine movement, the $Y$-axis vertically upward. A tuber, hitting the drum of the planting apparatus and being between the discs, will describe the cycloid in the selected coordinate system:

$$x(t) = V \cdot t - r_0 \cos(\omega t)$$

$$y(t) = h + r_0 \sin(\omega t)$$  \hspace{1cm} (7)

The position of the tuber will be described by equations (7) until the drum turns at a certain angle $\phi_0 = \omega t > \pi$, at which the tuber can start moving along the radius of the disk under the action of gravity.

Consider the movement of the tuber relative to the planting apparatus. To determine the angle of rotation of the drum and the time after which the tuber leaves the planting drum, consider the movement of the tuber relative to the disks of the planting drum. Let's take a tuber as a material point. Let us introduce a coordinate system rigidly connected with the disk: the $r$ axis is directed along the radius of the disk from the center, the $n$ axis is directed in the plane of the disk perpendicular to the radius (figure...
5. The position of the tuber (material point) in the selected frame of reference will be determined by the coordinate \( \rho \) measured from the axis of rotation of the drum.

![Calculation scheme for the position of the tuber in the selected reference system.](image)

Let us write down the differential equation of motion of a point in the selected frame of reference. The selected frame of reference will be non-inertial, since it is rigidly connected to a disk rotating with an angular velocity \( \omega = \text{const} \), therefore, inertial forces should be added to the active forces and coupling reactions acting on the point.

Active force - gravity - \( mg \). The connection for a tuber taken as a material point will be the surface of the disc. We neglect the forces of resistance of movement, then the reaction of the connection will be the normal reaction of the surface - \( N \) (figure 5).

We introduce the forces of inertia: portable - \( F^e = -m \ddot{a} \) and Coriolis - \( F^k = -m \ddot{a}^c \) since \( a^e = \omega^2 \rho \) (transferable acceleration), \( a^c = 2\omega \dot{\rho} \) (Coriolis acceleration), the modules of inertia forces are determined by the expressions:

\[
F^e = m\omega^2 \rho \\
F^k = 2m\omega \dot{\rho}
\]

The vector equation of motion is:

\[
ma = mg + N + F^e + F^k
\]

The projection of this vector equation on the \( n \)-axis gives an expression for determining the normal reaction \( N \):

\[
0 = N + 2m\omega \dot{\rho} - mg \cos \varphi
\]

\[
N = mg \cos \varphi - 2m\omega \dot{\rho}
\]

By projecting the vector equation onto the \( \tau \)-axis, we obtain the differential equation of motion of the point (center of mass of the tuber) along the radius of the disc of the planting apparatus:

\[
m\ddot{\rho} = mg \sin \varphi - m\omega^2 \rho
\]

Or, by reducing by \( m \) and considering that:
\[ \ddot{\rho} - \omega^2 \rho = g \sin \omega t \] (14)

The general solution of the second order inhomogeneous differential equation (14) consists of the general solution of the corresponding homogeneous equation and the particular solution of the inhomogeneous one:

\[ \rho_{\text{obs}} = \rho_{\text{odn}} + \rho_{\text{shast}} \] (15)

The general solution of the corresponding homogeneous equation has the form:

\[ \rho_{\text{odn}} = C_1 \text{ch}(\omega t) + C_2 \text{sh}(\omega t) \] (16)

Where \( C_1 \) and \( C_2 \) are integration constants.

We seek a particular solution of the inhomogeneous equation in the form:

\[ \rho_{\text{shast}} = A \sin(\omega t) \] (17)

where \( A \) is a constant, which we define by substituting (17) in (14):

\[ -2\omega^2 A \sin \omega t = g \sin \omega t \] (18)

From here:

\[ A = -\frac{g}{2\omega^2} \] (19)

Consequently:

\[ \rho_{\text{shast}} = -\frac{g}{2\omega^2} \sin(\omega t) \] (20)

The general solution of equation (14), taking into account (16) and (18), has the form:

\[ \rho_{\text{obs}} = C_1 \text{ch}(\omega t) + C_2 \text{sh}(\omega t) - \frac{g}{2\omega^2} \sin(\omega t) \] (21)

By transformations and substituting the found constants into the general solution (21), we obtain the equation of motion of a material point (tuber) relative to the disc of the planting apparatus:

\[ \rho(t) = r_0 \text{ch}(\omega t) + \frac{g}{2\omega^2} \text{sh}(\omega t) - \frac{g}{2\omega^2} \sin(\omega t) \] (22)

The time \( T_k \) after which the tuber, starting to move along the radius of the disc, leaves the drum of the planting apparatus is determined from the condition:

\[ \rho(t) = r_0 \text{ch}(\omega t) + \frac{g}{2\omega^2} \text{sh}(\omega t) - \frac{g}{2\omega^2} \sin(\omega t) \] (23)

Where \( R \) is the radius of the planting device disk.

The angle \( \varphi \) through which the disc (drum) of the planting apparatus will be turned:

\[ \rho(T_k) = R \] (24)

Where \( \omega \) is the angular velocity of the drum:

\[ \varphi = T_k \cdot \omega \] (25)
The obtained preliminary results of theoretical studies will be further used in experimental studies in order to ensure the uniformity of the layout of tubers along the row in accordance with agrotechnical requirements.

4. Conclusion
Thus, according to the results of the study, the following conclusions can be drawn:

- An equation of motion of a material point (tuber) relative to the disc of the planting apparatus is obtained, which describes the planting process;
- The angle of rotation to which the disc (drum) of the planting apparatus will be turned will be determined by the dependence $\theta = T_k \cdot \omega$, where $\omega$ is the angular velocity of the drum;
- The time after which the tuber leaves the drum of the planting apparatus is determined from the condition $\rho(T_k) = R$, where $R$ is the radius of the disc of the planting apparatus.

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