Improvement of the process of dosing sugar beet seeds using a cone-shaped sowing apparatus

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Abstract. To improve the quality of sowing seeds of sugar beets, the constructive and regime parameters of the high-speed cone-shaped device, which ensures the transportation of seeds with a cone-shaped dispenser, the increase in the grasping capacity of cells, the process of sowing seeds into cells and laying seeds in cells. As a result of analytical studies, regularities in the change in the supply of sugar beet seeds by a cone-shaped sowing device are revealed depending on the linear velocity, the angle of inclination of the cells and the thickness of the sowing ring. The high-speed seeder provides high accuracy of seed dosing, high uniformity of seeding and seed distribution without damage in the seed bed. This contributes to the survival and stability of the culture in the first days after sowing, which ultimately will ensure a reduction in the cost of growing sugar beet and increase yield. The analytical dependencies obtained and the calculation procedure can be used in the design of mechanical precision seeding machines. Empirical regression models are used to adjust the sowing apparatus to optimal operating conditions.

Keywords: sugar beet, cone-shaped seeder, sowing ring, sowing devices.

1. Introduction
Sugar beet is a technical culture, giving carbohydrate-rich root vegetables. With high agrotechnics, the yield of beet can be 8 t/ha or more. The most important factor in increasing the yield of sugar beet is the sowing of seeds in a compressed agrotechnical time with the optimal placement of plants in the area of nutrition. At present, seeders with mechanical and pneumatic sowing devices are used for sowing sugar beet. World practice proves that seeders with a mechanical sowing apparatus are better in seeding than pneumatic seeders [1-3]. Mechanical sowing apparatuses by design and principle of operation are divided into reel, cup, screw, vibratory, centrifugal, spoon, cellular and apparatus for laying a seed moisture-soluble tape. Apparatuses of cellular-tape type are used on precision seeders «Mammen» firm «Giraud», «Dalman», «Hillsheg» firm «Overum», «Stenhei» [4]. Disk sowing machines are installed on seeders SKNK-6, STH-4A, STSN-6A, SST-12V, McCormick, John Deer, Monodrill, Tuz, Ebra, Products, Webb, «Gloucester», «Exaclete» and others [4]. The cellular disk unit is used on the seed drills of «Webb» and «Gloucester», «Monocenter», «Exaclete», «Fendt», «Unicorn-2», «Sembner», «Monocenter-SP», «A-695», «A-765», «Tume-Mono», «Tank», «Massey Ferguson», «Palm» [5, 6, 7]. The sowing units of the drum type are used on the seeders such as «Palm Agromatic», «Unisem», «Monosem», SPP-12, SGU, STG-18, «Unikorn» and others. Seeding apparatuses of disk-and-spoon type are installed on seeders «Smat», «Nibex», «John Deere» and other.
The remaining devices for seed dosing have not found wide application, some due to the complexity and high cost of construction, others due to poor quality of sowing [8-9].

From the analysis of the operation of mechanical sowing machines, it is revealed that they have a number of disadvantages: the damage of seeds, which is obtained by removing excess seeds with the help of ejectors; the need for thorough seed calibration; the need for seed discs with different sizes and number of cells.

Also, in seeders with a mechanical seeder, the speed of movement is limited by the permissible rotational speed of the sowing disk [10-11]. The aim of the study is to improve the quality of sowing seeds of sugar beet, by improving the design of the sowing apparatus, ensuring the accuracy of dosing and the absence of damage to the seeds.

2. Materials and methods
To overcome the above-mentioned drawbacks, a model of a mechanical cone-shaped sowing device for precise seed sowing has been proposed. A mechanical cone-shaped precision seeding machine (Figure 1) includes a hopper 1 with an outlet window 2 located on the surface of the cylindrical body 3 on which the conical dispenser 5 is supported, connected to the shaft 10 by means of a drive bolt 11.

![Figure 1. Scheme of a cone-shaped seeder: 1 - hopper; 2 - outlet window; 3 - cylindrical body; 4 - damper; 5 - conical dispenser; 6 - sowing ring; 7 - through cells; 8 - rim’s circumference; 9 - groove; 10 - drive shaft; 11 - bolt drive.](image)

The amount of seed to be poured is controlled by the damper 4. On the side of the larger diameter, a sowing ring 6 is attached to the cone metering device with uniformly distributed through cells 7. With the cap on the end part 8 of the rim’s circumference which is made a groove 9. The lid is rotatable around its axis changing the angle of the slot arrangement, and recorded. The drive cone dispenser through a chain transmission from the dispenser shaft drills. The operation of the seeding machine is carried out as follows, the seeds from the hopper through the exit window under the action of gravity fall into the cavity of the rotating cone dispenser. Due to the frictional force and tilting of the conical wall of the dispenser during rotation of the seeds move along its axis and reach a certain layer seeder ring with cells.

The main factors influencing the exact seeding process by mechanical sowing machines are the type, shape and size of the sowing disk cells, the rotation speed of the sowing disk, the presence of input and output facets on the cells [12-16].
Seeds from the hopper through the exit window enter the cavity of the cylindrical body, crumble at the angle of the natural slope $\lambda$ and form a layer of $h_c$ height on the surface of the rotating cone metering device. The height of the layer of $h_c$ seeds entering the inner surface of the cone metering device depends on the area of the hopper exit window, the diameter and length of the cylindrical body. The value of this layer is regulated by the damper. The cross-sectional area of the seed layer $S_c$ captured by a rotating cone dosimeter is determined from the expression:

$$S_c = \frac{1}{2} [l_d \cdot R_k - N(R_k - h_c)],$$

(1)

where $l_d$ is the arc length, m; $R_k$ is the radius of cylindrical body, m; $N$ is the chord, m.

The height of the seed layer $h_c$ entrained rotating conical dispenser is determined by the formula:

$$h_c = 2R_k - \frac{L - L_o}{\cot \lambda},$$

(2)

where $L$ is the length of cylindrical body, m; $L_o$ is the length of the hopper’s outlet window, m; $\lambda$ is the angle of natural slope of seeds, deg.

Seeds with a layer of $h_c$ are fed to the inner surface of the cone dispenser from the side of smaller diameter. Feeding of grain material is continuous. When the cone dispenser rotates with the angular velocity $\omega$, the seeds rise together with the inner surface of the dispenser to the point determined by the elevation angle $\beta_k$, after which they begin to slide down. The seed rolls out at an angle of $\varepsilon$, which ensures the seeds move along the axis of rotation due to the frictional force and the slope of the cone forming the dispenser, at an angle $\alpha_k$ (Figure 2).

To obtain the angle of the largest slope at point M, draw through MD a vertical plane and rotate it around the line MD as around the axis until this plane becomes perpendicular to the edge of the angle of the dihedral angle, so that the angle CFD $= 90^\circ$.

Then the angle MFD $= \gamma$ is the angle of the largest tilt at point M, since the edge of the angular plane of the dihedral angle will be perpendicular to all lines drawn in the vertical plane MFD.

We define the angles: $\delta$, $\gamma$ and $\varepsilon$, assuming the slope angle of the generator of the dispenser $\alpha_k$ and the angle of seed raising $\beta$. By the known rules of trigonometry after the transformation, we get:

$$\sin \delta = \frac{tg \delta}{\sqrt{1 + tg^2 \delta}} = \frac{sin \alpha_k}{\sqrt{tg^2 \beta + sin^2 \alpha_k}}$$

(3)

$$cos \gamma = \frac{1}{\sqrt{cos^2 \alpha_k + sin^2 \alpha_k + tg^2 \beta}} \cdot cos \alpha_k \cdot cos \beta$$

(4)

$$tg \varepsilon = \frac{cos \alpha_k \cdot sin^2 \delta}{sin \alpha_k} = \frac{sin^2 \alpha_k}{2(tg^2 \beta + sin^2 \alpha_k)}$$

(5)

From formula (4) we conclude that the maximum angle of tilt $\gamma$ is greater than $\alpha_k$ and more $\beta$; for $\alpha_k = 0$, we obtain $\gamma = \beta$, and for $\beta = 0 \cdot \gamma = \alpha_k$; at $\beta = 90^\circ$ or at $\alpha_k = 90^\circ$, we obtain $\gamma = 90^\circ$.

From formula (5) we conclude that the deflection angle is $\varepsilon = 0$, both at $\alpha_k = 0$ and at $\alpha_k = 90^\circ$. The formula (5) is reduced to the form:

$$tg \varepsilon = tg \alpha_k \left[ \frac{cos^2 \alpha_k}{tg^2 \beta + sin^2 \alpha_k} \right],$$

(6)

from which it can be seen that at small tilt angles $\alpha_k$ and at $\beta \approx 30^\circ \ldots 35^\circ$

$$tg \varepsilon = tg \alpha_k ; \quad \varepsilon = \alpha_k.$$
We take, with sufficient accuracy for technical calculations, that the relative trajectory of the seed movement over the surface of the cone metering device is the correct helix with a lifting angle $W$, which is determined from the expression:

$$W = \varepsilon + \alpha_k = 2\alpha_k = \text{const.} \quad (8)$$

Thus, the relative trajectory of seed movement on the dispenser's tapered surface unfolded in the plane is shown as a straight line running at an angle $W$ of the unfolded circle so that the seeds have passed the entire length of the dispenser $L$, determined by the dependence:

$$L = V_{II} \cdot \tan W = V_{II} \cdot \tan 2\alpha_k, \quad (9)$$

Feed rate is determined:

$$V_{II} = V_0 \cdot \tan 2\alpha_k = \frac{\pi \cdot n \cdot R}{30} \cdot \tan 2\alpha_k \quad (10)$$

where $n$ is the frequency of rotation of the conical dispenser, min$^{-1}$; $R$ is the radius of the conical dispenser, m.

Consequently, the feed rate of the conical dispenser is directly proportional to the ratio of its diameters, angular velocity and tangent of the double tilt angle of the cone generator. From the length of the conical dispenser feeder $L$, the feed rate at steady state is completely independent. To increase the exciting capacity of the cells, cells are proposed that are located at an angle $\alpha_c$ (Figure 3) to the radius of the sowing ring. The length of the cell $L_c$ in this case is determined from the expression:
\[ L_c = \frac{d_c}{\cos \alpha_c} \]  \hspace{1cm} (11)

where \( L_c \) is the cell length, \( m \); \( d_c \) is the cell diameter, \( m \); \( \alpha_c \) is the angle of inclination of the cell to the radius of the sowing ring, deg.

As a result, leaving the diameter of the cell \( d_c \) unchanged, we increase the path \( L_c \) (cell length) that the seed passes through in the slip phase above the cell.

The process of seed sinking into the cells in the phase of sliding along the surface of the sowing ring depends, in the main, on the magnitude of the absolute angular velocity of the seeds, which varies from the rotational speed of the sowing ring. Exceeding the limiting value of this speed will result in the seeds not sinking into the cells of the sowing ring. Thus, in the process of sinking seeds into the cells, the rotation frequency of the sowing ring, the ratio of the mean diameter of the seed to the length of the cell, is closely related.

In the graphical form, the expression (11) is represented in Figure 3. As can be seen from the obtained expression and the presented graph (Figure 4), the angle of inclination of cells \( \alpha_c \) has the greatest influence on the seed yield angle \( \gamma \) from the cells of the sowing ring.

The number of seeds supplied to the cell depends on their diameter and the thickness of the seed ring. To place only one seed in the cell, it is necessary that the diameter of the cell is equal to or exceeds the diameter of the seed by some \( \Delta d \), depending on the ratio of the speed of movement of the seed and the cell.
Angle output $\chi$, deg.

Angular speed of rotation of the sowing ring, rad·s$^{-1}$

Figure 4. Graph of changes in the angle output $\chi$ seeds depending on the angular speed variation and sowing ring o angle cell $\alpha_c$

Let us establish the relationship between the diameter $D_c$ of the cells, the excess of the cell depth over the seed $\Delta t$ located in it and the immersion $\delta$ of the upper seed in the cell.

Figure 5. The scheme of laying seeds in a cell with different disk thickness

We get the expression:

$$D_c = \frac{d_c}{2} + \left[ \delta \cdot (d_c - \delta) \right]^\frac{1}{2} + [d_c^2 - (d_c + \Delta t - \delta)^2]^\frac{1}{2}$$

(12)

From formula (12) we find $\delta = f (d, \Delta t, D)$, having previously adopted the notation:

$$k = D_c - \frac{d_c}{2}, \quad d_{c1} = d_c + 2\Delta t, \quad \beta = k^2 + \Delta t^2 + 2d\Delta t$$

After mathematical transformations we get:

$$\delta = \frac{(2k^2d_c + d \cdot \beta) \pm \sqrt{(2k^2 \cdot d + d \cdot \beta)^2 - \beta^2(d^2 + 4k^2)}}{d^2 + 4k^2}$$

(13)

The seed supply by the cells of the seed ring depends on the length of the cells $L_c$ (Figure 6) and the thickness of the seed ring $t_{BK}$. Let us establish the relationship between the cell length $L_c$, the seed diameter $d$, the excess of the cell depth over the $\Delta h$ seed located in it, and the immersion $\delta$ of the upper seed in the cell.

The length and angle of the cell are found from the equation:

$$L_c = \frac{d_c}{2} (\cos \alpha_c - \sin \alpha_c) + \Delta h \cdot \sin \alpha_c + \frac{d_c^2}{2} - (d_c - \delta + \Delta h)^2 + \frac{d_c}{2 \cos \alpha_c}$$

(14)
The immersion $\delta$ of the upper seed in the cell is determined from the equation:

$$\delta = d_c + \Delta h - \sqrt{d_c^2 - \left[ L_c - \left( \frac{d_c}{2} \cos \alpha_c - \frac{d_c}{2} \sin \alpha_c + \Delta h \cdot \sin \alpha_c + \frac{d_c}{2\cos \alpha_c} \right) \right]^2}$$

(15)

Figure 6. Scheme of seed placement in inclined cells

The thickness of the seed ring $t_{BK}$ is determined from the equation:

$$t_{BK} = \delta + \sqrt{d_c^2 - \left[ L_c - \frac{d_c}{2} \left( \cos \alpha_c - \sin \alpha_c + \frac{2\Delta h \cdot \sin \alpha_c}{d_c} + \frac{1}{\cos \alpha_c} \right) \right]^2}$$

(16)

3. Results and discussion

In accordance with the method of investigating the properties defined seeds needed for experimental studies: the size of sugar beet seeds are normally distributed, the length of the test seed varieties ranging from 3.46 to 5.59 mm, the width varies from 3.26 to 5.58 mm, the thickness of the seeds ranges from 2.31 to 4.37 mm. Volume-weight properties of sugar beet seeds are concluded in the following intervals of variation: the mass of 1000 seeds is 19.25 ... 22.58 g, the bulk density of seeds is 252.51 ... 261.21 grams per liter, the angle of natural tilt is 38°18' ... 44°08'.

On the basis of theoretical studies, it was established that the following factors have the greatest influence on the process of single-grain seed supply by the apparatus: linear velocity of the cell of the sowing ring $V_c$, m·s$^{-1}$; angle of slope of cells $\alpha_c$, deg.; thickness of the sowing ring $t_{BK}$, mm.

Obtained statistical model establishes a mathematical relationship between the parameter optimization - the number of passes made by the cells - $Y_{p0}$, the number of twins $Y_{p2}$, secondary meshes serving $Y_M$, and linear velocity meshes $X_1$, $X_2$ angle meshes and a thickness of the seed ring $X_3$.

$$Y_{p0} = -10.95 + 67.49V_c + 0.065\alpha_c + 2.05t_{BK} - 0.34V_c\alpha_c - 9.66V_c t_{BK} - 0.0116\alpha_c t_{BK}$$

(17)

$$Y_{p2} = -7.92 + 20.86V_c + 0.155\alpha_c + 2.365t_{BK} - 0.355V_c\alpha_c - 7.399V_c t_{BK} - 0.0136\alpha_c t_{BK}$$

(18)

$$Y_M = 0.885 - 0.749X_1 + 4.25 \cdot 10^{-3}X_2 + 5.75 \cdot 10^{-2}X_3$$

(19)

As a result of determination of rational constructive and technological parameters of experimental mechanical cone-shaped sowing apparatus by constructing sections response surfaces, it was found that the high quality of single-grain seed dosing ($Y_{p0} \leq 2\%$, $Y_{p2} \leq 2\%$, $M \geq 1$) is provided at an angle cell seeding tilt ring $\alpha_c = 30$ degrees, the thickness of the sowing ring is 2.6 mm and the linear velocity of the sowing ring is 0.20 m·s$^{-1}$.

4. Conclusions
Sowing machines for sowing sugar beet seeds do not provide high accuracy of seed dosing, and the presence of an ejector and a reflector in the sowing apparatus results in damage to the seeds. To eliminate these drawbacks, a mechanical cone-shaped precision seeding machine is proposed, in the design of which there are no ejecting and reflecting devices, as a result of which there is no damage to the seeds. Increased the gripping capacity of cells by using obliquely located cells. The regularities of the change of inclination of the seed cell rings 30 degrees, the thickness of the seed ring 2.6 mm at a linear velocity of the seed ring 0.2 m·s⁻¹.

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