Movement of seeds in the underweep space of drill coulter in the condition of pneumatic feed

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Abstract. The analysis of various methods of sowing of grain crops showed that the introduction of indirect sowing in agricultural production contributes to the increase in their productivity. The authors propose justified structural and technological scheme of the sowing system in order to ensure a uniform distribution of seeds over the feeding area to a given depth with their subsequent seeding. The main element of the sowing system is the pneumatic seed feed. Due to the movement in the airflow, the seeds of grain crops at the moment of the concussion against the surface of the distributor have sufficient speed to reach any point on the surface under a V-shaped weep; this contributes to the uniform distribution of seeds across the entire width of the sowing strip.

1. Introduction

Nowadays, the use of resources-saving technologies in agricultural production is the guarantor of a stable grain crop yield. The improvement of the technology of cultivating grain crops by production identification allows increasing their productivity [1].

It is known that at today there is a large variety of grain seeders with both mechanical and pneumatic feed of grain and seed shoe fertilizer [2–5]. The use of these seeders allows implementing different technologies for grain crops sowing.

We can state that the use of indirect sowing is one of the reserves for increasing the productivity of grain crops among the wide variety of different methods of sowing grain crops. The indirect method of sowing most fully meets the requirements of agricultural machinery for the cultivation of grain crops. The existing direct seed drills of national brands SZS-6 and SZS-12 carrying out indirect sowing of seeds of grain crops have the advantage: they sow and introduce fertilizers and cut the roots of the sprouted weeds and at the same time. However, these seed drills also have a number of disadvantages, namely, uneven seeding of seeds over the entire width of the sowing coulter strip. To increase the uniformity of the distribution of seeds over the sown strip, a passive seed distributor is installed in the sub-valve space of the coulter [6]. However, this solution did not allow solving the problem of uniform distribution of seeds over the entire width of the coulter underweep space [7,8].

It is known that the degree of furrowing and seeding by the coulters affects the uniformity of the distribution of seed of cereal crops not only in the area of sowing, but also in the depth of placement.
One of the requirements of high-quality agricultural machinery is to place seeds on a compacted bed, because moisture is supplied to the dropped seed by capillaries. In order to ensure a compacted bottom of the furrow, only sliding weep coulters are used [9].

A uniform distribution of seeds over the sown strip can be obtained both due to the violation of the grain flow and due to its conservation. In the first case, it is possible due to multiple collisions of seeds between themselves, with the walls of drill tubes and of coulter. In the second case, having received a continuous flow, it is necessary to preserve it along the entire path of movement [10].

The purpose of our research is to develop and justify the design parameters of the sowing system for seeds of grain crops. The main element of the sowing system is the pneumatic feed of seed used during subsoil-spread sowing of grain crops.

2. Materials and methods
In order to ensure the implementation of the technological process of sowing grain, a structural and technological scheme of the sowing system for the subsoil spread sowing is proposed, which ensures uniform distribution of seeds over the spacing area at a given depth of planting [8].

Figure 1 presents the operation of the sowing system for the subsoil spread sowing of grain crops in the form of a structural and technological scheme.

![Figure 1. Structural and technological scheme of the sowing system for subsoil spread seeding of grain crops using pneumatic seed feed](image)

The summary of the above-mentioned scheme is as follows:
- V-shaped weep cuts and raises the topsoil;
- Pneumatic feed of seeds of grain crops is carried out in the space, with the help of a passive distributor the seeds are evenly distributed over the entire nutrition area;
- The raised topsoil leaves the V-shaped weep of coulter, closing the sown seeds;
- The rollers following V-shaped weep of the coulter cover the soil.
We determine the maximum width of the sown strip on which seeds can be theoretically distributed. It can be found by the formula (1), according to the scheme presented in Figure 2:

\[
B' = B - \frac{2\sigma}{\tan \beta}
\]

where \( B \) – weep width, mm; \( \sigma \) – grain thickness, mm; \( \beta \) – the angle of the blade to the furrow bottom, degree.

**Figure 2.** The scheme to determine the maximum width of the sowing strip: \( B \) - constructive weep width, mm; \( B' \) - the width of the sowing strip, \( \sigma \) - grain thickness, mm; \( \beta \) - the angle of the blade to the bottom of the furrow, degree.

Let us consider the movement of grain in a curved drill tube under the condition of air supply and set the coordinates of the moving grain \( x = x_0, \ y = y_0, \ z = z_0 \) and projections of its speed \( V_{ix}, V_{iy}, V_{iz} \) by initial conditions, at \( t = 0 \):

\[
x = x_0, \ \ y = y_0, \ \ z = z_0, \quad V_{ix} = V_{iy} = V_{iz}, \quad \text{at } t = 0:
\]

where \( x_0, y_0, z_0 \) – grain coordinate at the initial time

\( V_p = (V_{ipx}, V_{ipy}, V_{ipz}) \) – grain speed projections.

Since the grains move in a curved drill tube and the speed vector is always parallel to the tangent line of the bend (due to airflow), the coordinates are adjusted in flight.

Let us suppose that the modulus of the speed vector is a constant:

\[
|V| = \sqrt{V_{ipx}^2 + V_{ipy}^2 + V_{ipz}^2}
\]

If there is no collisions, we can accept grain \( V_{ix} = 0 \), because the air flow does not deflect the grain along the axis. When the angle of the direction of motion changes by \( \Delta u \) (Fig. 3), the values \( V_{ipx}, V_{ipz} \) change respectively. Let us denote their new values by \( \bar{V}_{ix}, \bar{V}_{ipz} \).
Figure 3. The movement scheme in a curved drill tube under the condition of air supply: \( R_s \) - the radius of bending of the pipe at the point where the grain is located; \( R_r \) - the outer radius of the pipe; \( r_s \) - the inner radius of the pipe; \( V \) - grain speed; \( V_o \) - the initial grain speed; \( U \) - the angle of the direction of movement of grain; \( \Delta U \) - the change in the angle of the movement direction of grain; \( U + \Delta U \) - the total value of the change in the angle of movement direction of grain.

In this case:

\[
V_{ps} = |V| \cdot \sin u, \ V_{pr} = |V| \cdot \cos u \quad \text{i.e.}
\]

\[
\overline{V_x} = |V| \cdot \sin (u + \Delta u) = |V| \cdot (\sin u \cdot \cos \Delta u + \cos u \cdot \sin \Delta u)
\]

(4)

\[
\overline{V_z} = |V| \cdot \cos (u + \Delta u) = |V| \cdot (\cos u \cdot \cos \Delta u - \sin u \cdot \sin \Delta u).
\]

(5)

In this case:

\[
\Delta u = \arctg \left( \frac{|V| \cdot \Delta t}{R_z} \right),
\]

(6)

Thus, it is possible to determine the probable direction of grain flight.

In order to most evenly fill the area limited by the width of V-shaped weep, the seeds, after entering the underweep space and hitting the arch-forming surface of the passive distributor, should move according to the diagram shown in Figure 4.

The time of grain flight in the underweep space occurs in a short period of time \( t \), which is much less, than the time required by the seed to achieve a critical speed \( V_{cr} \). Therefore, we consider the movement of grain without air resistance, i.e., we consider it only under the influence of gravity \( G \).
Figure 4. The scheme of grain flight in the underweep space after hitting the distributor surface: \( \beta \) - the angle of the blade to the furrow bottom, degree; \( \alpha \) - the angle formed by the speed vector \( V_2 \) and the horizontal plane, degree; \( \varphi \) - the angle formed by the surface of the distributor and the horizontal plane, degree; \( d \) - the horizontal component of the grain flight path; \( G \) - the gravity, \( h \) - the grain fall height, \( V_1, V_2 \) - the grain speed vectors, \( \gamma \) - the angle formed by the speed vector \( V_2 \) and the vertical plane, degree.

According to the accepted assumption, the differential equations of grain movement are as follows:

\[
m\ddot{x} = 0; m\ddot{y} = 0;
\]

where: \( m \) - grain mass, kg.

We use the initial conditions:

\[
x_0 = 0; y_0 = 0; \dot{x}_0 = V_2 \cdot \cos \alpha; \dot{y}_0 = V_2 \cdot \sin \alpha.
\]

where: \( V_2 \) - grain speed after hitting the distributor, m/s; \( \alpha \) - the angle formed by the speed vector \( V_2 \) and the horizontal plane, degree.

The equations of projections of grain velocities on the coordinate axis, at time \( t \):

\[
\dot{x} = V_2 \cdot \cos \alpha; \dot{y} = gt + V_2 \cdot \sin \alpha.
\]

After integrating expressions (4), we obtain the equations of grain movement at time \( t \):

\[
x = V_2 \cdot \cos \alpha \cdot t; \ y = gt^2/2 + V_2 \cdot \sin \alpha \cdot t.
\]

Expressing the parameter \( t \) and accepting the conditions for the lower part of the flight line, i.e. \( x = d, y = h \), we get:

\[
h = g \cdot d^2 / \left[2 \cdot V_2^2 \cdot \cos \alpha \right] + d \cdot \text{tg} \alpha,
\]

where: \( d \) - horizontal component of the flight line of grain, m; \( h \) - grain drop height, after impact hitting the surface of the distributor, m.

According to the formula (11) we express the speed that grains should have, after hitting the surface of the distributor, to move a distance \( d \), at impact height \( h \), from the supporting surface of the V-shaped weep:

\[
V_2 = \sqrt{\frac{g \cdot d^2}{2(h - d \cdot \text{tg} \alpha) \cdot \cos^2 \alpha}}.
\]
Expressing the angle $\alpha$ in terms of the known parameter $\phi$, taking into account that the angle $\beta = \phi$, we obtain the formula for calculating the flight speed of the grain after hitting the surface of the distributor:

$$V_2 = d \sqrt{g \cdot \left(1 + \left(\frac{tg \phi + k}{tg \phi \cdot (1 + k)}\right)^2\right) \left(h - d \cdot \left(\frac{tg \phi + k}{tg \phi \cdot (1 + k)}\right)\right)}, \quad (13)$$

where: $k$ – grain speed recovery coefficient after hitting; $\phi$ – the angle formed by the surface of the distributor and the horizontal plane, degree

Using the known quotations, through $V_2$ we find:

$$V_1 = \frac{V_2}{k}, \quad (14)$$

where: $V_1$ – grain speed at the moment of the start of hitting the surface of the distributor, m/s.

3. Conclusion

Scientific research was carried out using the equipment of the collective use center “Additive Technologies and Material Processing” of Omsk State Agrarian University. As a result of the studies, we found that, due to the introduction of the air flow, we can impact the necessary speed $V_1$ to seeds in order to achieve a given distance $d$, with the known parameter $\phi$. Thus, due to the airflow movement, the seeds of crops at the moment of hitting the surface of the distributor have sufficient speed to reach any point on the surface under the V-shaped weep, which contributes to a uniform distribution of seeds over the entire width of the sowing strip.

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