Precise seeding planter with automated monitoring and control system

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Abstract. In the “Q-factor” laboratory of the Don State Technical University, seeding planters are created with the original design of sowing devices, using modern materials and technologies. The design of a row seeding planter is considered, which allows coordinating the speed of the seed and the speed of the unit for a better sowing process. A new classification feature in the design of the row precise seeding planter is designated - the height of the sowing device from the bottom of the furrow. The characteristic features of the constructions of serial seeding planters on the basis of the aforementioned feature were identified and analyzed. The rationale for the need to improve the technological process of sowing seeds of row crops by serial seeding planters is given. The problem is indicated, which is the lack of automation in controlling the precision sowing process during the operation of the seeding planters. A functional diagram and design of a sowing device with a seed tube is proposed, in which the ability to control the flight speed of seeds directly during sowing is implemented. A setup for testing the sowing device is presented with the aim of increasing the accuracy of determining the parameters of the operating modes of the sowing device of precise seeding planters in laboratory conditions. The results of laboratory experiments are obtained, which makes it possible to judge the possibility of controlling the speed of seeds directly during sowing process.

1. Introduction

Current market conditions and the need to maintain food security in the country pose the scientific community with the task of improving the efficiency of the agricultural business and increasing the competitiveness of manufactured products. Today, the vector of development of agricultural machinery should be aimed at its automation and digitalization. This transition is possible only through the introduction of innovative technologies using the achievements of scientific and technological progress [1].

In the world arena, the market for Russian agricultural machinery, in commercial terms, is one of the most promising. In general, the dynamics of the production of mounted equipment repeats the dynamics of the production of large self-propelled equipment. In the structure of production of the main types of mounted and trailed equipment, the seeding planter production holds a share of 12% [2].

In serial seeding planters of foreign and Russian manufacturers, systems are widely represented that only monitor the quality of sowing and monitor the sowing process [3-4]. Analysis of the designs of modern precise seeding planters and a patent search for the latest technical solutions formed the basis
of our proposed functional diagram and developed design of a modernized sowing device with seed tube and a system for automatically measuring the speed of seeds at the exit of the seed tube with the ability to control this speed [5-8]. Analytical studies of ways to control the process of delivering seeds to the bottom of the furrow in row seeding planters, provided that the seed is taken as a material point of a certain mass, are known [9-10].

2. Materials and methods
Regardless of the manufacturer, as well as variations in the design, let us consider, as a classification indicator for precise seeding planters, the parameter - the height of the axis location of the sowing device from the bottom of the furrow, $H_0$. For precise seeding planters with a high location of the sowing device (Figure 1a), the parameter $H_0$ is about 60 cm, and for seeding planters with a low location of the sowing device (Figure 1b), the height of the axis of the sowing device from the bottom of the furrow is not more than 30 cm.

![Figure 1](image-url)

**Figure 1.** Types of precise seeding planters for location of the sowing device.

After analyzing the existing classifications of precise seeding planters, as well as a number of modern patents of seeding planters, we proposed a new classification feature in the division of the designs of row seeding planters - the height of the sowing device location (Figure 2). This classification feature is characteristic both for Russian-made seeding planters and for foreign seeding planters.
Figure 2. Classification of precise seeding planters according to the location of its sowing devices and key features of commercially available seeding planters.

An analysis of the design features of serial seeding planters showed that both options have the following disadvantages: limiting the maximum sowing speed, the presence of an oblique impact on the bottom of the furrow and the inversion of seeds, the uneven distribution of seeds in the row, and the complete lack of ability to control the sowing process after seed fall from the disk. Regardless of the design of the seeding planter, there are currently no direct analogues on the market that can provide automated control of the sowing process directly during the operation of the seeding planter. We believe that the solution to the above problem lies in the synthesis of the technology of the sowing device, namely the creation of a hybrid design with a low location of the sowing device and seed tube, which will make it possible to control the speed of seed flight in order to increase the accuracy of their location in the furrow.

A known design of a pneumatic sowing device having a seed tube with three sections: straight, curved and accelerating, a similar design eliminates points 1, 2, 3 of the characteristic features (drawbacks) of serial precise seeding planters (Figure 2). We have proposed the design of a sowing device with an automated system for monitoring and controlling the sowing process, which allows solving the problems indicated in points 4, 5, 6 of the characteristic features (drawbacks) of serial precise seeding planters (Figure 2).
The technical result that can be achieved using the proposed design of the sowing device, is to increase functionality by providing quality control of the sowing and automatic coordination of the speed of the sowing device and the speed of the seeds at the exit of the seed tube.

Using the assumption that the seed is taken as a material object of a spherical shape of a certain mass allows to determine the speed of the seed (for example, pea seeds) at the exit of the seed tube $v_s$ by the expression:

$$v_s = \sqrt{2C_w l v_{air}^2 + (2C_w l v_{air})^2 - \frac{2C_w l v_{air}^2}{g}(u_c \sqrt{2gh} + 2C_w l v_{air}^2)},$$

where $v_{air}$ - air flow velocity in the seed tube, m/s;
$C_w$ - coefficient of windage, m$^{-1}$;
g - free fall velocity, m/s$^2$;
$l$ - length of the accelerating section of the seed tube, m;
h - height of the horizontal “jump” of the seed during the transition from the curved section to the accelerating, m (Figure 4);
Figure 4. The movement of the seed during the transition of the seed tube from the curved section to the accelerating section.

\[ v_c = \frac{-a_1(Z+pC_w)}{2+az+apC_w} + \frac{Z\sqrt{Z^2(Z+pC_w)^2-(2+az+a\beta C_w)(aZv_c^2+apC_wv_c^2+4Zpgcos\beta-4gh_2-2v_c^2)}}{Z+az+apC_w}, \]

where \( v_{c*} \) - speed of the seed at the beginning of the curved section of the seed tube; 
\( \rho \) - radius of curvature of the seed tube (constant throughout the section), m; 
\( \beta \) - angle between the velocity vector and the horizontal at the starting point of the movement of the seed along the curved section of the seed tube, radian; 
\( \alpha \) - angle complementing the angle \( \beta \) to \( \frac{\pi}{2} \), radian;

Figure 5. The scheme of movement of the seed along the curved section of the seed tube, where \( \phi \) - angle between the velocity vector and the horizontal at any point in the movement of the seed along the seed tube.

\( Z \) - coefficient of friction of rolling seeds of spherical shape, equal

\[ Z = \frac{f}{r}, \]

where \( f \) - coefficient of friction of the seed on the surface; 
\( r \) - radius of the seed, m.

This mathematical model refines and complements the research of such authors as V.P. Goryachkin, P.M. Vasilenko, G.E. Listopad, A.A. Budagova, N.M. Bepamyatnova, V.A. Bogomyagkikh, F.G. Gusintsev, B.I. Zhuravlev, L.I. Zenin, S.V. Kardashevsky, P.Ya. Lobachevsky, N.P. Lobachevskaya, V.I. Khizhnyak, V.P. Chichkin, V.A. Chernovolov and other famous scientists. From (1)...(3) it follows that at the exit from the seed tube a large number of factors affect the speed of a seed, taken as a material object of a spherical shape of a certain mass. The angle of seed fall from the sowing disk (\( \beta \)), the radius...
of curvature of the curved section of the seed tube $\rho$ and the height of the horizontal “jump” of the seed $h$ during the transition from the curved section to the accelerating section are determined from the design features of the device of the seeding planter type SUPN, taken as the basis of the experimental sowing device; the length of the accelerating section of the seed tube $l$ is known; the coefficient of windage of seeds $C_w$, the mass of the seed of the sowing material $m$, the radius of the seed $r$ and its coefficient of friction on the seed tube $f$ are determined experimentally and depend on the sowed agricultural crop. Thus, as the main factor affecting the speed of seeds at the exit of the seed tube, the speed of the air flow in the seed tube $v_{air}$ is taken.

To test the hypothesis presented about, the possibility of changing the speed of the seed due to the air flow and the achievement necessary for a better sowing process, the equality of the speed of the seed and the speed of the device, we developed a test bench for sowing devices (Figure 6).

![Figure 6. Test bench for sowing devices for row seeding planters, where: 1 - frame of the test bench; 2 - electric motor; 3 - chain; 4 - frequency converter; 5 - sowing device; 6 - vacuum installation; 7 - compressor; 8 - seeding sensors; 9 - computer; 10 - stick conveyor belt.](image)

Consider the work of the test bench. After turning on the power source, the required number of revolutions of the sowing device (5) is set on the display and control panel of the frequency converter (4) (according to the operating conditions of the seeding planter). By pressing the “Start” button on the control unit of the frequency converter, the electric motor of installation (2) is started and thereby the chain device (3) connected to the rotation shaft of the sowing device comes into rotation. The DC motor and the stick conveyor belt (10) (seed collection tape) are set in motion at the same time, because they have a common shaft. After that, the vacuum installation (6) of the sowing device with a predetermined vacuum depth is turned on. In the presence of seeds falling from the sowing disk, the sensors (8) begin fixing the set parameters and modes. This happens as follows: the sensors are connected to a computer (9), on the screen of which, using a specialized application program, the finished result is displayed in the form of data on the presence of seeds, the number of doubles, omissions, etc.

To confirm the theory about the possibility of controlling the speed of seeds, the SUPN-8 sowing device and uncalibrated (selected) seeds of corn and peas were taken as an experimental sowing device.

3. Results and discussion
The purpose of laboratory tests that simulate real (field) operating conditions of a precise seeding planter with a seed tube is to check the possibility of matching the speeds of the seed and the sowing device at a constant air flow rate in the seed tube (18 m/s) by changing the angle of the valve rotation in the structure of the seed tube.

The test bench was set up according to the agrotechnical conditions of the sown crops (for corn and peas, the appropriate sowing disk was selected, the sowing step was determined and set, etc.). The angle of the valve rotation in the system is in the range from $90^\circ$ - the valve is fully open (maximum air flow in the seed tube) to $0^\circ$ - the valve is completely closed (minimum air flow in the seed tube). Each experiment was carried out with triplicate, the number of seeds in each repetition - 100 pcs.

The results of laboratory tests for seeds of corn and peas are presented in table 1-3.
Table 1. Parameters and results of laboratory testing No. 1 (corn seeds)

| Parameters       | Device speed | Valve rotation angle |
|------------------|--------------|----------------------|
|                  | 12 km/h (3.33 m/s) | 90°                  |
| Results          | The average value of the speed of the seed at the exit of the seed tube, m/s |
|                  | 3.34          | 3.31                 |
|                  | 3.31          |                      |
| Relative error   | between the speed of the seed at the exit of the seed tube and the speed of the device |
|                  | 0.30 %        | 0.60 %               |
|                  | 0.60 %        |                      |

Table 2. Parameters and results of laboratory tests No. 2 (corn seeds).

| Parameters       | Device speed | Valve rotation angle |
|------------------|--------------|----------------------|
|                  | 8 km/h (2.22 m/s) | 60°                  |
| Results          | The average value of the speed of the seed at the exit of the seed tube, m/s |
|                  | 2.28          | 2.26                 |
|                  | 2.25          |                      |
| Relative error   | between the speed of the seed at the exit of the seed tube and the speed of the device |
|                  | 2.70 %        | 1.80 %               |
|                  | 1.35 %        |                      |

Table 3. Parameters and results of laboratory testing No. 3 (pea seeds).

| Parameters       | Device speed | Valve rotation angle |
|------------------|--------------|----------------------|
|                  | 5.35 km/h (1.49 m/s) | 35°                  |
| Results          | The average value of the speed of the seed at the exit of the seed tube, m/s |
|                  | 1.48          | 1.51                 |
|                  | 1.46          |                      |
| Relative error   | between the speed of the seed at the exit of the seed tube and the speed of the device |
|                  | 0.67 %        | 1.34 %               |
|                  | 2.01 %        |                      |

The developed sowing device with a monitoring and seeding control system withstood the set parameters when the device speed changed over a wide range. The maximum relative error of the actual values of the speeds of the seeds at the exit of the seed tube from the given speeds of the sowing device was 2.7%, the minimum value - 0.3%.

4. Conclusions

- The scheme and design of a precise seeding planter with a quality management system using new polymer materials and modern digital technologies has been developed.
- A mathematical model to determine the speed of seeds at the exit of the seed tube, taking into account the characteristics of the seed material and the design features of the system has been developed.
- The obtained experimental data indicate minimal errors during operation of the developed system for monitoring and control of sowing.

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