Results of seeder pneumatic system distributor and aero-product stream flow in the pipeline numerical studies

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Abstract. Seed drills with a seed metering device and a pneumatic system of flow stream and distribution of grain seeds to the coulters of the seeder with pneumatic sowing have become widespread in the sphere of agriculture. The aim of this study was to establish the functional dependence of the aero-product stream flow nature in the pipeline and in the grain seeder distributor. The research method involved numerical studies of the developed 3D model of the seeder pneumatic system. The influence of the geometric features of the internal cavity of the distributor top of the seeder pneumatic system, the flow rate in the pipeline in the range from 15 to 25 m / s, the concentration of seeds in the flow stream from 0.52 to 1.57 kg / kg air were taken into account. The values of static, dynamic and total pressure, pressure losses by sections, rates of flow streams in the areas, areas of intense mechanical impact (surface wear) were studied. The regression equations of these indicators have been obtained the factors studied being taken into consideration. The greatest pressure losses have been observed in the distributor tops with a cap having the shape of a concave hemisphere. The flat surface of the cap makes it possible to achieve intermediate pressure losses in the distributor top. The smallest pressure loss is observed in the distributor top with a convex cone-shaped cap.

1. Introduction
Crop production has traditionally been the basis of obtaining food for humans and animals, as well as raw materials for industry. Nowadays existing technologies provide seasonal planting of seeds and as a rule seasonal production. To increase crops productivity the plants must receive the required amount of nutrients. Therefore the rated introduction of grain seeds and fertilizers, as well as a uniform distribution of plants on the soil surface has been applied. Existing mechanized technologies provide the use of seed drills, which must ensure both uniform seeds distribution along a row and uniform grains supply in rows through openers [1, 2].

The use of high-speed sowing units with a large capture width (more than 4-6 m) supplanted the use of seeders with a large number of parallel sowing units. They were replaced by more sophisticated seed drills with pneumatic introduction of grain seeds and granules of mineral fertilizers. [3].

At the moment, the low accuracy of the transverse distribution (transverse non-uniform seeding) is one of the most acute shortcomings of modern air seed drills. [4].

Typically, the accuracy of distribution of seeds between rows is estimated using the coefficient of variation (ISO-7256/2). According to agro-technical requirements, the coefficient of variation of seeds distribution should be below 5% for grain seeds and below 10% for fertilizers. [3]. Yatskul A. [5]
noted with reference to the research of McKay (1979) [6] that due to the fundamental impossibility of achieving at that time period indicators of uniformity of seeds distribution close to regulatory requirements (since they were based on indicators of mechanical drills), the requirements themselves were changed. In the updated technical requirements, the selection value of the coefficient of variation was increased up to 15% [6].

Despite the fact that pneumatic seeding has been used for more than 50 years, a small number of technical solutions for seed drill distributors have been implemented to increase the uniformity of seeds distribution. There are two main types of distributors - horizontal and vertical [2, 7].

The biggest advantage of horizontal distributors is the relatively low power consumption while creating a larger volume of air flow [3]. Energy losses in this case consist of linear pressure losses and losses due to the longitudinal expansion of the distributor. The absence of bends of the seed pipes makes it easier to install them and reduce their length, which has a positive effect on energy efficiency [3, 5]. The main problem is the distribution of seeds in the distributor along the seed tubes due to the effect of gravity.[3].

Vertical distributors are more widely used. A number of researchers are studying vertical distributors located directly above the ejector of the seeds supply [8]. However, such designs reduce the useful volume of hoppers, the working width of the aggregate and reduce the service life of the seed tubes. Therefore remote location of the distributor is used. In this case, pan-and-tilt devices or knees are used. A large number of researchers were engaged in the improvement of pneumatic seeding systems of the type. In papers [9], the influence of the pan-ant-tilt knee radius bending and the height of the vertical pipeline with turbulizing devices were studied. In papers [1, 3], the effect of the flow rate and the parameters of the seeds and the inclination of the seeder on the uneven distribution of seeds were studied. The authors [1, 10] studied the influence of the shape of the vertical distributor. So some of them [3] recommended a flat shape of the distributor cap, others [11] concave shape of a hemisphere like. The number of scientists [1] made conclusions about the efficiency of distributors with a guide cone at the cap. At the same time, the comparative results of different designs of different researchers were contradictory different [3, 10]. The results of air flow interaction with seed grains of different density under different flow turbulence are known [12, 13].Some researchers have noted that the seeds are too traumatized during the operation of the seeders [3, 14]. It should be noted that, as a rule, the compared designs had different number of distributor nozzles with different diameters of the supply vertical pipeline and different aero-product flows with different velocity were studied. The studies of pneumatic systems operation were carried out both naturally and numerically on 3D models [1, 3, 10, 11] to establish the irregularity of seeding process. They obtained results on the good convergence of the obtained information and experimental results. Pan-and-tilt knee wear was examined in paper [15]. The greatest wear is common in the places of the most active contact of the bulk material flow with the surface.

The analyzed papers allowed identifying the promising designs of distributors [1, 3, 11], providing regulatory requirements. Earlier analyzed papers had been aimed more at revealing the influence of individual design features of the distributor caps or elements of seeders’ pneumatic systems. At the same time, the issue of comprehensive comparison of actual configurations of pneumatic systems used in modern seed drills, both from the standpoint of the uniformity of distribution of the seeding material and from the point of view of grain damage and energy consumption of transportation of the seeding material by pneumatic flow, remains topical. Considering that regardless of the design of the distributor, it complies with the regulatory requirements for uniformity [1, 3, 11], the task of reducing energy consumption for transportation of the seeding material remains relevant.

The purpose of the study was to determine the functional dependencies of the influence of the technological parameters of the flow stream (initial velocity and concentration of the seeding material) on its speed and pressure drop depending on the distributor shape.
2. Research methods

The research methodology envisaged the development of 3D model of the pneumatic transportation system of the seeder with distributors 7 (Figure1) of various designs, conducting comparative numerical studies of various options for implementing the pneumatic transportation system of the seeder to identify indicators of the movement of aero-product mixed stream of the air and the seeding material.

![Figure 1. Pneumatic system of a Seed drill with pneumatic sowing: 1 – ventilator; 2 – air pipeline; 3 – ejector for seeding material supply; 4 – horizontal pipeline; 5 – pan-and-tilt knee; 6 – vertical pipeline; 7 – distributor; 8 – distributor pipe; 9 – seed tube; 10 – coulter; 11 – coulter nozzle. (Pneumatic system sections numbering is red)](image)

The results of the numerical simulation were the basis for identifying the functional dependencies of the relationship between the speed of the aero-product stream and the concentration of seeding material in the product stream by its movement indicators. In the numerical simulation, it was assumed that the flow velocity over the cross section of the onset of the simulation section is constant and equal to the specified value. That is, we consider the case of the ideal supply of the aero-product stream by its uniformity in a designated cross section. While creating numerical models, the distributor designs (Figure 2) with the concave surface of the cap [11], the flat cap [3] and the cap with the guide cone [1] were used. To make it possible to compare the design parameters of different distributors, the distributor model for 24 outlet pipes was upgrading and the structure was scaled to fit the diameter of the inlet vertical pipeline with a diameter of 104 mm. The speed of the aero-product stream while modeling was being varied in the interval \( \nu = 15-25 \text{ m/s} \), the concentration of the seeding material in the air stream being ranged in the values - \( \mu = 0.54-1.57 \text{ kg/kg} \).

![Figure 2. Investigated distributors of seed drill pneumatic system: (a) – with the concave surface of the distributor cap [11]; (b) –the cap with the guide cone [1]; (c) – flat cap [3]](image)
3. Research results
In the course of study, modeling of the aero-product stream flow in the seed drill pneumatic system was implemented. Under simulation, the area of aero-product stream from the onset of the horizontal pipeline to the coulter nozzles (opener) was investigated. The results were partially performed in graphs of the velocity and total pressure fields showed in Figures 3 and 4. The analysis of graphic materials allows concluding that a change in the velocities in the considered range does not have a significant effect on the stream nature. The stream relative to the right wall of the vertical pipe 6 has been more intense. In turn, in the pneumatic system there is a tendency to the stream core formation. The peculiarity of the vertical section of the pipeline has been the displacement of the core zone of the stream relative to the longitudinal axis of this section of the pipeline. This trend is clearly visible both in the velocity graph (Figure 3) and in the total pressure graph (Figure 4).

Ring convexity on the pipeline surface turbulize the stream, forcing the leveling of the particles concentration over its cross section [13]. The analysis of the graphs obtained shows that the presence of ring convexities on the walls shifts the stream core towards the center of the pipeline. Upon further stream movement along a smooth section, the stream core tends to return to its original position. The corrugated section of the pipeline of considerable length expands the stream core. However, the coincidence of the axis of the stream core with the longitudinal axis of the vertical section of the pipeline has not been observed. At the left wall (from the side of the horizontal pipeline supply) of the vertical pipeline, layers with minimal turbulence, velocity, and pressure remain. Based on the graphs (Figure 3, 4), it is possible to note the displacement of particles of seeding material to the external surface of the pan-and tilt knee, what affects the subsequent movement along the vertical section. The formed stream offset is being remained throughout the vertical section.

![Figure 3. Results of numerical simulation of aero-product stream velocity of the seed drill depending on the flow rate at the entrance to the horizontal pipeline (m/s) and seeding material concentration (kg/kg): (a), (d), (g) – pneumatic system distributor with the concave surface of the cap; (b), (e), (h) – pneumatic system distributor with the guide cone cap surface; (c), (f), (i) – pneumatic system distributor with the flat cap surface](image-url)
Recommendations of some researchers [3, 13] concerned the increase of the radius and vertical section length, contributing to the stream turbulization to ensure a better uniform distribution of particles in the flow, were simulated as well. The simulation results have been presented in Figures 7 and 8. The pressure at the distributor outlet having been assumed the pressure at the onset of the seed tubes in the previous series of numerical simulation.

A two-fold increase in the height of the studied column of the vertical section (Figures 5 (c) and 6 (c)) actually increases the width of the turbulent stream core. However, the presence of separate low-speed layers along the left wall remains invariable. This allows making an assumption about the existence of limitations of the indicated displacement of the stream core by numerical values of the uniformity of distribution of the seeding material over the coulters. Pan-and-tilt knee radius increases (Figures 5 (b) and 6 (b)) expands and partially aligns the zone of the stream core on the values in the lower part of the vertical section of the pipeline. However, the stream nature does not change. By means of simulating the motion of a uniform stream at the onset of a vertical section (which corresponds to the conceptual scheme [8]), the results presented in Figures 5 (a) and 6 (a) were obtained. It should be noted that the location of the stream core on the longitudinal axis of the vertical section allows ensuring a high uniformity of seeding material distribution over the coulters (openers). Thus, it can be concluded that it is necessary to ensure the location of the stream core on the longitudinal axis of the vertical section of the pipeline while pneumatic system operation. Accordingly, to ensure the specified condition, design changes are necessary, including the installation of additional elements centering the stream relatively to the vertical pipeline above the pan-and-tilt knee.

Figure 4. Results of numerical simulation of the total pressure of aero-product stream of the seed drill depending on flow rate at the inlet of the horizontal pipeline $\upsilon$ (m/s) and seeding material concentration $\mu$ (kg/kg): (a), (d), (g) – pneumatic system distributor with concave cap surface; (b), (e), (h) – pneumatic system distributor with the guide cone cap; (c), (f), (i) – pneumatic system distributor with flat cap.
Total pressure decrease on the sections of pneumatic system with concave cap of the distributor $P_a$: 

\[
\Delta P_{12} = 0.156 \cdot v^{2.17} \cdot \mu^{0.46} + 9; R = 0.9994; F_{test} = 0.9987;
\]
\[
\Delta P_{23} = 0.0443 \cdot v^{2.178} \cdot \mu^{0.5} + 10.81; R = 0.9977; F_{test} = 0.995;
\]
\[
\Delta P_{34} = 1.12 \cdot v^{2.1} \cdot \mu^{0.493} + 40.93; R = 1; F_{test} = 1;
\]
\[
\Delta P_{45} = 0.781 \cdot v^{2.3} \cdot \mu^{0.546} + 67.19; R = 0.9993; F_{test} = 0.99848;
\]
\[
\Delta P_{56} = 1.415 \cdot v^{2.22} \cdot \mu^{0.49} + 64.18; R = 0.9993; F_{test} = 0.9984.
\]

Where \(\mu\) – material concentration relative air, kg/kg; \(v\) – flow rate at onset of horizontal section (first section), m/s; \(R\) - correlation coefficient of simulation results and calculations on the regression equation; \(F_{test}\) – confidence probability of matching the simulation results and calculated values using a regression equation.

The drop in total pressure in the pneumatic system with a flat distributor cap, Pa: 

\[
\Delta P_{12} = 0.229 \cdot v^{2} \cdot \mu^{0.446} + 4.9; R = 0.99958; F_{test} = 0.9991;
\]
\[
\Delta P_{23} = 0.05 \cdot v^{2.16} \cdot \mu^{0.488} + 9.3; R = 0.9985; F_{test} = 0.9967;
\]
\[
\Delta P_{34} = 0.938 \cdot v^{2.13} \cdot \mu^{0.51} + 53; R = 0.9990; F_{test} = 0.9979;
\]
\[
\Delta P_{45} = 1.3 \cdot v^{2.24} \cdot \mu^{0.54} + 69.8; R = 0.9992; F_{test} = 0.9983;
\]
\[
\Delta P_{56} = 435.6 \cdot v^{0.69} \cdot \mu^{1.28} - 2722; R = 0.9763; F_{test} = 0.9475.
\]

The drop in total pressure in the pneumatic system with a guide cone distributor cap, Pa: 

\[
\Delta P_{12} = 0.16 \cdot v^{2.1} \cdot \mu^{0.46} + 8.3; R = 0.9996; F_{test} = 0.9991;
\]
\[
\Delta P_{23} = 0.06 \cdot v^{2.1} \cdot \mu^{0.4} + 7.9; R = 0.9985; F_{test} = 0.9968;
\]
\[
\Delta P_{34} = 1.41 \cdot v^{2} \cdot \mu^{0.5} + 23; R = 0.9993; F_{test} = 0.9984;
\]
\[
\Delta P_{45} = 0.97 \cdot v^{2.26} \cdot \mu^{0.54} + 64; R = 0.9992; F_{test} = 0.9983;
\]
\[
\Delta P_{56} = 1.28 \cdot v^{2.24} \cdot \mu^{0.49} + 67; R = 0.9993; F_{test} = 0.9984.
\]

The average flow rate over the cross-sections of the pneumatic system with a flat distributor cap, m/s:

\[
v_2 = 1.01 \cdot v \cdot \mu^{-0.0018}; R = 0.9999; F_{test} = 0.9955;
\]
\[
v_3 = 1.01 \cdot v \cdot \mu^{-0.001}; R = 0.9999; F_{test} = 0.9918;
\]
\[
v_4 = 1.08 \cdot v \cdot \mu^{0.05}; R = 0.9999; F_{test} = 0.9699;
\]
\[
v_5 = 0.91 \cdot v \cdot \mu^{0.01}; R = 0.9999; F_{test} = 0.9221;
\]
\[
v_6 = 1.25 \cdot v \cdot \mu^{0.019}; R = 0.9998; F_{test} = 0.906.
\]
Figure 5. Graphs of velocity on the sections of seeder pneumatic system with initial uniform flow: (a) - in the absence of a pan-and-tilt knee; (b) - with a twofold increased radius of the pan-and-tilt knee; (c) - with a typical radius of the pan-and-tilt knee and twice increased height of the vertical section of the pipeline; (d) - with a twofold increased radius of the pan-and-tilt knee and a double increased height of the vertical section of the pipeline.

The average flow rate over the cross sections of the pneumatic system with a guide cone distributor cap, m/s:

\[ \nu_2 = 1.01 \cdot v \cdot \mu^{-0.0016} \cdot R = 0.9999; \ F_{test} = 0.9938; \]
\[ \nu_3 = 1.01 \cdot v \cdot \mu^{0.0006} \cdot R = 0.99997; \ F_{test} = 0.9966; \]
\[ \nu_4 = 1.09 \cdot v \cdot \mu^{0.005} \cdot R = 0.9999; \ F_{test} = 0.974; \]
\[ \nu_5 = 0.86 \cdot v \cdot \mu^{0.006} \cdot R = 0.9999; \ F_{test} = 0.9447; \]
\[ \nu_6 = 1.244 \cdot v \cdot \mu^{0.016} \cdot R = 0.9998; \ F_{test} = 0.902. \]

Figure 6. Graphs of the total pressure in seeder pneumatic system sections with the initial uniform flow: (a) - in the absence of a pan-and-tilt knee; (b) - with a twofold increased radius of the pan-and-tilt knee; (c) - with a typical radius of the pan-and-tilt knee and a double increased height of the vertical section of the pipeline; (d) - with a twofold increased radius of the pan-and-tilt knee and a double increased height of the vertical section of the pipeline.
Graphs for some regression equations are depicted in Figures 7 and 8. Figure 7 shows that the greater pressure drop in the distributor is observed in the case of the structural design of the distributor cap with the concave surface (Figure 7 (a)). The use of a flat cap allows somehow keeping the pressure drop down (Figure 7 (c)). The smallest pressure losses are observed in a distributor cap having a guide cone (Figure 7 (b)). With an increase of flow rate and concentration of the seeding material, the required total pressure in the pipeline increases (Figure 8). The stream velocity has a greater effect on the pressure required than the concentration of the transported material.

The analysis of seeding material movement along the internal surfaces of the pneumatic system makes it possible to identify the places of the most intensive seeding material particles contact with the surface of the pipeline and the distributor. In the result of frontal impact on the cap (Figure 9 (a)), the cap wear is obvious over the exit of the vertical pipeline. It should be noted the orientation of the zone of increased wear in the direction of the pan-and-tilt knee. In the result of the tangential impact, the swivel knee is also intensively worn. The very presence of places of a frontal impact of the seeding material with the surface of the pneumatic system (the distributor cap and partially the knee) indicates a susceptibility to grain damage. Considering the recommended flow rate setting [1] for wheat of 24-28 m / s, which ensures uniform distribution of the material among the coulters, this issue is quite relevant.

Figure 7. Graphs of the total pressure drop along the distributors (the area between sections 4 and 5): (a) – with the concave surface of the cap; (b) – cap with a guide cone; (c) – flat cap

Figure 8. Graphs of the calculated values of the total pressure P1 (Pa) at the onset of the pneumatic system horizontal section: (a) – with the concave surface of the cap; (b) – cap with a guide cone; (c) – flat cap

Figure 9. Graphs of the most intensive impact zones within seeding material transportation pass way: (a) – frontal impact zone; (b) – tangential impact zone
4. Conclusion

The pressure drop on the pipeline sections is being described by expressions of a power type, and the average flow rates on sections are described by the product of the coefficient of the average flow rate at the inlet of the pipeline into the power dependence of the seeding material concentration relative to the air. Under flow rate changing and seeding material concentration in the flow stream, the nature of variation in flow rate limit has not been significantly different. Only the numerical values of the velocity of individual streams of the flow have being changed. The increase of the flow rate is increasing dynamical pressure loss. The design of seeders with pneumatic seeding requires additional modernization, targeted, among the other things, to centering the aero-product flow above the knee relative to the longitudinal axis of the vertical pipeline. The corrugated surface of the vertical pipeline in full does not cope with the assigned task. The design of the vertical section of the pipeline requires additional structural elements that center the flow above the knee, both along the length of this section of the pipeline, and especially at the inlet of the distributor.

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