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Development of the Design and Justification of the Parameters of the Distribution Head of the Pneumatic Fertilizer Seeder

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Abstract. To ensure a high yield of agricultural crops, a high accuracy of the distribution of mineral fertilizers and compliance with the specified application rates are required. Agrotechnical requirements for uneven distribution along the width of fertilizers - 10%, deviation from the application dose - 10%. Failure to comply with these requirements leads to uneven plant development, increased soil pollution, and a decrease in crop yields. The use of machines with centrifugal spreaders with an irregularity of 20% ... 25% application, leads to a decrease in yield by 20%. In contrast to disc centrifugal spreaders, rod and pneumatic seed drills have less uneven application. The simplest design solution is for fertilizer seeders with a pneumatic seeding system of central metering. The main reason for the irregularity of fertilization along the length of the run is the formation of flow cores, which is a consequence of a change in the air flow rate with a constructive change in the cross-section of the air ducts. The design of the pneumatic distribution system of the fertilizer seeder is proposed, which provides a constant channel section in the distribution head and a high uniformity of fertilizer distribution over the feeding area. As a result of the theoretical studies, the optimal parameters of the distribution head of the pneumatic system were determined, the dependences of individual structural elements on the channel cross-sectional area, the number of pipelines and the angle of inclination of the head base were obtained. The purpose of the research is to develop the design and substantiate the parameters of the pneumatic distribution system of the fertilizer seeder, the use of which will reduce the uneven distribution of fertilizers over the field and prevent the destruction of granulates during their transportation from the metering unit to the openers.

INTRODUCTION

Maintaining high soil fertility with modern technologies for the production of agricultural crops, the introduction of coordinate farming systems and the reduction of fertilizer losses are urgent tasks. Agrotechnical requirements for uneven distribution over the width of the application of mineral fertilizers - 10% and deviation from the application dose - 10% [1,2]. Failure to comply with the prescribed doses of fertilizers and the uniformity of their distribution

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over the feeding zone leads to uneven development of plants, an increase in soil and groundwater pollution, and a decrease in the quality and productivity of agricultural crops. In addition, the use of machines with centrifugal-type spreaders having an irregularity of application of the order of 20% ... 25%, leads to a decrease in the yield increase from the applied fertilizers by 20% [3]. The trends in the development of agricultural machinery are aimed at increasing the working width of agricultural implements and implements, and this applies, in particular, to seeding and planting machines. Pneumatic systems used to transport seeds and fertilizers from metering devices to openers are widely used in modern seeding machines. And first of all, this is justified by the simplicity of the design, the peculiarities of its execution and the ability to redistribute the mass of the hopper, opener section, additional tillage sections on the unit frame. However, there are a number of problems associated with both a significant difference in the physical and mechanical properties of mineral fertilizers and seeds of grain crops, and with the peculiarities of their application. So, they distinguish spread fertilization, local (below and to the side) and ultralocal, when the seeds are in close proximity to the fertilizers. Thus, as a result of significant differences in the specific gravity of seeds and fertilizers, pneumatic conveying and distribution systems for applying seeds and fertilizers must operate in different modes, which reduces the versatility of their application. In addition, horizontal and vertical pneumatic distributors have a high uneven distribution of fertilizers along the fertilizer lines.

First of all, this is caused by an increase in the cross-section of the conveying or distribution system in the plane perpendicular to the flow velocity vector, a decrease in its velocity and, as a consequence, the fallout of heavier particles from the air mixture. It should also be noted that the horizontal parts of pneumatic conveying systems are prone to clogging, since fertilizer particles in such areas move in the air flow, not hovering, but galloping.

Consequently, the task of increasing the uniformity of distribution and stabilization of the transportation of seeds and mineral fertilizers is significant and relevant.

ANALYSIS OF RECENT RESEARCH

Much attention is paid to the study of pneumatic conveying systems of grain-fertilizer and fertilizer seeders, both in domestic and foreign science. The main parameters that have a significant impact on the performance of the working process by pneumatic systems include the air flow rate, the values of which are in the range from 16 to 27 m/s [4]. First of all, the limitations are caused by the minimum speed of transportation and the maximum allowable speed of impact of granules with system elements. At the same time, the existing designs of pneumatic distribution and transport systems of sowing units allow uneven distribution in the range from 9% to 16% [4]. Most manufacturers of agricultural machinery apply mineral fertilizers simultaneously with sowing seeds using an ultra-local application system. In this case, the speed of the air flow reaches the limiting values from 25 to 27 m/s, and this leads to an even greater decrease in uniformity, both in the width of the unit and in the direction of its movement. The use of separate fertilization and sowing of seeds is widely used both in aggregates and in fertilizer seeders, for example, according to the technical characteristics of the SU-12 seeder of OJSC “Lidagroprommash”, the irregularity of application is allowed no more than 6% [5]. However, since the SU-12 seeder was developed on the basis of the SPU-6 grain seeder, the high distribution quality is maintained only for fertilizer granules commensurate with grain crops; in the case when the specific gravity of fertilizers (ammonium nitrate 810 kg / m^3, superphosphate 1000 ... 1100 kg / m^3) exceeds the weight of seeds (wheat 725 ... 764 kg / m^3), the irregularity of fertilization by the machine increases, and fertilizer granules are prone to delay on horizontal sections [4,6, 7,8]. To improve the quality indicators of fertilizer application, individual dosing is used, which is used in the design of the pneumatic spreader of AGT-6036 mineral fertilizers manufactured by RAUX [9]. However, this leads to a complication of the design of machines, an increase in their weight and cost.

PURPOSE OF RESEARCH

The purpose of the research is to develop the design and substantiate the parameters of the pneumatic distribution system of the fertilizer seeder, the use of which will reduce the uneven distribution of fertilizers over the field and the destruction of granules during their transportation from the metering unit to the openers.

MATERIALS AND METHODS

To achieve this goal, a design of the distribution system of a pneumatic fertilizer seeder is proposed (Fig. 1), including a vertical supply air duct 1, an ejector sluice 2, a vertical shaft 3, a downward-facing conical distribution head 4 in the form of a straight circular cone, fuel lines 5, a hopper 6, dispenser 7, designed to supply fertilizers from the bunker 6 to the sluice of the ejector 2.

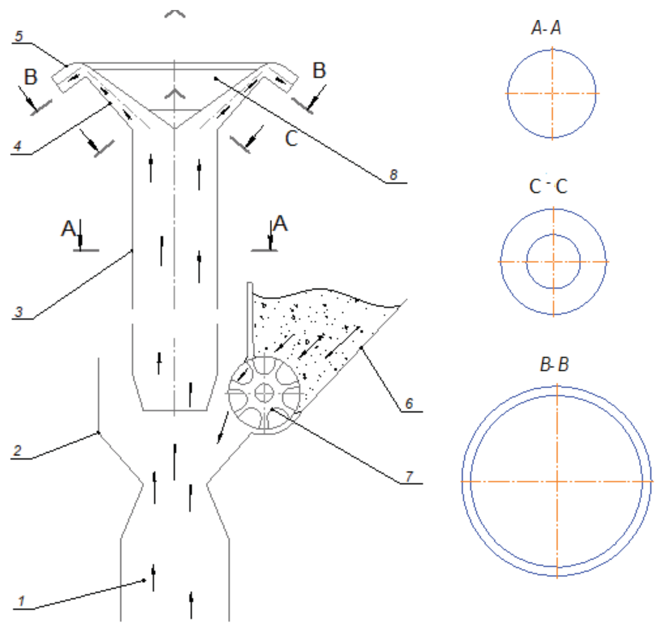

FIGURE 1. Technological diagram of the distribution system Pneumatic fertilizer seeder.

The distributor head 4 has a base made in the form of a hollow truncated cone facing downward and connected to a straight cylinder of a vertical shaft 3. The upper part of the distributor head is covered with a cover 8 made in the form of a cone facing downward, and together with the base forms an annular conical channel , at the upper level of which there are concentrically arranged branch pipes 5 of the pipelines. The annular conical channel of the distribution head 4 in sections, and has the shape of a surface in the form of a ring, which is bounded by the outer and inner circles, which are the walls of the base and the cover of the distribution head (Fig. 1, sections A – A, B – B, C – C). The lateral surface of the base of the distributor head 4 is inclined in the axial section to the horizontal plane at an angle α, the conical part of the cover - at an angle β.

The working process proceeds as follows. The air forced by the fan through the air duct 1, passing at high speed through the ejector 2 into the vertical shaft 3, creates a zone of reduced pressure in the sluice of the ejector 2. Due to the pressure in the stream below the atmospheric pressure, the fertilizer granules supplied by the reel dispenser 7 are sucked into the vertical shaft 3. Further, the fertilizers are intensively mixed with air, evenly distributed throughout the entire volume of the vertical shaft 3 and enter the distribution head 4. Since the sections of the conical part of the distribution head are perpendicular to the vector the movements of the air-fertilizer mixture have the same area, then according to Bernoulli's law, the flow rate in them will be constant. To ensure the specified throughput of the distributor head, the total area of the branch pipes of the pipelines 5 is equal to the cross-sectional area of the head B – B (Fig. 1). Taking into account that the mixture has the same concentration and speed, the uneven distribution of the mixture along the pipelines will be low.

RESULTS AND DISCUSSION

To ensure the stability of the movement of fertilizer particles along the pipelines, it is necessary that the flow rate be constant. In turn, the flow rate will be constant while ensuring the same cross-sectional area along the entire length of the pipeline. Analyzing the vertical distribution devices of pneumatic systems of central dosing, several elements can be distinguished in which the cross-section of the main transport line changes. As the first element, consider a vertical shaft 3, into which an air-fertilizer flow enters. The cross-sectional area of the shaft pipe 3 is designated as S_{sh}

(m^2) (Fig. 2, section A – A). Further, the flow enters the lower part of the distributor head in the form of an annular cavity with a cross-sectional area S_N (m^2) (Fig. 2, section B – B), which is perpendicular to the velocity vector V (m/s) of the fertilizer flow, or the generatrix of the dividing cone of the channel, then - to the upper part of the distributor head with a cross-sectional area of the annular channel S_V (m^2) (Fig. 2, section B – B).

To ensure a stable speed of movement of the air-fertilizer mixture according to the flow continuity equation, the following condition must be met:

$$S_{SH} \geq S_N \geq S_V. \quad (1)$$

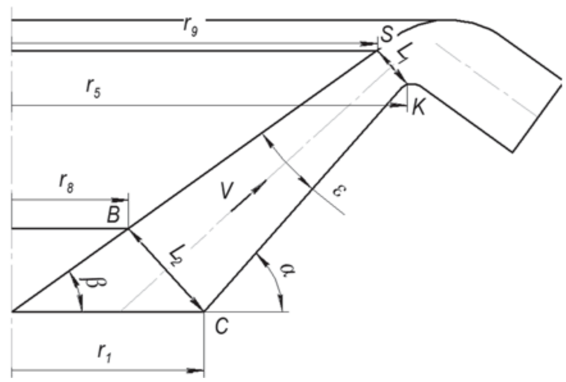

FIGURE 2. Sectional diagram of the channel of the conical distributor head.

In widespread industrial designs of pneumatic distribution systems, such as in SU-12, condition (1) is not met, which leads to a decrease in the air flow rate and the formation of plugs from suspended particles of fertilizer fertilizers. To prevent this effect, it is proposed to use a conical distribution head 4 (see Fig. 1).

To comply with condition (1), it is necessary that the cross-section of the vertical shaft 3 and the conical distributor head 4 have the same area, or that it decreases in the direction of the air flow. Considering that the fertilizer transport channel from the level of the upper end of the vertical shaft 3 and the top of the conical distributor head 4 and above changes its shape from a circle (see Fig. 1, section A – A) to an annular channel expanding in the diametrical direction (Fig. 1 , section B – B and section C – C), in order to comply with condition (1), it is necessary to narrow the channel section as it moves away from the upper end of the vertical shaft 3.

In order to determine the geometric parameters of the channel (see Fig. 2), we present a diagram of the axial section of the channel passing through the vertical axis of symmetry of the vertical shaft 3 and the conical distribution head 4. The CBSK trapezoid is a longitudinal section of the channel of the conical distribution head 4.

Since the conical distribution head 4 in its cross-section is annular, the corresponding points of the analyzed section of its channel are located at certain radii from the center. The highest point S of the section is at a distance r_9 from the vertical axis of symmetry of the conical distributor head 4, the point K farthest from the vertical axis of symmetry is at a distance r_5, point B, which is closest to the vertical axis of symmetry of the conical distributor head, is at a distance r_8 from it, the lowest point C is located from this axis at a distance r_1 (see Fig. 2).

The outer wall of the channel of the conical distributor head 4 is inclined to the horizontal plane at an angle α. To prevent the accumulation of fertilizers on its surface, the angle of inclination of this wall must be equal to or greater than the angle of friction of the fertilizer material against the wall of the conical distributor head and must satisfy the condition:

$$\alpha \geq \varphi_{max}, \quad (2)$$

where φ_{max} – maximum angle of friction between the fertilizer and the material of the conical distributor head body.

The angle ε of the tapered annular passage of the channel formed by the outer side surface of the conical distribution head and the inner side surface of the smaller base downwardly facing the hollow truncated circular cone is defined as:

$$\varepsilon = \alpha - \beta, \quad (3)$$

where β – the angle between the generatrix of the cone of the distributor head cover and the horizontal.
From the sectional diagram (see Fig. 2) we determine the parameters of the channel of the conical distributor head.

$$r_5 = r_1 + KC \cos\alpha. \tag{4}$$

$$r_8 = r_1 - BC \cdot \cos((\pi-\beta-\alpha)/2). \tag{5}$$

$$r_9 = r_5 - SK \cdot \cos((\pi-\beta-\alpha)/2). \tag{6}$$

The cross-sectional area of the channel cavity ring in the lower part of the distribution head is determined by the generatrix *BC*:

$$S_N = \pi \cdot BC\,(r_1 + r_8). \tag{7}$$

If $BC = L_2$, substituting expression (5) into expression (7), we get:

$$S_N = 2\pi \cdot L_2 \cdot r_1 - \pi \cdot L_2^2 \cdot \cos((\pi-\beta-\alpha)/2), \tag{8}$$

The cross-sectional area in the form of a ring of the channel cavity in the upper part of the distributor head S_v is determined along the generatrix $SK = L_1$:

$$S_V = 2\pi \cdot L_1 \cdot r_1 - \pi \cdot L_1^2 \cdot \cos((\pi-\beta-\alpha)/2), \tag{9}$$

where L_1 – width of the annular cavity in the upper part of the channel, measured in cross-section in the direction perpendicular to the velocity vector V in it, the middle part of the fertilizer flow, or the generatrix of the dividing cone of the channel, mm; L_2 – the width of the annular cavity in the lower part of the channel, measured in cross-section in the direction perpendicular to the velocity vector V in the middle part of the fertilizer flow, or the generatrix of the dividing cone of the channel, mm.

In the upper part of the channel of the conical distributor head, there are pipelines 5, along which the fertilizer granules move to the working bodies that apply fertilizers directly into the field. The radius along which the fuel lines 5 are located in the distributor head is also the maximum radius (r_5) of the inner surface of the annular channel of the conical distributor head and is determined by the formula:

$$r_5 = n \cdot (d_m + z)/(2\pi), \tag{10}$$

where n – number of pipelines, pcs.; d_m – inner diameter of the pipeline, mm; z – bulkhead thickness between adjacent pipelines channels, mm.

The main structural dimensions of the distributor head were determined from the geometric parameters:

$$L_2 = r_1 \cdot \sin(\alpha-\varepsilon)/(\sin((\pi+\varepsilon)/2)). \tag{11}$$

$$L_1 = r_1 \cdot \sin(\alpha-\varepsilon)/(\sin((\pi+\varepsilon)/2)) - 2(r_5 - r_1) \cdot \cos((\pi-\varepsilon)/2)/\cos\alpha. \tag{12}$$

$$r_8 = r_1 \cdot \cos(\alpha-\varepsilon) \cdot \sin((\pi+\varepsilon)/2-\alpha)/(\sin((\pi+\varepsilon)/2). \tag{13}$$

$$r_9 = r_5 - (\, r_1 \cdot \sin(\alpha-\varepsilon)/(\sin((\pi+\varepsilon)/2)) - 2(r_5 - r_1) \cdot \cos((\pi-\varepsilon)/2)/\cos\alpha) \cdot \cos((\pi+\varepsilon)/2) - \alpha), \tag{14}$$

According to the Bernoulli flow continuity equation, we have:

$$S_{SH} \cdot V_{SH} = S_N \cdot V_N = S_V \cdot V_V, \tag{15}$$

где VSH – speed of the air mixture in the mine, m / s; VSH – speed of the air mixture in the annular cavity of the lower part of the channel, m / s; VV – speed of the air mixture in the annular cavity of the upper part of the channel, m / s.

Subject to condition (1) and taking into account expression (15), we obtain:

$$V_{SH} \geq V_N \geq V_V, \tag{16}$$

which will ensure the stability of the movement of mineral fertilizer particles in the distributor head and prevent the formation of zones with different concentrations of fertilizers in the transported mixture.

Using the obtained dependences (10), (11), (12), (14) and based on the initial parameters of the distribution system (r_1, n, d_m), as well as conditions (2), the angle β of the slope of the generatrix of the upper conical surface, the distance between ducts *z* must be taken such that condition (1) is met.

When calculating the parameters of the distributor head, the dimensions of the standard distribution system of the SU-12 fertilizer seeder were taken into account. The radius of the vertical shaft is taken to be r_1 = 55 mm, number of pipelines on the distribution head n = 20 pieces, inner diameter of the branch pipes to which the pipelines are attached, d_m = 24 mm. Taking into account conditions (1), (8) and (9), we obtain the area of the vertical shaft, as well as sections in the lower and upper parts of the distributor head $S_{SH} = S_N = S_V$ = 9498.5 mm^2.

As a result of the calculations, a graph of the dependence of the change in the parameters of the distributor head on the angle of inclination of its lower conical part was obtained α (fig. 3).

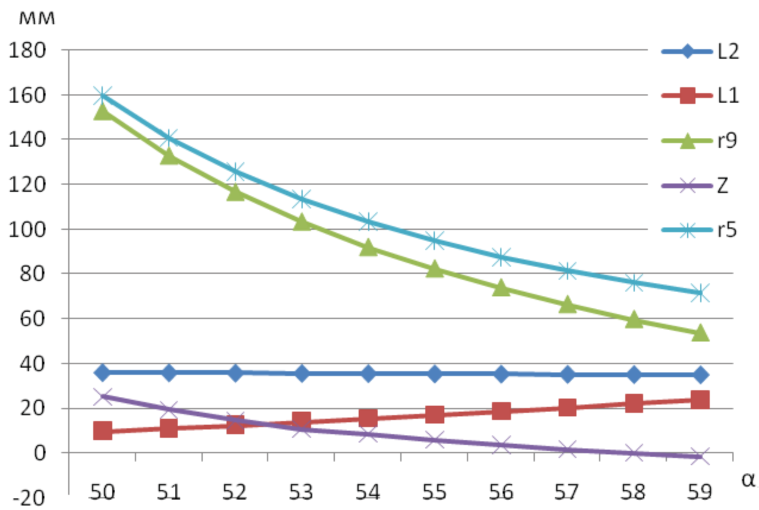

FIGURE. 3. Graph of the dependence of the change in the parameters of the distributor head on the angle α.

Analysis of the graph of the dependence of the change in the parameters of the distributor head on the angle α allows us to draw the following conclusions:

- an increase in the angle of inclination α, caused by the use of high-friction pipes, leads to a decrease in the dimensions of the radii r_5 and r_9, which affect the overall dimensions of the distributor head, which, in turn, makes it necessary to constructively reduce the gap z between the nozzle outlets, and at the value of the angle α = 58° the value z = 0 mm reaches the critical value;
- the value of the width of the annular cavity in the lower part of the channel of the distributor head L_2 is in the range from 35 to 36 mm, and the change in the angle α by the value L2 is minimal;
- the angle α significantly affects the value of the minimum width of the annular cavity in the upper part of the channel L_1, and with an increase in the values of the angle α from 50 ° to 59 °, the width increases from 10 to 24 mm.

CONCLUSIONS

An original design of the opener of a grain-fertilizer seeder for subsoil spread sowing is proposed, which ensures uniform distribution of seeds over the feeding area.

A formula for the flight range of a particle (grain) has been obtained, with the help of which the region of optimal scatterer dimensions and distance is determined.

On the basis of the performed theoretical studies, it has been established that the presence of oscillations of the scatterer does not significantly affect the flight range of the particle. However, due to the oscillation, the number of particles increases, with a large spread in the horizontal direction.

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