

Substantiation of the Parameters of the Central Distributor for Mineral Fertilizers

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ABSTRACT

The main problem of distribution systems with a centralized metering seed actions of pneumatic planters is deficient feed-rate consistency of seeds in supply coulters. Thus, the purpose of the study is to develop the optimal ways of decreasing the irregular distribution of the seeds and mineral fertilizers in the coulters. In order to achieve this goal, it is suggested to give the air-and-seed mixture a certain form of organized motion by installing inside the transport line in front of dividing attachment of helical spiral of an original construction. The authors observe that the pneumatic pipeline with distributor with equal turns gives the most qualitative distribution of the material. Moreover, offset value of turns, particle velocity in different sections of the transportation, which were used to calculate their design parameters were theoretically justified. The practical value is that the submissions can be used in current practice of increasing the production of horticulture.

KEYWORDS

Seeding systems, central distributor, transport line,
mineral fertilizers, helical spiral

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Introduction

In the context of increasing the production of horticulture, seeding and its quality are important (Ivzhenko, 1992). The main task of seeding is to ensure the best conditions for seed sprouting and further plant growth (Astahov, 1998; Jin et al., 2014).

An important agro-technical requirement for sowing is uniform distribution of seeds on the field area (Goottfried, 2000). Seeding machines are commonly used for sowing crops (Ljubushko, 2003). In their construction individual, group and centralized metering of seeds by mechanical devices with pneumatic handling into coulters are used (Yasir et al., 2012).

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Can add that centralized seeding systems (CSC) with general dosing should ensure the sowing of seeds with different physical and mechanical properties based on given agricultural standards: seed damage – no more than 1%, the unevenness of agro-technical requirements – no more than 5% (Jinli & Xiaohui, 2011).

Thus, it is important to develop fundamentally new materials distributor in a horizontal line of transport lines in order to decrease the irregular distribution of the seeds and mineral fertilizers in the coulters.

Literature Review

The quality of sowing by CSC is significantly affected by the structure of distribution devices and in particular the form of surfaces of elements which adjoin the seeds in the process of distribution in seed drill tubes (Johansen et al., 2012; Pandey, 2002).

The advantage of the design of the seeding machines is that the pneumatic delivery of seeds from distributor mechanism to coulters reduces specific consumption of seeding machine materials, improves the quality of the seed distribution in the rows (Zhang & Wu, 2015).

Scholars consider that the lack of uniform seed distribution in coulters is included to the defects of distribution systems with a centralized metering of seeds of an air-seeder (Séguy & Bouzinac, 2003; Beaujot, 2009; Memory et al., 2001).

It is pertinent to point out that the most common cylindrical dividing attachments include an intake pipeline and deflector, a collector with a lid and central pipes (Ivzhenko, 2005). The transportation and distribution of seeds in seed drill tubes with less energy consumption is performed in systems that use flat distribution attachments and outlet flat pipeline; and the attachments are situated at the outlet of the bunker (seeding machines «Leon», «Morris», «Symonds») (Never Pin).

Flat dividing attachments are used least of all because of its high level of irregularity in distribution of the material over the cross-section of the pipeline (Krjuchin, 2003). According to the Y. Li et al. (2016), such irregular distribution of seeds and fertilizers reaches 35-45%.

However, recent studies show that the additional devices in the distribution columns make the design of the sowing system more complicated and reduce the reliability of its work (Manasseri & Poggio, 2014; Jianbo et al., 2014).

R. Singh, G. Singh & D. Saraswat (2005) argue that another defect of the air-seeders with a centralized metering of seeds of an air-seeder is the high resistance of compressed air system due to the presence of vertical distribution columns with overlying dividing attachments, which requires a considerable amount of energy to create airflow to lift the seeds to the place of distribution in seed drill tubes.

Aim of the Study

The study aims at the design solution and mathematical investigation of methods of increase the uniformity of distribution of the seeds and mineral fertilizers in the coulters.



Research questions

What are the optimal ways of decreasing the irregular distribution of the seeds and mineral fertilizers in the coulters?

Method

The methodological basis of the research constitutes the usage of methods of elementary mathematics and classical methods of mathematical analysis. In order to justify the settings of the distributor and to develop the drawing of the pipe and distributor screw the method of mathematical modeling was applied (Ornek, 2008).

We also used the comparative analysis in order to examine the productivity level of different types of seeding machines.

Data, Analysis, and Results

Design Solution

Installing the distribution devices on the horizontal sections of the seed drill tube in order to redistribute concentrated particles throughout the cross-section of the pipeline before they come into the dividing attachment, there is a need of additional exposure to the material.

One of the solutions of increasing the uniformity of distribution is to give the air-and-seed mixture a certain form of organized motion. In particular, it can be realized by exposing the two-component flow to swirl, i.e., giving the screw motion dispersed phase of flow. For that purpose, directly inside the transport line in front of the dividing attachment an additional structural member – the distributor screw (Figure 1), made in the form of spiral wounded on the rod is hard-mounted.

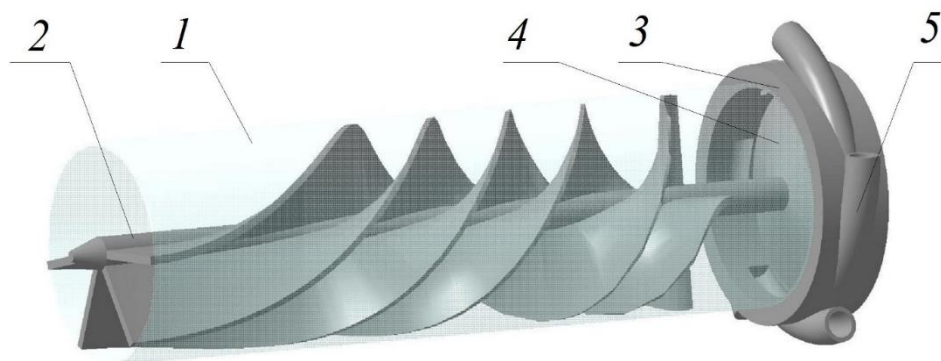


Figure 1. Distribution device.

The distributor screw occupies the whole cross-section of the transport line and includes pipeline (1) hard-mounted rod on which spiral is wounded (2), a dividing attachment, consisting of a body (3), a conical plug (4) and outflows (5).

The flow proceeded on the distributor becomes twisted and in consequence of rotational movement, under the action of centrifugal pull of inertness becomes pressed against the inner wall of transport line. It equally distributes through the wall, taking a shape of a quill cylinder in cross-section (Figure 2), and when

it leaves the distributor screw. Thus, the formed flow gets to outflows of dividing attachment.

The effect of such distributor screw is illustrated on Figure 2, which shows the development drawing of the pipeline (1), distributor screw (2) and trajectory of the discrete material (3).

Entering the distributor device, the material is moving through the pipeline at the bottom of its cross-section. If the flow would be twisted by dint of quadruple threaded screw (Fig. 2), the turns of which are located in the zone of highest concentration of the material, with their start in one cross-section, the material would be divided in equal amounts by sectors of the screw in cross-section of the pipeline.

The application of multiple-thread distributor screw, whose turns have different angles of twist, ensures smooth movement of the material and the same disposal of turns at the output, and respectively, the same square of pipeline sectors that divide the turns of distributor screw.

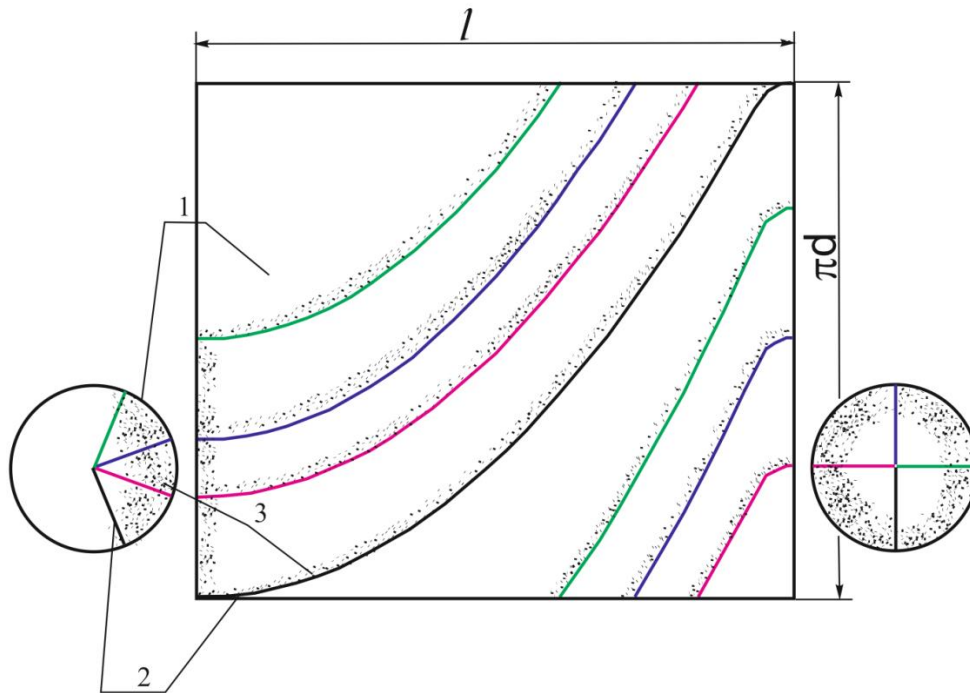


Figure 2. Development drawing of the pipe and distributor screw.

This design of the distributor screw contributes to mechanical redistribution of different concentrations of the material in the cross-section of the horizontal pipe, and it greatly improves the uniformity of distribution of material to the outflows.

Mathematical Investigation

In order to assert the offset value c , the process of movement of the material on turns of a helical spiral (Figure 3) was investigated. The arc length of the full sector and its development drawing are:

$$ABCDE = A_1B_1C_1D_1E_1 = \frac{\pi d}{360} \cdot \varphi, \quad (1)$$

where, d – diameter of transport line; φ – center angle filling.

The arc length of filled sector can be expressed in terms of:

$$AE = A_1E_1 = \pi d \cdot z, \quad (2)$$

where, z – filling degree of the transport line cavity, which can have values:

$1/2, 1/3, 1/4$, what corresponds to angles $\varphi: \pi/2, \pi/3$ и $\pi/4$.

The right sides of the last two expressions can be equated:

$$\frac{\pi d}{360} \cdot \varphi = \pi d \cdot z; \quad \varphi = 360 \cdot z. \quad (3)$$

For convenience of further conclusions we accept the notation:

$$A_0E_{10} = a; E_{10}E_0 = b; A_0E_0 = l.$$

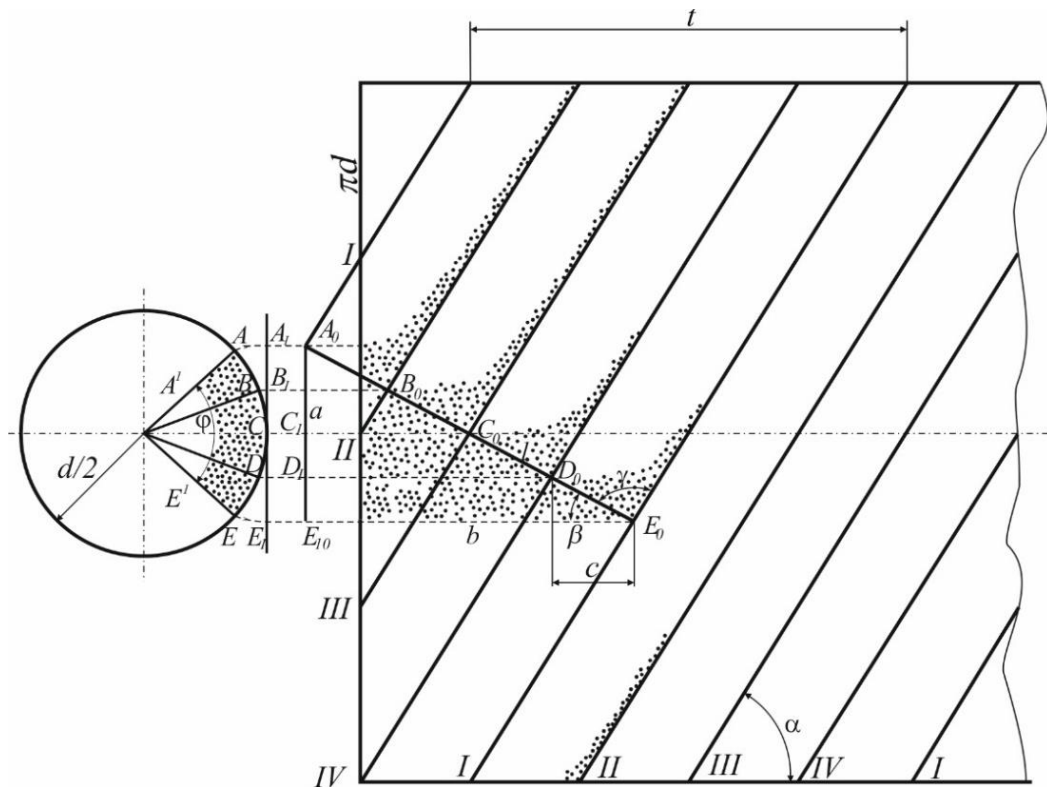


Figure 3. Work of helical spiral with staggered turns for uniform distribution of the discrete material.

Let us use the sine theorem:

$$\frac{t}{\sin \gamma} = \frac{l}{\sin \alpha}; \quad l = \frac{t \cdot \sin \alpha}{\sin(\alpha + \beta)},$$

where, $\gamma = \pi - (\alpha + \beta)$.

From Figure 3, we have:

$$l = \frac{a}{\sin \beta}.$$

Equating the last two expressions we get:

$$\tan \beta = \frac{a \cdot \tan \alpha}{t \cdot \tan \alpha - a}. \quad (4)$$

From Figure 3 we also receive:

$$b = \frac{a}{\tan \beta}.$$

Using the equation (4):

$$b = t - \frac{a}{\operatorname{tg} \alpha}. \quad (5)$$

in (5) lead of helix $t = \frac{\pi d}{\operatorname{tg} \alpha}$, $a = \pi d z$. Then:

$$b = \frac{\pi d}{\operatorname{tg} \alpha} (1 - z). \quad (6)$$

If we set the number of leads of helix as n_3 , the offset value is:

$$c = \frac{\pi d}{n_3 \operatorname{tg} \alpha} (1 - z). \quad (7)$$

Let us calculate the offset value for the parameters: $\alpha = 60^\circ$, $n_3 = 4$; $d = 40$ mm and $z = 1/4$.

$$c = \frac{3,14 \cdot 40}{4 \cdot \sqrt{3}} (1 - 1/4) = 13,61 \text{ mm}.$$

Obtained value corresponds strictly to graphically built parameters, which are written above.

The material conveyed by air flow and concentrated at the bottom of transport line undergoes twisting and becomes mechanically separated by the screw turns on parts. Further, the material comes into a separating attachment, where distributes over the outflows, which are located on the motion trajectory of the material particles.

To justify the settings of the distributor, let us consider the motion of fertilizer in the transport line. The transport line can be divided into two sections - I, II, Figure 4.

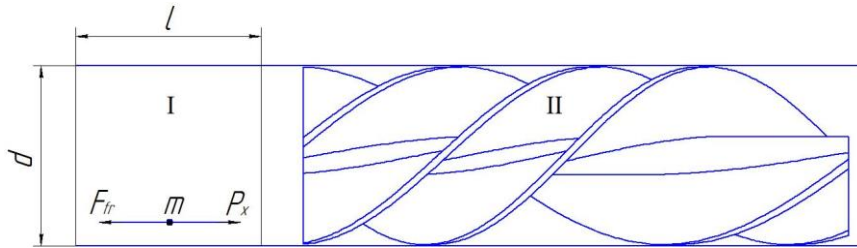


Figure 4. Sections of the transport line.

It is known that in order to maintain a uniform motion of the fluid (gas) in a horizontal pipe (section I) it is necessary to maintain the pressure difference, which is determined by an equation of Darcy-Weisbach:

$$\Delta p = p_1 - p_2 = \lambda \frac{l}{d} \cdot \frac{\rho v^2}{2}, \quad (8)$$

where ρ – density of fluid (gas); λ – resistance factor; p_1 и p_2 – pressure in sections 1 and 2; d and l - diameter and length of the transport line without distributor screw; v – average velocity of fluid; $\frac{\rho v^2}{2}$ - dynamic pressure.

In (8) λ can be replaced by aerodynamic drag coefficient k_x , and ratio l/d - to the midsection A_r . The dynamic pressure for two-component flow is calculated by the difference in velocities of each component. At the same time the aerodynamic drag in the straight pipeline (8) is:

$$P_x = \frac{1}{2} k_x A_r \rho (v - u)^2, \quad (9)$$

where v and u – average velocities of two flow components.

Solid component of a two-component flow in a horizontal pipe without screw is influenced by the friction force, which is proportional to the normal pressure on the bottom wall. Therefore, the differential equation of the flow in the area I is:

$$m \frac{du}{dt} = P_x - fN. \quad (10)$$

Considering (9) and comparing N to mg , receive:

$$m \frac{du}{dt} = \frac{1}{2} k_x A_r \rho (v - u)^2 - fmg. \quad (11)$$

At the beginning of the movement the speed of the solid component $u_H = 0$, therefore $\frac{du}{dt} = 0$.

Then, from equation (11) we obtain:

$$v_H = \sqrt{\frac{2fmg}{k_x A_r \rho}}, \quad (12)$$

where v_H - the initial velocity of the air flow in which the particle is suspended.

Let us define k_x from (12) and put it in (11):

$$\frac{du}{dt} = fg \left[\left(\frac{v-u}{v_h} \right)^2 - 1 \right]. \quad (13)$$

The solution of equation (13) with initial conditions $u_h = 0$ and $t_h = 0$:

$$u_1 = \frac{v \left(e^{\frac{2qt}{v_h}} - \frac{v-v_h}{v+v_h} \right) - v_h \left(e^{\frac{2qt}{v_h}} + \frac{v-v_h}{v+v_h} \right)}{e^{\frac{2qt}{v_h}} - \frac{v-v_h}{v+v_h}}. \quad (14)$$

Equation (14) shows the dependence of particle velocity in the pipe from its aerodynamic properties and the time of passing through the pipeline. Knowing it, it is possible to calculate the length of the pipeline.

For computational convenience, we introduce the coefficient of air flow velocity gradient:

$$\frac{v_h}{v} = \zeta.$$

The expression (14) takes the form:

$$u_1 = \frac{v \left(e^{\frac{2qt}{v_h}} - \frac{1-\zeta}{1+\zeta} \right) - v_h \left(e^{\frac{2qt}{v_h}} + \frac{1-\zeta}{1+\zeta} \right)}{e^{\frac{2qt}{v_h}} - \frac{1-\zeta}{1+\zeta}}. \quad (15)$$

In section II the screw surface is set, which serves to twist the two-component flow. The force impact on the particle M of mineral fertilizer is represented schematically in Figure 5. Here, the normal reaction N_1 is balanced

by the centrifugal force $\frac{mu^2}{R}$, the normal reaction of the support surface N is directed along the optical axis and balanced by projection of gravitation force mg . The aerodynamic moving force P_x is balanced by the frictional force F .

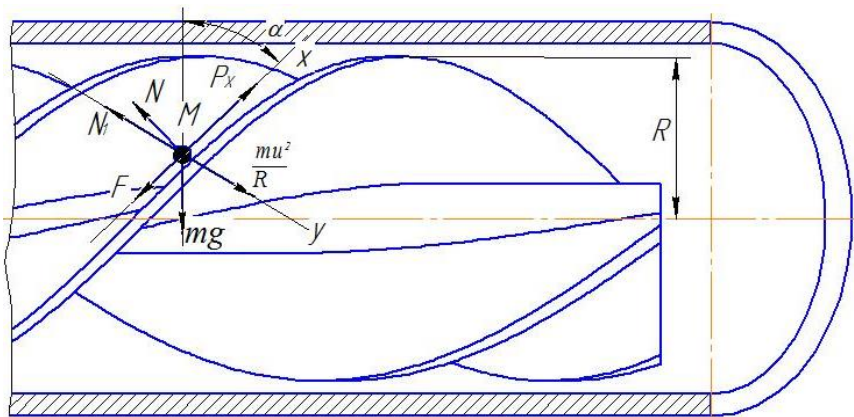


Figure 5. Acting forces in the section II.



The system of equations describing the motion of a particle in the natural axes x, y, z can be written as follows:

$$\begin{aligned} m\ddot{x} &= P_x - F - mg\cos\alpha = 0; \\ m\ddot{y} &= \frac{mu^2}{R} - N_1 = 0; \\ m\ddot{z} &= N - mg\sin\alpha = 0. \end{aligned} \quad (16)$$

From the system (16) let us define N, N_1 , and F taking into account:

$$P_x = m \frac{du}{dt},$$

then rewrite first equation to (16):

$$\frac{du}{dt} = f(g\sin\alpha + \frac{u^2}{R}) + g\cos\alpha. \quad (17)$$

This is the differential equation of motion of a particle of mineral fertilizer on screw surface by the aerodynamic moving force.

Transforming the equation (17) by taking the following notation:

$$g(f\sin\alpha + \cos\alpha) = A; \quad \frac{f}{R} = B. \quad (18)$$

Therewith the last equation takes the form:

$$\frac{du}{A + Bu^2} = dt. \quad (19)$$

Differential equation with separable variable is obtained, the solution of which is as follows:

$$\frac{1}{\sqrt{AB}} \operatorname{arctgu} \sqrt{\frac{B}{A}} + C = t. \quad (20)$$

when $t = 0, u = u_2$

$$C = \frac{1}{\sqrt{AB}} \operatorname{arctgu}_2 \sqrt{\frac{B}{A}}.$$

Let us substitute the value of C in (20):

$$\operatorname{Arctgu}_3 \sqrt{\frac{B}{A}} = \sqrt{AB} \cdot t - \operatorname{arctgu}_2 \sqrt{\frac{B}{A}}. \quad (21)$$

Equation (21) connects the helical screw surface parameters such as the radius and helix angle of ascent, by which it is possible to calculate its lead and length.

In order to check the obtained results, let us calculate the velocity of the particle at each stage of the passing the air tube conveyor. This requires parameters, some of which can be taken from the literature, and some are set in preliminary laboratory experiments:

$v_n = 5$ m/s – the initial velocity of the particle in the air tube conveyor;

$v = 20$ m/s – the operating speed of the air flow;

$f=0,5$ – coefficient of external friction;

$d=0,1$ m – pipe diameter;

$\alpha = 60^\circ$ - helix angle of ascent.

Substituting the values into equation (15)

$$u_1 = \frac{20 \left(e^{\frac{29,811}{5}} - \frac{1-0,25}{1+0,25} \right) - 5 \left(e^{\frac{29,811}{5}} + \frac{1-0,25}{1+0,25} \right)}{e^{\frac{29,811}{5}} - \frac{1-0,25}{1+0,25}} = 14,87 \text{ m/s}$$

we received the velocity of the particle in the section I.

The speed value is needed in order to determine the time during which the fertilizer particles get maximum speed and, consequently, a certain stable distribution over the cross-section of the transport line. The equation (15), and Figure 6 shows that the acceleration time of the particles ranges from 1 to 1.4 second.

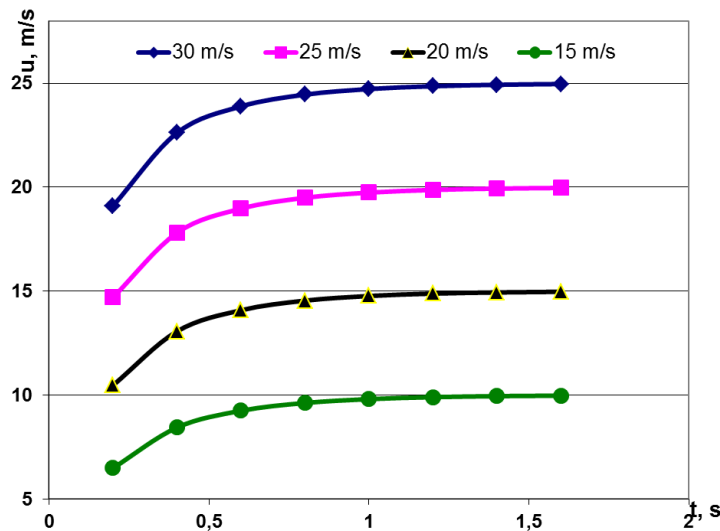


Figure 6. The particle velocity-time relationship.

To calculate the speed of the particles on the screw surface, let us use equation (21). For this, coefficients A and B of the formula (18) should be pre-calculated:

$$\text{Arctg}u_3 \sqrt{\frac{1}{9,15}} = \sqrt{9,15 \cdot 1} - \text{arctg}6,22 \sqrt{\frac{1}{9,15}} = 1,921;$$

$$u_3 = 5,82 \text{ m/s.}$$

Knowing the required outlet velocity of the particles, which satisfies the transportation and their uniform distribution to outflows, using the velocity and the underway, possible diameter of the pipeline can be calculated.

It is clear from Fig. 7 that the dependence of the uniformity of distribution of the material from the blower speed is proportional. Moreover, this is also correct either with or without the distributor. Since there is a direct relationship between the rotary velocity of the blower and the air flow pressure, it can be

concluded that with an increase of blower's rotary velocity the uniformity of material distribution rises. The positive impact of the rotary velocity increase on the distribution of the discrete material is obtained due to high kinetic energy of the solid particles, equally filling the cross-section of the pipeline.

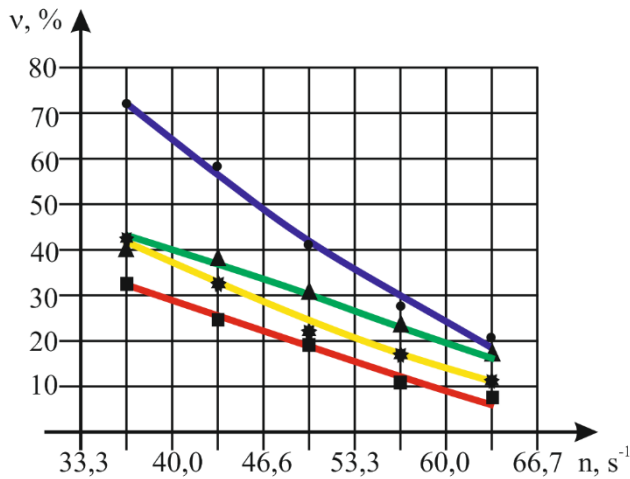


Figure 7. The uniform material distribution and rotary velocity dependence.

- - without distributor
- - with quadruple threaded distributor
- - with quadruple threaded distributor with offset turns
- - with quadruple threaded distributor with equal turns.

The increasing the blower's rotary velocity has the greatest influence on the uniformity of distribution of the material, without a distributor in pneumatic pipeline. Thus, by increasing the rotary velocity by about half (from 36.66 rad/s to 53.33 rad/s), the coefficient of variation decreased more than double (from 72.23% to 31.07%).

The next degree of impact of rotary velocity on uniformity of distribution of the material has the pneumatic pipeline with quadruple threaded distributor with offset turns. At the same level of increasing of rotary velocity by half, the variation coefficient is reduced by half (from 49.3% to 17.91%). The least impact of rotary velocity on the distribution is observed in the pneumatic pipeline with simple with quadruple threaded distributor. Also, with increasing rotary velocity by 1.5 times, the coefficient of variation reduces just about by 1.5 times (from 29.7% to 39.59%).

Another feature of these dependencies is that at a relatively low blower's rotary velocity (36.66 rad/s) the quality of the material distribution of pneumatic pipeline with distributor and without it differs significantly (39.59% and 43.38% with the distributor, 72.23 % without the distributor). However, this difference decreases sharply with further increase of the rotary velocity. Thus, when the rotary velocity is at level of 53.33 rad/s, the qualities of the material distribution of pneumatic pipeline with quadruple threaded distributor and without it are almost equalized (26.76% and 31.07%).

The pneumatic pipeline with distributor has an undoubted advantage considering the quality of material distribution. This advantage is 1.5-2 times

higher in all of the modes. However, the design features of the distributor also affect the quality of the material distribution. Thus, in the initial mode (36.66 rad/sec) the distribution coefficient of variation of pneumatic pipeline material equal and offset turns of the distributor, can be considered identical within the limits of experimental error (39.59%, 43.38%). By increasing the rotary velocity of blower, the distributor with offset turns begins to outstrip the quality of the distribution of the material. At a frequency of 53.33 rad/s, the difference is 1.7 times (29.76% and 17.91%).

Discussion and Conclusion

Can note that in the result of examining foreign seeding machines used in our fields, it was founded that seeding unevenness index is 16-19% (Moris-620). Better seed distribution was obtained in seeding machines, pneumatic conveyor system of which was improved with additional devices: equalizer of the flow, adjustable reflectors, diffusers, director cones and activators (Pronto 3 DC Horsch).

To test the efficiency of the proposed helical spiral, the experimental study had been conducted by L. Rumshinskij (1971). In the course of experiment the wheat "Saratov 29" with 14.6% humidity and bulk density of 0.512 g/cm³ was selected as discrete material.

The aim of the first series of experiments was to determine the effect of the rotary velocity of pressure blower on uniformity of distribution of the discrete material on the outflows. Few cases were studied:

- distribution of pneumatic flow of sowing material without distributor;
- with quadruple threaded distributor, 160mm length;
- with quadruple threaded distributor with offset turns, 220 mm length;
- with quadruple threaded distributor with equal turns.

An indicator of uniformity of distribution of material in the outflows is the coefficient of variation. Thus, the lower the coefficient of variation is, the uniformity of distribution grows. Similar results are described in the paper of H. Jin et al. (2014).

In summary, the theoretical justification of the offset turns, the particle velocity in the horizontal spiral, before dividing attachment, allows performing calculations of their design parameters. It is established that the pneumatic pipeline with distributor with equal turns gives the most qualitative distribution of the material. This can be explained by the fact that the material is moving generally in the lower part of the pipeline, and it is better distributed between the turns of the distributor.

Implications and Recommendations

The practical value is that the proposed method of installation of the helical spiral in the form of quadruple threaded screw with linear offset turns on the flow path facilitates the equal distribution of the particles through the inner wall of transport line. It can be defined as an effective method of increasing the production of horticulture.

Disclosure statement

No potential conflict of interest was reported by the authors.



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References

- Astahov, V.S. (1998). Sowing Machinery: Analysis and Prospects of Development. *Tractors and Agricultural Machinery*, 10, 7-9.
- Beaujot, P.M. (2009). U.S. Patent No. 7,555,990. Washington, DC: U.S. Patent and Trademark Office.
- Goettfried, E. (2000). Wie die Saat, so die Ernt. *Profi-Magazin Fur Agrartechnik*, 4, 44-49.
- Ivzhenko, S.A. (1992). Mechanical and Technological Bases of Perfection of Pneumatic Seeding: Dissertation. Doctor of Engineering Sciences. Chelyabinsk: Landtechnik, 506 p.
- Ivzhenko, S.A. (2005). Theoretical Research of the Process Seeds Egress in the Air Intake Chamber of Sowing Apparatus. Actual Problems of Agricultural Science and Education: Collection of Research Papers. Samara: *Infra-Engineering*, 101-103.
- Jianbo, Z., Junfang, X., Yong, Z., & Shun, Z. (2014). Design and Experimental Study of the Control System for Precision Seed-metering Device. *International Journal of Agricultural and Biological Engineering*, 7(3), 13.
- Jin, H., Zhiqiang, Z., Hongwen, L., & Qingjie, W. (2014). Development of Small/Medium Size No-till and Minimum-till Seeders in Asia: A Review. *International Journal of Agricultural and Biological Engineering*, 7(4), 1.
- Jinli, C., & Xiaohui, Z. (2011). Design and Test of One-step Centralized Type Pneumatic Seeding System. *Transactions of the Chinese Society of Agricultural Engineering*, 2011(1).
- Johansen, C., Haque, M.E., Bell, R.W., Thierfelder, C., & Esdaile, R.J. (2012). Conservation Agriculture for Small Holder Rainfed Farming: Opportunities and Constraints of New Mechanized Seeding Systems. *Field Crops Research*, 132, 18-32.
- Krjuchin, N.P. (2003). Sowing Machines. Design Features and Development Trends: a Monograph. Samara: *RTS of Samara State Agricultural Academy*, 117 p.
- Ljubushko, N.I (2003). Development of Wide-cut Seeders on the Basis of the Autonomous Sowing Systems. *Tractors and Agricultural Machinery*, 11, 19-20.
- Li, Y., Bingxin, Y., Tao, C., Yiming, Y., Xiantao, H., Quanwei, L., & Dongxing, Z. (2016). Global Overview of Research Progress and Development of Precision Maize Planters. *International Journal of Agricultural and Biological Engineering*, 9(1), 9.
- Manasseri, R.C.C., & Poggio, C.A.R. (2014). U.S. Patent No. 8,789,481. Washington, DC: U.S. Patent and Trademark Office.
- Memory, R.J., Benneweis, R.K., Klassen, N.D., Wilson, R.J., & Wilson, J.N. (2001). U.S. Patent No. 6,296,425. Washington, DC: U.S. Patent and Trademark Office.
- Never Pin – disk air drill: brochure MORRIS, 20 p. Canada.
- Ornek, F. (2008). Models in Science Education: Applications of Models in Learning and Teaching Science. *International Journal of Environmental and Science Education*, 3(2), 35-45.
- Pandey, S. (2002). Direct Seeding: Research Strategies and Opportunities. *International Rice Research Institute*, 384 p.
- Rumshinskij, L.Z. (1971). Mathematical Processing of the Experimental Results. Moscow: *Science*, 192 p.

- Séguy, L., & Bouzinac, S. (2003). Direct Seeding on Plant Cover: Sustainable Cultivation of Our Planet's Soils. *In Conservation Agriculture*, 93-99. Springer Netherlands.
- Singh, R.C., Singh, G., & Saraswat, D.C. (2005). Optimisation of Design and Operational Parameters of a Pneumatic Seed Metering Device for Planting Cottonseeds. *Biosystems Engineering*, 92(4), 429-438.
- Test Reports for Celinnaja MIS the Canadian drills «Moris-620" (MIS protocol № 30-72-85) and «Fiexi-Coil» drills (Celinnaja MIS report № 30-76-90).
- Test Run of the Universal Drill Seeder Pronto 3 DC Horsch. Tractors and Agricultural Machinery. Profi – 2005. – Special Issue of “Profi” Magazine, 70-73p.
- Yasir, S.H., Liao, Q., Yu, J., & He, D. (2012). Design and Test of a Pneumatic Precision Metering Device for Wheat. *Agricultural Engineering International: CIGR Journal*, 14(1), 16-25.
- Zhang, D.H., & Wu, X.Q. (2015). The Design of Seeding Machine Based on the Motion Controller. *In Applied Mechanics and Materials*, 713, 845-848. Trans Tech Publications.