Design and rationale for parametres of the seed-fertilizer seeder coulter for subsoil broadcast seeding

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Abstract. For sowing grain crops on stubble, stubble seeders with tine coulters are used, which perform technological operations in one pass. However, they do not meet the requirements of the agricultural machinery to ensure an even distribution of seeds in the sub-spear space. The subsoil no-drill planting creates the most favorable conditions for growth and development of cultivated crops and at the same time, grain crop yields are increased on average by 10...30%. Using no-drill planting, seeders equipped with spear coulters with spreaders for no-drill subsoil seeding provide the best quality and distribute the seeds evenly over the field. The article proposes the original design of the seed drill coulter for no-drill planting, which provides an even seed distribution over the feeding area. As a result of the theoretical researches the optimal parameters of the diffuser for the grain drill coulter are determined and the dependence between the unevenness on the test parameters of the diffuser and the height of the pendulum spreader, the base diameter are obtained. The purpose of this research is to develop the design and rationale of parameters of the grain drill for subsoil no-drill planting, the use of which will reduce the uneven distribution of grain crops seeds or mineral fertilizer granules.

1. Relevance of the problem

For sowing grain crops on stubble, stubble seeders with tine coulters are used, which perform technological operations in one pass. This helps to reduce soil compaction, retain moisture in upper layers of the soil and save fuel. However, the coulters of these seeders do not meet the requirements of the agricultural machinery to ensure an even distribution of seeds in the sub-spear space, which leads to uneven seedlings, increasing of weed infestation, reducing of grain quality and grain yields. The subsoil no-drill planting creates the most favorable conditions for growth and development of cultivated crops [1]. This happens due to the fact that seeds are distributed in the field more evenly than using the ordinary method of seeding. [2]. At the same time, grain crop yields are increased on average by 10...30% using no-drill planting in comparison with close sowing and ordinary methods

[3]. Using no-drill planting, seeders equipped with spear coulters with spreaders for no-drill subsoil seeding provide the best quality and distribute the seeds evenly over the field. [4]. The most common and simple in design is the passive distributer having various forms. However, the uneven distribution of seeds and fertilizers over the operating width of such distributors is high [5], vibrating distributors create low irregularity, but they have a complex design.

It follows that the problem of reducing the uneven distribution of grain seeds or mineral fertilizer granules is relevant.

2. The analysis of the recent research
The review of the schemes for the subsoil no-drill planting [6] showed that a promising direction for improving the process of the subsoil no-drill planting of grain crops is the development of coulters that ensure the combination of the pre-sowing cultivation, even sowing over the entire width of the claw and fertilization.

The analysis of the coulter studies of the stubble seed drill SZS-2.0 showed that the uneven distribution of the wheat seeds over the width of the grip, depending on various parameters of the distributors, exceeds 44-45% [7].

3. The purpose of the research
The purpose of this research is to develop the design and rationale of parameters of the grain drill for subsoil no-drill planting, the use of which will reduce the uneven distribution of grain crops seeds or mineral fertilizer granules.

4. Materials and methods
To achieve this goal, an original design of the coulter with a pendulum distributor is proposed. To ensure an even distribution of grain seeds or mineral fertilizer granules in the coulters of stubble grain drills of the SPS type, it is necessary to provide space for the flight of seeds or granules. For this purpose the duckfoot shovel contains a canopy located above its cutting edges, forming a closed subsoil space together with the inner side walls of the duckfoot fender [8]. A pendulum distributor in the form of hemisphere is established inside a sub-spear space on the swinging mounted brace. The hemisphere rotation axis is parallel to horizontal axis of symmetry of the suspension joint brace and coincides with the driving direction of the machinery.

The Coulter for subsurface-no-drill planting (figure 1) includes a duckfoot shovel 1 with a pointed leg 2 fixed to it by means of a bolted connection 11.
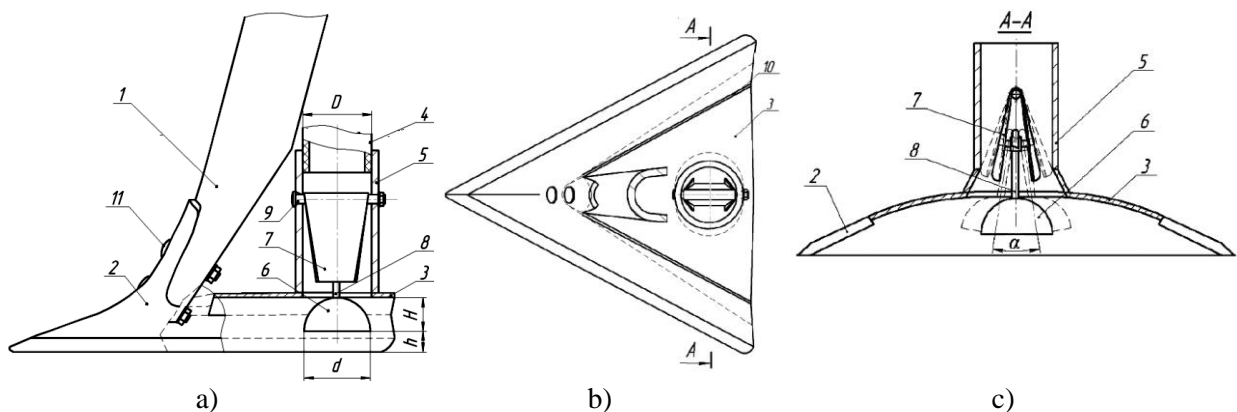

Figure 1. Coulter: a – side view; b – top view; c – distributor.

The duckfoot shovel 2 contains a visor 3 fixed to it with the help of antennas 10, located above its cutting edges. The Pendulum distributor 6 is installed inside the sub-spear space on a bracket 7 and a rod 8 which are swing joined with the help of a cotter pin 9 .A thin-walled elastic seed pipeline 4 is attached to the upper part of the rigid frame 5 of a seed pipeline . When driving the tractor, seeds and fertilizers from grain drills box serves to seed pipeline in the distributor, hit to vibrated brackets 7 and further to a ring of the circular hemisphere of the distributor 6 and are uniformly scattered over the entire area formed within a closed subsoil underground space, covering seeds and fertilizers the entire width of the duckfoot shovel. During the movement of the seeder, the duckfoot shovel cuts weeds, loosens the ground, which is moving back along the surface of the visor and falling down, covers the sown seeds and mineral fertilizers. Subsequently, the entire passage is compacted with rollers.

As a result, grain inter-oppression is eliminated, the growing zone increases, better conditions for plant growth and development appear, germination rate increases and crop infestation decreases, grain yield increases by 18 ... 25% per hectare [1, 9].

5. Results and discussion
The width of the seeding depends on the distance of the seed input, the value of which is exact opposite to the speed of seed departure from the seedpipe rack. To substantiate the optimal parameters of the Coulter, it is necessary to determine the rate of seed departure from the seedpipe rack of the experimental coulter [10]. Grain movement is divided into three sections (figure 2): *AB, BC, CD.*
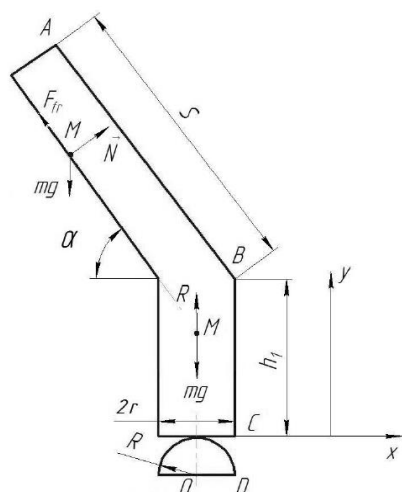
Figure 2. Scheme of grain movement along the the seedpipe rack.

Let's consider the movement of the grain on the *AB* section. Speed at point $A: V_A = V_0$, at point B – V_1 .

The grain is under the gravity force *mg* (*m* is grain weight, *kg, g* – acceleration of free fall m/s^2), *N*; friction force трения – $F = fmg\cos\alpha$ (*f* coefficient of friction, α – angle); *N, N* – the normal reaction of the inclined plane, *N*.

According to the theorem of kinetic energy change, the speed of the grain can V_1 $\left(m/s\right)$ be calculated according to the formula

$$V_1 = \sqrt{2gS(\sin\alpha - f\cos\alpha) + V_0^2}. \tag{1}$$

Let's consider BC that carries out the flow of the grain to the pendulum distributor (figure 2).
On the basis on II Newton's law, the equation of the grain movement has the form

$$m\frac{dV}{dt} = -mg - kmV_2, \tag{2}$$

where $k -$ coefficient of resistivity, c^{-1}; $V_2 -$ grain speed at point C, m/s.

Having accepted the initial conditions $t = 0$, $V = V_1$, from the formula (2) we define V_2

$$V_2 = 1/k(g + kV_1)e^{-kt} - g/k. \tag{3}$$

Having integrated the formula (3), we get

$$y = gt/k - 1/k^2(g + kV_1)e^{-kt} + C_2. \tag{4}$$

Since $t = 0$ $y = h$ ($h -$ the distributor height from the bottom of the furrow, m), $C_2 = h + (g + kV_1)/k^2 -$ if the integration is constant, then formula (4) will take the form of
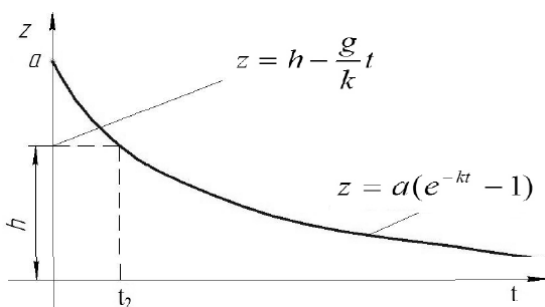
$$y = h - gt/k + 1/k^2(g + kV_1)(1 - e^{-kt}). \tag{5}$$

Considering the point C: $y = 0$, $V = V_2$, $t = t_2$ equation (5) will take the form
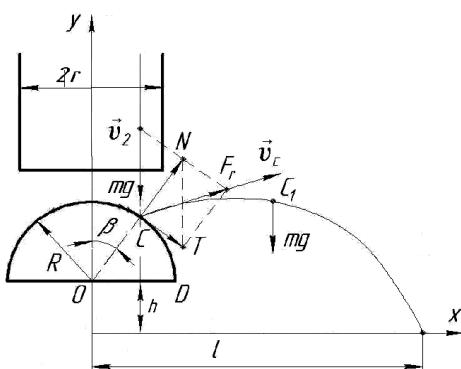
$$h - gt/k = a(1 - e^{-kt}). \tag{6}$$

where $a = 1/k^2(g + kV_1)$.

Equation (6) is solved graphically (figure 3).

Figure 3. Dependence between the change of flight time and the height of the vertical rack.

To determine the range of grain flight, let's consider its movement on the *CD* section (figure 4).

Figure 4. The pattern of the grain flight.

We can assume that the hit of the grain on the pendulum distributor is absolutely elastic. The grain hits the distributor of radius - R at an absolute speed V_2. The equation of the grain motion under the claw space after the hitting of the pendulum dispenser has the form

$$m\ddot{y} = -mg,$$
$$m\ddot{x} = 0. \tag{7}$$

Having integrated the equation (7), we obtain

$$y = -gt^2/2 + C_3 t + C_4,$$
$$x = -C_3 t + C_4, \tag{8}$$

where C_3, C_4 – constant integration.

At the initial time when $t = 0$: $x = r$ (r – internal diameter of the coulter stand, m); $y = R$ (R – radius of the distributor's pendulum hemisphere, m), equation (8) will have the form of

$$y = -gt^2/2 + (V_2 \cos 2\beta)t + h,$$
$$x = (V_2 \sin 2\beta)t + r, \tag{9}$$

where β – the angle between the radius of the hemisphere and the direction of force application, deg.

The time t_3 when the grain falls to the ground is determined from the condition $y = -gt_3^2/2 + (V_2 \cos 2\beta)t_3 + h = 0$, it follows that

$$t_3 = (V_2 \cos\beta/g) + \sqrt{(V_2^2/g) + (2h/g)}. \tag{10}$$

From the dependencies (9) and (10), it is possible to determine the distance of the grain flight under the claw space of the coulter

$$x_{\max} = (V_2 \sin\beta)t_3 + r. \tag{11}$$

Let's consider the case when an ellipsoid-shaped diffuser performs plane oscillations with an angle of deviation from the vertical φ. The scheme of movement of a particle under the claw space with the diffuser is shown in figure 5.
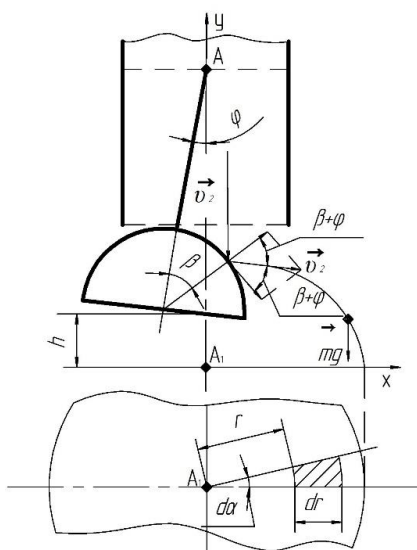
Figure 5. The diagram of the particle motion under the claw space with a diffuser.

A vertically falling particle absolutely elastically hits the surface of the ellipsoid at a speed of V_2. The hit angle and the angle of rebound of the particle from the normal to the surface is equal to $\beta + \varphi$, where the angle β changes between 0 to 90°; the deviation angle of the particle from the vertical axis is $180^0 - 2(\beta + \varphi)$. Meanwhile, the particle transmits an impulse to the diffuser which is equal to $2mV_2 \cos(\beta + \varphi)$, in the direction of the normal to the surface. According to the experimental data, the grain weight m is about 8000 times less than the mass of the diffuser.

In view of the above, the motion of the diffuser is neglected due to the particle hit. However, it should be taken into account that when the particle hits the other vertically falling particles, the impulse is transmitted from one particle to the other, and as a result, the scattering distance remains the same as that of the initially considered particle. The research [11] proved that the particle under the claw space has a sufficiently high speed of 3-4.2 m/s. Therefore, the environment resistance can be ignored.

The equation of the particle motion in the field of gravity

$$dV_y / dt = -g,$$
$$dV_x / dt = 0. \tag{12}$$

Moving from the time derivative to the coordinate derivative y and having integrated the expression (12), we get

$$V_y^2 / 2 = -gy + C, \tag{13}$$

where the integration constant C we find from the initial condition for $y = y_M$ the projection of the initial speed $V_y = V_{0y}$: and substituting in the equation (13), we get

$$V_y = \sqrt{2g(y_M - y) + V_{0y}^2}. \tag{14}$$

The particle moves with the acceleration in the vertical direction g, and in the horizontal direction it moves at a constant speed. The equations of the motion have the form.

$$y = -gt^2 / 2 + V_{0y}t + y_M,$$
$$x = V_{0x}t + x_M. \tag{15}$$

From the condition $y = 0$ we find the flight time $t = 1/(g(V_{0y} + \sqrt{(V_{0y}^2 + 2gy_M)}))$.

The distance of the particle flight (grain flight)

$$L = (-V_2^2 / 2g)\sin 4(\beta + \varphi) + \sqrt{(V_2^4 \sin^2 4(\beta + \varphi))/4g^2) + (y_M / g)V_2^2(1 + \cos 4(\beta + \varphi))} + x_M. \tag{16}$$

The maximum flight distance is observed at

$$\sin 4(\beta + \varphi) = 1. \tag{17}$$

This condition is fulfilled when $\beta + \varphi = 25^0$. The formula (16) will take the form of

$$L_{max} = (-V_2^2 / 2g) + \sqrt{(V_2^4 / 4g^2) + (y_M / g)V_2^2} + x_M. \tag{18}$$

From the equation of the normal to the ellipse the angle β is determined as the tangent of the inclination angle of of the normal to the ellipse with semi-axes $d/2$ and H

$$tg\beta = ((d/2)^2 y_0)/(H^2 x_0), \tag{19}$$

where $(x_0 : y_0)$ are the coordinates of the point in a movable coordinate system (figure 6).
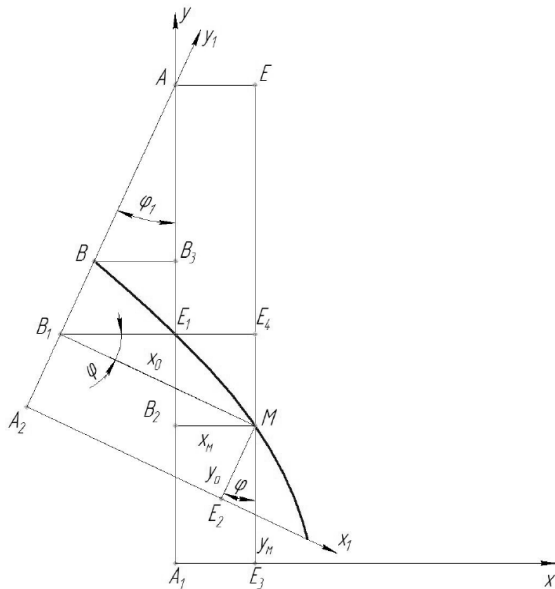
Figure 6. The diagram for determining the relations of the particle coordinates in the movable and immovable coordinate systems.

Thus, the rebound angle of the particle depends on the parameters: $\beta = \beta(d, H, x_0, y_0)$.

The relation of the coordinates $(x_M : y_M)$ to coordinates $(x_0 : y_0)$ in a movable system is defined as

$$
\begin{aligned}
x_M &= x_0 \cos\varphi - (l_0 + H - y_0)\sin\varphi, \\
y_M &= l_0 + H + h - (l_0 + H - y_0)\cos\varphi - x_0 \sin\varphi.
\end{aligned}
\tag{20}
$$

where $l_0 -$ the diffuser suspension length, m; $H -$ the diffuser height, m; $h -$ the distance from the horizontal surface to the diffuser in its lowest position, m.

According to figure 6 it follows

$$
\begin{aligned}
y_0 &= x_M \sin\varphi + y_M \cos\varphi - h, \\
x_0 &= (l_0 + H + h)\sin\varphi + x_M \cos\varphi - y_M \sin\varphi.
\end{aligned}
\tag{21}
$$

Based on the obtained flight distance formula, the area of the optimal size of the diffuser is determined d, H and the distance h. The calculations are taken: $g = 9{,}81 m/s^2$; $V_2 = 3 m/s$; $l_0 = 0{,}06m$.
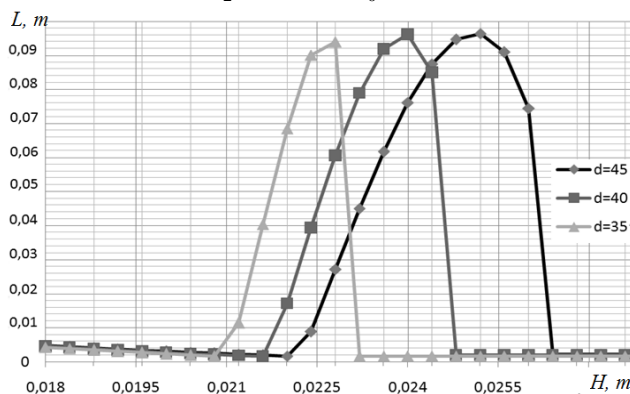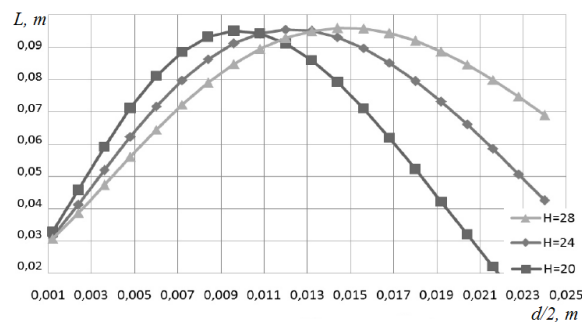

Figure 7. The dependence between the flight distance and the height of the distributor H with fixed values of the distributor base diameter d.

Figure 7 shows the dependence of the flight distance to the height of the distributor H for fixed values of the distributor base diameter d, it takes into account the particles that have a bounce angle from 0 to 90° [12].

It follows from the diagram that the value H less than 0.02 m does not significantly affect the value of the particle's flight distance. Peak values of the flight distance are associated with the condition (17).

Further the sudden decreases in the flight distance are explained by the fact that the particles with coordinates more than x_0 or x_M pass without colliding with the diffuser. Based on the diagrams (figure 7), we can come to the following conclusion: when the diameter of the diffuser changes from 30 to 50 mm, the optimal height of the diffuser lies in the range from 20 to 27 mm.

Further we have studied the effect of the value varying d at the fixed values of H (figure 8). The diagrams show that the most flight distances are associated with the condition (17), and when the diameter of the diffuser changes from 12 to 28 mm, the optimal diffuser width is in the range from 14 to 36 mm.

Figure 8. The dependence between the light distance and the diameter of the distributor d for the fixed values of the distributor height H.

Further we have studied the effect of the particle bounce angle on the flight distance, taking into account the oscillation of the diffuser (figure 9).
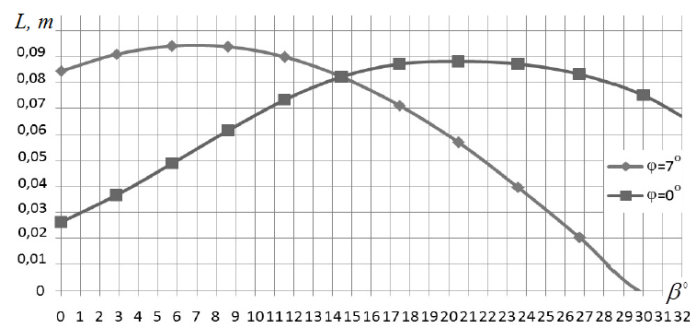
Figure 9. The dependence of the flight distance with the oscillation of the diffuser.

The presence of a vibrated oscillation did not significantly affect on the particle distance. However, due to the vibrations, the number of the particles with a large spread in the horizontal direction increases. The trajectory of the particle motion has the form of a quadratic parabola:

$$y_M - y = (g(x - x_M)^2)/(2V_{0x}^2) - (V_{0y}/V_{0x})(x - x_M).$$

Let's express the vertical component of the speed V_y in terms of the initial speed V_2

$$V_y = \sqrt{ax^2 + bx + c}, \tag{22}$$

where $a = (g^2/V_2^2)(1 + tg^2(2(\beta + \varphi)))$; $b = (-2x_M g^2/V_2^2)(1 + tg^2(2(\beta + \varphi))) + 2gtg(2(\beta + \varphi))$;

$$c = (x_M^2 g^2 / V_2^2)(1 + tg^2(2(\beta + \varphi))) - 2gx_M tg(2(\beta + \varphi)) + V_2^2(tg^2(2(\beta + \varphi)))/(1 + tg^2(2(\beta + \varphi))).$$

To estimate the influence of the optimized factors *d, H,* and *h* on the seeding unevenness, we find the second consumption of the particles per time unit. Let's assume that in one second, the precipitating particles, hitting the surface of the diffuser, will occupy the area *S*, which is a circle, the radius of which is determined by the particle distance $(R \cong L)$.

The particle expenditure per time unit

$$Q = \frac{\pi \ln(2\sqrt{aL^2 + bL + c} + (b + 2aL)/\sqrt{a})(b^3 - 4ac)}{16a^{5/2}} + \frac{\pi\sqrt{aL^2 + bL + c}(2abL - 3b^2 + 8a(aL^2 + c))}{24a^2} -$$

$$- \frac{\pi\ln(b/\sqrt{a} + 2\sqrt{c})(b^3 - 4ac)}{16a^{5/2}} + \frac{\pi\sqrt{c}(3b^2 - 8ac)}{24a^2}. \tag{23}$$

The quantity variations of granular body from the bin outlet

$$\eta = \sigma / Q, \tag{24}$$

where $\eta -$ unevenness %; $\sigma -$ standard deviation; $Q -$ particle expenditure per time unit, *kg/s*.

Substituting the formula (24) in (23), we obtain the dependence between the seeding unevenness and the studied parameters *d, H* и *h* in an implicit form through the introduced notation *a, b*, and *c*.

The analysis of the obtained equations allows us to come to the following conclusions:

- theoretically, the optimal diameter value of the distributor base is in the range from 34 to 43 mm, the seeding unevenness is up to 10%;
- theoretically, the optimal value of the distributor height is in the range from 18 to 24 mm, the seeding unevenness is up to 10%;
- depending on the distributor height from the furrow bottom *h*, the seeding unevenness gradually decreases, which is explained by the accepted model of the particle as an absolutely elastic body.

6. Conclusions
The original design of the seed drill coulter for no-drill planting is proposed, which provides an even seed distribution over the feeding area.

The formula of the particle (grain) flight distance is obtained, which is used to determine the area of the optimal size of the diffuser d, H and the distance *h*.

On the basis of the theoretical studies, it is established that the presence of a scattering oscillation does not significantly affect the flight distance of the particle. However, due to vibrations, the number of the particles increases, with a large spread in the horizontal direction.

References
[1] Heege H J 1981 Zur Frage der Satechnik fur Getreide *Landtechnik*. **36(2)** 66-9
[2] Karayel D and Ozmerzi A 2007 Comparison of vertical and lateral seed distribution of furrow openers using a new criterion *Soiland Tillage Research*. **95** 69-75
[3] Ponomareva O A 2014 Uniform placement of seeds over the sown area with an active opener *Bulletin of the Kurgan State Agricultural Academy* **2** 62-4
[4] Laryushin N P, Machnev V A, Machnev A V, Shumaev V V and Larin M A 2012 Theoretical studies of the opener with a seed guide-distributor of a pneumatic seeder-cultivator *Niva Povolozhya*. **4(25)** 57-64
[5] Demchuk E V 2010 *Substantiation of the parameters of the double-band opener of the grain seeder* (Novosibirsk)
[6] Krasilnikov E V 2009 *Substantiation of parameters of pneumomechanical seeding system*

providing uniform distribution of seeds of grain crops (Omsk)

[7]   Nukusheva S A 2010 *Substantiation of technological and design parameters of the opener for scattered subsoil sowing of grain crops* (Astana)

[8]   Nukeshev S O, Yeskhozhin D Z, Kakabaev N A, Toigambayev S K, Shilo I N, Romanyuk N N and Ageychik V A 2014 Pat. of the Republic of Kazakhstan No 29217 appl. 11.12.2013, publ. 15.12.2014

[9]   Ponamareva O A 2008 *Development and substantiation of the parameters of the vibrating distributor of the opener for subsoil-spread sowing of seeds* (Kurgan)

[10]   Nukeshev S O, Romanyuk N N and Kakabaev N A 2016 Results of experimental studies of the pendulum distributor of the seed drill opener *Research results*. **02(070)** 163-70

[11]   Artamonov V A 2007 *Substantiation of the parameters of the distributor of seeders for row-free sowing of grain crops* (Moscow)

[12]   Kakabaev N A 2017 *Substantiation of the parameters of the opener scatterer of a grain-fertilizer seeder* (Astana)

[13]   Gyachev L V 1992 *Fundamentals of the theory of bunkers* (Novosibirsk: Publishing house of NSU)