Seed distribution by the coulter for the subsoil broadcast seeding

E P Alekseev¹, I I Maksimov¹, A G Terentev¹ and E A Maksimov²

¹ Chuvash State Agricultural Academy, 29, K. Marx St., Cheboksary, Russia, 428003
² Tsivilsky agricultural engineering College of the Ministry of education of Chuvash Republic, Tsivilsk, Russia

³ E-mail: zhenia_alex@mail.ru

Abstract. The article studies the efficiency of the subsoil broadcast seeding of grain crops, which differs from other methods with the way seeds are placed into the soil: not in rows but on the whole distributing width. This method is also determined by the evenness of seeding depth by placing the seeds on the ready hard spot, which provides equal conditions of heat, light, water, food and gas supply that influence seed sprouting, seedling formation, tillering, shooting, head formation, earing, blossoming, kernel milk line formation, middle dough and fully ripe stage development. The analysis of coulter with active and passive distributors has been conducted. The use of air flow during the transportation of seeds from the sowing device to the coulter and the distributor oscillating process is recommended for the higher quality seed distribution below the spinning wheel. The oscillations of the elastic tube – distributor under the influence of the air-grain mixture have been theoretically studied. The obtained results allow creating dependency diagrams of oscillation frequency \( \omega \) and damping parameter \( h \). The experimental research has been made to study the evenness of seed distribution with the help of the coulter with the elastic tube – distributor.

1. Introduction

Crop growing includes a number of technological operations such as: preparation of soil, seeding, management, harvesting, etc. The most significant among all these technological operations is seeding because head formation and harvesting capacity depend on the quality of width and depth of seed distribution on the field.

Grain seeders can sow the seeds by row, closed drill, crossed and long line methods. As the results the seeds are placed unevenly and form an oblong rectangular. That is why it is better to use the subsoil broadcast seeding.

However, the analysis of the current constructions of the coulters for the subsoil broadcast seeding with a passive distributor showed that they have rather low evenness of seed distribution on the field (the coefficient of evenness does not exceed 60-65%), under-width of seed distribution below the spinning wheel. Moreover, in case of uneven placement of the seeds on the field, as a rule, the seedlings are clogged up by weeds, cultivated plants are in a stress condition, and the non-planted acreage increases [1].

The usage of the coulters with the active distributor helps to increase the evenness of seed placement on the field as they are less sensitive to different disturbing effects (oscillating of the stilt at the vertical and diametric planes, the work of a seeding rig on the slopes, etc.). The current coulters with an active
distributor unfortunately have a small sowing width that leads to the growth in the number of tools and implements what can cause the decrease of efficiency in seeding wet soils and increase of their clogging. The usage of movable elements in the coulter space makes them wrapped with the crop residues, while in case of deepening the coulter into the soil mechanical activators break down. The usage of air flow during the transportation of seeds from a seeding rig to a coulter and the oscillating process of a distributor seems perspective to save the time in a seed drop tube and obtain a better distribution below the spinning wheel [2, 3, 4].

2. Experimental
According to all the ideas stated above it seems relevant to study the distribution of the seeds in the space below the spinning wheel with the elastic tube and the air flow with such assumptions:

- Cross normal sections of the elastic tube, flat before the deformation, remain normal and flat after the deformation, i.e. shift sand extensions of the back wall are not calculated.
- Centre line of the elastic tube is considered inextensible.
- Saint-Venant’s principle, which states that different but statistically equivalent local loads cause the same tension in a tube, is right.

The main peculiarity of elastic bars is that the centre line of the loaded elastic tube can differ a lot from the centre line of the tube in its natural condition and we will consider that the elastic tube in case of deformation is subjunctive to the Hooke’s law. That is why we find it relevant to study the oscillations of the elastic tube – distributor geometrically non-linear but physically linear.

![Figure 1. Scheme to determine the frequency of the elastic tube – distributor’s oscillation.](image)

We need to stress that with such assumptions we can consider the formulating of the task of the elastic tubes’ oscillations as the dynamics of sleeves, envelopes, and bars taken in equation of the equal balance of the thin-walled bar.

When the air seed mixture goes at a steady flow through the hung and rigidly restrained end of the elastic tube-distributor, there is the loss of stability when the tube does not have any form of equal balance and makes oscillating movements.

To determine the frequency of oscillations of the elastic tube let us consider its spatial movements. In static condition it has a straight form. We can guess that the exit from this state happens due to the shear forces of inertia, the linear forces will be disregarded.

From Figure 1 let us take the element of the tube \(dz\), \(m\); then, the mass of the tube of the length unit \(L\) we will denote as \((m_1 / L)dz\) [kg/m\(\cdot\)m]; the mass of air grain mixture of the same length unit \((m_2 / L)dz\) [kg/m\(\cdot\)m]. The movement of the air grain mixture will be considered as complicated, the accelerations of the particular element of the tube will be equal to:
\[ a_1 = \frac{\partial^2 y}{\partial t^2}, \quad a_2 = 2\nu \frac{\partial^2 y}{\partial \zeta \partial t}, \quad a_3 = \nu^2 \frac{\partial^2 y}{\partial \zeta^2}, \tag{1} \]

where \(a_1, a_2, a_3\), are translational, Coriolis and normal accelerations; m/s\(^2\); \(t\) is the time, s.

Then, the sum of inertial forces that influence the tube and air-grain mixture in the area \(d\zeta\) will be:

\[ \sum F_{\zeta} = \left(\frac{m_1}{L} + \frac{m_2}{L}\right) \frac{\partial^2 y}{\partial t^2} \, d\zeta - \frac{m_2}{L} \frac{2\nu}{\partial \zeta \partial t} \, d\zeta - \frac{m_1}{L} \nu^2 \frac{\partial^2 y}{\partial \zeta^2} \, d\zeta \tag{2} \]

where \(\nu\) is the speed of the air grain flow, m/s.

It is known that the equation of the transverse free oscillations of bars in our case of the tube is:

\[ EI \frac{\partial^4 y}{\partial \zeta^4} \, d\zeta = -\frac{m_1}{L} \frac{\partial^2 y}{\partial t^2} \, d\zeta \tag{3} \]

where \(EI\) is the tube hardness when it is bended, H·m\(^2\).

Taking into consideration equations (2) and (3) we can denote the intensity of the transverse load dividing the equation in advance by \(d\zeta\):

\[ EI \frac{\partial^4 y}{\partial \zeta^4} = \left(\frac{m_1}{L} + \frac{m_2}{L}\right) \frac{\partial^2 y}{\partial t^2} \; - \; \frac{m_2}{L} \frac{2\nu}{\partial \zeta \partial t} \; - \; \frac{m_1}{L} \nu^2 \frac{\partial^2 y}{\partial \zeta^2} \tag{4} \]

Let us introduce dimensionless variables:

\[ y = Y e^{(h+i\omega)At}, \quad A = \left(\frac{EI}{(m_1/L + m_2/L)L^3}\right)^{1/2}; \quad z = L\xi \tag{5} \]

If \(Y\) is the function that characterizes the form of the own oscillations; \(L\) is the tube length, m; \((h+i\omega)\) is a complex number where \(h\) is the damping parameter, s\(^{-1}\); \(\omega\) – the frequency of oscillations, s\(^{-1}\).

Let us take them in the equation (4):

\[ \frac{d^4Y}{d\xi^4} + \beta \frac{d^2Y}{d\xi^2} + 2\beta \mu(h + i\omega) \frac{dY}{d\xi} + (h + i\omega)^2Y = 0 \tag{6} \]

Where

\[ \beta = \nu \left(\frac{m_2/L}{EI}\right)^{1/2}, \quad \mu = \left(\frac{m_2/L}{m_1/L + m_2/L}\right)^{1/2}; \tag{7} \]

The first equation formula (7) defines the outflow capacity of the air seed mixture through the elastic tube-distributor while the second formula denotes the ratio of the air-grain mixture mass to the mass of the tube.

According to the boundary conditions on the restrained end, if \(\xi = 0\), we will have

\[ Y = 0; \quad \frac{dY}{d\xi} = 0. \]

While on the free, non-restrained end, if \(\xi = 1\)

\[ \frac{d^3Y}{d\xi^3} = 0; \quad \frac{d^3Y}{d\xi^3} = 0. \]

The total integral of the differential equation (6) we will show in a complex form:
Where \( n \) is a number of the sequence member.

Then, from the boundary conditions, we will get for the restrained end \( C_0 = C_1 = 0 \), while for the free one:

\[
\sum C_n n(n-1) = 0; \quad \sum C_n n(n-1)(n-2) = 0
\]

From these formulas for the constant coefficient \( C_2 \) and \( C_3 \) we will have the system of equations:

\[
\begin{align*}
ac_2 + bC_3 &= 0 \\
cC_2 + dC_3 &= 0
\end{align*}
\]

The system of equations (10) has non-zero values in case if the determinant of the matrix is equal to zero:

\[
\begin{vmatrix} a & b \\ c & d \end{vmatrix} = ad - bc = 0
\]

Let us write the equation (11) in the real-valued form:

\[
Y = Y_1 + iY_2
\]

this will give us correspondingly:

\[
C_n = A_n + iB_n, \quad Y_1 = \sum A_n \zeta^n, \quad Y_2 = \sum B_n \zeta^n.
\]

Placing the equation (12) into the equation (6) and dividing it into the real and imaginary parts we will get the system of the recurrent equations to denote \( A_n \) and \( B_n \):

\[
\begin{align*}
A_n &= \frac{1}{n(n-1)(n-2)(n-3)} \left(-\beta^2 A_{n-2} (n-2)(n-3) - 2\beta \mu h A_{n-3} (n-3) + \\
&+ (\omega^2 - h^2) A_{n-4} + 2\beta \mu \omega B_{n-3} (n-3) + 2\omega h B_{n-4}\right) \\
B_n &= \frac{1}{n(n-1)(n-2)(n-3)} \left(-\beta^2 B_{n-2} (n-2)(n-3) - 2\beta \mu h B_{n-3} (n-3) + \\
&+ (\omega^2 - h^2) B_{n-4} - 2\beta \mu \omega A_{n-3} (n-3) - 2\omega h A_{n-4}\right).
\end{align*}
\]

We will also submit in the form the real and imaginary components. As the result we will get 4 equations:

\[
a = a_1 + ia_2; \quad b = b_1 + ib_2; \quad c = c_1 + ic_2; \quad d = d_1 + id_2
\]

Thus, we will have the system of 2 equations, where the condition of the coexistence of the non-zero values is the case when the determinant is equal to zero:

\[
\begin{align*}
D_1 &= a_1 d_1 - a_2 d_2 - b_1 c_1 + b_2 c_2 = 0 \\
D_2 &= a_1 d_2 - a_2 d_1 - b_1 c_2 + b_2 c_1 = 0
\end{align*}
\]

To denote \( a_1, a_2, b_1, b_2, c_1, c_2, d_1, d_2 \) from the system (16) let’s find the numerical values of the constant coefficients of the system (10).
In case of $C_2=1$ and $C_3=0$, from the equation (9) and the system (10) the first sum is equal to $a$, and the second one to $c$. According to the equation (13), $A_2=1$, $B_2=B_3=A_3$, which gives us the equation:

$$a = \sum A_n n(n-1)$$

$$a_2 = \sum B_n n(n-1)$$

$$c_1 = \sum A_n n(n-1)(n-2)$$

$$c_2 = \sum B_n n(n-1)(n-2)$$

(17)

If $C_2=0$, $C_3=1$ then $A_2=B_2=B_3=0$, $A_3=0$, and we get equations for the following quantities:

$$b_1 = \sum A_n n(n-1)$$

$$b_2 = \sum B_n n(n-1)$$

$$d_1 = \sum A_n n(n-1)(n-2)$$

$$d_2 = \sum B_n n(n-1)(n-2)$$.

In order to find $h$ and $\omega$ that suit the system (16) it is necessary to use the numerical method of solution. For this purpose we will place in the equation (7) the quantities of the following parameters: the speed of the air-seed flow, $v$, the mass of the tube and the air-seed mixture per unit length of the tube $m_1/L$ and $m_2/L$ correspondingly, the hardness of the tube $EI$. Then on the conventional plane $h$ and $\omega$ we set three points, place their quantities in the equation (14) and find $A_n$ and $B_n$. From the equations (17) и (18) we denote $a$, $b$, $c$, $d$ and the quantities $D_1$ and $D_2$ of the system (16). Three received coordinates are the equation of two planes. The line of intersection of the planes intersects the plane of $h$ and $\omega$ at the point whose values are roots of the system equation (16).

3. Results and considerations

As the result of the described calculation algorithm we get the dependence of the oscillation frequency $\omega$ and the damping parameters of $h$ of the elastic tube-distributor on the speed of the air-grain flow (figure 2).

Figure 2. The dependence of the frequency $\omega$ and the damping parameter $h$ of the elastic tube-distributor on the speed of air-grain flow $v$ in the first form of oscillations.

The results of numerical calculations.
Figure 3. Dependence of frequency of oscillations $\omega$ and the damping parameter $h$ of the elastic tube-distributor on the speed $v$, the second form of oscillations ($N=5.5$ million pieces/ha, $V_m=2.5$ m/s, $L=0.07$ m, $EI=5\cdot10^{-4}$ N·m).

The graph (figure 2) shows that the increase in the rate of air-grain flow in the first form of oscillation leads at first to an increase in the frequency of oscillation $\omega$, and then to decrease to zero, and the damping parameter $h$ has a negative value. This phenomenon shows the lack of steady oscillations at any speed of the flow, that is why this form of oscillations does not have any significant influence on seed distribution below the spinning wheel. The appearance of stable oscillations is observed in the second form of oscillations (figure 3), when the parameter $h$ turns from the negative into the positive region, thus increasing the frequency $\omega$. With increasing seeding rate and $N$ and the speed of the unit $V_m$, the moment of transition of the damping parameter $h$ in the positive region occurs at lower speeds of air-grain flow $v$.

The analysis showed that if the hardness of the material is $EI=5\cdot10^{-4}$ N·m², the appearance of oscillation frequencies $\omega$ can be observed at the speed of $v=10$ m/s, if the hardness of the material increases this parameter can be observed at the speed of more than $v=15$ m/s. To decrease the air flowrate we have chosen the tube made of rubber with the hardness of $EI=5\cdot10^{-4} - 6\cdot10^{-4}$ N·m².

In order to carry out the experiment to determine the evenness we use the stable parameters: the diameter of the air pipe, the hardness of the tube $EI$, the diameter of the elastic tube-distributor. As the variable parameters we take the speed of the air-grain flow $v$ within $0...30$ m/s, the norm of seeding $N$ within $4.0...5.5$ ml pieces/ha, the length of the elastic tube-distributor $L=0.03...0.07$ m with the interval of $0.02$ m and the speed of the rig $V_m=1.0...2.5$ with the interval of $0.5$ m/s.

The results of the laboratory research gave the dependencies of the seed distribution evenness on the speed of the air-grain flow $v$, the norm of the seeding $N$, the length of the elastic tube-distributor $L$, and the speed of the rig $V_m$ (figures 4).

Figure 4. The dependence of the distribution coefficient $P_d$ along the length of the seeding line on the speed of air-grain flow $v$ with $N=4.0$ ml pieces/ha, $V_m=2.5$ m/s.

The analysis of the dependencies (figures 4) shows that the evenness of the seed distribution increases with the increase of the speed of the air-grain flow. Also, the higher increase of the evenness of the seed
distribution can be observed with the increase of the speed of the seeding rig and the elongation of the elastic tube-distributor [5].

4. Conclusion

The result of the research is analytical dependencies, which characterize the deviations of the elastic tube-distributor under the influence of the air flow and seeds as well as the seeding distance below the spinning wheel. The numerical calculation of the differential equations and graphical dependence revealed a range of stable oscillations of differential equations and graphical dependences revealed a range of stable oscillations of the elastic tube-distributor with the frequency range of $\omega=9…20$ s$^{-1}$ and the air-grain flow speed range of $v=10…25$ m/s.

The experiments helped to determine the fact that the use of the coulter with the elastic tube-distributor allows increasing the distribution evenness of the seeds below the spinning wheel along the length and width of the seeding line correspondingly $P_d=71\pm2\%$ and $P_w=73\pm1.7\%$.

References

[1] Alekseev E P, Vasiliev S A and Maksimov I I 2018 Investigation of seed uniformity under field and laboratory conditions IOP Conf. Ser.: Mater. Sci. Eng. 450 062011

[2] Smirnov M, Smirnov P, Alexeev E, Kazakov Y and Prokopeva E 2019 Influence of soil-protective technologies on the characteristics of the soils of hop plants IOP Conf. Ser.: Earth and Environmental Science 346(1) 012018

[3] Smirnov P A, Makushev A E, Kazakov Y F, Vasilyev A O and Andreev R V 2019 Influence of types of tractor running gears on the value of hop garden row spacing compaction INMATEH - Agricultural Engineering 57(1) 19-28

[4] Alexseev E P et al 2011 RF Patent 2423037 Byull. Izobret. 19

[5] Vasilyev S A, Maximov I I, Vasilyev A A and Vasilyeva E A 2018 Elaborating of the device for the importation of liquid ameliorants into the soil IOP Conf. Ser.: Mater. Sci. Eng. 450 062011