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THEORETICAL RESEARCHES OF SEED MOVEMENT IN RADIAL SEED TUBE

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Abstract. The article presents theoretical studies of seeds movement in the radial seed tube. Mathematical dependencies that describe the movement of seeds in the air stream through the rotating seed tube have been established. The pattern of seeds moving along the seed tube in the function of the rotation angle, depending on the airflow speed and the angular speed of the planting section working wheel, has been determined. It has been proved, that to ensure the process of seed supply to the shutting working body, the air stream speed in the seed tube should be in 3... 4 times higher than the critical seed speed.

Key words: Rotating seed tube; Airflow; Second-order differential equation; Angular rotor speed; Taylor's range; Critical seed speed.

INTRODUCTION

One of the reasons leading to the disruption of the normal functioning of the technological process of the rotary-hole seeder is the long duration of the movement of seeds through the seed tube. It is proved that increasing the speed movement of the seeder occurs seed ejection on soil surface, due to the delay in the seeds supply to hole formers. Therefore, in order to make an reasonable choice of seeder working regimes and to manage them correctly, it is necessary to have data about seeds movement patterns through the seed tubes. The seed tubes of a rotary-hole seeder in rotor rotation plane can, in principle, be installed with different axial orientations. The seed tube leading directional parameter can be the angle formed by the longitudinal axis of the seed tube and rotor radius passing through the alveolar (suction cup) of the sowing device.

Theoretically, it is impossible to exclude options with any values of seed tube installation angle. However, the most practical interest represents, of course, seeders with the installed seed tube at angles of 0 ... 0...π/2 radians. Further, seed tubes with a zero-installation angle will be called radial, with an installation angle of π/2 radian-tangential.

MATERIALS AND METHODS

The seed, separated from the sucker and caught in rotating seed tube channel, begins to move along it in airflow (Figure 1). In this way, the applied force to the seed also includes the force of the air force, which is determined by the well-known formula (Летошнев, М.Н. 1955; Турбин, Б. Г. и др. 1967):

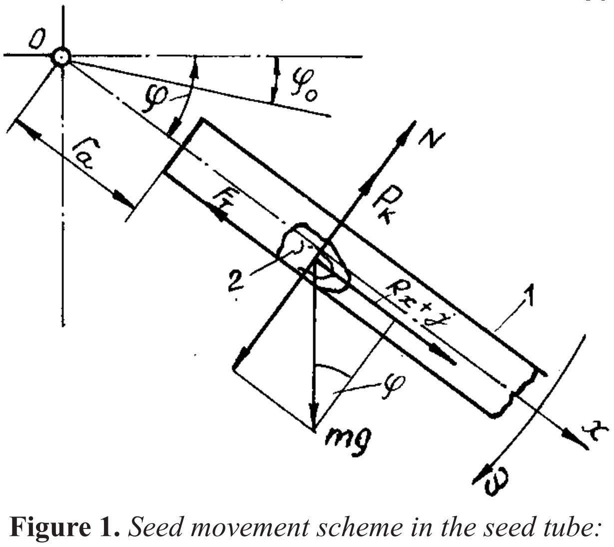


Figure 1. *Seed movement scheme in the seed tube:*
1-seed; 2-seed; r_a- radius of sowing device; φ-rotation angle of seed tube; φ_o - seed dropping angle in seed tube; R_x - air jet force acting on the seed; P_x - Coriolis acceleration force.

$$R_x = k\rho F(u - \dot{x})^2 \tag{1}$$

where: F - mid-cut seed section;

u - air speed in the seed tube;

x- seed speed relative to seed tube

In the force's projections on the coordinate axis, the equation of seed movement in the seed tube will be as follows:

$$m\ddot{x} = R_x + j + mgSin\varphi - F_T \tag{2}$$

$$N + P_k - mgCos\varphi = 0 \tag{3}$$

Meaning that:

$$F_T = fN = f\left(mgCos\varphi - P_k\right) \tag{4}$$

We get:

$$m\ddot{x} = k\rho F(u - \dot{x})^2 + m\omega^2 x + mgSin\varphi - f\left(mgCos\varphi - 2m\omega\dot{x}\right) \tag{5}$$

By dividing all the terms of this equation by the mass of the seed, it will have:

$$\ddot{x} = k_{\ddot{\imath}}(u - \dot{x})^2 + \omega^2 x + gSin\varphi - f\left(gCos\varphi - 2\omega\dot{x}\right) \tag{6}$$

The following observation is required regarding the resulting equation. As can be seen from the equilibrium equation, the seed bond reaction, caused by gravity and Coriolis, can change in direction depending on what sum sign of these forces will be. What is clear is that with the increase in the seed tube rotation angle and with the increasing seed movement speed, the effect of the Coriolis force on the reaction of the connection will become predominant. Then according to (4), provided that the , force of friction in the specified expression changes its direction. In fact, this does not happen. Therefore, when solving the equation of reaction of the seed relation with the seed tube should be taken by its absolute value i.e.

$$\ddot{x} = k_{\ddot{\imath}}(u - \dot{x})^2 + \omega^2 x + gSin\varphi - f\left|gCos\varphi - 2\omega\dot{x}\right| \tag{7}$$

Thus, the seed movement in the seed tube is described by the second-order differential equation, which is non-linear relative to the first derivative function. As is known, equations of this type are not solved in quadrature (Камке, Э. 1976). To solve such equations approximate methods are usually used. We will look for a solution to this equation in the form of Taylor's series by sequentially differentiating (Бермант, А.Ф., Араманович, И.Г. 1971; Пискунов, Н.С. 1978; Корн, Г., Корн, Т. 1984; Бронштейн, И.Н., Семендяев, К.А. 1986). A function of type x = f (t) expanded in a Taylor's series has the form:

$$x = f(t) = f(t_0) + \frac{f'(t_0)}{1!}(t - t_0) + \frac{f''(t_0)}{2!}(t - t_0)^2 + \frac{f'''(t_0)}{3!}(t - t_0)^3 + \ldots + \frac{f^n(t_0)}{n!}(t - t_0)^n \tag{8}$$

Applied to the equation being solved, we express time through the seed tube rotation angle. Because $\omega t_0 = \varphi_0, \omega t = \varphi$ we will have:

$$t_0 = \frac{\varphi_0}{\omega}; t = \frac{\varphi}{\omega}$$

where: φ - seed tube rotation angle,

ω - seed tube angular speed.

Therefore, the desired equation solution, expressed in the formula of Taylor's series, will be as follows:

$$x = f\left(\frac{\varphi}{\omega}\right) = f\left(\frac{\varphi_0}{\omega}\right) + \frac{f'\left(\frac{\varphi_0}{\omega}\right)}{1!}\left(\frac{\varphi - \varphi_0}{\omega}\right) + \frac{f''\left(\frac{\varphi_0}{\omega}\right)}{2!}\left(\frac{\varphi - \varphi_0}{\omega}\right)^2 +$$

$$+ \frac{f'''\left(\frac{\varphi_0}{\omega}\right)}{3!}\left(\frac{\varphi - \varphi_0}{\omega}\right)^3 + \ldots + \frac{f^n\left(\frac{\varphi_0}{\omega}\right)}{n!}\left(\frac{\varphi - \varphi_0}{\omega}\right)^n \tag{9}$$

Let's show the validity of the expansion of this equation in a row. First of all, it should be noted that the function under consideration has sufficient signs of convergence: firstly, it is differentiable infinitely many times, secondly, all members of the series are positive, moreover, the general term of the series with an unlimited increase in its number tends to zero.

$$\frac{\varphi - \varphi_0}{\omega} \langle 1 \tag{10}$$

The interval or numerical axis, on which the convergence of this series is examined is determined from the operating conditions of the seeder sowing system. As it can be seen from figure 1, the seed from the alveoli, gets into seed tube when it is rotated through an angle φ_o. Subsequent seed movement along the seed tube continues until it rotates through an angle, which, according to the conditions of the problem, should not exceed π/2 radian:

$$\varphi \leq \frac{\pi}{2} \tag{11}$$

Thus, the seed movement, expressed in a series of Taylor function, interest us only in the numerical axis interval, limited by the rotation angles of φ_0 and π/2. However, not every seed tube angular velocity satisfies the sign of convergence. From (10) we find that:

$$\omega \rangle \left|\varphi - \varphi_0\right|$$

So in the range of seed tube rotation angles with boundary values (j_0 =0; j_0 = π/2) we have:

$$\omega = \frac{\pi}{2} = 1{,}52 ðàä / c \tag{12}$$

The practical value of the seeder rotor angular speed is 4...10 rad/s. Therefore, it is obvious that this condition for the convergence of the series is fulfilled with a large margin. Therefore, for the seed tube angular speed exceeding the speed of 1.52 rad/s, the resulting series has signs of convergence, and its sum in the rotation angles range of (φ_o, π/2) tends to the value of the desired function. The problem solution accuracy is limited by a member of the series, containing the fourth derivative function. The terms coefficients of the series are found by equation (7) sequential differentiation.

$$x''' = 2k_{ï}\left(x'x'' - ux''\right) + \omega^2 x' + g\omega Cos\varphi - f\left|- g\omega Sin\varphi - 2\omega x''\right|.. \tag{13}$$

$$x'''' = 2k_{ï}\left(\left(x''\right)^2 + x'x''' - ux'''\right) + \omega^2 x'' - g\omega^2 Sin\varphi - f\left|- g\omega^2 Cos\varphi - 2\omega x'''\right|.. \tag{14}$$

Initial conditions of seed movement:

$$\varphi = \varphi_0;\ x_0 = r_a \Rightarrow f\left(\frac{\varphi_0}{\omega}\right);\ x_0' = f\left(\frac{\varphi_0}{\omega}\right) = 0 \tag{15}$$

where: r_a – alveoli device radius, or the distance from the seed tube to the rotation axis.

Other members coefficients of the series are determined from the expressions:

$$x'' = f''\left(\frac{\varphi_0}{\omega}\right) = k_{ï}u^2 + \omega^2 x_0 + gSin\varphi_0 - fgCos\varphi_0 \tag{16}$$

$$x_0''' = f'''\left(\frac{\varphi_0}{\omega}\right) = -2k_{ï}ux_0'' + g\omega Cos\varphi_0 - f\left|-g\omega Sin\varphi_0 - 2\omega x_0''\right| \tag{17}$$

$$x_0'''' = f'^{v}\left(\frac{\varphi_0}{\omega}\right) = 2k_{ï}\left(\left(x_0''\right)^2 - ux_0''\right) + \omega^2 x_0'' - g\omega^2 Sin\varphi_0 -$$
$$- f\left|-g\omega^2 Cos\varphi_0 - 2\omega x_0'''\right| \tag{18}$$

To determine the numerical values of the series coefficients and the function as a whole, we will set specific conditions and physical characteristics of the object under study that are close to reality. To do this, we will use the study results of physico-mechanical properties of sugar beet seeds, which showed friction coefficient, when moving in ethylene seed tube, f= 0.54...0.67 (φ= 30...34⁰) and windage coefficient $K_п$= 0.1, 1/m.

We will also ask for the following technical data:

r_a = 0,085 м.; j = 30 ⁰

The calculations of the function coefficients were made on the personal computer ASUS OEMI 10728. Their numerical values, obtained at seed tube angular speeds of 5 and 8 rad/s varying from 0 to 40 m/s airflow speed, are shown in table 1.

By substituting these coefficients into function (9) expanded in the Taylor series, we obtain formulas for calculating the path of seeds movement. For example, for rotor angular speed of 8 rad/s and zero airflow speed in the seed tube, the calculation formula will be as follows:

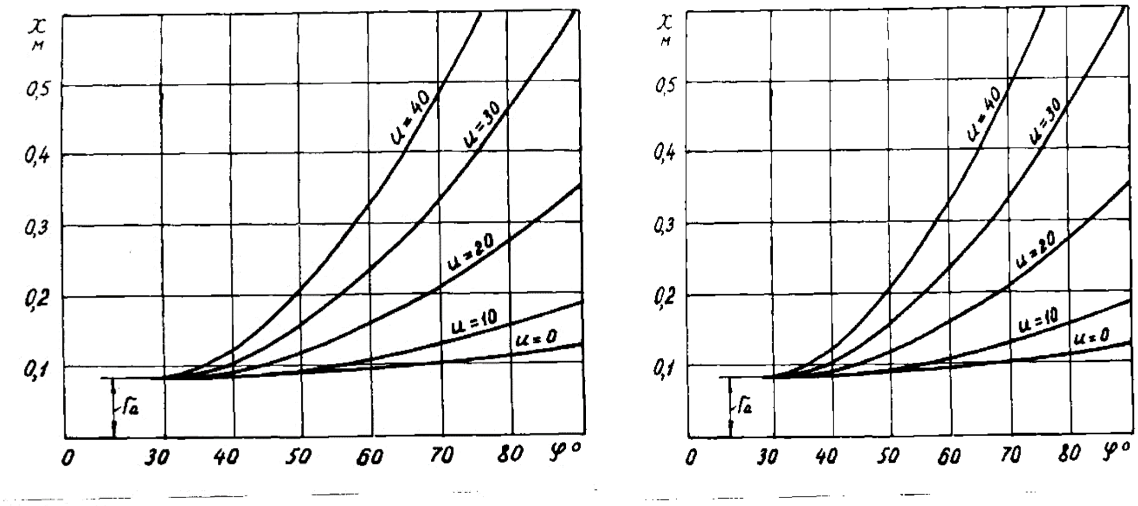
$$x_0 = 0,085 + \frac{4,6}{2!}\left(\frac{\varphi - 30}{8}\right)^2 - \frac{8}{3!}\left(\frac{\varphi - 30}{8}\right)^3 + \frac{340}{4!}\left(\frac{\varphi - 30}{8}\right)^4 \tag{19}$$

Table 1. *Member ratios of functions row*

ω	u, м/с	0	10	15	20	25	30	40
	$\tilde{o}_0'$	2,2	12,2	24,7	42,2	64,7	92,2	-
5	$\tilde{o}_0''$	16,0	-65,4	-18,6	-380	-664	-1050	-
	$\tilde{o}_0'''$	-35	684	1728	3414	5915	9438	-
	$\tilde{o}_0'$	4,6	14,6	27,2	44,6	67,2	94,6	164,94
8	$\tilde{o}_0''$	-8,2	-145	-331	-616	-1014	-1541	-3041
	$\tilde{o}_0'''$	340	2453	5300	9627	15684	23750	47188

RESULTS AND DISCUSION

The function data calculation is summarized in the chart (Figure. 2). When analyzing the results of the calculations, first of all, an extremely insignificant seeds movement in the absence of air flow in the seed tube is noted. So, when the seed tube rotates by a final angle equal to 90°, this movement relative to the alveolar disk, depending on the angular speed, is only 69 and 41 mm. The air flow speed of 10 m/s does not significantly affect the seed movement, although it is accelerated by 2 times compared with the movement at zero airflow speed. This, however, indicates that the airflow is a very effective means for intensifying the seeds movement in the seed tube. With an increase in the airflow speed, the increment rate of the seed path increases. Moreover, for different angular speed this increment is different. So, for example, for an angular speed of the seed tube 5 rad/s with an airflow speed of 20 m/s and when the seed tube rotated at an angle of 80°, the absolute movement of the seed is 0.524 m, while at an angular speed equal to 8 rad/s, and the same others conditions, the seed will pass a path equal to only 0.275 m. This confirms the earlier established patterns according to which the seed movement path decreases with an increase in the angular speed of the seeder wheel.



a) b)

Figure 2. *Chart of seed path in seed tube (a) - at angular speed ω= 5 rad s⁻¹; b) - at angular speed ω=8 rad s⁻¹.*

In conditions of seed movement intensification by airflow, this pattern, as we see, is manifested even more. The studied movement significantly depends on seeds windage coefficients.

It is logical to assume that seeds with low windage coefficients, under the same conditions, will travel a smaller path. Calculations of the movement of corn seeds with a windage coefficient $K_п$= 0.05 1/m, performed for the same conditions as for sugar beet seeds, confirm this. From the corn seeds movement chart (Figure 3) can be seen, that when the airflow speed in the seed tube is 20 m/s, in the phase of seed tube rotation by 80°, the seed passes the path of 0,2 m, while the path of the sugar beet seed in the same phase reaches 0,28 m. With an increase in air flow rate, this difference increases.

Analysis of obtained calculated data allows to determine the value of airflow speed in the seed tube, which ensures the timely transportation of seeds to the furrow opening devices. If we consider 0,25...0,40 m the optimal radius of hole wheels of the seeder, the airflow speed in the seed tube 30...40 m/s can be considered quite acceptable for practical support of the seeder normal operation.

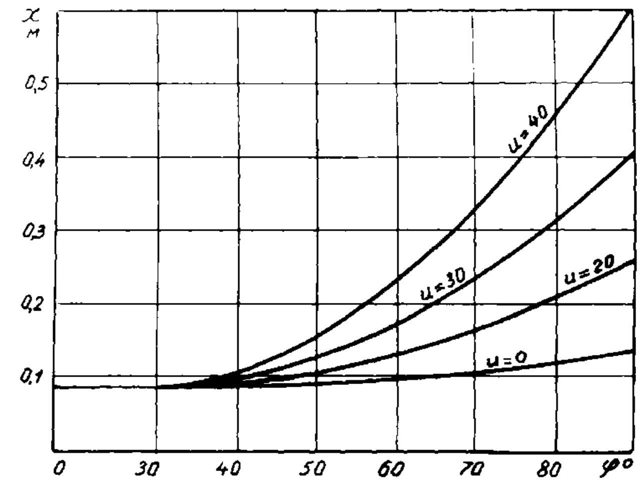


Figure 3. *Seed moving schedules with windage coefficient $K_п$= 0,05 m^{-1} at angular speed ω=8 rad·s^{-1}*

Since the critical seed speeds of different row crops vary within 9...14 m/s [3], this, in essence, means that the airflow transporting speed must be commensurate with three or four times the critical seed speed:

$$u = (3...4)V_{\text{кр}} \quad (20)$$

Or:

$$u = (3...4)\sqrt{\frac{g}{k}}. \tag{21}$$

The same ratio, expressed in terms of the seed windage coefficient, makes it possible to numerically predict the airflow speed in the seed tube, in particular for sugar beet seeds:

$$u = (3\ldots4)\sqrt{\frac{9{,}8}{0{,}1}} \approx 30\ldots40\,\text{ì ñ}^{-1}$$

and corn seeds:

$$u = (3\ldots4)\sqrt{\frac{9.8}{0{,}05}} \approx 42\ldots56\,\text{ì ñ}^{-1}$$

CONCLUSIONS

Differential equations describing the seeds movement with airflow in rotating radial seed tube have been composed and resolved.

The process output parameters revealed the advantages of radial seed tubes and the priority of their use in rotary-hole seeders.

The pattern of seed moving along the seed tube in the function of rotation angle, depending on airflow speed and wheel angular speed, has been established. At the same time, it has been proved that the airflow speed in the seed tube, which provides timely seed supply to the furrow opening devices in the technologically determined interval angle, should be 3...4 times higher than the seed critical speed.

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