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Justification of parameters of seed treater with an eccentrically fixed drum influencing the motion character and seed treatment modes

Eduard Khasanov, Ildar Gabitov, Salavat Mudarisov, Rim Khamaletdinov, Zinnur Rakhimov, Ilshat Akhmetyanov, Ildar Farkhutdinov*, Ilgam Masalimov, Radik Musin

Federal State Budgetary Educational Establishment of Higher Education "Bashkir State Agrarian University", Ufa 450001, Bashkortostan, Russia
**Corresponding author:* hasan_ed@mail.ru

Abstract

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The examination of the state of the problem shows that the lack of serial treating machines capable of high-quality, high-coverage treatment with microbiological preparations prevents the widespread practice of treating seeds with biological products. Among the machines produced, the most suitable for using microbiological preparations are drum-type treaters, in which the distribution of a biological product is carried out using a nozzle, which does not have a detrimental effect on microorganisms. However, the quality of their work, assessed by the coefficient of seed surface coverage with the preparation, does not exceed 70%, which does not meet agro-technical requirements. In this regard, the aim of the work is to improve the quality of seed coverage with a biological preparation with a drum-type treater by improving and substantiating its structural and technological parameters. It was established that in order to improve the quality of the treatment process with drum treaters, a non-stationary mode of moving seeds inside the working drum is necessary. This is realized by eccentric fastening of the drum, which ensures the non-stationary mode of moving seeds relative to the working surface during its operation. As a result, its working surface is most fully used and, as a result, the quality of the seed treatment process is improved. The technique is considered and a mathematical model of seed movement in a drum treatment machine for pre-sowing treatment is proposed, which provides an increase in the quality of the coating. The studies of the seed movement inside an eccentrically fixed drum are carried out. The paper deals with dependences that determine the conditions of relative dormancy and detachment of the seed from the inner surface of the drum. The proposed mathematical model of the movement of a seed inside an eccentrically fixed drum of a seed treater allows its structural and technological parameters to be determined during non-stationary operation.

*Keywords***:** plant science; drum treatment; machine; pre-sowing treatment; seed movement; non-stationary mode; coating quality

Introduction

One of the main conditions for obtaining high yields of grain crops is the use of high-quality seeds (Hozzein et al., 2019). In the complex of measures ensuring the obtaining of seeds of good quality, the correct implementation of measures to combat fungal, bacterial and virus diseases of plants, and especially those of them that are transmitted through seed material, is important (Kamaletdinov et al., 2009a; Li et al., 2018). Diseases of cereals propagating through seeds impair their sowing qualities and cause a significant decrease in yield. In addition, infected seeds are a source for the further

spread of plants diseases (Kadege & Lyimo, 2015; Lopez-Reyes et al., 2016; Zegeye et al., 2017).

Currently, the main method of protecting seeds from pests and diseases is the use of chemicals (treatment). It allows reducing potential yield losses by 50-55% (Cessna & Westcott, 2018), which determines its primary use in plant protection systems, in addition, seed treatment is a more cost-effective way to control diseases than spraying crops (Najar et al., 2017).

However, in most developed countries of the world, scientists have come to the unequivocal conclusion (Nasu et al., 2018). This is due to the fact that all chemical preparations, as well as dust emissions during their seed treatment, cause chronic poisoning of soil, water and air (Zaller et al., 2016; Rudelt et al., 2017), and the accumulated residues in agricultural food and feed reduce their biological value and safety (Annis, 2016).

Currently, technologies have been developed for the production and use of biological products based on symbiotic and associative nitrogen-fixing and phosphate-mobilizing microorganisms, as well as microorganisms producing phytohormones, vitamins, organic acids, antibiotics and other biologically active substances (Gurav et al., 2017).

This helps to improve the mineral nutrition of plants, increase their resistance to various stresses and phytopathogens, increase yields and quality of crop production while preserving and fertility of the soil (Ivantsova et al., 2015; Kosulnikov & Laktionov, 2018; Moharam et al., 2018; Oral et al., 2018). But the widespread use of biological products in the practice of agriculture is hampered by the fact that there are no technical means for seed treatment of grain crops adapted for using microbiological preparations, which in turn significantly reduces their effectiveness (Kamaletdinov et al., 2007). We have investigated the influence of technological processes occurring in technical means for treatment on the vital activity of bacteria of the genus *Bacillus subtilus*. According to them, when using devices that distribute a biological product using discs, the microorganisms used are significantly inhibited, while the effect of overpressure, spraying through a nozzle, and seed treatment in the drum did not affect the development of colonies of microorganisms (Kamaletdinov et al., 2007).

In addition, our research on injuring seeds during their pre-sowing treatment showed that their least damage occurs when using drum treaters ((Kamaletdinov et al., 2009a), the disadvantage of which is the stationary mode of seed movement that does not allow full use of the working volume of the treater chamber (Figure 1a) (Reznichenko, 1964).

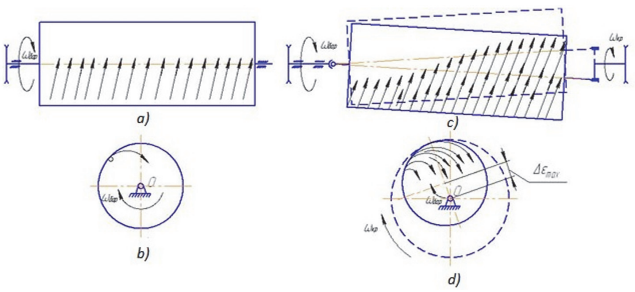

Fig. 1. Using the working volume of the drum: *a* – traditional drive method (top view); *b* – the proposed drive method (top view); *c*, *d* – the cross section of the drum with the traditional and the proposed methods of drives

The long-term experimental studies have established that eccentric fixing of the drum of the treater with the correct choice of the kinematic mode provides a non-stationary mode of moving the seeds (Figure 1c). Based on the obtained results, we developed a device for pre-sowing treatment of seeds, which was confirmed by a patent for a useful model (Kamaletdinov et al., 2009b).

On this basis, it is advisable to use drum-type treaters, in which the distribution of the biological product is carried out using a nozzle. An urgent task is the modernization of the drum treater with the introduction of new structural and technological parameters that provide a more complete coverage of the seed surface with biological products while simultaneously sparing the effects on biological products and seeds. The purpose of the study is to build a mathematical model of the movement of seeds in a drum-type treater with a non-stationary mode of movement.

Material and Methods

In drum treaters mixing occurs in a rotating drum with the free fall of the components lifted by the drum wall due to friction forces arising between the wall surface and the material being mixed. The duration of mixing depends on the angle of the drum to the horizon.

In the study of such installations, as a rule, it is assumed that the movement of bulk material in the drum is similar to the movement of one of its particles, taken as a material point, and the coefficient of sliding friction is taken to be a

constant value, which corresponds to its average value along the entire path of movement along the surface.

The steady-state cycle of particle motion inside a rotating drum manifests itself in three variable states (Figure 2):

- 4-1 – relative rest;
- 1-2; 3-4 – relative movement on the drum surface;
- 2-3 – free movement.

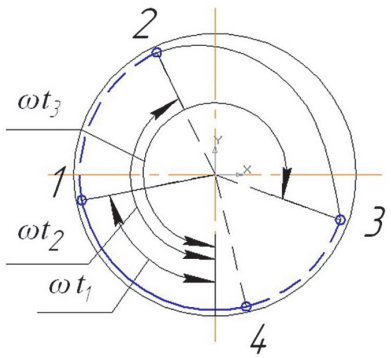

Fig. 2. Cycle phases of the motion of a material point on the surface of the drum

Of practical importance is the state of free movement of the particle, when there is full (over the entire surface) contact of the particle with the working mixture.

In turn, the mode of operation of the treater is characterized by the length of the trajectory of the particle flight in the phase of free movement. If at the steady-state mode of the flight paths of a particle obey the law of Gaussian distribution, then in the non-stationary mode there is no pattern in the distribution of the length of the flight of particles. Obviously, the entire working volume of the drum of the treater will be used most fully.

Let's consider the movement of a particle in the 4-1 state (Figure 2), when the grain is at rest relative to the drum wall, that is, it moves without sliding. The following forces act on the particle (material point M with mass *m*) (Figure 3):

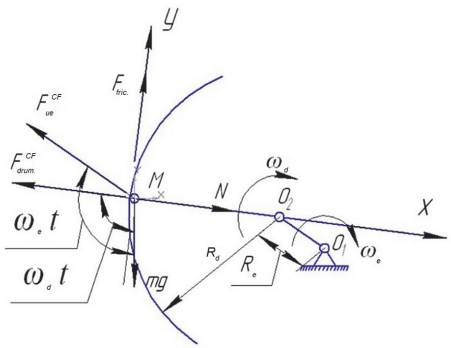

Fig. 3. Diagram of the forces acting on the material point *M* in the 4-1 state

$F_{fric.}$ – is the friction force of the particle on the surface of the drum, directed tangentially to the surface in the direction of rotation of the drum:

$$F_{fric.} = N\text{tg}\phi, \tag{1}$$

where N is the reaction force of the support (drum wall); – is the coefficient of particle friction, which depends on its type and the surface of the drum; tgϕ – is gravity, directed vertically downwards.

F^{CF}_{drum} – is centripetal force of inertia of the grains, resulting from the rotational motion of the drum:

$$F^{CF}_{drum} = m\omega^2_d R_d, \tag{2}$$

where ω_d – is the angular velocity of rotation of the drum; R_d – is the radius of the drum.

$F^{CF}_{eccentr.}$ – is the centripetal force of inertia of the particle, arising due to the rotational motion of the eccentricity:

$$F^{CF}_{eccentr.} = m\omega^2_e R_e, \tag{3}$$

where ω_e – is the angular velocity of rotation of the eccentricity; R_e – is the magnitude (radius) of eccentricity.

Let's accept the coordinate system M_x and M_y. The axis M_x is directed to the center of the drum from a point M, the axis M_y is directed tangently to the circumference of the drum at a point M in the direction of rotation of the drum. Regarding the adopted reporting system, the sum of all forces acting on the grain M is zero, therefore the projections of these forces on the axes M_x and M_y are equal to zero:

$$\sum FM_x : N + mg\cos(\pi - \omega_d t) - F^{CF}_{drum} - F^{CF}_{eccentr.}\cos(\omega_e t - (\pi - \omega_d t)) = 0, \tag{4}$$

$$\sum FM_y : F_{fric} + F^{CF}_{eccentr.}\sin(\omega_e t_1 - (\pi - \omega_d t_1)) - mg\sin(\pi - \omega_d t_1) = 0. \tag{5}$$

Let's express the force N from equation (1):

$$N = \frac{F_{mp}}{\text{tg}\phi}. \tag{6}$$

Let's substitute N from expression (6) into equation (4):

$$\frac{F_{fric.}}{\text{tg}\phi} + mg\cos(\pi - \omega_d t) - F^{CF}_{drum} - F^{CF}_{eccentr.}\cos(\omega_e t - (\pi - \omega_d t)) = 0 \tag{7}$$

$$F_{fric.} = F^{CF}_{drum} + F^{CF}_{eccentr.}\cos(\omega_e t - (\pi - \omega_d t))\text{tg}\phi - mg\cos(\pi - \omega_d t)\text{tg}\phi \tag{8}$$

Let's analyze equation (7). For the time when $t_4 \le t \le t_1$ the expression is true:

$$F^{ult.}_{fric.} = F^{CF}_{drum} + F^{CF}_{eccentr.}\cos(\omega_e t - (\pi - \omega_d t))\text{tg}\phi - mg\cos(\pi - \omega_d t)\text{tg}\phi \tag{9}$$

$$F^{ult.}_{fric.} = F^{CF}_{drum} + F^{CF}_{eccentr.}\cos(\omega_e t - (\pi - \omega_d t))\text{tg}\phi - mg\cos(\pi - \omega_d t)\text{tg}\phi \quad (10)$$

where $F^{ult.}_{fric.}$ is the ultimate friction force capable of holding the particle on the inner surface of the drum wall without sliding.

The condition when the particle moves without sliding can be written in the following form:

$$F^{ult.}_{fric.} \le F_{fric.} \quad (11)$$

Over time, i.e. with an increase t, the component of gravity on the axis M_x $mg\cos(\pi - \omega_d t)$ will increase due to an increase in the angle $\omega_d t$. This will lead to the fact that at the moment of time t_1 the right side of inequality (11) decreases to a value $F^{ult.}_{fric.}$. Inequality (11) takes the form:

$$F^{ult.}_{fric.} = F^{CF}_{drum} + F^{CF}_{eccentr.}\cos(\omega_e t - (\pi - \omega_d t))\text{tg}\phi - mg\cos(\pi - \omega_d t)\text{tg}\phi \quad (12)$$

Equation (12) characterizes the position of the particle at point 1 (Figure 2), when the grain begins to slip relative to the drum surface.

Equation (12) for the moment of time t_1 takes the form:

$$F^{ult.}_{fric.} + F^{CF}_{eccentr.}\sin(\omega_e t_1 - (\pi - \omega_d t_1)) - mg\sin(\pi - \omega_d t_1) = 0 \quad (13)$$

Let's express $F^{ult.}_{fric}$ from equation (13):

$$F^{ult.}_{fric.} = mg\sin(\pi - \omega_d t_1) - F^{CF}_{eccentr.}\sin(\omega_e t_1 - (\pi - \omega_d t_1)) \quad (14)$$

Equating the right sides of equations (12) and (14), we obtain the equation for determining the time t_1:

$$F^{CF}_{drum} + F^{CF}_{eccentr.}\cos(\omega_e t_1 - (\pi - \omega_d t_1))\text{tg}\phi - mg\cos(\pi - \omega_d t_1)\text{tg}\phi = mg\sin(\pi - \omega_d t_1) - F^{CF}_{eccentr.}\sin(\omega_e t_1 - (\pi - \omega_d t_1))$$

$$F^{CF}_{drum} + F^{CF}_{eccentr.}\cos(\omega_e t_1 - \omega_d t_1 - \pi))\text{tg}\phi - mg\cos(\pi - \omega_d t_1)\text{tg}\phi - mg\sin(\pi - \omega_d t_1) + F^{CF}_{eccentr.}\sin(\omega_e t_1 + \omega_d t_1 - \pi) = 0 \quad (15)$$

Using the reduction formulas, simplifying equation (15), we obtain:

$$F^{CF}_{drum} - F^{CF}_{eccentr.}\cos(\omega_e t_1 - \omega_d t_1)\text{tg}\phi + mg\cos(\omega_d t_1)\text{tg}\phi - mg\sin(\omega_d t_1) - F^{CF}_{eccentr.}\sin(\omega_e t_1 + \omega_d t_1) = 0 \quad (16)$$

Substituting the expressions F^{CF}_{drum} and $F^{CF}_{eccentr.}$ from (2) and (3) into equation (16) and reducing both parts to m, we get:

$$\omega_d^2 R_d - \omega_e^2 R_e\cos(\omega_e t_1 + \omega_d t_1)\text{tg}\phi + g\cos(\omega_d t_1)\text{tg}\phi - g\sin(\omega_d t_1) - \omega_e^2 R_e\sin(\omega_e t_1 + \omega_d t_1) = 0 \quad (17)$$

Equation (14) allows us to determine the time t_1 when the particle begins to slip against the drum surface. In turn, time allows us to determine the angle $\omega_d t$ – how much the drum turns before the particle starts to slip, and the angle $\omega_e t$ – the position of the eccentricity at the moment the particle starts to slip.

A distinctive feature of the behaviour of a particle in the 1-2 state is (Figure 4) that the particle moves relative to the surface of the drum with negative angular acceleration .

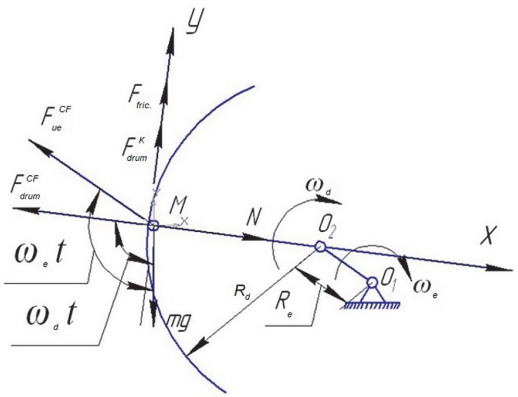

Fig. 4. Diagram of the forces acting on the material point *M* in the state of 1-2

As a result, the particle is additionally affected by one more force F^{TF}_{drum} – the tangential force of inertia of the particle relative to the drum, directed along the tangent to the circumference of the cross section of the drum in the direction of rotation of the drum. Force F^{TF}_{drum} is expressed as:

$$F^{TF}_{drum} = m\varepsilon R_d. \quad (18)$$

The position of the particle relative to the surface of the drum is determined by the angle $\omega_d t - \omega t$ where ω is the angular velocity of the grain relative to the surface of the drum, c^{-1}.

The projection of forces on the axis M_x and M_y allows defining two equations:

$$\sum FM_x = 0 : N + mg\cos(\pi - (\omega_d t - \omega t)) - F^{CF}_{drum} - F^{CF}_{eccentr.}\cos(\omega_e t - (\pi - (\omega_d t) = 0 \quad (19)$$

$$\sum FM_y = 0 : F_{fric} + F^{TF}_{drum} + F^{CF}_{eccentr.}\sin(\omega_e t - (\pi - \omega_d t + \omega t)) - mg\sin(\pi - \omega_d t + \omega t) = 0 \quad (20)$$

The joint solution of equations (19) and (20) leads to the following equation:

$$\varepsilon = \frac{d\omega}{dt} = \omega_d^2\text{tg}\phi + \frac{g}{R_d}\cos(\omega_d t - \omega t) + \frac{\omega_e^2 R_e}{R_d}\cos(\omega_e t + \omega_d t) - \frac{\omega_e^2 R_e}{R_d}\sin(\omega_e t - \omega_d t + \omega t) - \frac{g}{R_d}\sin(\omega_d t + \omega t) \quad (21)$$

Under this condition, the detachment of the particle from the surface of the drum is the equality of the reaction N zero:

$$N = 0 \tag{22}$$

The projection of forces on the axis M_x takes the for:

$$mg\sin(\omega_d t - \omega t - 90°) - F^{CF}_{drum} - F^{CF}_{eccentr.}\cos(\omega_e t - \omega_d t + \omega t) = 0 \tag{23}$$

After simplifying the expression, we obtain an equation characterizing the position of the particle at time t_2, when it is detached from the drum surface:

$$\cos(\omega t_2 - \omega_d t_2) + (\omega_d - \omega)^2 R_d + \omega_e^2 R_e \cos(\omega_e t_2 - \omega_d t_2 + \omega t_2) = 0 \tag{24}$$

The absolute speed of the grain at time t_2 relative to the O_2 point is determined by the expression:

$$\Omega = \omega_d - \omega, \tag{25}$$

where Ω is the absolute velocity of the particle.

The angle of inclination of the tangent to the trajectory of the particle at time t_2 is determined by the angle $\omega_d t_2$. The position of the eccentricity is determined by the angle $\omega_e t_2$.

In the future, equation (24) and integration of equation (21) give a system of equations of a mathematical model of the behaviour of a particle in the state of 1-2, with which we can justify the non-stationary mode of movement of seeds within the working drum.

Let's consider the cycle of free movement of a particle (flight) when it moves independently of the surface inside a rotating drum.

We accept the coordinate system with the beginning at the point O_2. We will direct an axis O_2x horizontally; axis O_2y vertically, as shown in Figure 5.

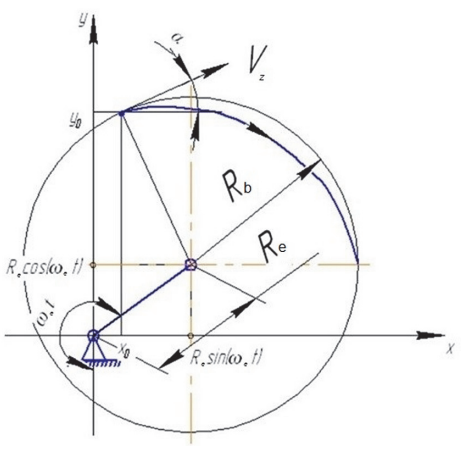

Fig. 5. Calculation scheme

The flight of a body thrown at an angle to the horizon is described as follows:

$$\begin{cases} x = x_0 + V_0 t\cos\alpha \\ y = y_0 + V_0 t\sin\alpha - \dfrac{gt^2}{2} \end{cases} \tag{26}$$

where x_0 is the projection of the point M on the axis O_2xs.

In our case:

$$\begin{aligned} x_0 &= -R_e\cos(\omega_e t_2 - \frac{\pi}{2}) - R_d\cos(\omega_d t_2 - \omega t_2 - \frac{\pi}{2}) = \\ &= R_e\cos(\frac{\pi}{2} - \omega_e t_2) - R_d\cos(\frac{\pi}{2} - \omega_d t_2 + \omega t_2) = \\ &= -R_e\sin(\omega_e t_2) - R_d\sin(\omega_d t_2 + \omega t_2) \end{aligned} \tag{27}$$

V_0 – is the initial particle velocity, $V_0 = V_z$; y_0 – is the projection of the point M on the axis O_2y. For our case:

$$\begin{aligned} y_0 &= -R_e\sin(\omega_e t_2 - \frac{\pi}{2}) + R_d\sin(\omega_d t_2 - \omega t_2 - \frac{\pi}{2}) = \\ &= -R_e\sin(\frac{\pi}{2} - \omega_e t_2) - R_d\sin(\frac{\pi}{2} - \omega_d t_2 + \omega t_2) = \\ &= -R_e\cos(\omega_e t_2) - R_d\cos(\omega_d t_2 - \omega t_2) \end{aligned} \tag{28}$$

$$\begin{cases} t - \text{is the particle flight time, for our case } t_0 = t_2 \\ x = -R_e\sin(\omega_e t_2) - R_d\sin(\omega_d t_2 + \omega t_2) + V_z(t - t_2)\cos\alpha \\ y = -R_e\cos(\omega_e t_2) - R_d\cos(\omega_d t_2 - \omega t_2) + \\ \quad + V_z(t - t_2)\sin\alpha - \dfrac{g(t - t_2)^2}{2} \end{cases} \tag{29}$$

The system of equations (29) describes the motion of a particle during free flight, i.e. it determines the position (coordinates x and y) depending on time t.

The surface of the drum in cross section is projected into a circle described by the following equation:

$$(x - x_0)^2 + (y - y_0)^2 = R^2, \tag{30}$$

where x_0 – is the deviation of the center of the circle along the axis O_2x; $x_0 = R_e\sin(\omega_e t)$; y_0 – is the axis deviation of the center of the circle O_2y; $y_0 = R_e\cos(\omega_e t)$; R – is the radius of the drum, $R = R_d$.

From here:

$$(x - R_e\sin(\omega_e t))^2 + (y - R_e\cos(\omega_e t))^2 = R_d^2. \tag{31}$$

Expression (31) is an equation of a circle with the radius R_d of the drum surface, the center of which, in turn, moves around the circle with a radius R_e (eccentricity) depending on time .

The mutual solution of equation (31) and system of equations (29) gives the coordinates of point 3 (x_3, y_3) at the time when the point of position of the particle M lies on the drum circumference, i.e. it is picked up by the surface of the drum:

$$\begin{cases} x = -R_e\sin(\omega_e t_2) - R_d\sin(\omega_d t_2 + \omega t_2) + V_z(t - t_2)\cos\alpha \\ y = -R_e\cos(\omega_e t_2) - R_d\cos(\omega_d t_2 - \omega t_2) + \\ \quad + V_z(t - t_2)\sin\alpha - \dfrac{g(t - t_2)^2}{2} \\ (x - R_e\sin(\omega_e t))^2 + (y - R_e\cos(\omega_e t))^2 = R_d^2. \end{cases} \quad (32)$$

Thus, the derived system of equations in an implicit form, which allows to determine the time corresponding to a particle hit the drum surface, makes it possible to determine the duration of its free flight, i.e. time when there is a full (over the entire surface) contact of the particle with the bio product.

Substantiation of the design parameters of the treater with an eccentrically fixed drum in the future should be aimed at increasing the duration and achieving the dispersion of the value of this time, which will allow improving the quality of seed treatment and reducing the constructive dimensions of the treater.

Results and Discussion

The derived equations (17, 21, 24) and the system of equations (32) allow us to determine the required values for the study of t_1 (time when the seed begins to slip relative to the drum surface), t_2 (time of the seed position at the moment of detachment relative to the drum surface), ω (angular seed slipping speed relative to the drum surface) and t_3 (time of position of the seed at the moment of crossing with the drum surface).

All determined values are interdependent, so t_1 allows determining t_2 and ω; t_2 and ω allow us to determine t_3; the difference t_3 and t_2 gives in turn Δt. $\Delta t = t_3 - t_2$ – is the seed flight time.

To determine the optimal value of the radius of the crank we use the following method:

• Set the value of R_e;

• Collect a series of data characterizing the ingress of seed onto the drum surface at various positions of the angle of rotation of the crank. Obviously, the full cycle will be one full cycle of the crank around its axis.

We divide the full cycle of crank rotation into 29 sections with 30 points, with step i:

$$i = \frac{\omega_e}{2\pi * 29}, \text{ [s]};$$

where i is the time step corresponding to the angle of rotation of the crank at the angle of $\frac{2\pi}{29}$; ω_e – is the angular velocity of the crank, s^{-1}.

For research, we specify the angular velocity of the crank $\omega_e = 5\ s^{-1}$. Further, after determining the optimal radius of the crank R_e, the angular velocity of the crank ω_e will also be optimized.

The experiment step i is set in time, since the mathematical model includes time t as a variable. The derived equations (17, 21, 24) and the system of equations (32) are transformed in such a way as to be able to change the initial angle of rotation of the crank, i.e. in all expressions $\omega_e t$ t is replaced by $t + i$: $\omega_e t = \omega_e(t + i)$. The angle of rotation of the grain relative to the center of the drum is $\omega_d t$:

$$\omega_d^2 R_d \text{tg}\phi - \omega_e^2 R_e \cos(\omega_e(t_1 + i) + \omega_d t_1)\text{tg}\phi + g\cos(\omega_d t_1)\text{tg}\phi - g\sin(\omega_d t_1) - \omega_e^2 R_e \sin(\omega_e(t_1 i) + \omega_d t_1) = 0 \quad (33)$$

$$\begin{cases} \dfrac{t_2^2}{2}\omega_d^2\text{tg}\phi + \dfrac{g\sin(\omega_d t_2 - \omega t_2)}{R_d(\omega_d - \omega)} + \dfrac{\omega_e^2 R_e \sin(\omega_e(t_2 + i) + \omega_d t_2)}{R_d(\omega_e + \omega_d)} + \\ + \dfrac{\omega_e^2 R_e \cos(\omega_e(t_2 + i) - \omega_d t_2 + \omega t_2)}{(\omega_e - \omega_d + \omega)} + \dfrac{g\cos(\omega_d t_2 - \omega t_2)}{R_d(\omega_d - \omega)} \\ - \dfrac{t_1^2}{2}\omega_d^2\text{tg}\phi - \dfrac{g\sin(\omega_d t_1 - \omega t_1)}{R_d(\omega_d - \omega)} + \dfrac{\omega_e^2 R_e \sin(\omega_e(t_1 + i) + \omega_d t_1)}{R_d(\omega_e + \omega_d)} - \\ - \dfrac{\omega_e^2 R_e \cos(\omega_e(t_1 + i) - \omega_d t_1 + \omega t_1))}{(\omega_e - \omega_d + \omega)} - \dfrac{g\cos(\omega_d t_1 - \omega t_1)}{R_d(\omega_d - \omega)} - \omega = 0 \\ g\cos(\omega t_2 - \omega_d t_2) + (\omega_d - \omega)^2 R_d + \\ + \omega_e^2 R_e \cos(\omega_e(t_2 + i) - \omega_d t_2 + \omega t_2) = 0 \end{cases} \quad (34)$$

$$\begin{cases} x = -R_e\sin(\omega_e(t_2 + i)) - R_d\sin(\omega_d t_2 + \omega t_2) + V_z(t - t_2)\cos\alpha, \\ y = -R_e\cos(\omega_e(t_2 + i)) - R_d\cos(\omega_d t_2 + \omega t_2) + \\ \quad + V_z(t - t_2)\sin\alpha - \dfrac{g(t - t_2)^2}{2}, \\ (x - R_e\sin(\omega_e(t + i)))^2 + (y = -R_e\cos(\omega_e(t + i)))^2 = R_d^2. \end{cases} \quad (35)$$

The time step i will have the following value:

$$i = \frac{5}{2*3.1415*29} = 0.02744 \text{ s}.$$

For different values of $t + i$ from the crank rotation cycle, we determine the value of time t_1 from expression (33) in the MatCad program. We do the same to determine the moments of time t_2, the angular sliding velocities of the grain ω, and the moments of time t_3. Next, the time of flight of the seed Δt is determined, corresponding to different values of the initial angle of rotation of the crank $\omega_e(t + i)$ at the moment the seed hits the surface of the drum.

We increase the value of R_e by 0.003 m until it is possible to determine all the quantities from equation (33) and system of equations (34) and (35). This moment, when one of the equations becomes unsolvable, characterizes the behaviour of the system that goes beyond the variable states of the particle's motion cycle inside a rotating drum.

In our case, the system of equations (34) has become unsolvable when the crank radius value is R_e = 0.054 m.

The optimal value of the crank radius will be determined by the following criteria:

1. Total accumulated flight time $\Sigma\Delta t$, s. It characterizes the total flight time of seeds falling on the drum surface with a step $\omega_e(t + i)$ during one cycle of the crank. The higher the value $\Sigma\Delta t$, the more time the seeds spend in free flight and have full contact with the bio product.

2. Non-stationarity of the mode of movement of seeds is characterized by a spread of values Δt, i.e. interval $\Delta T = \Delta tmin_{max}$, [s]. The higher the value ΔT, the higher the area in the cross section of the drum, which is covered by seeds that are in free flight, and the higher the efficiency of the installation.

3. The radius of the crank R_e. The higher the R_e, the greater the inertial forces acting on the treater nodes, the higher the vibration, the noise and the percentage of seed damage due to the impact. It is necessary to take R_e as little as possible.

For each value of the series Δt, we determine $\Sigma\Delta t$, and ΔT is the amplitude of the curve Δt (Figure 6).

According to $\Sigma\Delta t$, and ΔT we construct dependency graphs $\Delta t = f(t_0)$ for different values of R_e (Figure 7). From Figure 7 it is seen that with increasing R_e the position of the graph $\Sigma\Delta t = f(R_e)$ rises, and the interval of the graph $\Delta T = f(R_e)$ increases.

According to the data $\Sigma\Delta t$ and ΔT we construct dependency graphs $\Sigma\Delta t = f(R_e)$ (Figure 8) and $\Delta T = f(R_e)$ (Figure 9).

Based on the criteria above, we take R_e = 0.03*m* as the optimum value for the radius of the crank. From the graph of dependences $\Sigma\Delta t = f(R_e)$, it can be seen that a further increase in the crank radius does not lead to an increase in the total accumulated flight time of the grain. The interval (amplitude) Δt continues to grow with an increase in the crank radius, but the device vibration and the proportion of damaged seeds increase as well.

To determine the optimal angular velocity of the crank we use a method similar to the method of determining the size of the crank.

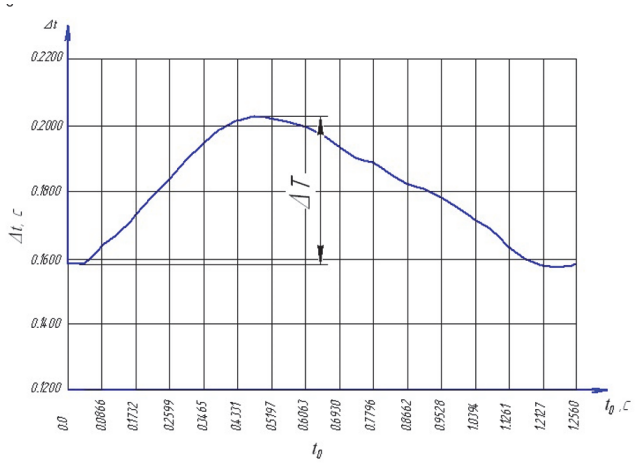

Fig. 6. The graph of dependencies $\Delta t = f(t_0)$ at R_e = 0.03 m

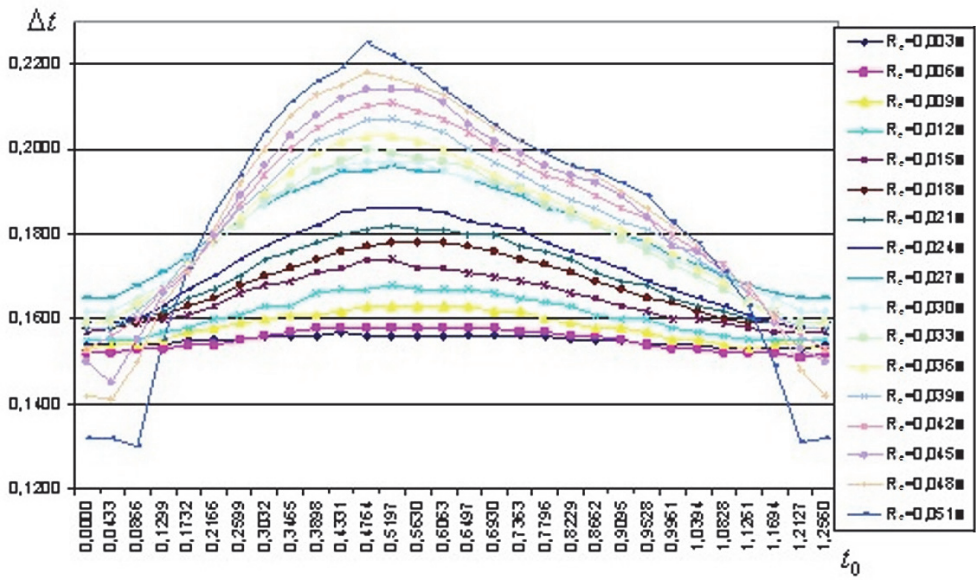

Fig. 7. Graphs of dependences of the duration of the flight of the seed Δt on the time corresponding to the initial angle of rotation of the eccentricity t_0 at different values of the crank radius R_e

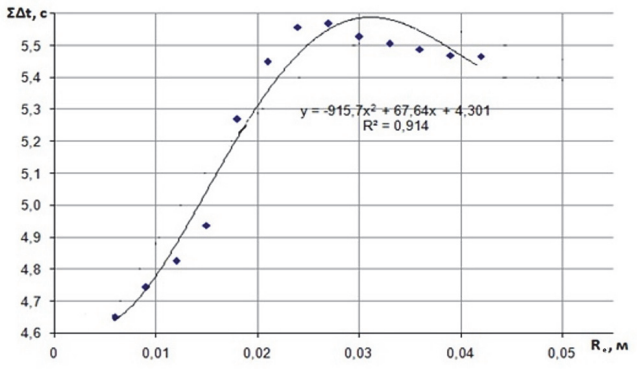

Fig. 8. Graph of dependency of accumulated time of the seed flight $\Sigma\Delta T$ on the radius of the crank R_e

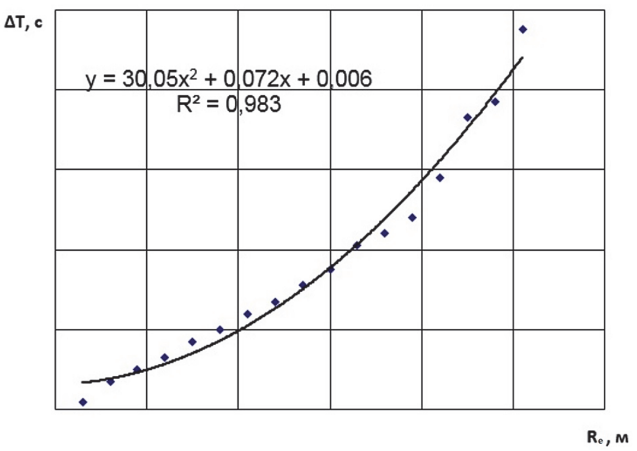

Fig. 9. Graph of the dependence of the descent interval ΔT on the radius of the crank R_e

We are given a series of values of ω_e, for each of which we determine a series of values Δt. We investigate this series, i.e. we determine the total accumulated flight time $\Sigma\Delta t$, we determine the interval of values Δt: $\Delta T = \Delta t min_{max}$. According to the obtained values, we construct dependency graphs $\Sigma\Delta t = f(\omega_e)$ and $\Delta T = f(\omega_e)$, by which we determine the optimal value of the angular velocity of the crank ω_e.

When setting a number of values of ω_e, we use the results of research obtained by us experimentally. Studies have shown that the optimal value of ω_e lies within 4 ... 8 s^{-1}. Proceeding from this, we set a series ω_e = 2; 4; 6; 8 s^{-1}. It also makes sense to use negative values of ω_e, i.e. when the crank rotates opposite to the rotation of the drum. We take the series ω_e = -8; -6; -4; -2; 2; 4; 6; 8 s^{-1}.

When determining the optimal value of ω_e, the full cycle of crank rotation is variable for different values of ω_e. Therefore, for research, we take a series of t values from the interval corresponding to the full crank cycle with the minimum value of ω_e, i.e. when ω_e = 2 s^{-1}. Turnover time is determined from the expression:

$$t = \frac{2\pi}{\omega_e} = \frac{2\pi}{2} = \pi = 3.14 \text{ s.}$$

Obviously, for the time t = 3.14 s, the number of cycles (revolutions) for the case ω_e = 8 s^{-1} will be:

$$N = \frac{\omega_e^{(8)}}{\omega_e^{(2)}} = \frac{8}{2} = 4.$$

On this basis, for greater accuracy of calculations, we divide the time t = 3.14 s not by 29, but by 40 plots and the number of points n = 41.

We define a series with a step:

$$i = \frac{t}{40} = \frac{3.14}{40} = 0.0785 \text{ s.}$$

t = 0; 0.0785; 0.1570;…; 3.14 s

For each value of ω_e we define the results of calculations t_1, t_2, ω, t_3 and Δt for a series of values t = 0; 0.0785; 0.1570; ...; 3.14 s. According to the obtained Δt data, we construct the dependence graph $\Delta t = f(t)$ (Figure 10). It is seen that the graph is a sinusoid tilted to the left. The sine wave period is equal to the crank rotation time.

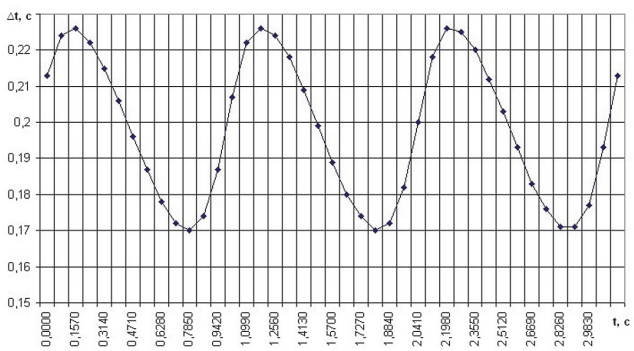

Fig. 10. Dependency graph of seed flight duration on time with ω_e = 6 s^{-1}

According to the Δt data obtained during the calculations, we determine the total accumulated flight time $\Sigma\Delta t$ and the interval ΔT, using the data obtained, we construct the dependency graphs $\Delta T = f(\omega_e)$ (Figure 11) and $\Delta t = f(\omega_e)$ (Figure 12).

From Figure 11 it can be seen that the total accumulated flight time of the grain grows with an increase in the module

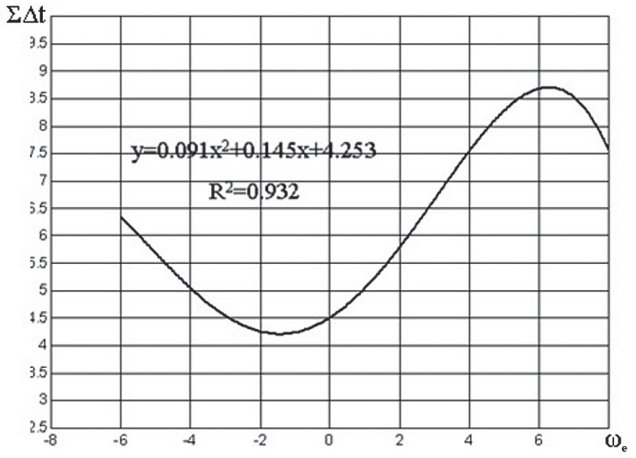

Fig. 11. Graph of dependency of the total accumulated time of flight of the seed ΣΔt o n the angular velocity of the crank ω_e

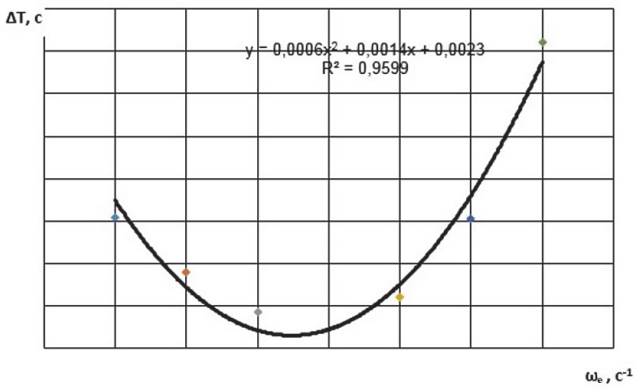

Fig. 12. Graph of dependency of the amplitude ΔT on the angular velocity of the crank ω_e

of the angular velocity of rotation of the crank to ω_e= 6s^{-1} and decreases with its further increase, and the growth of $\Sigma\Delta t$ with negative values of ω_e lags. This suggests that with the same magnitude of the module of the angular velocity of eccentricity, it is more acceptable to choose the direction of rotation of the crank, which coincides with the direction of rotation of the drum. The same explains the slope of the sinusoid – the graph of dependence $\Sigma\Delta t = f(t)$ (Figure 10) and the change in the slope of the sinusoid when the direction of rotation of the crank is changed.

The graph of the dependence $\Delta T = f(\omega_e)$ (Figure 12) generally repeats the behaviour of the graph of the dependence $\Sigma\Delta t = f(\omega_e)$. The graph $\Delta T = f(\omega_e)$ has maximum values at angular velocity values ω_e = -6 s^{-1} and ω_e = 6 s^{-1}. It is seen that the angular speed of rotation of the crank has optimal values at values close in magnitude to the angular velocity of rotation of the drum.

Conclusions

The constructed mathematical model of the movement of the seed inside the eccentrically fixed drum of the seed treater promotes fuller utilization of the working volume of the drum and high-quality coating of seeds with preparations.

Based on the theoretical studies of seed movement in an eccentrically fixed drum and modelling using the Mathcad program, it has been established that the total seed flight time inside the drum increases with an increase in the radius of its crank to 0.03 m and if the direction of rotation of the crank coincides with its direction of rotation. The design and technological parameters of the drum treater are determined at which a high-quality seed coating with a preparation is achieved: crank radius R_e=0.03 m; crank rotation frequency ω_e=6 s^{-1}, and the direction of rotation of the eccentricity coincides with the direction of rotation of the drum.

According to the results of theoretical studies, experimental drum treaters with a capacity of 1.5; 4; 10 t/h are designed and tested. The quality of the seed coating with the product meets agro-technical requirements the coverage ratio was more than 98%. It was determined that in order to ensure a productivity of 4 t/h, the treater should have the following design parameters: drum diameter – 0.5 m; length – 1.5 m, the angle of the drum should be made with the possibility of change in the range of 6 ... 10°. The use of a treater with an eccentrically fixed drum with a capacity of 4 t per hour during the pre-sowing treatment of seeds allowed increasing the yield of spring wheat by 12.7%.

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