ANALYSIS OF THE WORKS PERFORMED BY PNEUMATIC AND MECHANICAL SEEDING DEVICE WITHOUT USING VACUUM

АНАЛІЗ РОБОТИ ПНЕВМОМЕХАНІЧНОГО ВИСІВНОГО АПАРАТА БЕЗ ВИКОРИСТАННЯ ВАКУУМУ

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Keywords: *pneumatic and mechanical seeding device, cell, seed, dosage, angular velocity*

ABSTRACT

The construction of a new pneumatic and mechanical seeding device for precision seeding of tilled crops with peripheral location of cells on a seed disk and a passive device for removing unnecessary seeds in a centrifugal method is suggested. It is assumed that the seeding device works even without the creation of vacuum. The parameters of the seeding device have been determined analytically. It was proved that the proposed design of the pneumatic and mechanical seeding device provides qualitative dosage of seeds without creating vacuum in the system, but with a limited angular velocity of 11.25 rad/s.

To remove extra seeds in the pneumatic and mechanical seeding device we used pockets in the casing of the seeding device above the filling section in which, under the influence of inertia forces, excess seeds get in and are directed back to the filling section. In order not to remove the main seed along with the extra seed when the rotation velocity of the seed disc approaches the velocity of the seeding device, additional force should be applied that would keep the main seed in the cell, that is, the force of suction.

РЕЗЮМЕ

Запропоновано конструкцію нового пневмомеханічного висівного апарата для точного висіву насіння просапних культур з периферійним розташуванням комірок на висівному диску та пасивним пристроєм для видалення зайвого насіння відцентровим способом. Прийнято припущення, що висівний апарат працює навіть без створення вакууму. Аналітичним шляхом визначено параметри висівного апарата. Доведено, що запропонована конструкція пневмомеханічного висівного апарату дозволяє якісно дозувати насіння без створення вакууму в системі, але при обмеженій кутовій швидкості у 11,25 рад/с.

Для видалення зайвого насіння в пневмомеханічному висівному апараті запропоновано використання порожнини в копусі висівного апарата над зоною заповнення, в яку під дією сил інерції потрапляє зайве насіння та спрямовуються назад до зони заповнення. Для не видалення разом із зайвою насіниною основної насінини при наближенні колової швидкості обертання висівного диска до швидкості руху посівного агрегату, необхідно використати додаткову силу, яка утримала б основну насінину в комірці, тобто силу присмоктування.

INTRODUCTION

The formation of a single-seed stream is the main task for seeding devices of tilled crops. The effectiveness of their operation is assessed by the quality of seed flow formation. The quality is higher if the number of misfed seeds and "twin" seeds is lower. Both misfed and "twin" seeds negatively affect the yield of crops. In the first case the number of plants decreases and in the second case the problem is their mass, due to the ineffective distribution of feeding areas of the root system and the competition of the above-ground part for obtaining sunlight.

Many scientists (*Boyko A. I., 2003; Sysolin P.V., 2004; Amosov V.V., 2007; Sydorchuk O., 2014; Voytyuk, D. G., 2005*), studied the problem of the formation of single-seed flow. As a result, the designs of high-performance pneumatic-mechanical seeding devices were created. They exceed technological parameters of the best reliable mechanical devices. However, the quality of the operation of pneumatic and mechanical seeding devices considerably depends on providing the specified value of rarefaction in the vacuum system for each crop and maintaining its stability.

In real conditions, with the intervention of unmanaged random factors, this is a rather complicated problem which is confirmed by differences in the results of laboratory and field studies.

Therefore, the main task is to create the design of a pneumatic and mechanical seeding device which operates with the least impact of the pressure changes in the system.

Having analyzed the design features of seeding devices for tilled crops precision seeding (*Boyko A. I., 2003; Sysolin P.V., 2004; Mursec B., 2007; Amosov V.V., 2007; Sysolin P.V., 2001*), a perspective direction of its improvement was determined.

The design of a unique pneumatic and mechanical device (*Petrenko M. M., 2011; Petrenko M. M., 2013*) (Fig. 1) was developed at the Department of Agricultural Engineering of Central Ukrainian National Technical University. The seed disk *1* has cells *2* which are formed by sectoral cut-outs of the disk and blades *3*. Externally, the cells are covered by the device casing *5*.

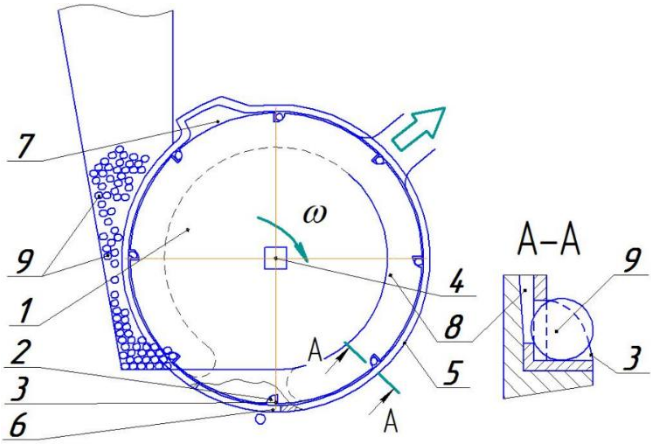

Fig. 1 - The model of the pneumatic and mechanical seeding device

1 – seed disk; 2 – cell; 3 – blade; 4 – driving shaft; 5 – casing; 6 – seeding outlet;
7 – inactive appliance for removing extra seeds; 8 – vacuum chamber; 9 – seeds.

The process of the seeding device operation is as follows. When the disk is rotating, the blades catch a seed and automatically place it in a cell. The vacuum created in the system keeps the seed from transverse tangential and radial displacement. In addition, the blades prevent the trapped particles to fall out in the tangential direction, and the casing prevents falling out in the radial direction. In this way, the particles move to the pocket *7* where the excess "twin" seeds are removed.

The suggested device has a significant advantage over the classical ones, since it ensures the forced seizure of the seeds with blades and the constructive elements to be kept in cells. Let us consider the operation of the device in the worst conditions with the absence of vacuum.

The analysis of the suggested design of the seeding device (*Petrenko M. M., 2011; Petrenko M. M., 2013; Vasylkovska K.V., 2016*) allows us asserting that seeds can be caught, removed and dropped even without the use of vacuum in the vacuum chamber.

MATERIALS AND METHODS

The objective of the research is to identify the performance of the suggested pneumatic and mechanical seeding device in the conditions of an unstable vacuum in the system, in particular, when it is absent.

Research tasks:

- creation of the physical model of the experimental pneumatic and mechanical seeding device;
- mathematization of the physical model if there is no vacuum;
- obtaining the correspondence which characterizes the performance of the seeding device if there is no vacuum;
- the analysis of the correspondence and development of scientific and methodological recommendations (*Vasylkovska K. V., 2014*).

Theoretical studies were carried out using the elements of theoretical mechanics, differential and integral calculus and mathematical modelling. The research results were processed by the "MathCAD 14" program.

RESULTS

Let us consider the operation of the suggested pneumatic and mechanical seeding device if there is no vacuum.

At the first stage a seed is caught by a blade (Fig. 2). In this case, it is possible to catch several "twin" seeds in the *YOZ* plane (Fig. 2b). The tangential movement of the caught seeds with the absence of vacuum is possible due to the corresponding ratio of centrifugal force to the gravity of the grain:

$$K = \frac{I}{G} \geq 1 \tag{1}$$

where K is the property of kinematic mode;

I is the centrifugal force;

G is the gravity force.

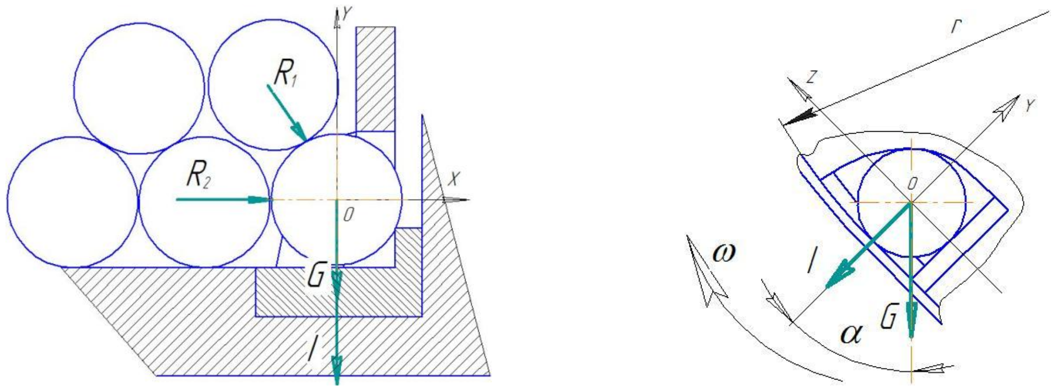

Fig. 2 - Catching a seed by the blade:

a – in the XOY plane; b – in the YOZ plane

Removing the captured "twin" seeds occurs in the pocket of the seeding device casing (Fig. 3).

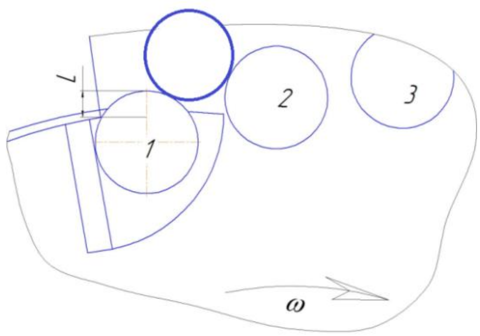

Fig. 3 - Removal of the “twin” seeds in the pocket of the seeding device casing

To prevent the removal of the main seed, the velocity of its radial displacement and the angle of pocket opening ε (Fig. 4) must be such as to follow the assumption:

$$L < \frac{d}{2} \tag{2}$$

where d is the diameter of the seed.

Let us consider the process of moving the main seed on the blade in the moving coordinate system $\tau - n$ in general case with an installed blade at the angle α to the normal (Fig. 4).

The seed is influenced by the gravity force G, the centrifugal force I and the friction force F_{mp}. We shall not take into account other forces as they are not important.

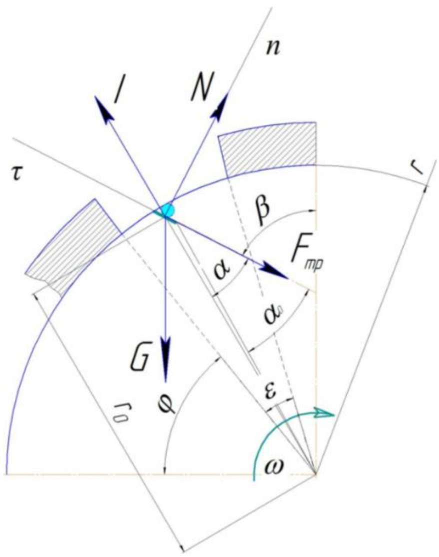

Fig. 4 - Physical model of the seed movement on the blade in the pocket

The differential equation of the seed moving on the blade in the pocket is the following:

$$m \cdot S'' = -f \cdot (-m \cdot \omega^2 \cdot r \cdot sin\alpha + m \cdot g \cdot sin\beta) - m \cdot g \cdot cos\beta + m \cdot \omega^2 \cdot r \cdot cos\alpha \quad (3)$$

where G is the gravity force, $G = m \cdot g$, [N];

I is the centrifugal force, $I = m \cdot \omega^2 \cdot r$, [N];

F_{mp} is the friction force, $F_{mp} = f \cdot N = f \cdot (-m \cdot \omega^2 \cdot r \cdot sin\alpha + m \cdot g \cdot sin\beta)$, [N];

N is the normal response force, [N];

f is the coefficient of the seed friction on the casing material;

m is the mass of the seed, [kg];

β the angle of the blade adjustment vertically, $\beta = \frac{\pi}{2} - \varphi + \alpha_0 + \omega t$;

φ is the angle of the pocket placement;

α_0 is the angle which defines the position of the blade beginning.

To shorten the mass *m*, we shall have:

$$S'' = (f \cdot \omega^2 \cdot r \cdot sin\alpha - f \cdot g \cdot sin\beta) - g \cdot cos\beta + \omega^2 \cdot r \cdot cos\alpha \quad (4)$$

From Fig. 4 we have: $r \cdot sin\alpha = r_0 \cdot sin\alpha_0 = const$

Therefore: $r \cdot cos\alpha = S + r_0 \cdot cos\alpha_0$

where S is the movement along the axis τ during the period of turning of the disk at the angle ε.

We have the equation of second order with the fixed factor relatively to the required function $S = S(t)$:

$$S'' - \omega^2 S = -f \cdot g \cdot sin(\frac{\pi}{2} - \varphi + \alpha_0 + \omega t) - g \cdot cos(\frac{\pi}{2} - \varphi + \alpha_0 + \omega t) + C \quad (5)$$

$$C = f \cdot \omega^2 \cdot r_0 \cdot sin\alpha_0 + \omega^2 \cdot r_0 \cdot cos\alpha_0 .$$

After generation we have:

$$\begin{aligned} S = & \left(\frac{f \cdot r_0 \sin\alpha_0 + r_0 \cos\alpha_0}{2} + \frac{\sqrt{2} \cdot g}{4 \cdot \omega^2} cos(\alpha_0 - \varphi - \frac{\pi}{4}) + \frac{\sqrt{2} \cdot f \cdot g}{4 \cdot \omega^2} sin(\alpha_0 - \varphi - \frac{\pi}{4}) \right) \cdot e^{\omega t} + \\ & + \left(\frac{f \cdot r_0 \sin\alpha_0 + r_0 \cos\alpha_0}{2} + \frac{\sqrt{2} \cdot g}{4 \cdot \omega^2} sin(\alpha_0 - \varphi - \frac{\pi}{4}) - \frac{\sqrt{2} \cdot f \cdot g}{4 \cdot \omega^2} cos(\alpha_0 - \varphi - \frac{\pi}{4}) \right) \cdot e^{-\omega t} - \\ & - f \cdot r_0 \cdot sin\alpha_0 - r_0 \cdot cos\alpha_0 - \frac{g}{2 \cdot \omega^2} sin(\alpha_0 - \varphi + \omega t) + \frac{f \cdot g}{2 \cdot \omega^2} cos(\alpha_0 - \varphi + \omega t) \end{aligned} \quad (6)$$

or:

$$S=\frac{r_0}{2}\left(e^{\frac{\omega}{2}t}-e^{-\frac{\omega}{2}t}\right)^2\cdot(\cos\alpha_0+f\cdot\sin\alpha_0)+$$
$$+\frac{\sqrt{2}\cdot g}{4\cdot\omega^2}\cdot\left[\begin{array}{l}(\cos\alpha_1+f\cdot\sin\alpha_1)\cdot e^{\omega t}+(\sin\alpha_1-f\cdot\cos\alpha_1)\cdot e^{-\omega t}-\\-\sqrt{2}\cdot(\sin(\omega t+\alpha-\varphi)-\cos(\omega t+\alpha-\varphi))\end{array}\right] \quad (7)$$

$\alpha_1=\alpha_0-\varphi-\frac{\pi}{4}$.

The movement of a seed in the radial direction L is in the range of:

$$0<L=S\cdot\cos\alpha_0<\frac{d}{2} \quad (8)$$

To fulfil the assumption (8), the seed should move in radial direction for the period of time needed for the disk to return to angle ε. That determines the size of the pocket of the inactive appliance for removing excess seeds:

$$t=\frac{\varepsilon}{\omega} \quad (9)$$

where ε is the angle which determines the size of the inactive appliance, [rad];
ω is the angular velocity of the seed disk, [rad/s].

Thus, we get:

$$L=\left[\begin{array}{l}\frac{r_0}{2}\left(e^{\frac{\omega}{2}t}-e^{-\frac{\omega}{2}t}\right)^2\cdot(\cos\alpha_0+f\cdot\sin\alpha_0)+\\+\frac{\sqrt{2}\cdot g}{4\cdot\omega^2}\cdot\left[\begin{array}{l}(\cos\alpha_1+f\cdot\sin\alpha_1)\cdot e^{\omega t}+(\sin\alpha_1-f\cdot\cos\alpha_1)\cdot e^{-\omega t}-\\-\sqrt{2}\cdot(\sin(\omega t+\alpha-\varphi)-\cos(\omega t+\alpha-\varphi))\end{array}\right]\end{array}\right]\cdot\cos\alpha . \quad (10)$$

We shall form the correspondence of the seed movement on the blade relatively to the disk rotation angle at different angular velocities for the radially installed blade (Fig. 5) (*Amosov V.V., 2007; Babak V. P., 2004*).

As can we can see on the graph of the dependence of the particle movement on the spade from the disk rotation angle (Fig. 5), to ensure the ascent of the excess seed, the centrifugal force must exceed the seed force of gravity, namely, the angular velocity must exceed the limiting value of 11.25 rad/s. With a smaller value of the angular velocity the particle will move on the shoulder blade backwards which will result in its falling to the pick-up chamber.

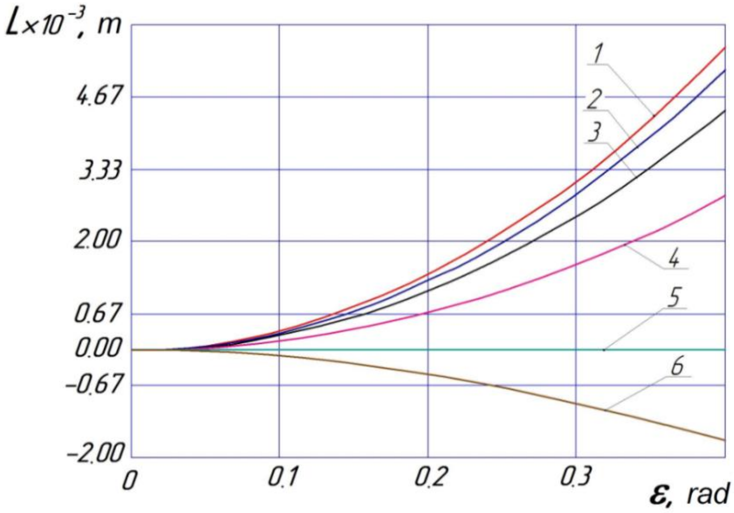

Fig. 5 - Correlation of seed movement on the blade to disk rotation angle at the angular velocity - ω [rad/s]

1 – 30 rad/s, 2 – 25 rad/s, 3 – 20 rad/s, 4 – 15 rad/s; 5 – 11.25 rad/s; 6 – 10 rad/s

However, when the rotation speed of the seed disk is approaching the seed drill speed, the main seed along with the extra seed can be removed from the cell. For the guarantee that the main seed does not fall out, it is necessary to use additional force that would keep it in the cell, which is the force of suction P.

CONCLUSIONS

The design of the new pneumatic and mechanical device increases the angular velocity of cells and reduces their number on the sowing disk and significantly reduces thinning in the vacuum chamber. Therefore, the proposed sowing device increases technological efficiency of seeding tilled crops and reduces energy intensity.

Consequently, the proposed construction of a new pneumo-mechanical seeding machine with peripheral arrangement of cells and inertial removal of excess seed allows the sowing of seeds of different cultivars. Thus, the design of the seeding device can operate without the use of vacuum but with a limited angular velocity of 11.25 rad/s.

The blade, which is behind the cell, allows you to reliably grab the seeds and hold it during movement to the reset zone. In order that the main seed does not fall out together with the extra seed when the rotation speed is approaching the seeding device speed, it is necessary to use additional force to keep the main seed in the cell, that is, the force of suction.

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