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Modelling of force action on ellipsoid-shape seed in separator channel

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Summary. The behavior of seed in pneumo-electric separator channel is revealed. The characteristic of the active forces on ellipsoid-shape seed is demonstrated. Due to a differential equations you can find the coordinates of seed mixtures particles' motion to determine the conditions under which we get maximum effect.

Key words: air separator, small-seeded mixtures, grass seeds, speed of air blast, tension of the electrostatic field.

INTRODUCTION

Ways of improvement of postharvest seed-preparation of small-seeded plants are determined. It is highlighted that to improve the quality of the seed and to take out the weeds which are difficult to identify are possible in the process of additional seed-cleaning using proper machines which use electric current and corona discharge as additional operating element. Under such conditions it is possible to get high quality seed material of studied small-seeded plants that meet the demands of the existing standards.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The increase in gross yield of seeds of crops is impossible without a sufficient number of high-quality seed mass [1], by its sowing qualities, quantitative content of weeds' impurities, which are difficult to separate, would be able to meet the existing standards [2]. We can possibly achieve this by improving postharvest processing technologies and facilities. This is especially true for small seeded crops (vegetables, industrial, fodder grasses, etc.). We meet significant difficulties of objective nature to bring it to the required sowing condition [3,4]. For this reason there is a need to conduct additional cleaning that is performed on special seed purification machines.

Among them, an important place is given to pneumatic separators where seed purification is carried out by their aerodynamic peculiarities of components.

Separation of seed mass by aerodynamic peculiarities of their components is a sufficiently widespread method [10, 11, 13]. It is based on particles' differences in resisting airflow. This resistance depends on several factors and is not the same for some of them [12]. Therefore, the particles move in the air stream with different speeds and on different paths [9].

Nowadays, in theoretical terms the issues of separation of seed mixtures by their aerodynamic peculiarities in pneumatic separators are sufficiently covered [5,6,7]. A number of authors have devoted their researches identifying the critical speed of floating and soaring ratios of components of seed mixtures [5], calculations of air flow [10] and justification of ventilator parameters for their construction [7], the definition of structural forms and geometric dimensions of pneumatic channels etc. [10].

Some of them studied the force of interaction of seed mixtures with air flow [6], its influence on the path of the movement and the possibility of their separation by aerodynamic peculiarities.

This interaction takes into account the cumulative effect of gravity and force of air flow on the particles. However, in condition of improving the designs of pneumatic separators using, as an additional working body, the electric field in their separating channels, the particles will be influenced by an additional electrical force. In this case there is a need to study the interaction of power that will be taken at the same time as the action of gravitational and electrical forces.

SETTING OBJECTIVES

To increase the efficiency of separation of hard-to-separate seed mixtures in air flows is possible if we concentrate an additional force action and this force would be different for biologically viable seed of crops and for non-viable (without embryo) or weed seeds. To implement such power effect on components of seed mixtures could be possible in a separator channel with uniform electric field.

In this case there is a need to study the combined action of forces on a particle of seed mixture in the channel.

THE MAIN MATERIAL

In order to consider the behavior of particles of the seed mixture in pneumo-electric separator channel we should understand and characterize the forces which affect them. As a rule in such separators seed mixtures which have the shape of an ellipsoid are separated. With this in mind, we will consider the impact of forces on a seed of this shape. It can be described, using the data presented in Fig. 1.

The seed is impacted by the resultant of three power factors:

1) resultant force of gravity *G*, which is directed vertically downward and attached to the center of mass of the particle:

$$G = mg, \quad (1)$$

where: *m* – mass of seed; *g* – gravity of Earth.

2) resultant electrostatic force Fe, which is directed horizontally and attached to the axis of symmetry of the ellipsoid particles at point O_2:

$$F_e = E\,q, \quad (2)$$

where: *E* – electric field intensity; *q* – charge of a particle.

3) resultant forces F_a caused by the action of air flow on the particle:

$$F_a = KV_aA_m \quad (3)$$

where: V_a – speed of the air stream; A_m – midship section area; *K* – coefficient of resistance of the circumference.

Resultant force F_a is directed vertically upward and applied at the geometric center of the ellipsoid *O*.

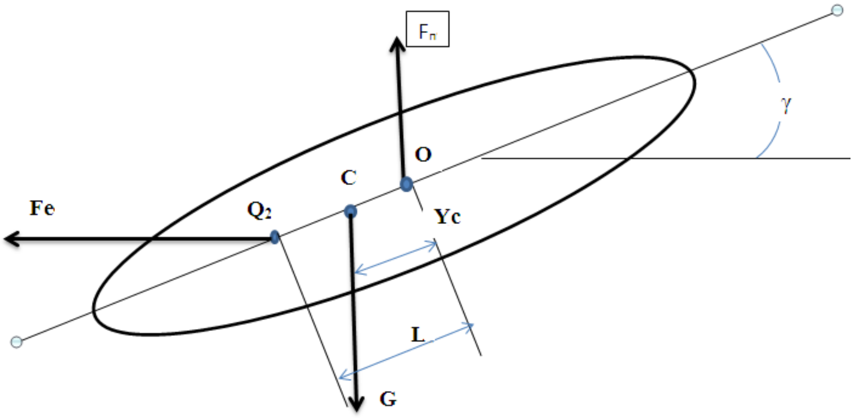

Fig. 1. Forces' effect on a particle of a seed mixture in pneumo-electric channel

Let us consider some cases of the actions of these forces on a particle of seed mixture.

1. The force of the airflow F_a is equal to force of gravity *G*.

Then the resultant of three forces is equal to $R = F_e$ and will pass through the center of masses *C*, in the condition:

$$\sum_{К=1}^{П} \mathrm{M_c}(F_{П}) = 0. \quad (4)$$

In this case, from (3) we can find the speed of air flow:

$$V_a = \frac{G}{KA_M} \quad (7)$$

where: A_m – midship area of the particle.

Expand the condition (4):

$$F_{П} \cdot Yc \cdot cos\,\varphi - Fe \cdot L \cdot sin\,\varphi = 0\ . \quad (5)$$

Since $F_a = G$, then using (5) we determine the angle φ:

$$\mathrm{t}g\,\varphi = \frac{G \cdot Yc}{Fe \cdot L}. \quad (6)$$

If we want to determine the force of airflow by these conditions we need to calculate the midship area A_m of a seed mixture particle where: A_M – a projection of a seed area on a plane which is perpendicular to the direction of air flow in the channel of pneumo-electric separator. It should be also kept in mind that seed has the shape of an ellipsoid of revolution with semi-axes *a* and *b* (Figure 2).

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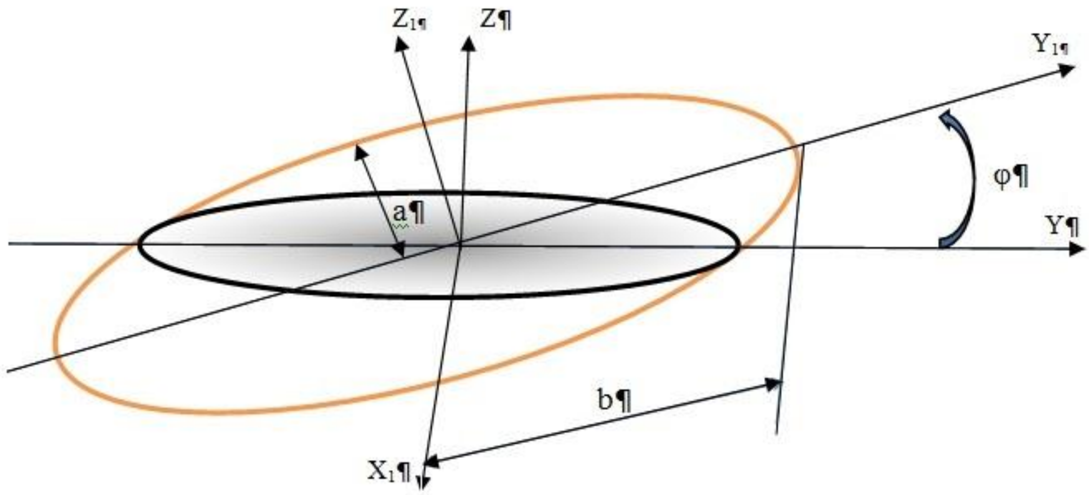

Fig. 2. Figure to determine a midship section of an ellipsoid-shaped particle

Then the equation of the surface of the ellipsoid in canonical form looks like:

$$\frac{X_1^2}{a^2}+\frac{Y_1^2}{\text{в}^2}+\frac{Z_1^2}{a^2}=1\,. \qquad (8)$$

If the coordinate system is rotated by an angle φ around the axis OX, the relationship between the coordinates of points in the old and new coordinate systems will be expressed by the formulas:

$$Y_1=y\cos\varphi+z\sin\varphi;$$
$$\mathrm{Z}_1=\ z\cos\varphi+y\sin\varphi \qquad (9)$$

Substituting (9) into (8), we obtain the equation of the surface of the ellipsoid in turned coordinate system:

$$\frac{X^2}{a^2}+\frac{(y\cos\varphi+z\sin\varphi)^2}{\text{в}^2}+\frac{(z\cos\varphi-y\sin\varphi)^2}{a^2}=1 \qquad (10)$$

Taking into account that $z = 0$, we obtain the equation of the ellipse

$$\frac{X^2}{a^2}+y^2\left(\frac{\cos^2\varphi}{\text{в}^2}+\frac{\sin^2\varphi}{a^2}\right)=1 \qquad (11)$$

with semi-axes a and $b=\frac{a\text{в}}{\sqrt{a^2\cos^2\varphi+\text{в}^2\sin^2\varphi}}$.

Due to (11), the expression for determining of midship section equals:

$$\mathrm{A_м}=\boldsymbol{\pi}\frac{\mathrm{a}^2\text{в}}{\sqrt{a^2\cos^2\varphi+\text{в}^2\sin^2\varphi}} \qquad (12)$$

Having expression (12) for determining midship area and taking into account (6), we can calculate the speed of air flow that meets the condition (3):

$$V_a=\frac{G}{\pi K a^2 b}\sqrt{\frac{(aF_eL)^2+(bGY_c)^2}{(F_eL)^2+(GY_c)^2}} \qquad (13)$$

When the power of the air flow F_a is less than seed gravity G:

$$G>\ K\,V_a\,\mathrm{A_м}. \qquad (14)$$

This inequality is right for any φ, if:

$$V_a<\frac{G}{K\pi ab}\,. \qquad (15)$$

This seed will do plane-parallel movement consisting of the center of mass C and rotary motion around it (Fig. 3).

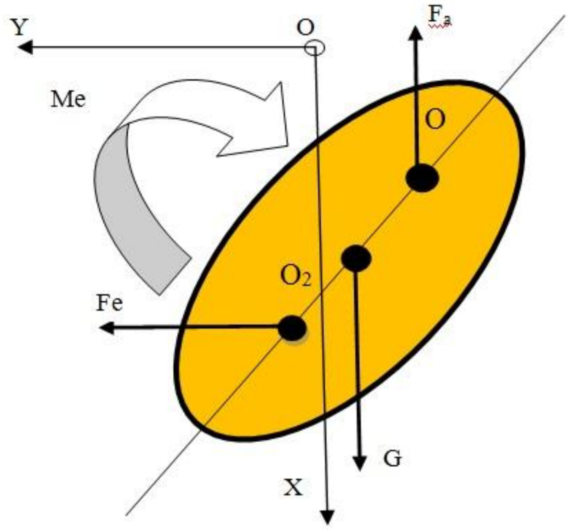

Fig. 3. Scheme of seed movement in pneumo-electric separator channel

In the projections on the axis *XOY* differential equations of motion will have the form:

$$m\frac{d^2x_c}{dt^2} = mg - K\left(V_a + \frac{dx}{dt}\right)A_1;$$
$$\mathrm{m}\frac{\mathrm{d}^2\mathrm{y_c}}{\mathrm{dt}^2} = \mathrm{F_e}\text{-}\mathrm{K}\frac{\mathrm{dy}}{\mathrm{dt}}\mathrm{A_2} \qquad (15)$$

$$\mathcal{J}\frac{d^2\varphi}{dt^2} = K\left(V_{\text{п}} + \frac{dx}{dt}\right)A_1 \cdot Y_c \cdot \cos\varphi - F_e \cdot L \cdot$$
$$\cdot \sin\varphi - 2\mathrm{K}\frac{d\varphi}{dt} \cdot a\int_0^b y^2\sqrt{1-\frac{y^2}{b^2}}\,dy \qquad (16)$$

where: $A_1 = A_m$; $\mathcal{J}$ - moment of inertia of ellipsoid (seed) with respect to the axis of rotation.

$$\mathrm{A}_2 = \frac{\pi\alpha^2 b}{\sqrt{a^2\sin^2\varphi \quad + b^2\cos^2\varphi}},$$

$$\int_0^b y^2\sqrt{1-\frac{y^2}{b^2}}\,dy = b^3\frac{\pi}{16}. \qquad (17)$$

The system of differential equations must be integrated with the initial conditions:

$$t = 0;\ \mathrm{Xc} = 0;\ Yc = 0;\ \varphi = 0; \qquad (18)$$

$$\frac{d\varphi}{dt} = 0;\ \frac{dx_c}{dt} = 0;\ \frac{dy_c}{dt} = 0.$$

It can be solved by number of methods, including Runge Kutta's one.

Having solutions of equations (15), we can find the coordinates of a particle's motion of seed mixture as a function of time. In this case, to identify the conditions under which you can get the greatest effect of separation in pneumo-electric separator it is necessary to investigate the coordinate xc, which characterizes movement of a particle along the channel. The analysis of the equations shows us that the most significant effect on their value makes midship section area of the separating particles which undergoes the airflow. This area much depends on the electrical properties of seed particles, since the electric field is created between the plates of pneumo-electric channel and directs them along the force lines. Seeds of crops and weeds belong to separate biological species and their electrical properties are different. Because of this, they will interact differently with the electric field. Consequently, the components of seed mixtures will be guided in the channel at different angles, thus changing its midship area and will react differently on forces of air flow. With this we can come to the conclusion that there is a possibility to separate seeds of crops and weeds, especially of an ellipsoid shape, in the process of separation in a pneumo-electric separator.

To determine the behavior of particles in the form of an ellipsoid, models that characterize real seeds are developed: quality seeds of a crop $\mathrm{M_1}=f(m_1, a_1, в_1, L_{e1}, L_{c1}, V_n, F_e)$ if $L_e > L_c > 0$; low-quality seed (without embryo) $\mathrm{M_2}=f(m_2, a_2, в_2, L_{e2}, L_{c2}, V_n,, F_e)$ if $L_e = L_c = 0$; quality weed seeds $\mathrm{M_3}=f(m_3, a_3, в_3, L_{e3}, L_{c3}, V_n, F_e)$ if $L_e > L_c > 0$; quality seeds of another culture $\mathrm{M_4} = f(m_4, a_4, в_4, L_{e4}, L_{c4}, V_n, F_e)$.

Having solved the system of the equation by a numerical method in the MATLAB environment, the coordinates of the trajectories of the motion of the seeds of the seed mixture are determined as well as the influence of the regulated factors on them: the velocity of the air flow V_n and the forces of the electrostatic field F_e.

The analysis of the obtained results (Figure 3) has shown that the studied particles have different trajectories of motion at $F_e = 2\cdot10^{-6}$ i $3\cdot10^{-6}$ H. This is important for successful separation, the efficiency of which is the highest, provided that the maximum difference between the trajectories of the seeds of high quality M1, without germs M2, weeds M3 and other crops M4.

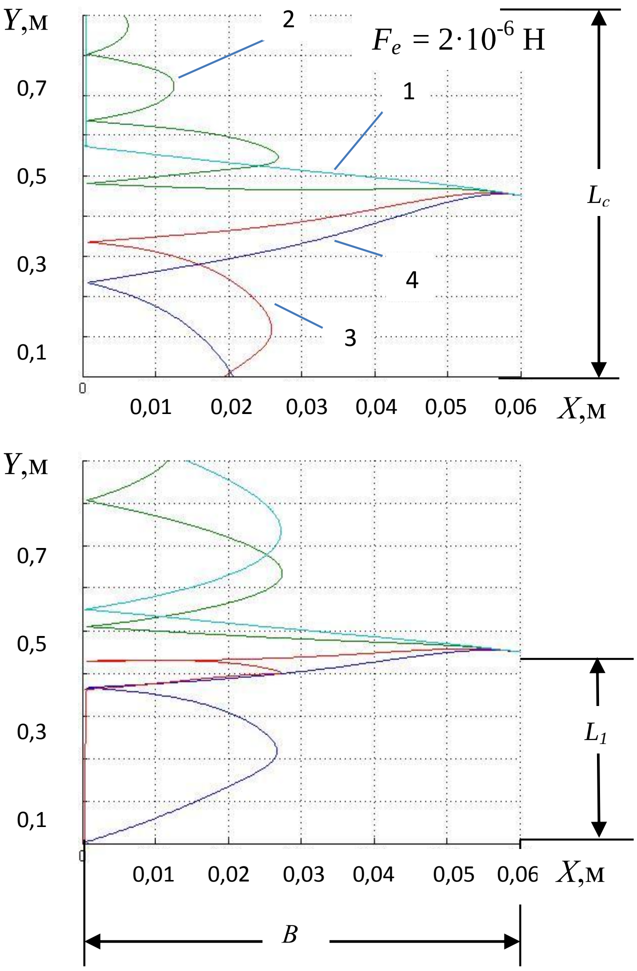

Fig. 3. Influence of additionally applied electrostatic force of F_e on the trajectory of motion of particles at air flow velocity

$V_n = 5$ m / s = const:

1 – $\mathrm{M_1}$; 2 – $\mathrm{M_2}$; 3 – $\mathrm{M_3}$; 4 – $\mathrm{M_4}$;

L – the length of the channel;

L_1 - distance from the base of the channel to the place of delivery of the initial mixture;

B – the channel width.

The obtained calculation trajectories of motion confirm that the separation from a seed of a culture of poor quality biologically defective seeds without germs is most effective at V_n = 5 m/c and F_e = 2…3·10^{-6} H. Under such conditions, the particles M1 and M2 are carried by the air flow to the upper part the channel. In it they are divided: the qualitative, reflected by the model M_1, fall into the receiver of conditioned seeds, but biologically defective M_2 are drawn into a centrifugal fan, from which they are blown in a filter of light impurities. The particles M_3, M_4 move down the pneumo-electric channel and fall into the waste container.

Based on the data obtained, the geometrical dimensions of the working part of the pneumatic electric channel are substantiated, in which the effective separation of the components of the small-seed mixture is achieved (see Figure 3): the width of the channel B = =0,06 m; length L = 0,9 m; distance from its base to the place of delivery of the initial mixture L_1 = 0,45 m.

We can find this possibility by modelling the force action on a particle of mixtures and find it by using such the parameters pneumoseparation under which coordinate x_c for one component takes a positive value (going up), and for another - negative (fall down). Under these conditions, the separation will be the most effective.

CONCLUSIONS

1. We described the combined effect of forces on a seed of ellipsoid form in the pneumo-electric separator channel.
2. Differential equations of motion of an ellipsoid-shaped particle of seed mixture in the channel of a separator are presented. Their solutions allow you to find the coordinates of the separating particles' motion and evaluate the possibility of their separation.
3. After the analysis of the dependences we can conclude that the use of electric field in pneumo channels leads to different changes of the midship section of a crop seed and weeds due to differences in their electrical properties. This is the basic condition of the possibility of their effective separation in the proposed pneumo-electric separator.

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МОДЕЛИРОВАНИЕ СИЛОВОГО ВОЗДЕЙСТВИЯ НА СЕМЕНА ЭЛЛИПСОИДНОЙ ФОРМЫ В КАНАЛЕ СЕПАРАТОРА

Степан Ковалишин, Алексей Швец,
Виктор Дадак

Аннотация. Рассмотрено поведение эллипсоидальных частиц семян в канале пневмоэлектрического сепаратора под действием гравитационных, электрических и сил воздушного потока. Получены дифференциальные уравнения, позволяющие определить координаты траекторий их перемещения. Расчетные траектории движения свидетельствуют, что отделение от семян культуры некачественных, биологически неполноценных семян без зародышей эффективно происходит при V_n = 5 м/с та $F_e = 2\ldots3\cdot10^{-6}$ Н.

На основании полученных данных обоснованы геометрические размеры рабочей части пневмоэлектрического канала, при которых достигается эффективное разделение компонентов мелкосеменных смесей: ширина канала B = 0,06 м; длина канала L = 0,9 м; расстояние от основания канала к месту подачи исходной смеси L_1 = 0,45 м.

Ключевые слова: пневмоэлектросепаратор, злаковые травы, скорость воздушного потока, напряженность электростатического поля, биологически неполноценные семена, семена без зародышей.