RESEARCH ON THE PHOTOELECTRONIC SEPARATOR SEED SUPPLY BLOCK FOR OIL CROPS
/
ДОСЛІДЖЕННЯ БЛОКА ПОДАЧІ ФОТОЕЛЕКТРОННОГО СЕПАРАТОРА НАСІННЯ ОЛІЙНИХ КУЛЬТУР

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ABSTRACT

The results of numerical simulation and experimental research on the seed transfer process under the influence of the working part of the photoelectronic separator seed supply unit are presented. There has been developed physics and mathematical model, which links the productivity of the seed supply unit of the photoelectronic separator, its power consumption and the average time interval between falling seeds from the seeds supply, the frequency of vibroplate oscillations and the rotational speed of the barrel. During research, there has been solved a compromise problem of maximization of the average time interval between falling seeds and the minimization of the power consumed by the seed supply unit, with the maximum value of its productivity, which is comparable to the value of the seed supply.

РЕЗЮМЕ

Представлені результати чисельного моделювання і експериментальних досліджень процесу переміщення насіння під дією робочого органу блока подачі насіння фотоелектронного сепаратора. Наведено розроблену фізико-математичну модель, яка зв'язала продуктивність блоку подачі насіння фотоелектронного сепаратора, його споживаєму потужність і середній інтервал часу між падаючим насінням від подачі насіння, частоти коливань віброплотка і частоти обертання барабана. В процесі досліджень була вирішена компромісна задача, а саме максимізація середнього інтервалу часу між падаючим насінням і мінімізація потужності, що споживається блоком подачі насіння, при максимальному значенні його продуктивності, яка порівняна із значенням подачі насіння.

INTRODUCTION

The unsatisfactory quality of the seeds leads to a significant decline in agricultural productivity and a high over expense of seed material *(Aliev E. B., 2016)*. According to the current standards, oilseed crops varietal and crop yields are determined mainly by their varietal purity, which should be for the elite seed (elite, superelite) – 99.6 - 99.9% depending on the crop.

One of the ways to increase the efficiency of the seed material separation in the seed treatment plant is to fractionate it *(Shaforostov V.D., Priropov I.E. 2015)* by using a photoelectronic separator *(Priropov I.E., 2015)* at the final stage of its treatment. Despite the increasing usage of photoelectronic separators in the control and sorting of seed material, their application continues to be rather narrow. In the theses *(Clien S., Chiang Y.P., Pomeranz Y., 1994; Thomson W.H., Pomerang Y., 1991; Shazzo A. Y., Usatikov S.V., 2012; Tischenko A. I., 2000)* the great prospects of photoelectronic separation in grain-processing industries are described. It is possible to predict the distribution of photoelectronic separation by colour in seed and breeding with a high degree of probability.

However, even in the framework of finished agricultural products processing, the potential of photoelectronic separators is still not fully used up. This is primarily due to the lack of available technical tools and mathematical models and algorithms that are suitable for their operation.

Therefore, in order to solve the problem of oil material separation from oilseed crops, development of a photoelectronic separator design, theoretical and experimental research of its operational process and the substantiation of its rational structural and technological parameters are envisaged.

MATERIALS AND METHODS

The developed photoelectronic separator consists of three blocks: a seed supply unit, a seed recognition unit and a seed flow separation unit. The seed feeder of the photoelectronic separator (Fig. 1) consists of a bunker *1*, a barrel *2* with radially positioned blades *3* and a vibroplate *4* with longitudinal channels *5*. The seeds enter the bunker *1* under gravity. Next, the barrel *2* with radially positioned blades *3*, executing rotational motion captures the seeds from the bunker *2* and transfers to the vibroplate *4*. The vibroroll *5*, while being located angled to the horizon line, performs a periodic transverse movement from one side to another, forcing the seeds to move along longitudinal channels *5*. After this the seeds leave the vibroroll *5* and fall into the next block of the photoelectronic separator.

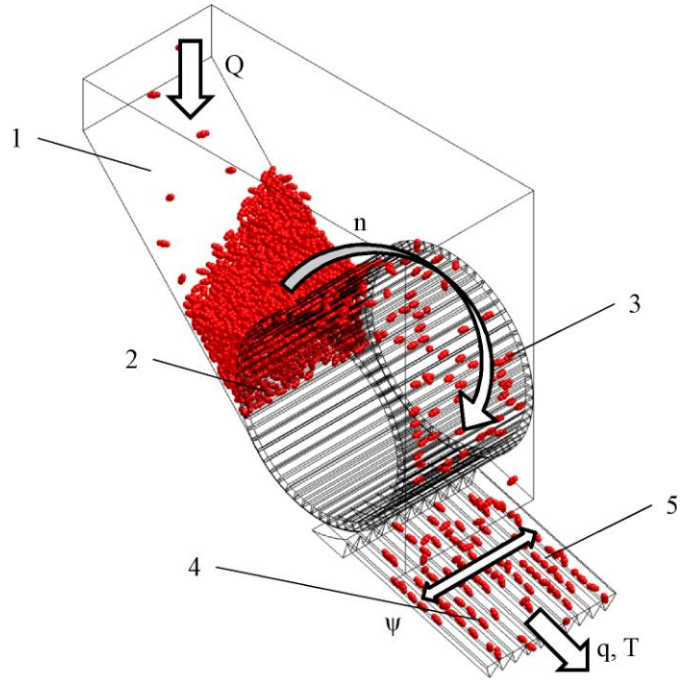

Fig. 1 - Structural and technological scheme of the photoelectronic separator seed supply unit
1 – bunker; 2 – barrel; 3 – blades; 4 – vibroplate; 5 – longitudinal channels

The study of the seed supply unit operational process has been conducted in two stages.

The first step for determining the rational regime parameters of the working part of the photoelectronic separator seed supply unit is the realization of corresponding physical models in the software package STAR-CCM +. The following physical models were selected for numerical simulation: k-ε model of the separated flow turbulence, gravity field, Van der Waals real gas model, model of discrete elements, and model of multiphase interaction. The method of discrete elements is based on the laws of the impulse conservation and impulse momentum for LaGrange models of multiphase environment *(Shevchenko I.A., Aliyev E. B., Doruda S.O., 2013; Boyko V.B., Aliyev E. B., 2015; Aliyev EB, Labatyuk Y.M., 2017)*. However, for the construction of a physics and mathematical model, it must be assumed that the seeds are presented in the form of identical ellipsoids with a defined density and effective diameter. The following physical and mechanical properties of seeds have been determined: Poisson's ratio – 0.5 Young's modulus – 0.2 MPa; density – 800 kg/m^3; effective diameter – 0.008 m; coefficient of friction in quiescence – 0.8; normal recovery factor – 0.5; tangential recovery factor – 0.5; coefficient of rolling resistance – 0.3. Properties of the environment have been determined as follows: environment - air; dynamic viscosity – $1.85508 \cdot 10^{-5}$ Pa·s; the Prandtl turbulent numeric is 0.9; free fall acceleration – 9.8 m/s^2; temperature – 293 K; pressure – 101325 Pa. The size of the grid cell modeling has been set as 0.001 m. To simplify the mathematical and time operations, the following structural and technological parameters of the seed supply unit have been determined: the fluctuation amplitude of the vibroplate A = 0.008 m (corresponding to the size of the vibroplate channel); external barrel radius r_0 = 0.07 m; number of blades N = 38; the length of the blade is l = 0.01 m. It should be noted that the vibroroll consists of 10 identical longitudinal channels, which are used to transfer seeds. Exposure duration was 100 s.

The second stage has been the conduct of experimental research on the plant, consisting of an experimental sample of the seed supply unit, a laboratory power supply unit with the voltage change option and control equipment (photo-converters connected to an analog-to-digital converter). The design and technological scheme and the general view of the experimental sample of the photoelectronic separator seed supply unit are shown in Fig. 2. The calibrated valve has been used to limit the input performance and to provide a certain level of seeds supply. The frequency and amplitude of the vibroplate vibration has been provided by changing the voltage of the laboratory power unit connected to the wind turbine. The schematic diagram of photoconductors connected to an analog-to-digital converter is shown in Fig. 3. It should be noted that the vibroplate consists of 20 identical longitudinal channels, on which the seeds movement occurs. The control and measuring apparatus works as follows. Falling seed from the longitudinal channel enters between the emitter and the photodetector receiver. As a result, a signal goes to an analog-to-digital converter, which converts the signal to a digital one and displays in a personal computer. There is a measurement of time between falling seeds. In the experimental research course of the experimental sample of the photoelectronic separator seed supply unit, the flax seeds of the Vodogray oilseed grade have been calibrated to a size of 2.5 mm. One experiment has been conducted by passing through a pilot sample of a feed unit of 10 kg of seed.

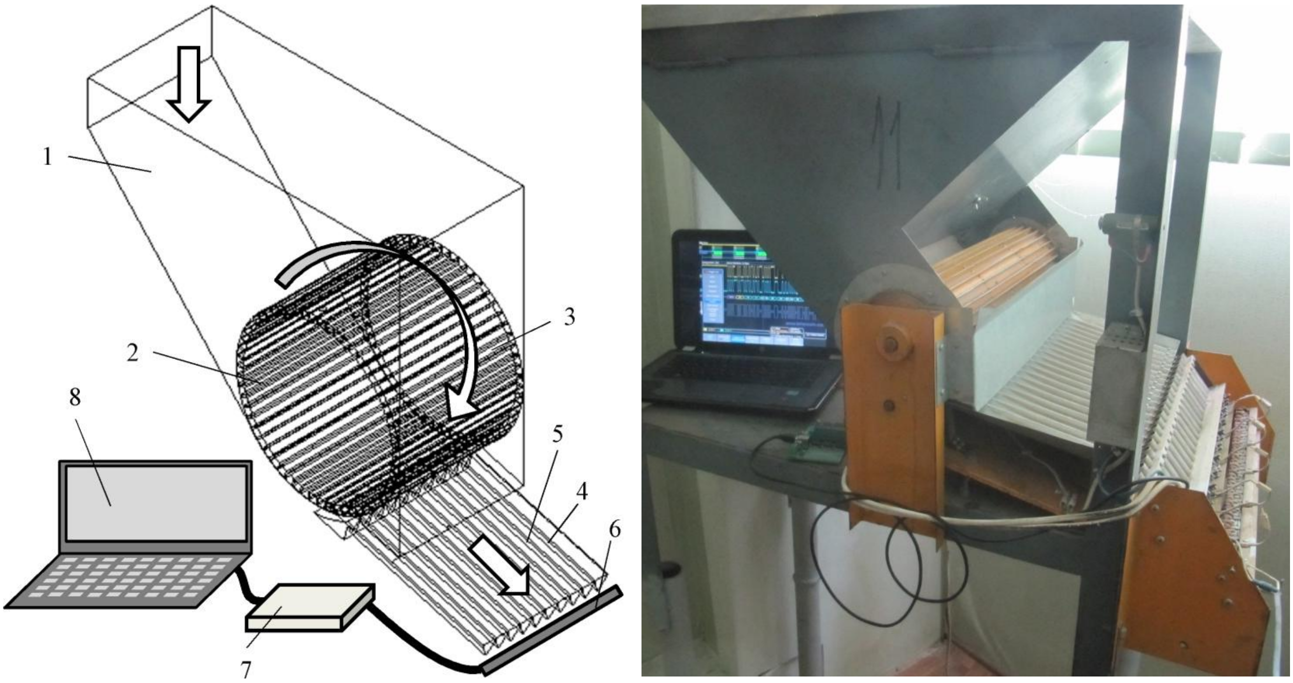

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Fig. 2 - Structural-technological scheme (a) and general view (b) of the pilot sample of the photoelectronic separator seed supply unit

1 – bunker; 2 – barrel; 3 – blades; 4 – vibroplate; 5 – longitudinal channels; 6 – photoconductors; 7 – analog-to-digital converter; 8 – personal computer

The variation intervals and levels of factors in theoretical and experimental studies are given in Table 1.

The following optimization criteria have been determined:

- seeds delivery part productivity – q, kg/hr;
- power consumption – P, kW;
- the average time interval between falling seeds is t, s.

The productivity of the seed supply unit q has been determined by measuring the mass of the seed M passing through it and the corresponding time τ. The calculation has been made by the formula:

$$q = \frac{M}{\tau}. \qquad (1)$$

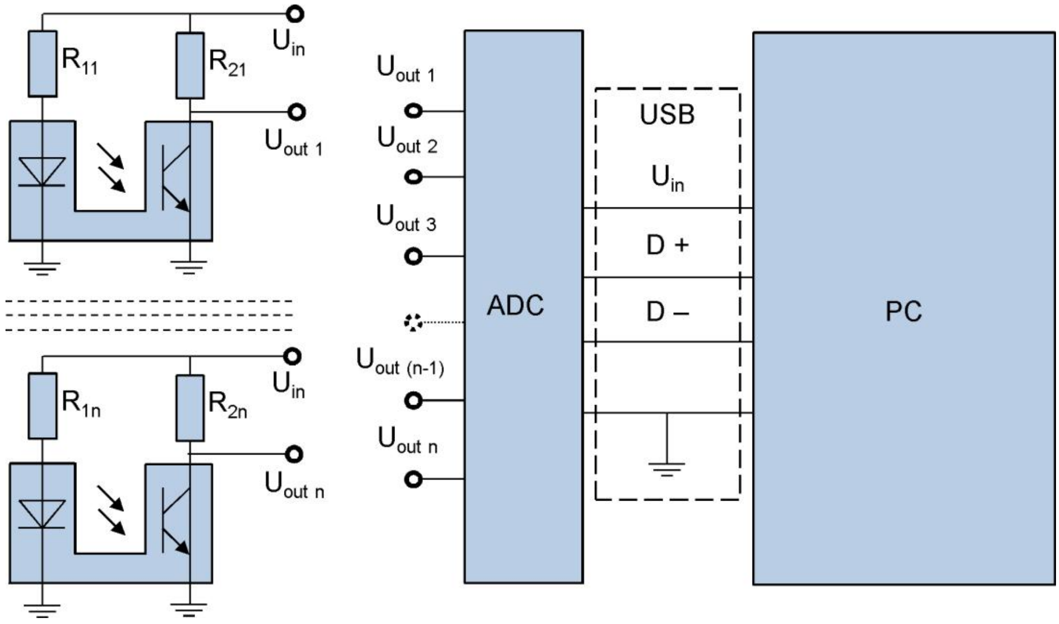

Fig. 3 - Principal electrical circuit of photoconductors

ADC – analog-to-digital converter; PC – personal computer

Table 1

Variation levels and intervals of factors when conducting researches on the operation process of the photoelectronic separator seed supply unit

Factors variation level	Factors		
	Seed supply Q, kg/hr	Vibroplate oscillations frequency ψ, s^{-1}	Barrel rotation frequency n, rpm
Upper level (+)	15	10	15
Basic level (0)	9	7.5	10
Lower level (–)	3	5	5
Factors variation interval	6	2.5	5

In experimental studies, the power consumed by the seed supply unit has been measured using an authorized electric meter and calculated using the formula:

$$P = \frac{\Delta E}{\tau}, \tag{2}$$

where: ΔE – meter results, W·hr;

τ – time of experiment conduction, hr.

The average time interval between falling seeds has been determined in experimental studies using photoconductors connected through an analog-to-digital converter to a personal computer and calculated by the formula:

$$t = \frac{1}{N}\sum_{i=1}^{N} t_i, \tag{3}$$

where: N – seeds count;

t_i – the time interval between two falling seeds, s, c.

The first stage, namely numerical simulation, has been conducted on a complete factorial study with a total number of experiments – $3^3 = 27$.

The second stage was conducted in a D-optimal second-order Box-Benkin plan for three factors (15 experiments) in a three-time repetition.

The research results processing have been carried out by the method of mathematical factor planning of experiments, using the computer program Mathematica.

The mathematical model is determined by one optimization criterion.

RESULTS

According to the first stage, as a result of numerical simulation, a visualization of the technological process of moving seeds under the influence of the working part of the photoelectronic separator seed supply unit has been obtained (Fig. 4).

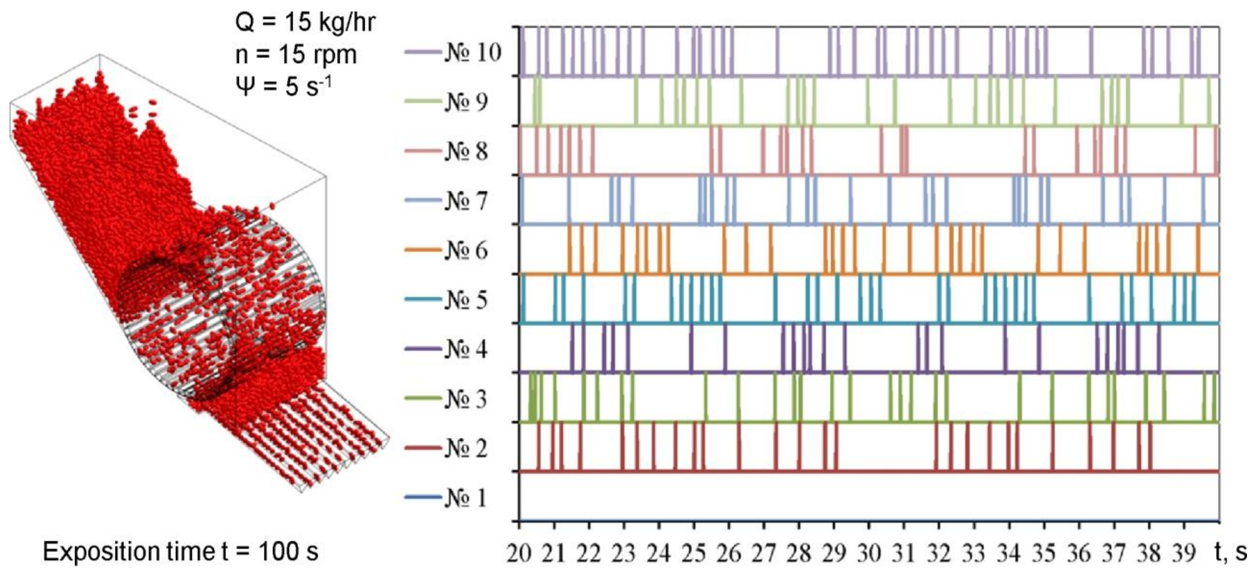

Fig. 4 - Distribution of seedling time intervals from the vibroplate of the photoelectronic separator seed supply unit

The approximation of the obtained data has been made using the software package Mathematica. It resulted into the equation of dependence of the seed supply block efficiency of the photoelectronic separator q from the above-mentioned factors in the encoded form:

The approximation of the obtained data has been made using the software package Mathematica. It resulted into the equation of dependence of the seed supply block efficiency of the photoelectronic separator q from the above-mentioned factors in the encoded form:

$$q = 4.46961 + 1.50378\,x_1 - 1.37183\,x_1^2 + 1.94412\,x_2 + 1.06579\,x_1 x_2 + 0.634078\,x_2^2 + 0.150011\,x_3 - 0.160614\,x_1 x_3 + 0.171217\,x_2 x_3 - 0.147393\,x_3^2 \quad (4)$$

The calculated coefficients of the correlation coefficient (R = 0.96) and Student's criterion $t_{0.05}$ (27) = 2.05 are significant at the confidence level of more than 95 %, with coefficients for the following terms of the equation: x_1, x_2, x_1x_2, x_1^2, x_2^2.

In a decoded form, the model (4) after the contraction has the form:

$$q = 3.79771 + 0.403651\,Q - 0.0381064\,Q^2 - 1.38361\,\psi + 0.0710524\,Q\,\psi + 0.101452\,\psi^2 \quad (5)$$

Analyzing equation (5), we can conclude that with the increase of the vibroplate oscillations frequency ψ, the productivity of the seed supply unit of the photoelectronic separator q increases. In turn, the rotational speed of the barrel practically does not affect the specified criterion. And for the supply of seeds Q there is an optimal value of Q = 14.4 kg/hr, in which the maximum value of the seed supply block of the photoelectronic separator is observed.

Also, the equation for the time interval between the incident seed t and the factors of research is established:

$$t = 0.058287 - 0.0167361\,x_1 + 0.0253472\,x_1^2 - 0.0436111\,x_2 + 0.00802083\,x_1 x_2 + 0.0138889\,x_2^2 + 0.00375\,x_3 + 0.00239583\,x_1 x_3 - 0.00364583\,x_2 x_3 - 0.00194444\,x_3^2 \quad (6)$$

According to the calculated values of the correlation coefficients (R = 0.95) and Student's criterion $t_{0.05}$(27) = 2.05, the coefficients at the level of confidence probability greater than 95% are coefficients for the following terms of the equation: x_1, x_2, x_3, x_1x_2, x_1^2, x_2^2.

In a sketched form, the model (6) after the contraction has the form:

$$t = 0.42485 + 0.00075\,n - 0.0194734\,Q + 0.00070409\,Q^2 - \\ - 0.0555903\,\psi + 0.000534722\,Q\,\psi + 0.00222222\,\psi. \quad (7)$$

From equation (7) it is evident that at low values of the oscillation frequencies of the vibroplate ψ, the rotational speed of the barrel n and the optimum seed supply Q = 10.31 kg/hr, there is a minimum of the average time interval between the falling seeds t.

The analysis of the presented dependencies proves the necessity of solving a compromise problem, which is as follows: to ensure the efficient operation of the photoelectronic separator's seed supply unit, it is necessary to provide its productivity q at maximal and equal to the seed supply Q level, with the average time interval between falling seed t being maximum:

$$\begin{cases} q(Q,\psi,n) = Q, \\ t(Q,\psi,n) \rightarrow \max, \\ Q \rightarrow \max. \end{cases} \quad (8)$$

or

$$\begin{cases} q(Q,\psi,n) = Q, \\ Q \times t(Q,\psi,n) \rightarrow \max. \end{cases} \quad (9)$$

Using the software package Mathematica the system of equations (9) solution is

$$\begin{cases} Q = q = 4{,}7 \text{ kg/hr}, \\ \psi = 10 \text{ s}^{-1}, \\ n = 12 \text{ rpm}, \\ t = 0{,}047 \text{ s}. \end{cases} \quad (10)$$

The second stage, namely, the experimental research of the operation process of the photoelectronic separator seed supply unit has been carried out using the method of multifactorial experiment mathematical planning, which allows determining mathematical models of processes in the form of regression equations. The obtained mathematical model of the investigated factors influence on the average time interval between the falling seeds has the following form:

$$t = 0.07462 - 0.0171528\,x_1 + 0.0253056\,x_1^2 - 0.0436112\,x_2 + \\ + 0.0084375\,x_1 x_2 + 0.0121805\,x_2^2 + 0.00350001\,x_3 + \\ + 0.00197917\,x_1 x_3 - 0.00239584\,x_2 x_3 - 0.00115278\,x_3^2 \quad (10)$$

For this equation, the 95% dispersion probability level is homogeneous, the value of the Cochran criterion $G = 0.1354 < G_{0.05}\ (2, 15) = 0.3346$.

Dispersion of the adequacy of the mathematical model $S_{ad}^2 = 3.76 \cdot 10^{-6}$; dispersion of experimental error $S_y^2 = 1.77 \cdot 10^{-6}$; Fisher's criterion $F = 2.12 < F_{0.05}\ (5, 30) = 2.53$; the model is adequate at any level of confidence probability.

According to calculated values of correlation coefficients and Student's criterion $t_{0.05}\ (30) = 2.04$ significant at the level of confidence probability greater than 95% are all coefficients. In a sketched form, the model (10) has the form:

$$t = 0.415665 - 0.0000461111\,n^2 + 0.000702933\,Q^2 + 0.00246598\,n + \\ + 0.0000659722\,Q\,n - 0.000191667\,\psi\,n - 0.0203901\,Q + \\ + 0.0005625\,\psi\,Q - 0.0498236\,\psi + 0.00194889\,\psi^2. \quad (12)$$

By analyzing equation (12), it can be stated that all of the above factors are influenced by the average time interval between falling seeds. At the same time, with the increment of the vibroplate fluctuations frequency and the barrel frequency of rotation, the average time interval increases as well. Also, with an increased supply of seeds, the average time interval decreases.

The obtained mathematical model of the investigated factors influence on the productivity of the seed supply unit has the following form:

$$q = 7.58444 + 2.95042\,x_1 - 2.87556\,x_1^2 + 3.8375\,x_2 + 2.49917\,x_1 x_2 + \\ + 1.55361\,x_2^2 + 0.157083\,x_3 - 0.27\,x_1 x_3 + 0.309167\,x_2 x_3 - 0.425556\,x_3^2 \quad (13)$$

For this equation, the 95% dispersion probability level is homogeneous, the value of the Cochran criterion $G = 0.1296 < G_{0.05}\ (2, 15) = 0.3346$.

Dispersion of the adequacy of the mathematical model S_{ad}^2 = 0.2326; variance of experimental error S_y^2 = 0.1170; Fisher's value F = 1.98 <$F_{0.05}$ (6, 30) = 2.42; the model is adequate at any level of confidence probability.

According to the calculated values of the correlation coefficients and Student's criterion $t_{0.05}$ (30) = 2.04 significant coefficients at the confidence level greater than 95% are all coefficients. In a sketched form, the model (13) has the form:

$$q = 9.74785 - 0.0170222\, n^2 - 0.0798765\, Q^2 + 0.235944\, n - \\ - 0.009\, Q\, n + 0.0247333\, \psi\, n + 0.769931\, Q + 0.166611\, \psi Q - \\ - 3.9405\, \psi + 0.248578\, \psi^2 \quad (14)$$

Analyzing equation (14), it can be argued that the productivity of the seed supply block is influenced by all the above-mentioned factors. At the same time, with the increase in the frequency of the vibroplate oscillation and the supply of seeds, the productivity of the supply block increases. For the barrel rotation frequency n = 10.3 rpm, the optimum is observed.

The obtained mathematical model of the investigated factors influence on the power consumed by the seed supply unit has the following form:

$$P = 222.667 + 48.625\, x_1 + 0.625\, x_1^2 + 17.5\, x_2 - 4.0\, x_1 x_2 - \\ - 2.29167\, x_2^2 + 40.2083\, x_3 + 0.0833333\, x_1 x_3 - \\ - 7.66667\, x_2 x_3 + 6.79167\, x_3^2 \quad (15)$$

For this equation, the 95% confidence level of the dispersion is homogeneous, the value of the Cochran criterion G = 0.1977 < $G_{0.05}$(2, 15) = 0.3346.

Dispersion of the adequacy of the mathematical model S_{ad}^2 = 169.24; variance of experiment error S_y^2 = 80.33; Fisher's criterion F = 2.11 <$F_{0.05}$ (9,30) = 2.21; the model is adequate at any level of confidence probability.

According to the calculated values of the correlation coefficients and Student's criterion $t_{0.05}$ (30) = 2.04, the coefficients at the confidence level greater than 95% are the coefficients for the following variables: x_1, x_2, x_3, x_2x_3, x_3^2. In a sketched form, the model (15) has the form:

$$P = -2.02083 + 0.271667\, n^2 + 8.10417\, Q + 7.20833\, n - \\ - 0.613333\, \psi\, n + 13.1333\, \psi. \quad (16)$$

The graphical interpretation of the obtained dependence (16) is presented in Fig. 5.

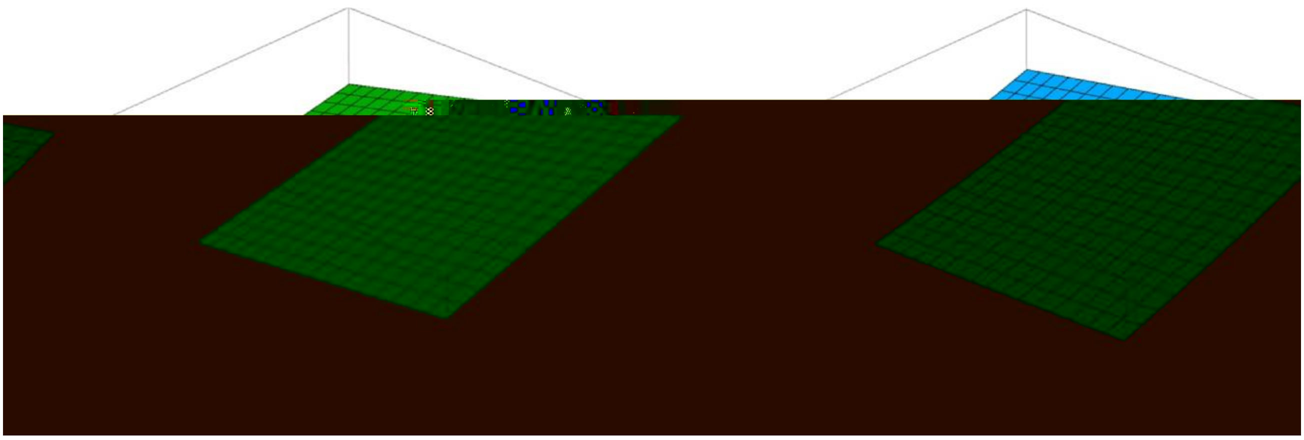

Fig. 5 - The dependence of the power P, consumed by the seed supply unit, on the seed supply Q, the vibroplate frequency oscillation ψ and the barrel rotational speed n

Analyzing equation (16), it can be stated that the power consumed by the seed supply unit is influenced by all the above-mentioned factors. At the same time with their increase, also increases power.

The task of solving a compromise problem was to maximize the average time interval between falling seeds and minimize the power consumed by the seed supply unit, with the maximum value of its productivity, which is comparable to the value of the seed supply, that is:

$$\begin{cases} t(Q,\psi,n) \to \max, \\ P(Q,\psi,n) \to \min \\ q(Q,\psi,n) = Q \to \max. \end{cases} \tag{17}$$

Convert the system of equations (17) to the form:

$$\begin{cases} \dfrac{q(Q,\psi,n) \times t(Q,\psi,n)}{P(Q,\psi,n)} \to \max, \\ q(Q,\psi,n) = Q. \end{cases} \tag{18}$$

The solution of the problem (18) using Mathematica software package has resulted in the optimal parameters and operating modes of the photoelectronic separator seed supply unit:

$$\begin{cases} Q = q = 15 \text{ kg/hr}, \\ \psi = 9{,}9 \text{ s}^{-1}, \\ n = 6{,}6 \text{ rpm}, \\ t = 0{,}058 \text{ s}, \\ P = 269 \text{ W}. \end{cases} \tag{19}$$

The comparison of theoretical and experimental data for the productivity functions of the seed supply unit (5) and (14) in the studied range of variation is presented in Fig. 6. Due to the fact that in theoretical research the seed supply block has 10 channels, and in the experimental - 20, the productivity will differ by 2 times, obviously. Statistical analysis has shown that the correlation coefficient between theoretical and experimental data with variation of the factors values is 0.92.

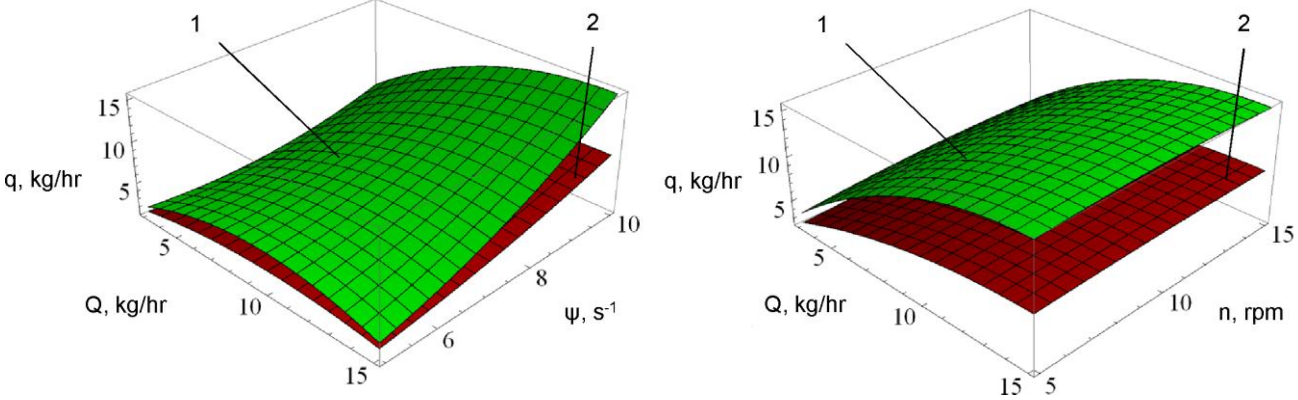

Fig. 6 - Comparison of the experimental (1) and theoretical (2) dependencies of the seed supply unit q

The comparison of theoretical and experimental data for functions of the average time interval between falling seeds (7) and (12) in the studied range of variation is presented in Fig. 7. Statistical analysis showed that the correlation coefficient between the theoretical and experimental data with variation of the factors values is 0.94.

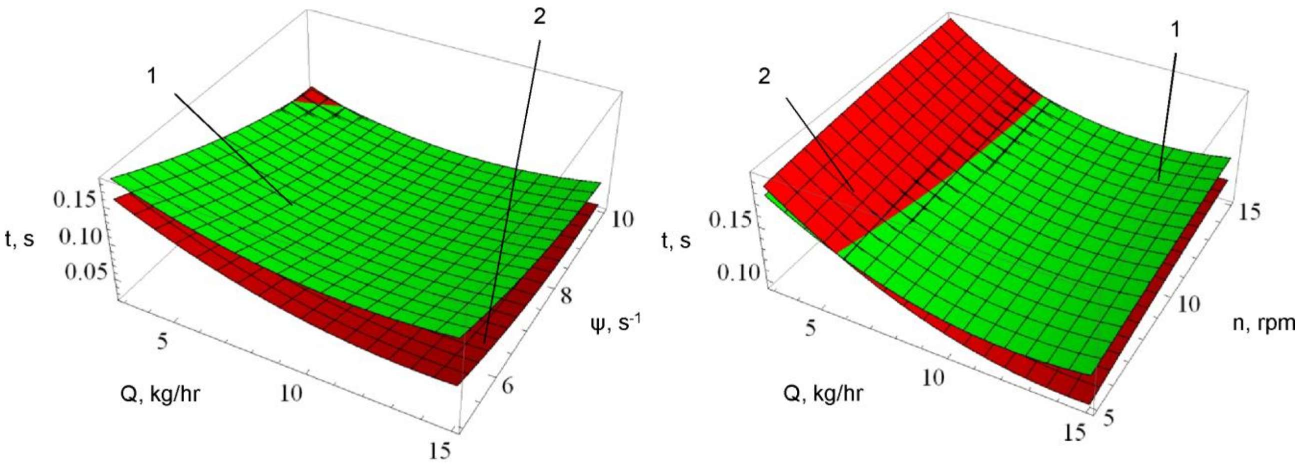

Fig. 7 - Comparison of the experimental (1) and theoretical (2) dependencies of the average time interval between falling seeds *t*

Due to the fact that in experimental studies the optimal parameters have been determined on the basis of a more extended compromise problem (the function of power dependence was introduced), the actual rational structural and technological parameters of the seed supply unit are taken into account (19).

CONCLUSIONS

As a result of numerical simulation of the seed transfer process under the influence of the working part of the photoelectronic separator seed supply unit, a physics and mathematical model that links the productivity of the photoelectronic separator seed supply unit q and the average time interval between the falling seeds t from the seed supply Q, the vibroplate oscillation frequency ψ and barrel rotation frequency n has been developed. As a result of solving a compromise problem, which is to ensure the efficient operation of the photoelectronic separator seed supply unit, it is necessary for its q efficiency to be maximal and equal to the seed supply Q value, with the average time interval between falling seeds t being the maximum, the rational parameters of the supply unit seeds: Q = q = 4.7 kg/hr, ψ = 10 s^{-1}, n = 12 rpm, t = 0.047 s.

As a result of experimental studies of the photoelectronic separator seed supply unit, the physics and mathematical model, that links the productivity of the photoelectronic separator seed supply unit q, its power consumption P, and the average time interval between falling seeds t from the seed Q supply, the vibroplate oscillation frequency ψ and barrel rotation frequency n, has been developed. During research, the following compromise problem has been solved: the maximization of the average time interval between falling seeds t and the minimization of the power P consumed by the seed supply unit at the maximum value of its productivity q, which is comparable to the value of the seed Q. Due to the optimal parameters being determined on the basis of a more extended compromise problem (the function of power dependence has been introduced) in experimental research, the actual rational structural and technological parameters of the seed supply unit are: Q = q = 15 kg/hr, ψ = 9.9 s^{-1}, n = 6.6 rpm, t = 0.058 s.

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