Scientific and Experimental Substantiation of the Key Geometric and Kinematic Parameters of Vibrocutting Machines

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Scientific and experimental substantiation of the key geometric and kinematic parameters of vibrocutting machines

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Abstract

The process of cutting with a blade is largely applied in technological equipment used
10 in the agricultural production complex and is used to process raw materials with different physical and mechanical properties. Nonetheless, the relation between the parameters of processing with vibroblade and the rheological properties of the processed material is insufficiently studied, while it is an important issue of practical significance.

As a result of laboratory experiments, it became possible to obtain the power
15 characteristics of vibrocutting of common reed, establish an optimal combination of factors: vibration amplitude, frequency and the speed of the blade delivery to ensure the minimum vibro-cutting force. As a desirable kinematic regime, $K = \frac{V}{V_t}$, the following relation of speed of delivery and vibration speed of the toothed blade: $\cong 0.004$.

20 Introduction

The wide use of mechanization means of agricultural production processes, as a priority
objective, is aimed at raising the agricultural production to the industrial level. For such progress, it is necessary to create a complex of machinery with high technical and economic indicators that will ensure the high quality of implementation of the required technological
25 processes.

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Design of such machines and equipment should be based on new principles of intensification of technological process through developing relevant technical equipment, which will rely on more efficient working principles.

Most of the tools and equipment used by man, starting from the tools of primeval period up to the latest equipment in the present day, work with the principle of Archimedean lever. And we can say that only a small segment is occupied by technological equipment and devices working by the principle of vibration.

Numerous theoretical and scientific and experimental studies have been carried out related to the issues of chopping and cutting of material with a blade, and a considerable experience has been gained; however, despite the urgency of the issue, vibrocutting of materials as a specific and prospective version of cutting with a blade has not gained enough attention.

As it is known, all phenomena in nature that take place in the micro and macro world are related to fluctuations. Therefore, it is considered that everything that moves, simultaneously performs also fluctuation (**Yarullin R.B.**, 2007, **Blekhman I.I.**, (1994)). In the world of fluctuations, mechanical fluctuations have a special place, among which those fluctuations have a considerable role which have comparatively small amplitude and not so low frequency, and this is what is called vibration (**Vibrations in the technology**, 1978).

In our days machines working by the vibration principle are largely spread, being an important factor of intensification and optimization of technological processes. The directions of using vibration are really amazing both in terms of the sector, technology, and the working parameters, starting from vibro-arc fusing of renewable machine parts up to combing goat fur, and from construction vibration tool to massage of cow udders (**Blekhman I.I.**, (2013)).

In soil cultivation vibration harrows, cultivators and plows are widely known, with their working body subjected to self-excited vibrational motion (**Fedorenko I.Ya.**, 2016, **Vasilenko V.V.**, **Vasilenko S.V.**, **Achkasova N.N.**, 2018, **Loveykin V.**, **Dyachenko L.**, 2013).

As a result of the laboratory experiments carried out by the authors (**Vasilenko V.V.**, **Vasilenko S.V.**, **Achkasova N.N.**, 2018) it was revealed that in case of vibration amplitude of 2...4mm and frequency of 22...24Hz, the angle of contact between the soil and the steel decreases by about 16%. In addition, it facilitates the high-quality mplementation of the technological process, excluding soil sticking and accumulation of weed mass on the working

body. During one of the tests, when the vibration amplitude of the working body was chosen 5mm and the frequency 8...10Hz, a 14% decrease in tractive resistance was recorded.

Analysis of the results of field tests by another group of researchers (Loveykin V.,
60 Dyachenko L., 2013) has indicated that vibration has a positive impact on the decrease of tractive resistance of the plow. The working bodies of vibratory plow receive vibration motion from the hydraulic vibrator. The obtained data indicate that at $\alpha = 65^{\circ}9'$ of location angle of vibrator and at the values of $\nu = 33,4 \text{ Hz}$ of vibrational frequency, the tractive resistance decreases by 54%. The authors also mention that in case of using vibratory plow, the number
65 of small fractions increases dramatically in soil. The number of 1mm...10mm size particle almost does not change, and particles that are larger than 10mm are decomposed. At the same time deviation from the set depth of tillage does not exceed the permitted limits.

There are a number of machines working by the developed vibrational technological principle (Tarverdyan A.P., 2014, Vasilenko V.V., Vasilenko S.V., Achkasova N.N., 2018), soil
70 cultivation machines used in agriculture, vibrodrills, as well as mowers, devices cutting with blade, etc. However, in the theory of their dimensioning, basics of rheological modeling are not used at all or not enough attention is paid to them, and the rheology of interaction of the cultivated medium and the working body has not been taken into consideration.

The design of vibration machinery to be used in agriculture and processing enterprises
75 become difficult in practice due to a number of circumstances.

The first circumstance is related to the processes underway in machine working by the principle of vibration, despite the fact that those machines can be very simple in terms of their structure. The main goal of vibrational impact is to assure such a dynamic state of the cultivated medium that will boost the intensification of the technological process and the improvement
80 of quality indicators as well as the decrease of force parameters.

In this case a complicated interaction between the vibration working bodies and the cultivated medium take place, with transfer of the mass, impulse and energy, etc.

The second circumstance, which makes the design works difficult, is the variety and the diversity of the cultivated medium, agricultural materials and raw products and their
85 physical-mechanical and rheological properties. This makes it difficult to establish a causal relationships between the parameters of the machine's working process and the final result indicator of its action.

In different times and in different phases of development of technologies and methods, researchers claim a simple truth that is still relevant (**Reznik N.Ye.**, 1975): “In different phases
90 of development of the theory of cutting with blade, one of the priorities and most important objectives should be seeking a method of determination of those properties of a material that have the most direct impact on the cutting process.” And, despite the critical significance of the physical-mechanical properties of the material being cut for the entire cutting process and other circumstances derived from it, while studying the sector (cutting and chopping
95 agricultural crops and plants with thick stems, feed crushers, silage and sewage crushers, food industry, consumer goods manufacturing, etc.), the researchers are mostly guided by traditional methods of studying the properties of materials. This experience is nothing more than borrowing from such advanced sciences as strength of materials and material science, from where not only the methodological forms of the study but also the group of properties
100 under research have been borrowed. As such properties, the indicators of strength and decomposition in cases of deformations of compressing, tension, sliding, and bending are the most relevant ones.

Academician A. Tarverdyan has attached importance to the physicochemical and anatomical-morphological properties of the material being cut, in particular, to the stem of the
105 plant (**Tarverdyan A.P.**, 2004), mentioning that ignoring their roles during the study of those properties and the process of cutting may seriously constraint the enhancement of the productivity of mowing machines.

The resistance of the working environment in the form of dry contact, and demonstration of non-Newton viscosity, slip deformation, relaxation of tensions, and
110 thixotropic properties leads to nonlinear differential equations that characterize the processes in the vibrational technological machines, and, as a consequence, makes their estimation and analysis difficult.

On the other hand, the nonlinearity is a source of numerous positive impacts and demonstrations of vibration, which are available in different technologies.

115 With this paper, we will try to identify the impact of purely mechanical properties of vibration on static forces and motions. This creates basis for further research works related to theoretical analysis of the quantitative size of the mechanical impact of vibration through modeling of rheological properties of the material with the help of different physical values.

This kind of approach will obviously enable to create cutting devices that are efficient from the standpoint of intensification of technological processes and at the same time energy efficient.

As the results of the research have shown (Yarullin R.B., 2007), the effective values of vibration amplitude and frequency in technological equipment working by vibration principle in the food and agriculture sector do not exceed 10 mm and 300 rad sec⁻¹ (or 47.75 Hz), respectively, except for some technological processes (Fig.1). The author offers also an empirical formula that establishes a correlation between the optimal parameters of vibration. It looks as follows:

$$A = \frac{0,39}{\omega},$$

where A is the amplitude, m, and ω is the frequency, rad sec⁻¹.

Fig.1 Optimal values of vibration amplitude and frequency (according to R.B. Yarulin) in the technological processes applied in the agro-industrial complex

Δ – livestock, * – engineering and road construction, + – equipment repair, x – centrifugal vibro-machines, □ – smoothly sieving vibrator machines, ● – friction vibrator machines

Results and discussions

We have previously carried out theoretical research (Altunyan A.V., (2009), Tarverdyan A.P., (2004)) dedicated to the force analysis of vibrocutting with blade. According to the data obtained as a result of theoretical analyses and calculations, the dependence of the normal and tangential components of contact forces occurring on the surface of the blade in

the vibrocutting process from the index of kinematic regime describing the vibrocutting process has been defined:

$$K = \frac{V}{V_{\tau}},$$

where V is the speed of parallel movement of the machine (or the peripheral speed of the blade),

and V_{τ} is the vibration amplitude of the cutting blade.

The studies have revealed that below the $K \approx 0,55$ value of the index of kinematical regime, the normal component of contact force decreases and, vice versa, the value of the tangential component increases.

To confirm the data and the patterns obtained as a result of theoretical research, as well as to reveal the real picture of the force process of vibrocutting, we have conducted laboratory scientific trials.

The goal of the scientific/experimental research was to measure via resistance tensioners the values of the normal and tangential components of the cutting force needed during the vibrocutting process in case of the change in the abovementioned three factors.

To conduct the trials, a laboratory equipment was designed (Fig. 2), which enables to change the frequency and the amplitude of vibration of the cutting tool and manage the delivery speed of the blade.

Fig. 2. The general view of the experimental device for determining the specific force of vibrocutting of the plants with thick stems

160 During the trials, two types of serrate blades were used as cutting tools (Fig.3), the geometric parameters of which are provided in Table 2.

Table 2

Types of blade	Move of tooth: S (mm)	Height of tooth: h (mm)
Fine-toothed	2	2
Large-toothed	4	4

a) $S = 4\text{mm}, h = 4\text{mm},$

b) $S = 2\text{mm}, h = 2\text{mm}:$

Fig.3. Types of toothed blades used for vibrocutting

165 A vibrational movement is transmitted to the cutting instrument through the slider-crank linkage (3) mechanism, which in turn is linked with the asynchronous (1) engine of direct current through the pulley (2).

Fig. 4. The general scheme of the experimental vibrocutting device

During the trial, the vibration frequency of the toothed blade (6) changed between 25 and 33.32 s^{-1} , which was achieved by changing the tension with the help of lator of the direct current. The number of rotations was measured with a tachometer. The resistance tensioner (7) of recording the numeric value of the normal component of the vibrocutting force was glued on the pulley of attachment of the blade.

The speed of delivery of the material being cut was selected in the range of $2.5 \dots 7.5 \text{ mm s}^{-1}$. The delivery was performed through a specially prepared metal container (4), where the samples (5) intended for cutting had been placed. In the place of attachment of the handle of the container a resistance tensioner (8) was glued, with the help of which the numeric value of the tangential component of the vibrocutting force was recorded.

The cutting trials were done with the stems of common reed. The samples were placed in a special container prepared for scientific experiments, which allowed to provide a 10 cm cutting width of the layer of stems, trying to imitate the cutting of stems in a dense medium.

The relevant signals characterizing the values of the normal and tangential components of the vibrocutting force were recorded independently from each other but simultaneously.

To make the conduct of trials, data recording and processing of the results more comfortable, the levels of the factors are encoded, specifying “+1” as the upper limit and “-1”

190 as the lower limit, and “0” as the main one. Transition from coded values to actual values is performed according to the linear law:

$$\tilde{X}_i = d \cdot x_i + \tilde{X}_2, i = 1, 2, 3, \quad (2)$$

where $\tilde{X}_i$ is the actual value of the i -th level,

$\tilde{X}_2$ is the actual value of the main level of the relevant factor,

d is the range of misinterpretation of the particular factor, and

195 x_i is the coded value of the i -th level.

However, it is often impossible to make a transition from the coded value of the factor to the actual value, making use of the linear equation (2), as the values of the factors change with unsteady step; in this case other approaches are applied, one of which is the analytic method. In our case, vibration amplitude is such a factor (Table 1). In this case the transition
200 from the coded value to the actual value as well as vice versa for our example is expressed as follows:

$$(\tilde{X}_2 - a)^2 = (\tilde{X}_1 - a)(\tilde{X}_3 - a), \tilde{X}_1 < \tilde{X}_2 < \tilde{X}_3 \quad (3)$$

The following are the values of the vibration amplitude: $\tilde{X}_1 = 8\text{mm}$, $\tilde{X}_2 = 10\text{mm}$, $\tilde{X}_3 = 14\text{mm}$.

205 Solving the equation (3), we will have $a = 6$. This is followed by the following appointments:

$$z_1 = \tilde{X}_1 - a = 2, \quad z_2 = \tilde{X}_2 - a = 4, \quad z_3 = \tilde{X}_3 - a = 8:$$

where z_1, z_2 and z_3 make a geometric progression with the following denominator:

$$q = \frac{z_2}{z_1} = \frac{z_3}{z_2} = 2. \quad (4)$$

210 Let's change the values of z_i ($i = 1, 2, 3$), so that they make an arithmetic progression with the difference $d_1 = 1$:

$$u_1 = \log_q z_1, u_2 = \log_q z_2 + 1, u_3 = \log_q z_3 + 2.$$

We will obtain a linear equation:

$$x_i = \frac{u_i - u_2}{d_1} = u_i - u_2, \quad i = 1, 2, 3,$$

215 through which the initial values of the factors will be brought to a coded shape: “+1”, “-1” and “0”.

Taking into consideration all the above mentioned transformations, we will obtain the following laws that express the linkage between the actual and coded values:

$$x_i = \log_q \frac{\tilde{X}_i - a}{\tilde{X}_2 - a}, \quad (5)$$

$$\tilde{X}_i = a + (\tilde{X}_2 - a) \cdot q^{x_i} : \quad (6)$$

220 Inserting the obtained values of a and q (3.6) into the equation and taking into consideration that for the case under discussion $\tilde{X}_2 = 10\text{mm}$ (the main level), to determine the actual value of the variable factor from the coded value, we will obtain the following expression:

$$\tilde{X}_i = 6 + (\tilde{X}_2 - 6) \cdot 2^{x_i} = 6 + 4 \cdot 2^{x_i} \quad (7)$$

where $\tilde{X}_i$ is the actual value of the i -th level of vibration amplitude (Table 1),

225 $\tilde{X}_2$ is the actual value of the main level of vibration amplitude (Table 1), and x_i is the coded value of the i -th level (Table 1).

The scientific trials were conducted in two phases, and the same plan/matrixes were composed to perform vibrocutting with a large-toothed blade in one case (Fig. 3.a) and with a fine-toothed blade in another case (Fig. 3.b).

230 The data obtained as a result of the scientific experiments were processed according to the methods of regression and dispersion analysis. The significance of the obtained coefficients of regression equation was tested according to the Student's t -test, with all statistically not significance coefficients being removed from the equation. The compliance of the eventually obtained equation was reviewed according to the F-test.

235 While performing vibrocutting with the large-toothed blade, after processing the scientific-experimental data received for the normal component of the cutting force by the mentioned methodology, we have obtained the following regression equation:

$$Y_N^L = 127,98 - 30,626X_1 - 9,542X_2 - 7,816X_3 - 20,34X_1X_2 + 12,59X_1X_3 + \quad (8)$$

$$+18,97X_2X_3, (N).$$

Analyzing the obtained regression equation as well as the constructed graphs, we can draw the following conclusions: the normal component of the vibrocutting force is largely impacted by the vibration amplitude of the blade through linear impact, the value of the coefficient of which, is the largest in terms of its absolute size: $b_1 = -30,626$. The subsequent factors in terms of linear impact are the vibration frequency and the speed of delivery. Among the linear impact factors only the delivery speed of the blade has a negative impact, so that increasing its actual value results in increase of the normal component of the cutting force.

Among the interacting efficiency factors, the couple amplitude-frequency, $b_{12} = -20,34$, has the largest impact. All interacting efficiency factors have a positive impact, i.e. increase of their actual value results in decrease of the normal component.

None of the square effect factors was significant according to the Student's t -test.

With the help of the obtained equation and «OriginPro» software, let's construct the family of curves depicting the values of the normal component of the needed force for vibrocutting of the tested common reed. The provided data of force parameters are given in "Newton".

X3=1

X3=0

X3=-1

255 **Fig. 5.** The family of curves of surface reaction, which characterizes the normal component of the cutting force (Y_N^L, N), depends on the vibration amplitude (X_1) and vibration frequency (X_2), in case of the fixed values of the normal component (X_3) of the cutting speed.

260 The regression equation obtained for the tangential component of the vibrocutting force looks as follows:

$$Y_T^L = 34,167 - 11,081X_2 - 5,471X_3 - 9,05X_1X_2, (N). \quad (9)$$

Analyzing the regression equation and the graphs built on its basis, we come to the following conclusions: the factor of vibration amplitude has a great impact on the tangential component of vibrocutting through linear impact, and this impact has a positive effect on the decrease of the cutting force. Another significant linear impact factor is the factor of blade delivery speed; however, its increase has a negative effect on the tangential component of force

265

(Fig. 6). The impact of the vibration amplitude on the value of the tangential component is not significant.

270 Among the interacting efficiency factors only the couple amplitude-frequency is significant, with its positive effect on the decrease of the value of the tangential component.

 None of the square effect factors has a significant impact on the tangential component of the vibrocutting force.

$X_3=1$

$X_3=0$

X3=-1

Fig. 6. The family of curves of surface reaction, which characterizes the tangential component of the cutting force (Y_T^L, N), depends on the vibration amplitude (X_1) and vibration frequency (X_2), in case of the fixed values of the normal component (X_3) of the cutting speed.

The second phase of the scientific experiments was dedicated to vibrocutting with a fine-toothed (Fig. 3.b) blade. It was carried out with the same methodology and plan/matrix as that of the large-toothed blade.

As a result of processing and analysis of the obtained statistical data, we have obtained the regression equations of the normal and tangential components.

The regression equation obtained for the normal component of the vibrocutting force looks as follows:

$$Y_N^F = 161,65 - 36,84X_1 + 29,54X_2X_3 + 11,45X_2^2 \text{ (N)}. \quad (10)$$

Analysis of the equation and the curve of surface reaction indicates that among the significant factors the vibration amplitude has the most impact through the linear effect. Its effect on the tangential component of the cutting force is positive. The coefficients of the rest of the linear effect factors, i.e. that of vibration frequency and the blade delivery speed, are not significant according to the Student's t -test.

Among the interacting efficiency factors, only the frequency-delivery speed couple is significant, with its positive effect on the normal component of the cutting force.

Among the square impact factors, only the vibration frequency is significant; however, its effect on the normal component is negative.

$X_3=1$

$X_3=0$

$X_3=-1$

Fig. 7. The family of curves of surface reaction, which characterizes the normal component of the cutting force (Y_N^F, N), depends on the vibration amplitude (X_1) and vibration frequency (X_2), in case of the fixed values of the normal component (X_3) of the cutting speed.

The regression equation obtained for the tangential component of vibrocutting force looks as follows:

$$Y_T^F = 14,22 + 6,44X_2X_3 + 8,95X_2^2, (N). \quad (11)$$

As it is seen from the equation, the factor of vibration amplitude is not part of the equation as it is not significant according to the Student's t -test.

None of the factors has a linear effect. Among the interacting efficiency factors, only the frequency-speed couple is significant. Its effect on the force value of the tangential component is positive.

Among the factors, only vibration frequency has a square effect, being the largest among the coefficients of the other factors, also with its absolute value. However, its effect is negative on the force value of the tangential component.

Fig. 8. The family of curves of surface reaction, which characterizes the normal component of the cutting force (Y_T^F, N), depends on the vibration amplitude (X_1) and vibration frequency (X_2), in case of the fixed values of the normal component (X_3) of the cutting speed.

The obtained regression equations give a general idea of the force of the vibrocutting of common reed as well as an information on the patterns of change in the cutting force in case of vibrocutting of thick-stemmed plants. It should be taken into consideration that the

obtained expressions refer to vibrocutting of not one stem but joint cutting of several stems with cutting width of 10 cm each and that they had been placed in the container provided in Fig. 2 and Fig.4 to create imitation of cutting in a dense medium.

Given that the equivalent of the vibrocutting force is the square root from the square sums of the normal and the tangential components:

$$F = \sqrt{Y_N^2 + Y_T^2},$$

then we can calculate the values the relevant factors providing the minimum value of that equivalent force. Using the “Minimize” order of the MathCAD software, as well as (8), (9), (10), and (11) expressions, we can find the values of those factors.

As a result, the following optimal regimes have been obtained, when the angle between the vibrational (tangential) and normal components of the cutting speed is 90°.

Large-toothed blade:

Vibration amplitude: $A = 14mm$, (coded value: +1);

Vibration frequency: $n = 33,32 \text{ s}^{-1}$, (coded value: +1);

Normal component of the cutting speed: $= 7,5 \times 10^{-3} \text{ m s}^{-1}$, (coded value` -1)

Fine-toothed blade:

Vibration amplitude: $A = 14mm$, (coded value` +1)

Vibration frequency: $n = 25 \text{ s}^{-1}$, (coded value` -1)

Normal component of the cutting speed: $= 2,5 \times 10^{-3} \text{ m s}^{-1}$, (coded value` +1)

In case of the mentioned values of the factors, we obtain the following optimal values of the vibrocutting force: the optimal force for a large-toothed blade was $F=47.87 \text{ N}$, in which case the value of the normal component is 43.7 N , that of the tangential component is 19.51 N , and for the fine-toothed blade the optimal vibrocutting force obtained was $F=108 \text{ N}$, in case of which the normal component is 106.73 N , and the tangential component is 16.74 N . It should be mentioned that the obtained force parameters do not refer to the cutting of just one stem of common reed but a sheaf placed in a container (Fig. 4), where the cutting width is 10 cm (the height of the container).

During the scientific trials the value of the tangential component of the cutting speed was determined from the following expression, which takes into account the structural characteristics of the experimental device:

$$V_t = nA \left(1 + \frac{A \cos \alpha}{\sqrt{\ell^2 - A^2 \sin^2 \alpha}} \right) \sin \alpha ,$$

where n is the rotation speed of rotation, s^{-1} ,

A is the vibration amplitude, mm,

355 ℓ is the length of pulley, ($\ell = 10mm$) (Fig.4), and

α is the rotation angle of the crank.

We have averaged the value of the tangential component of the speed on the section π of the vibration periodicity. Taking into consideration the values of the factors of optimal vibrocutting force: $A=14$ mm, $n = 33,32 s^{-1}$ and $V = 7,5 \times 10^{-3} m s^{-1}$, we will obtain $V_t =$
360 $1,866 m s^{-1}$, while the index of the critical regime will be:

$$K = \frac{V}{V_t} = \frac{7,5 \times 10^{-3}}{1,866} = 0,004.$$

Conclusion

1. Experimental and scientific experimental research is one of the key methods to obtain
365 data of applied significance on the process of vibrocutting with blade. This is due to both the complicated technological process of vibrocutting and its impact on the anatomic and morphologic properties of the material being cut (plant raw material), causing partial change.
2. The wide use of the technological process of cutting with blade speaks of the high
370 efficiency and workability of this method. Therefore, intensification of the process of cutting with blade, through optimal regime parameters chosen on the basis of force equations, will definitely have a positive effect on the efficiency of the technological process, ensuring a high productivity.
3. The results $A = 14mm, n = 33,32 s^{-1}$ and $V = 7,5 \times 10^{-3} m s^{-1}$ were obtained as the
375 values of factors providing optimal regime for vibrocutting of common reed, in case of toothed vibrocutting, when the tooth is 4mm high and the step is 4mm.
4. As a result of theoretical research the defined desirable value of the index of the kinematical regime $K < 0,55$, was proven by the results of the scientific experimental research of the vibrocutting force, the experimental value of which is $K \cong 0,004$.

Methods

Given the abovementioned research results and the theoretical research, laboratory experiments have been planned and an orthogonal central plan/matrix has been chosen for implementation of scientific experiments. The number of experiments in the plan/matrix was N=17, of which $n_0=3$ scientific experiments were completed at the “zero point”.

According to the management of the levels of factors influencing the optimization parameters of the scientific experiments, active experiments were carried out, during which an experimenter has the possibility to personally manage any change in the levels of those factors. According to the goal of the scientific experiments, extremum scientific experiments were carried out to identify such a combination of managed factors influencing on optimization parameters that will ensure an optimal regime of vibrocutting.

In the scientific experiments, the following optimization parameters were chosen: the normal, Y_1 (N) and the tangent, Y_2 (N), components of the cutting force of the serrate blade. As factors influencing the optimization parameters (Y_1, Y_2), amplitude of vibrocutting, X_1 (mm), frequency of vibration of serrate blade, X_2 (s^{-1}) and the speed of delivery of the blade X_3 ($m s^{-1}$) were selected. The values of determination of the sphere of factors impacting on the optimization factors and the values of the range of misinterpretation are presented in Table 1. To assess the normal and the tangential components, the experiments were carried out with the help of the second class trifactor orthogonal planning matrix.

Table 1

Values of the spheres of determination of the factors and the misinterpretation ranges

Parameters of matrix	Code	Vibrocutting amplitude, X_1 , mm	Frequency of vibration, X_2, s^{-1}	Normal component of cutting speed, $X_3 \times 10^{-3}, ms^{-1}$
Range of misinterpretation	-	-	4,17	-2,5
Main level	0	10	29,16	5
Upper level	+1	14	33,32	2,5
Lower level	-1	8	25	7,5

The review of the literature available in the sector (Igathinathane, C., Pordesimo, L. O., Schilling, M. W. & Columbus, E. P., 2011) indicates that the needed precision for

theoretically describing the raised issue and for presenting the results of the scientific experiments through mathematical modeling can be assured, if, as a model of scientific experiments, we apply a second class polynome as follows:

$$y = b_o + \sum_{1 \leq i \leq N} b_i x_i + \sum_{1 \leq i < j \leq N} b_{ij} x_i x_j + \sum_{1 \leq i \leq N} b_{ii} x_i^2, \quad (1)$$

where b_o, b_i, b_{ij} and b_{ii} are the unknown coefficient of the polynome to be determined,

x_i is the i -th factor of the plan/matrix of the scientific experiments,

N is the number of trials in the plan/matrix,

and i and j is the serial number of the factors in the plan/matrix, $i < j$.

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Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Figures

Figure 1

Optimal values of vibration amplitude and frequency (according to R.B. Yarulin) in the technological processes applied in the agro-industrial complex Δ – livestock, * – engineering and road construction, + – equipment repair, x – centrifugal vibro-machines, $\square$ – smoothly sieving vibrator machines, $\boxtimes$ – friction vibrator machines

Figure 2

The general view of the experimental device for determining the specific force of vibrocutting of the plants with thick stems

a) $S = 4\text{mm}$, $h = 4\text{mm}$,

b) $S = 2\text{mm}$, $h = 2\text{mm}$:

Figure 3

Types of toothed blades used for vibrocutting

Figure 4

The general scheme of the experimental vibrocutting device

$X_3=1$

$X_3=0$

$X_3=-1$

Figure 5

The family of curves of surface reaction, which characterizes the normal component of the cutting force ($\frac{F_n}{F_t}$), depends on the vibration amplitude (A) and vibration frequency (f), in case of the fixed values of the normal component (X_3) of the cutting speed.

X3=1

X3=0

X3=-1

Figure 6

The family of curves of surface reaction, which characterizes the tangential component of the cutting force (F_{t1}, F_{t2}), depends on the vibration amplitude (X_1) and vibration frequency (X_2), in case of the fixed values of the normal component (X_3) of the cutting speed.

$X_3=1$

$X_3=0$

$X_3=-1$

Figure 7

The family of curves of surface reaction, which characterizes the normal component of the cutting force ($\square \square \square$), depends on the vibration amplitude ($\square 1$) and vibration frequency ($\square 2$), in case of the fixed values of the normal component ($\square 3$) of the cutting speed.

Figure 8

The family of curves of surface reaction, which characterizes the normal component of the cutting force ($F_{n, \text{cut}}$), depends on the vibration amplitude (A) and vibration frequency (f), in case of the fixed values of the normal component (V_n) of the cutting speed.