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# Mathematical simulation of the saprapel grinding by means of the shock loads

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Abstract. The article discusses the process of grinding of the solid aggregates of the lacustrine sapropel based on the model of mechanics of deformed solid body. As the result of simulation the initially-final problem on theory of elasticity is solved by the method of integral transformations. The research presents a numerical description of the tensed and deformed states of the solid aggregates of sapropel in dependence with the rates of loadings and geometric parameters. It discovered space and time distribution of the main tangent stresses influencing sufficiently the process of destruction and degree of the given material grinding.

Key words: theory of grinding, dynamic problem, shock load, integral transformations, main tangent stress.

## INTRODUCTION

The fertility of soils is a crucial factor of a highly effective agricultural production under current conditions. The main organic fertilizers provider until very recently was animal husbandry. However for the last 20 years their volumes dropped considerably and this led to the 5 times decrease of the norms of organic fertilizers application in some regions [1]. The world technologies of crop growing are oriented only on the improvement of their industrially technological systems and their optimization to receive the highest outcomes [2, 3, 4], neglecting ecological effects of economic management. On the other hand, the permanent increase of fuel costs may lead to the situation when the application of organic fertilizers of the animal origin would be ineffective. We currently get, therefore, an urgent need in seeking new types of organic fertilizers and new ways of their application. One of these may be the lacustrine sappropel found in freshwater bodies.

## RECENT RESEARCH AND PUBLICATIONS ANALYSIS

The major problem of the lacustrine sapropel utilization in the natural state is its high (92 - 96%) humidity. For its further utilization as an organic fertilizer its humidity should not exceed 60 %. The sapropel humidity decrease, however, may result in the loss of nutrients [5, 6, 7]. When utilizing the lacustrine sapropel as an organic fertilizer by the surface method one should keep to the norms of 40/60 t/ha [7, 8, 9, 10]. The attemps of developing new fertilizers on the basis of sapropel faced the problems linked with the lack of industrial facilities of their manufacturing [14,15]. One of the ways of their utilization as a fertilizer, therefore, is the local application of frozen sapropels. This allows to diminish several times the norm with the simultaneous saving of the nutrient complex for the plants.

The received experimental results prove the fact that frozen lacustrine sapropels change their properties under the influence of environmental conditions. High humidity sapropels get some solid inclusions and this phenomeon should be taken into consideration when choosing the way of sapropel application in the soils. In case of local application of frozen lacustrine sapropels without any processing these solid aggregates may negatively affect the crops yielding capacity. Therefore, there appeared an urgent necessity of developing and putting into practice elementary but effective technology of sapropel grinding during its application.

Mathematical simulation of the technological process of grinding is used in different branches. Grinding is supposed to be accompanied with the destruction of inter-molecular and inter-atom connections. Therefore, to make its quantities description one may use energetic approaches [13, 14]. In particular, in stimulation of the process of grinding, the work for destructing external forces is frequently associated with the area of the surfaces formed in the result of destructing area and the volumes of the grinded materials.

Unlike the solid bodies, soils and, in particular, solid aggregates of sapropel are compound mixtures. Their destruction takes place, primarily, by the loss of adhesion of some components and is mostly determined by these components' composition, humidity, temperature, etc. In general, the mentioned above problems are referred to complex, geometrical and physical nonlinear models of mechanics of continuums. Nevertheless, quite a number of vital regularities and effects proceding the process of soil mixtures destruction and in many respects facilitating them may be found and researched with application of a linear model of the theory of elasticity [15]. The object of research is suggested to be a rectangular fragment of sapropel solid aggregate. Two opposite sides of this rectangle are high intensively loaded with an effect of self-balance. In addition, because of the effect of this material sticking to the destructive tool, its surface lacks tangent movements. Two other sides of the rectangle are considered free of loading.

## SETTING OF THE PROBLEM

Let us consider the $2h \times 2l$ rectangle with $x_1$, and $y_1$ accordingly (Fig. 1). At the moment $t = 0$ the rectangle's sides $x_1 = \pm l$ are effected by normal forces $p(t)$. These sides are given the condition of the absence of tangential component of the vector of displacement. Other surfaces $y = \pm h$ for all the period of deformation stay free of loading.

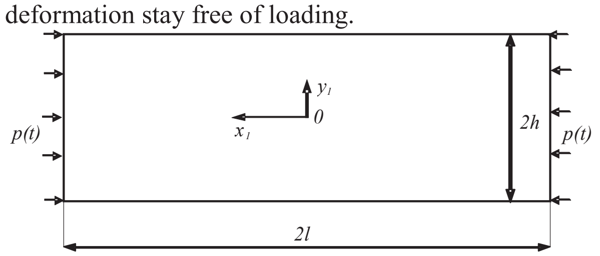


**Fig. 1.** Scheme of the objective

For the convenience in describing mathematical phenomena and revealing the most characteristic parameters determining dynamic tensed and deformed state, we introduce into our analysis dimensionless variables and the values $x = x_1 / l$, $y = y_1 / l$, $\tau = c_1 t / l$, $x_0 = h / l$, $\kappa^2 = c_1 / c_2 = (\lambda + 2\mu)/\mu$, where: $c_1$, $c_2$, – is the rate of spreading waves of compression and shift in the material of sapropel, $\lambda$ $\mu$ – are elastic constants.

In terms of these variables when $t = 0$ and the material is in the state of rest, the objective is formulated in the following way:

- equation of the moment of elastic environment:

$$\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2} = \frac{\partial^2\theta}{\partial\tau^2}. \qquad (1)$$

$$\frac{\partial^2 u_y}{\partial x^2} + \frac{\partial^2 u_y}{\partial y^2} = \kappa^2 \frac{\partial^2 u_y}{\partial\tau^2} - (\kappa^2 - 1)\frac{\partial\theta}{\partial y}. \qquad (2)$$

- initial conditions:

$$\theta = \frac{\partial\theta}{\partial\tau} = 0,\ u_y = \frac{\partial u_y}{\partial\tau} = 0, \quad \tau = 0. \qquad (3)$$

- conditions on the loaded surfaces:

$$\sigma_{xx}(\pm 1, y, \tau) = \mp p(\tau),\ u_y(\pm 1, y, \tau) = 0. \qquad (4)$$

- conditions on the free surfaces:

$$\sigma_{xx}(x, \pm y_0, \tau) = 0,\ \sigma_{xy}(x, \pm y_0, \tau) = 0. \qquad (5)$$

where: $\theta(x, y, \tau) = \dfrac{\partial u_x}{\partial x} + \dfrac{\partial u_y}{\partial y}$ - is the volume expansion, $u_x(x, y, \tau)$ $u_y(x, y, \tau)$ - components of the vector of elastic displacement,

$$\sigma_{xx} = \lambda\theta + 2\mu\varepsilon_{xx};\ \sigma_{yy} = \lambda\theta + 2\mu\varepsilon_{yy};$$

$$\sigma_{xy} = 2\mu\varepsilon_{xy};\ \varepsilon_{xx} = \frac{\partial u_x}{\partial x};\ \varepsilon_{yy} = \frac{\partial u_y}{\partial y};$$

$$\varepsilon_{xy} = \frac{1}{2}\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right);$$

- components of the tensor of stress and tensor of deformation.

- Using the condition (4) and taking into consideration:

that

$$\theta(\pm 1, y, \tau) \equiv \left.\left(\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y}\right)\right|_{x=\pm 1} = \left.\frac{\partial u_x}{\partial x}\right|_{x=\pm 1},$$

we receive:

$$\mu^{-1}\sigma_{xx}(\pm 1, y, \tau) = \kappa^2\theta(\pm 1, y, \tau). \qquad (7)$$

## CONSTRUCTION OF SOLVING THE PROBLEM

Let us employ the Laplace integral transformation on the temporary variable and the Fourier *cos* final construction on the variable $x$ [17], to the equation (1).

Taking into consideration the problem's symmetry, initial zero condition (3), the correlation (7) and the conditions (4), after all transformations instead of the equation (1), we shall receive:

$$\frac{d^2\bar{\theta}_n}{dy^2} - (\xi_n^2 + s^2)\bar{\theta}_n = (-1)^{n+1}\frac{2\xi_n}{\kappa\mu}\bar{p}(s), \qquad (8)$$

where: $\xi_n = \pi(2n+1)/2$ a $\bar{\theta}_n(y, s) =$

$= \int_{-1}^{1}\cos(\xi_n x)\int_{0}^{\infty}\theta(x, y, \tau)\exp(-s\tau)d\tau dx$ - is a representation by Laplace and Fourier.

Instead of the equation (2) we, accordingly, receive:

$$\frac{d^2\bar{v}_n}{dy^2} - (\xi_n^2 + \kappa^2 s^2)\bar{v}_n = (1 - \kappa^2)\frac{d\bar{\theta}_n}{dy}, \qquad (9)$$

where:

$$\overline{v}_n(y,s) = \int_{-1}^{1} \cos(\xi_n x) \int_0^\infty u_y(x,y,\tau)\exp(-s\tau)\,d\tau dx.$$

Taking into consideration that $\overline{\theta}_n(y,s)$ is a binary correlation function of a variable, the equation (7) is solved in the following way:

$$\overline{\theta}_n = A_n(s)\cosh(\gamma_1 y) + \frac{(-1)^n 2\xi_n \overline{p}(s)}{\mu\kappa^2\gamma_1^2}, \quad (10)$$

at $\gamma_1 = \sqrt{\xi_n^2 + s^2}$.

Taking into consideration (10), the equation (9) is solved in the following way:

$$\overline{v}_n = B_n(s)\sinh(\gamma_2 y) + \frac{\gamma_1}{s^2} A_n(s)\sinh(\gamma_1 y), \quad (11)$$

at $\gamma_2 = \sqrt{\xi_n^2 + \kappa^2 s^2}$.

Another component of the vector of displacement can be found taking into consideration the correlation:

$$\overline{u}_n(y,s) = \int_{-1}^{1} \sin(\xi_n x) \int_0^\infty u_x(x,y,\tau)\exp(-s\tau)\,d\tau dx$$

$$\overline{u}_n = \frac{1}{\xi_n}\left(\overline{\theta}_n - \frac{d\overline{v}_n}{dy}\right) \text{ in the form:}$$

$$\overline{u}_n(y,s) = -B_n(s)\xi_n^{-1}\gamma_2\cosh(\gamma_2 y) - \frac{\xi_n}{s^2} A_n(s)\cosh(\gamma_1 y) + \frac{(-1)^n 2\overline{p}(s)}{\mu\kappa^2\gamma_1^2}. \quad (12)$$

The values $A_n(s)$ and $B_n(s)$ can be determined under the limiting conditions (5), which in transformants by Laplace and Fourier and in the terms of the found above expressions will have the following form:

$$(\kappa^2 - 2)\overline{\theta}_n + 2\frac{d\overline{u}_n}{dy} = 0,$$
$$-\xi_n \overline{v}_n + \frac{d\overline{u}_n}{dy} = 0, \quad y = \pm y_0. \quad (13)$$

Taking into consideration the expressions (10)-(12) from the conditions (13) we shall find the following:

$$A_n(s) = \frac{s^2(\xi_n^2 + \gamma_2^2)\sinh(\gamma_2 y_0)\overline{p}_n(s)}{\gamma_1^2\Delta(\xi,s)};$$
$$B_n(s) = \frac{-2\xi_n^2\sinh(\gamma_1 y_0)\overline{p}_n(s)}{\gamma_1\Delta(\xi,s)} \quad (14)$$

where:

$$\Delta(\xi,s) = 4\xi_n^2\gamma_1\gamma_2\sinh(\gamma_1 y_0)\cosh(\gamma_2 y_0) - (\xi_n^2 + \gamma_2^2)^2\cosh(\gamma_1 y_0)\sinh(\gamma_2 y_0),$$

$$\overline{p}_n(s) = \frac{(-1)^n 2\xi_n(\kappa^2 - 2)\overline{p}(s)}{\mu\kappa^2}.$$

Finally, by the known values $A_n(s)$ i $B_n(s)$ we shall receive:

$$\overline{v}_n(y,s) = \gamma_1^{-1}\Delta^{-1}\left[(\xi_n^2 + \gamma_2^2)\sinh(\gamma_2 y_0)\sinh(\gamma_1 y) - 2\xi_n^2\sinh(\gamma_1 y_0)\sinh(\gamma_2 y)\right]\overline{p}_n;$$
$$\overline{u}_n(y,s) = \left(\frac{1}{(\kappa^2 - 2)\xi_n} + \frac{\xi_n}{\Delta}\left[2\gamma_1\gamma_2\sinh(\gamma_1 y_0)\times \cosh(\gamma_2 y) - (\xi_n^2 + \gamma_2^2)\sinh(\gamma_2 y_0)\cosh(\gamma_1 y)\right]\right)\frac{\overline{p}_n}{\gamma_1^2}. \quad (15)$$

We shall carry out transformations by Laplace using the theorem of decomposition [17]. In this case we consider the first expression (15) and find singular points of the denominator. Apparently the roots of the expression $\gamma_1 = 0$ are not the singular points of the dominator and, therefore, let us consider the equation:

$$4\xi_n^2\gamma_1\gamma_2\sinh(\gamma_1 y_0)\cosh(\gamma_2 y_0) - (\xi_n^2 + \gamma_2^2)^2\cosh(\gamma_1 y_0)\sinh(\gamma_2 y_0) = 0. \quad (16)$$

The roots of the characteristic equation (16) are purely imaginary and comprehensively-connected.

Therefore, it is reasonable to substitute $s = i\eta$ and, correspondingly, to receive:

$$\gamma_1 = \sqrt{\xi_n^2 - \eta^2} \quad \gamma_2 = \sqrt{\xi_n^2 - \kappa^2\eta^2}.$$

The roots $\eta_{n,k}$ apparently, depend on the discrete value $\xi_n$, and, therefore, there exist three cases of their arrangement :

$$0 \le \left|\eta_{n,k}\right| \le \frac{\xi_n}{\kappa};\ \frac{\xi_n}{\kappa} < \left|\eta_{n,k}\right| \le \xi_n;\ \left|\eta_{n,k}\right| > \xi_n. \quad (17)$$

For the first interval the characteristic equation saves the form (16) and gets the final number of roads $\eta_{n,k,1}$. For the interval $\kappa^{-1}\xi_n < \left|\eta_{n,k}\right| \le \xi_n$ the characteristic equation gets the form:

$$4\xi_n^2\gamma_1\tilde{\gamma}_2\sinh(\gamma_1 y_0)\cos(\tilde{\gamma}_2 y_0) - (\xi_n^2 + \tilde{\gamma}_2^2)^2\cosh(\gamma_1 y_0)\sin(\tilde{\gamma}_2 y_0) = 0, \quad (18)$$

at $\tilde{\gamma}_2 = \sqrt{\kappa^2\eta^2 - \xi_n^2}$. It has the final number $k_2$ of the roots $\eta_{n,k,2}$.

And, accordingly, for the interval $\left|\eta_{n,k}\right| > \xi_n$ the equation:

$$4\xi_n^2\tilde{\gamma}_1\tilde{\gamma}_2\sin(\tilde{\gamma}_1 y_0)\cos(\tilde{\gamma}_2 y_0) + (\xi_n^2 + \tilde{\gamma}_2^2)^2\cos(\tilde{\gamma}_1 y_0)\sin(\tilde{\gamma}_2 y_0) = 0 \quad (14) \quad (19)$$

at $\tilde{\gamma}_1 = \sqrt{\eta^2 - \xi_n^2}$ has the infinite number of roots $\eta_{n,k,3}$.

For the use of the expression (15), with employment of the theorem of decomposition one must determine the value of the denominator [17]. Accordingly, we get the value of the derivative from the expressions for different intervals of arrangement of the characteristic equation roots:

$$0<\left|\eta\right|\le\frac{\xi_n}{\kappa},\ \ \Delta'\Big|_{s=\pm\eta_{n,k,1}}\equiv\tilde{\Delta}_1(n,k)=\pm i\eta_{n,k,1}\left\{4\xi_n^2\left[\frac{\gamma_2}{\gamma_1}\sinh(\gamma_1x_0)\cosh(\gamma_2x_0)+\frac{\kappa^2\gamma_1}{\gamma_2}\times\right.\right.$$
$$\left.\times\sinh(\gamma_1x_0)\cosh(\gamma_2x_0)+x_0\gamma_2\cosh(\gamma_1x_0)\cosh(\gamma_2x_0)+\kappa^2x_0\gamma_1\sinh(\gamma_1x_0)\sinh(\gamma_2x_0)\right]-$$
$$-4\kappa^2(\xi_n^2+\gamma_2^2)\cosh(\gamma_1x_0)\sinh(\gamma_2x_0)-(\xi_n^2+\gamma_2^2)^2\frac{x_0}{\gamma_1}\sinh(\gamma_1x_0)\sinh(\gamma_2x_0)-\tag{20}$$
$$\left.-(\xi_n^2+\gamma_2^2)^2\frac{\kappa^2x_0}{\gamma_2}\cosh(\gamma_1x_0)\cosh(\gamma_2x_0)\right\}.$$

$$\frac{\xi_n}{\kappa}<\left|\eta\right|\le\xi_n,\ \Delta'\Big|_{s=\pm\eta_{n,k,2}}\equiv\tilde{\Delta}_2(n,k)=\mp\eta_{n,k,2}\left\{4\xi_n^2\left[\frac{\tilde{\gamma}_2}{\gamma_1}\sinh(\gamma_1x_0)\cos(\tilde{\gamma}_2x_0)-\right.\right.$$
$$\left.-\frac{\kappa^2\gamma_1}{\tilde{\gamma}_2}\sinh(\gamma_1x_0)\cos(\tilde{\gamma}_2x_0)+x_0\tilde{\gamma}_2\cosh(\gamma_1x_0)\cos(\tilde{\gamma}_2x_0)+\kappa^2x_0\gamma_1\sinh(\gamma_1x_0)\sin(\tilde{\gamma}_2x_0)\right]-$$
$$-4\kappa^2(\xi_n^2-\tilde{\gamma}_2^2)\cosh(\gamma_1x_0)\sin(\tilde{\gamma}_2x_0)-(\xi_n^2-\tilde{\gamma}_2^2)^2\frac{x_0}{\gamma_1}\sinh(\gamma_1x_0)\sin(\tilde{\gamma}_2x_0)+\tag{21}$$
$$\left.+(\xi_n^2-\tilde{\gamma}_2^2)^2\frac{\kappa^2x_0}{\tilde{\gamma}_2}\cosh(\gamma_1x_0)\cos(\tilde{\gamma}_2x_0)\right\}.$$

$$\left|\eta\right|>\xi_n,\ \Delta'\Big|_{s=\pm\eta_{n,k,3}}\equiv\tilde{\Delta}_3(n,k)=\mp\eta_{n,k,3}\left\{4\xi_n^2\left[\frac{\tilde{\gamma}_2}{\tilde{\gamma}_1}\sin(\tilde{\gamma}_1x_0)\cos(\tilde{\gamma}_2x_0)+\right.\right.$$
$$\left.+\frac{\kappa^2\tilde{\gamma}_1}{\tilde{\gamma}_2}\sin(\tilde{\gamma}_1x_0)\cos(\tilde{\gamma}_2x_0)+x_0\tilde{\gamma}_2\cos(\tilde{\gamma}_1x_0)\cos(\tilde{\gamma}_2x_0)-\kappa^2x_0\tilde{\gamma}_1\sin(\tilde{\gamma}_1x_0)\sin(\tilde{\gamma}_2x_0)\right]-$$
$$-4\kappa^2(\xi_n^2-\tilde{\gamma}_2^2)\cos(\tilde{\gamma}_1x_0)\sin(\tilde{\gamma}_2x_0)-(\xi_n^2-\tilde{\gamma}_2^2)^2\frac{x_0}{\tilde{\gamma}_1}\sin(\tilde{\gamma}_1x_0)\sin(\tilde{\gamma}_2x_0)+\tag{22}$$
$$\left.+(\xi_n^2-\tilde{\gamma}_2^2)^2\frac{\kappa^2x_0}{\tilde{\gamma}_2}\cos(\tilde{\gamma}_1x_0)\cos(\tilde{\gamma}_2x_0)\right\}.$$

Apart from the roots of the characteristic equitation (16) as singular points of at denominator, the second expression (15) has the roots of equation $\gamma_1=0$: $s=\pm i\xi$.

Taking it into consideration, the final expression for the component vector of displacement will get the following form:

$$u_x(x,y,\tau)=-\frac{4}{\mu}\left(1-\frac{2}{\kappa^2}\right)\sum_{n=0}^{\infty}(-1)^n\xi_n^2\sin(\xi_nx)\times$$
$$\times\left\{\sum_{k=1}^{k_1}\frac{2\gamma_1\gamma_2\sinh(\gamma_1y_0)\cosh(\gamma_2y)-\left(2\xi_n^2-\kappa^2\eta_{n,k,1}^2\right)\sinh(\gamma_2y_0)\cosh(\gamma_1y)}{\gamma_1^2\tilde{\Delta}_1(n,k)}f(\eta_{n,k,1},\tau)+\right.$$
$$+\sum_{k=1}^{k_2}\frac{2\gamma_1\tilde{\gamma}_2\sinh(\gamma_1y_0)\cos(\tilde{\gamma}_2y)-\left(2\xi_n^2-\kappa^2\eta_{n,k,2}^2\right)\sin(\tilde{\gamma}_2y_0)\cosh(\gamma_1y)}{\gamma_1^2\tilde{\Delta}_2(n,k)}f(\eta_{n,k,2},\tau)+\tag{23}$$
$$\left.+\sum_{k=1}^{\infty}\frac{2\tilde{\gamma}_1\tilde{\gamma}_2\sin(\tilde{\gamma}_1y_0)\cos(\tilde{\gamma}_2y)+\left(2\xi_n^2-\kappa^2\eta_{n,k,3}^2\right)\sin(\tilde{\gamma}_2y_0)\cos(\tilde{\gamma}_1y)}{\tilde{\gamma}_1^2\tilde{\Delta}_3(n,k)}f(\eta_{n,k,3},\tau)\right\}$$

$$\begin{aligned} u_y(x,y,\tau) = -\frac{4}{\mu}\left(1-\frac{2}{\kappa^2}\right)\sum_{n=0}^{\infty}(-1)^n \xi_n \cos(\xi_n x) \times \\ \times\Bigg\{\sum_{k=1}^{k_1}\frac{\left(2\xi_n^2-\kappa^2\eta_{n,k,1}^2\right)\sinh(\gamma_2 y_0)\sinh(\gamma_1 y)-2\xi_n^2\sinh(\gamma_1 y_0)\sinh(\gamma_2 y)}{\gamma_1\tilde{\Delta}_1(n,k)} f(\eta_{n,k,1},\tau) + \\ +\sum_{k=1}^{k_2}\frac{\left(2\xi_n^2-\kappa^2\eta_{n,k,2}^2\right)\sin(\tilde{\gamma}_2 y_0)\sinh(\gamma_1 y)-2\xi_n^2\sinh(\gamma_1 y_0)\sin(\tilde{\gamma}_2 y)}{\gamma_1\tilde{\Delta}_2(n,k)} f(\eta_{n,k,2},\tau) + \\ +\sum_{k=1}^{\infty}\frac{\left(2\xi_n^2-\kappa^2\eta_{n,k,3}^2\right)\sin(\tilde{\gamma}_2 y_0)\sin(\tilde{\gamma}_1 y)-2\xi_n^2\sin(\tilde{\gamma}_1 y_0)\sin(\tilde{\gamma}_2 y)}{\tilde{\gamma}_1\tilde{\Delta}_3(n,k)} f(\eta_{n,k,3},\tau)\Bigg\}, \end{aligned} \quad (24)$$

where:

$$f(\eta,\tau) = \int_0^{\tau} p(\tau - t)\sin(\eta t)dt \,. \quad (25)$$

The component of the tensor of deformation and the tensor of stress are calculated by the formula (6) at the known components of the vector of displacement (23). One may also show that all the series of the solution (23) uniformly converge and, therefore, differentiating operations at determining component-tensor of deformations and tensor of stresses can be carried out under the sign of a sum.

Under conditions simulating the sapropel grinding the dynamic loadings is determined and depends upon the velocity of rotor blades rotation. It increases monotoneously from the zero to its maximum values. When carrying out the numerical calculations we employed the following dependence $p(t) = p*(1-\exp(-at))^2$ which for the unlimited time $\tau$ will have the form:

$$p(\tau) = p^*(1-\exp(-\tau_0\tau))^2 , \quad (26)$$

at: $\tau_0 = (l \cdot a)/c_1$ .

Such dependence allows to coordinate the initial and final conditions and, in many a case, to approach rather accurately the real dependence of dynamic loading on the time (Fig. 2).

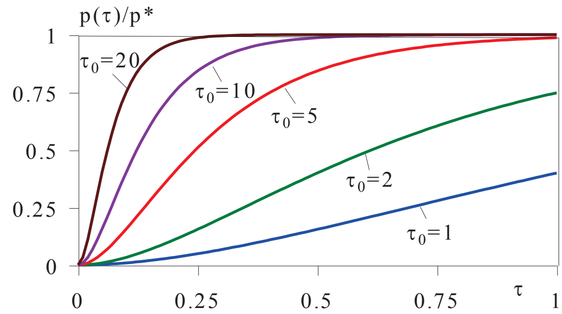


**Fig. 2.** Dependence of loading upon the time

The integral calculation (25) for the dependence of loading (26) allows to determine the function $f(\eta,\tau)$:

$$\begin{aligned} f(\eta,\tau) = \frac{1}{\eta} - \frac{2\eta\exp(-\tau_0\tau)}{\eta^2+\tau_0^2} + \frac{\eta\exp(-2\tau_0\tau)}{\eta^2+4\tau_0^2} + \\ + \cos(\eta\tau)\left(\frac{2\eta}{\eta^2+\tau_0^2} - \frac{\eta}{\eta^2+4\tau_0^2} - \frac{1}{\eta}\right) + \\ + \sin(\eta\tau)\left(\frac{2\tau_0}{\eta^2+4\tau_0^2} - \frac{2\tau_0}{\eta^2+\tau_0^2}\right). \end{aligned} \quad (26)$$

For such type of loading we calculated the tensed state of the sapropel solid aggregates of a rectangular form for different values $\tau_0$ at different correlations of the width and length of a rectangle. Fig. 3-5 illustrate the results of calculating the tensed state of the sapropel solid aggregate of the quadratic form ( $l = h$ ) at different values of the rates of loading. Fig. 3-5 illustrate the results of calculating the stained state of the sapropel solid aggregate of the quadratic form ( $l = h$ ) at different values of the rates of loading.

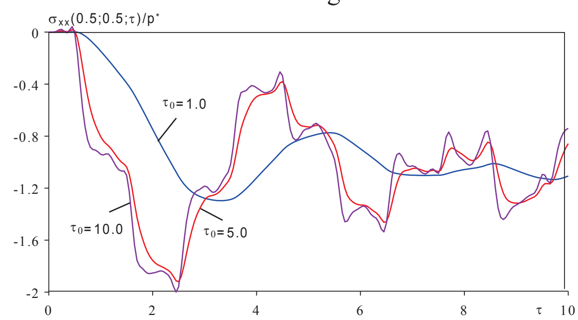


**Fig. 3.** Prolonged stress in sapropel depending on the rate of loading

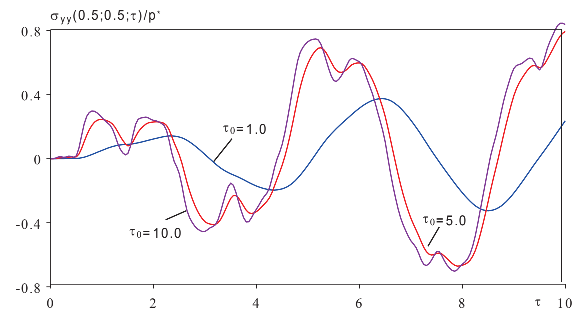


**Fig.4.** Transversal stress in sapropel depending on the rate of loading

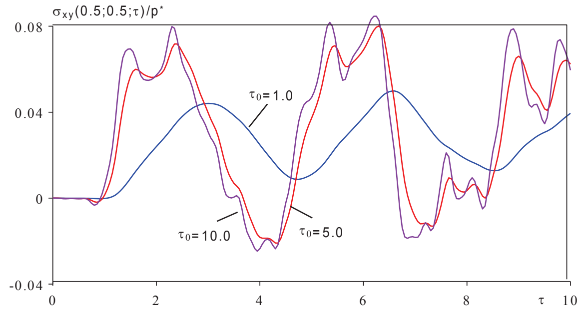


**Fig.5.** Tangent stress in sapropel depending on the rate of loading

Fig. 3-5 allow to make a conclusion that at the adequate rate of loading ($\tau_o \geq 5$) the prolonged dynamic stress is two times higher than the corresponding static value by an amplitude.

At some moments the transversal stresses are about 80% of the static ones. As to the tangent stresses, they are only about 8% of them. The similar results are received in calculating the stressed states at other points and other correlations of the heights and width of the sapropel solid aggregate. Moreover, any variations in the correlation between the height and width of the solid aggregate lead to dropping of the tangent stresse levels.

This fact allows to state that in such a way of formulating the objective the axes of the chosen systems of coordinates may be considered the principal axes of the tensor of stress at any points of the right-angled area. In its turn, this sufficiently simplifies the calculation of the main tangent stress in the material of sapropel.

In such case the maximum tangent stresses by module are known to act on the sites inclined to the axes of coordinates under the angle of 45°[3] and form:

$$T_{max} = \left| \frac{\sigma_{xx} - \sigma_{yy}}{2} \right| . \quad (27)$$

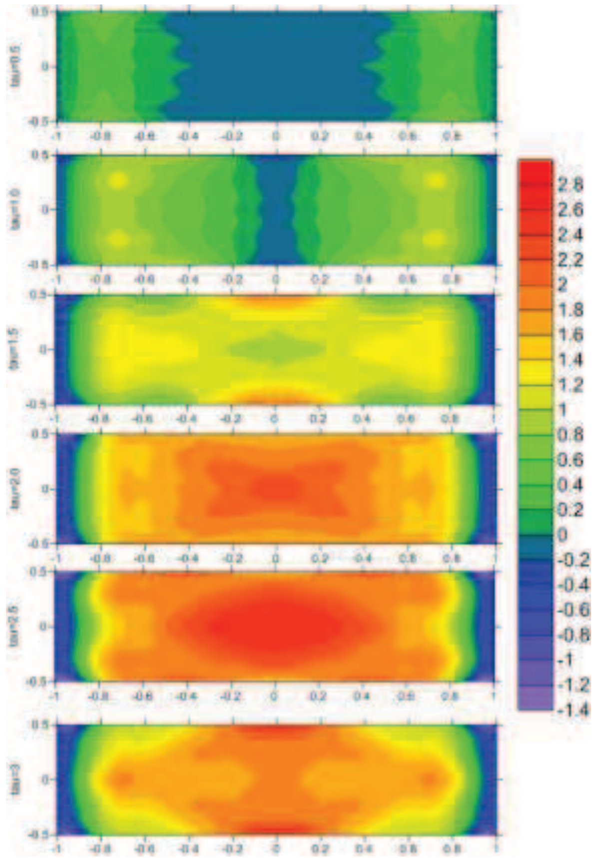


**Fig. 6.** Distribution of the main tangent stress in sapropel at $h = 0.5l$

The Fig. 6 presents the results of calculating spatial and time distribution of refered to $p^*$ of the main tangent stresses in the element of the element of sapropel which has the rectangular form with correlation of the hight and width 2 : 1, at $\tau_0 = 5$ for different values of infinite time.

## CONCLUSIONS

Our research resulted in the following qualitative positions. At first moments after the load application, zones of maximum tangent forces are concentrated in the local areas. Their disposal allows to forecast the pattern's breaking down into 6-8 segments under condition of the tangent forces getting their maximum values. At these momentit it is correlated with the value of external loading. If these forces are not sufficient enough for destruction, they have the chance to increase twice at $\tau_0$=1. ($t$ = 0.2mc) because of the climbed waves covering. In case of the reflected waves arrival these forces increase three times comparing with the value of applicated loading. Nevertheless, zone of these forces action is concentrated closer to the pattern's centre which gives the opportunity to forecast the pattern's breaking down into 2-4 segments. The analogous results are also received for other geometric correlations between the pattern's height and width. Thus, taking into consideration simulation constructions and numerical calculations one may state that the maximum value of the main tangent stress is reached in the areas situated closer to the patterns centre and make up about 300% of the external loading level. But for the more accurate grinding one must lead external loading to the level of maximum static value of the net destruction which can be determined experimentally.

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# Experimental research of the resilient keyed joints statics

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Abstract. This article deals with the problem of shaft-hub connections rigidity and one way of solving it by using the new constructions of resilient keyed joints. Methods of experimental research of the resilient parallel keyed joints statics are described by showing dependences between their deformations, torque and sizes, and conclusions in comparison with theoretical research are made.

Key words: shaft-hub connection, resilient parallel key, torque transfer.

## INTRODUCTION

The need to improve the efficiency and reliability of the drives of machines and mechanisms requires the improvement of their parts connections designs. The most common connections of machine elements in mechanical engineering are the connections of a shaft-hub type, which include keyed connection as well. Traditionally, rigid keys are being used in machinery. These keys have a high rigidity and transmit the torque from the shaft to the hub, or vice versa, instantaneously, that often causes shock loading, which negatively affects the durability of parts and whole drive in general. When transmitting torque there is a possibility that shaft will twist at a certain angle. Then in the case of rigid connection, for example, the position of gears is effected and tooth contact line may decrease. The shaft-hub connections with resilient parallel keys transmit torque more softly due to forces of the key deformation. We have obtained theoretical dependences between deformations, torque and sizes of these keys in previous research [7-10]. Therefore, there is a need for experimental verification of static loading mode in such connections, and that will be the theme of the following work.

## RECENT RESEARCH AND PUBLICATIONS ANALYSIS

The connections with rigid keys are widely known [1]. In addition, a number of resilient keys for connections of shafts with hubs were developed at the level of patents [2-6]. Use of these keys allows to change the stiffness of the connection and to transmit torque from the shaft to the hub, or vice versa, softer, i.e. without shock, which positively affects the durability of the drive.

Works [7-10] are dedicated to theoretical issues of resilient parallel keyed connections statics. However, these theoretical studies require further experimental research and confirmation of the results.

The aim of this work is to conduct experimental research of statics of resilient parallel keyed joints used to connect various rotation parts during the torque transfer.

## MAIN PRESENTATION

Among all new constructions of resilient keys we have chosen the one presented on the Fig. 1 due to relative simplicity of its manufacturing and because it reflects the principle of work of the whole class of resilient keys, perhaps, in the best and most simple way. It's called resilient parallel key with the cavity equidistant to its external surface.

**Fig. 1.** Resilient parallel key with the equidistant cavity

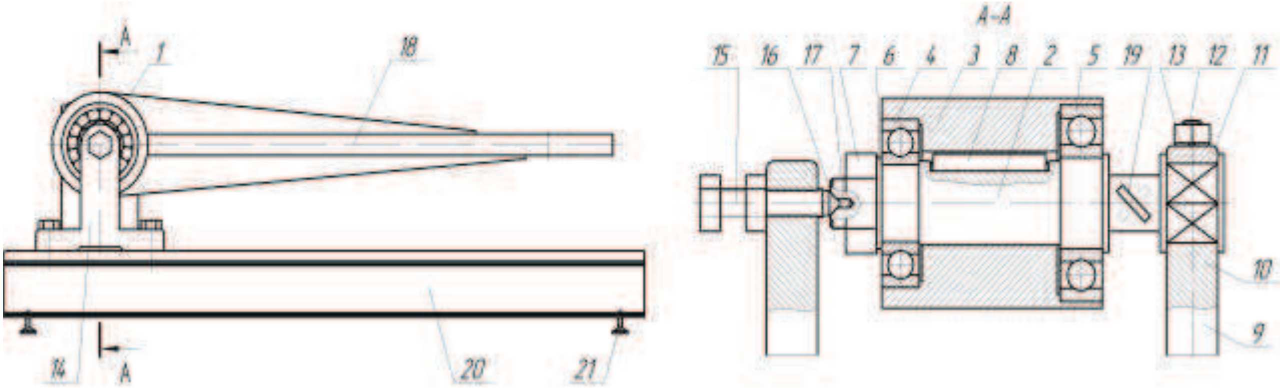


**Fig. 2.** Scheme of the basis of stand for the experimental research of the parallel keyed connections

The method of theoretical calculations for this resilient key is presented in [7]. Here we are going to verify its results by experiment.

Experimental research of the static properties of such connections in comparison with the rigid ones were conducted on a specifically designed and manufactured stands [11-15].

Scheme of the basis of patented stands for the experimental research of the static and dynamic properties of resilient parallel keyed connections is shown on Fig. 2, and it contains the keyed connection 1 itself, which consists of a fixed shaft 2, loading bushing 3, bearings 4 and 5, washer 6, nut 7 and key 8. Fixed shaft is rigidly mounted through a square tail section by studs 12 and nuts 13 in the resistance 9, which consists of a body 10 and cover 11. To avoid bending deformations of the fixed shaft the removable support 14 was installed and the screw 15 was set in the threaded holes of it, which through a conical end 16 interacts with a pivot hole 17 of the fixed shaft. Loading bushing of the keyed connection is rigidly connected to one end of the lever 18 by welding, and on the second end of it - special equipment for different types of loading can be placed. Measurement of strain and vibration phenomena in keyed connections for different types of loads is taken by measure sensor 19. Keyed connection with resistors mounted on the frame 20. To install the frame in the horizontal position there are legs 21 for regulation.

One should mention, that this stand allows you to research keyed connections not only under static loading but also subjected to various types of stress, caused, for instance, by periodical or dynamic loadings of other nature. It uses additional removable equipment for that case.

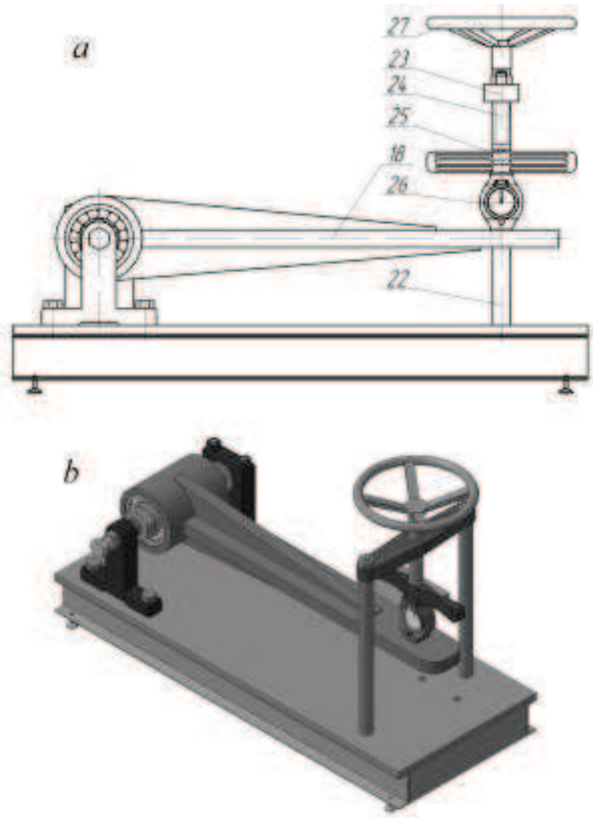


**Fig. 3.** Stand with equipment for the research of statics and calibration of the measure sensor:

*a* – scheme of pressure sensor calibration; *b* – general view or the stand.

During research of resilient keyed connections loaded with static torque we use equipment shown on Fig. 3, where vertical uprights 22 with the crossbar 23 are installed on the frame, above the free end of the lever, and screw 24 is set in the threaded hole of bar, which is due to dynamometer 25 interacts with the lever 18. Screw is driven by flywheel 27.

Diameter of shaft-hub connections $d$ = 60 *mm*, and parallel resilien key (Fig. 4, *a*) has the following dimensions of width, height, length and width of cavity: $b \times h \times l = 18 \times 12 \times 90$ *mm*, $b_1$ = 4, 6, 8, 10 *mm*, -i.e. the ratio $b_1 / b$ equals from 0.3 to 0.6, respectively.

By way of comparison compounds with standard rigid parallel key of compared sizes $b \times h \times l = 18 \times 12 \times 90$ mm (Fig. 4, *b*) were also tested.

All aforementioned dimensions are shown on Fig. 4.

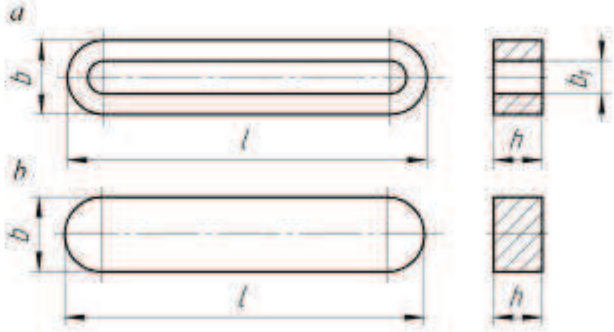

**Fig. 4.** Parallel keys: a – resilient; b – rigid

Experimental research of statics was performed as shown on Fig. 5. Static torque was created by loading of rigid or resilient keyed connection with weights mounted on the free end of lever. Each cargo weight is $F_g$ = 100 N. To create a static torque on the lever loads $F_g$ = 100, 200, 300, 400, 500 N were installed. The lever arm of the force from the cargo weight $l_{Fg}$ = 700 mm, and the weight of lever itself $F_{gl}$ = 358,3 N with lever arm of the force from lever weight applied in the center of mass $l_{Fgl}$ = 240 mm. Then the static torque created by these loads is respectively: 156, 226, 296, 366 and 436 N·m. A measure sensor attached to the fixed shaft and gage station TS-8 was used to record findings.

Measurement of deformations was carried out using the hardware and software gage station TS-8 (Fig. 6). It is designed to measure, decode and transmit signals of strain gauges for storage to determine the deformation and moments by means of tenzometric measurements.

The structure of TS-8 gage station is shown on Fig. 6. It includes:

- Control unit,
- Block with strain gauges - 8 pcs,
- Battery 12 V,
- Power unit 12V 0,6 A,
- Connecting cables.

Given gage station provides:

- continuous measurement and recording of signals of strain gauges for eight hours,
- display of measured signals on the PC screen in real-time,
- remote adjustment of balance and signal amplification,
- setting frequency separately for each channel within specified limits.

In our case, we used a single channel of the TS-8 complex to measure the deformation of the shaft due to installed on the shaft measure sensors, depending on the torque and size of investigated keys.

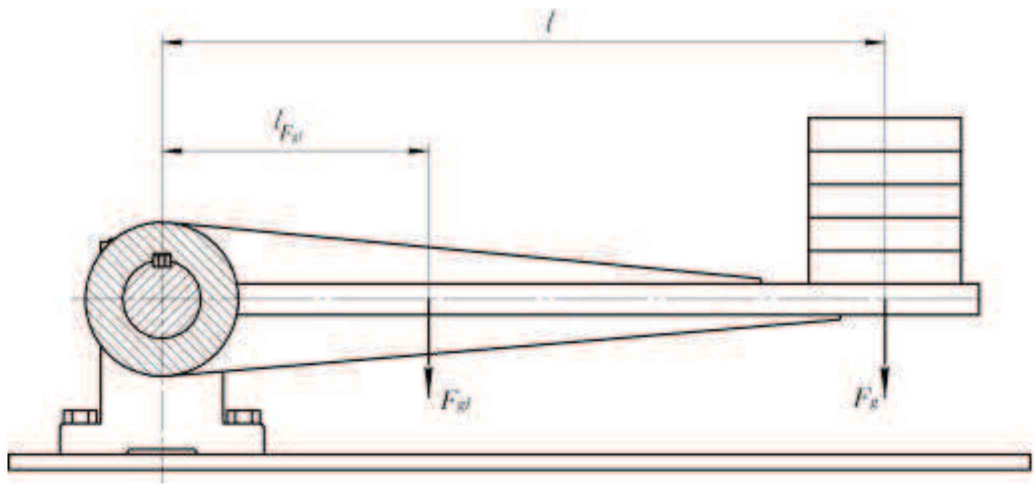

**Fig. 5.** Stand with equipment for the research of static loadings due to weight

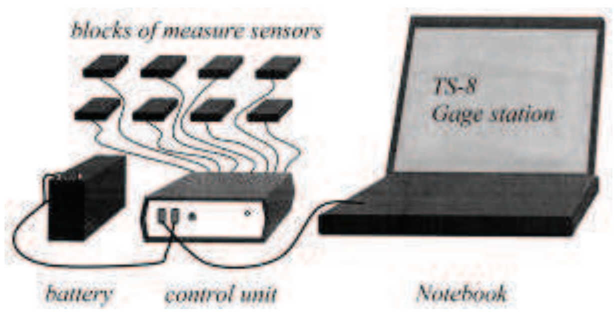


**Fig.6.** Gage Station TS-8

Decryption of obtained oscillograms was performed according to the results of the sensor calibration carried out on the equipment, where at the free end of the lever on the frame vertical uprights with crossbar were mounted. Crossbar had a threaded hole with set screw that through dynamometer DOS 200 interacted with the lever (Fig. 3, *b*). The screw is driven by handle. Through the measure sensor and measure station TS-8 data were recorded for constructing the calibration graph.

Fig. 7 shows a scheme of the resilient deformation of parallel key in shaft-hub connection. If you turn the hub relative to the shaft at the angle φ, key deformation will be $\delta$.

**Table 1.** Results of the theoretical and experimental research of the resilient parallel key deformation dependence from the torque

| *T, N·m* | $b_l = 4mm$ | | $b_l = 6mm$ | | $b_l = 8mm$ | | $b_l = 10mm$ | |
|---|---|---|---|---|---|---|---|---|
| | $\delta_t$ | $\delta_e$ | $\delta_t$ | $\delta_e$ | $\delta_t$ | $\delta_t$ | $\delta_t$ | $\delta_e$ |
| 156 | 0,098 | 0,12 | 0,187 | 0,20 | 0,380 | 0,36 | 0,863 | 0,90 |
| 226 | 0,143 | 0,15 | 0,271 | 0,28 | 0,550 | 0,52 | 1,251 | 1,33 |
| 296 | 0,186 | 0,16 | 0,354 | 0,34 | 0,721 | 0,69 | 1,638 | 1,61 |
| 366 | 0,231 | 0,26 | 0,438 | 0,45 | 0,891 | 0,87 | 2,026 | 2,00 |
| 436 | 0,275 | 0,29 | 0,522 | 0,49 | 1,062 | 1,03 | 2,413 | 2,22 |

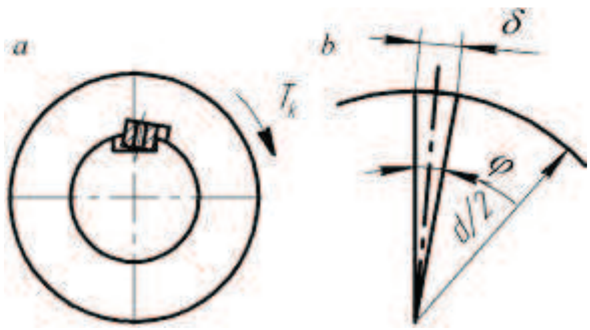


**Fig.7.** Scheme of the resilient parallel key deformation:

*a* – hub positioning according to shaft; *b* – *δ*-*d* relation through angle *φ*.

To determine the resilient deformation of parallel key in conjunction with the shaft hub we used scheme shown on Fig. 6, which graphically shows the dependences between the angular displacement of the lever 2, and at the same time of the hub 1. Measuring of the angular displacement of lever 2 is performed by indicator 3, shown on Fig. 8 and 9.

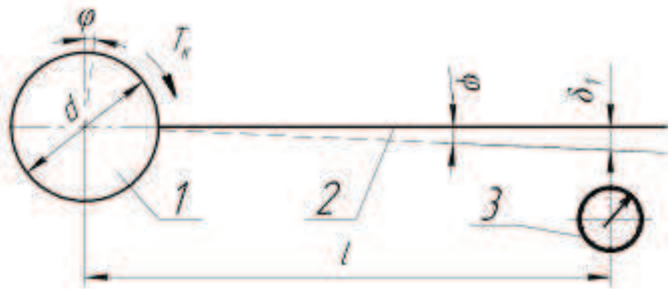


**Fig. 8.** Scheme for definition of the resilient key deformation that is the result of lever angular displacement

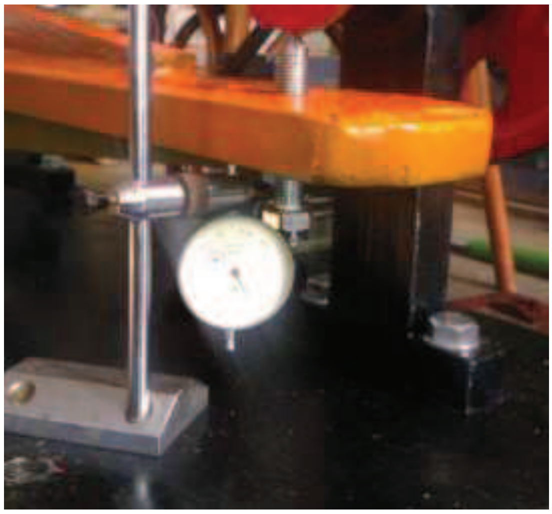

**Fig. 9.** Measuring of the lever angular displacement by the dial indicator

Experimental deformation δ of resilient parallel key was found depending on $\delta_1$ based on the following proportion:

$$\frac{\delta_1}{l} = \frac{2\delta}{d}. \qquad (1)$$

Hence:

$$\delta = \delta_1 \frac{d}{2l}, \quad \text{or} \quad \delta = 0{,}042857\ \delta_1. \qquad (2)$$

At every stage of the experimental research of resilient keys we conducted experiments ten series each and processed them according to recommendations [17].

The results of theoretical calculations [7] and experimental research results of the dependences between the deformation of the resilient parallel keys and torque are summarized in Table 1. According to Table 1 theoretical and experimental graphical dependences between torque and deformation, obtained for a set of connection with resilient parallel keys of the same external dimensions but different width of equidistant internal cavity, were built, as shown on Fig. 10.

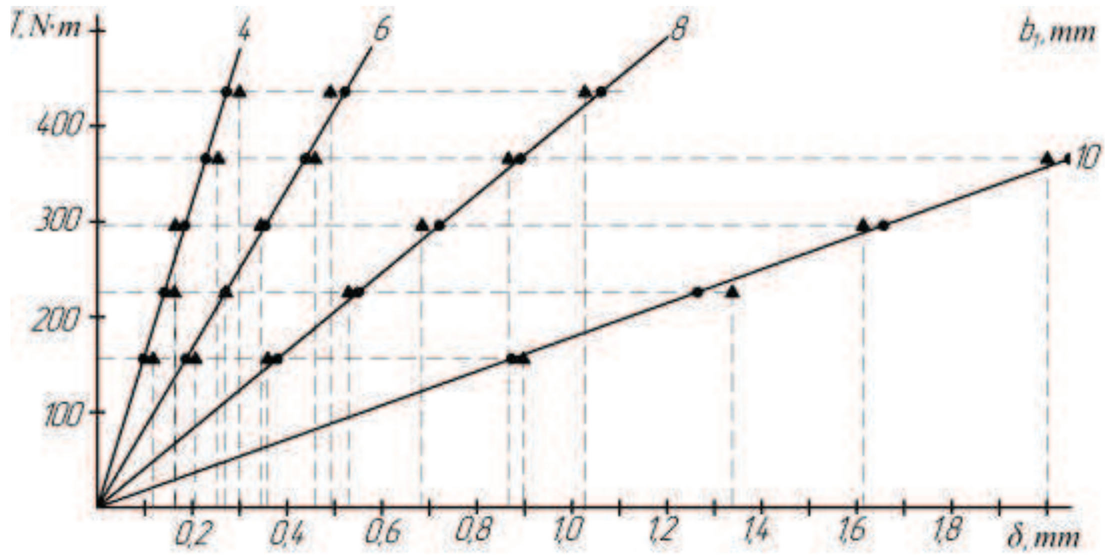


**Fig. 10.** Graphical dependences between torque and key deformation: ● – theoretical; ▲ – experimental

## CONCLUSIONS

Experimental results have confirmed the theoretical principles derived for resilient parallel keys while transferring the static torque.

As we can see it from the graph (Fig. 10) deviation is not big and quantitatively does not exceed 5-7 % most.

So the developed stand with the equipment for experimental research of resilient keyed joints in static loading mode can be used and in fact does verify the results of analytical calculations. That gives an opportunity for further experimental research of the subject, not only in static loading mode, but also dynamic, by using specified removable equipment for periodical and instant shock loadings.

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# Analytical description of the functioning of electromagnetic pulser of pairwise action

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Abstract. The article analyses the distribution of forces in statical equilibrium on the example of electromagnetic pulser of pairwise action. It views specifications of two stable states of equilibrium corresponding to the cycles of sucking and compression in the operation of the milking unit. The research suggests the way of determining durations of transition states of a pulser which directly impacts the quantities of technical characteristics of a milking unit and the nature of machine milking of cows.

Key words: electromagnetic pulser, vacuum-gauge pressure, valve, membrane, gauged hole, the constant of time.

## INTRODUCTION

Automatization of milk production requires an employment of electromagnetic pulser in milking units for cow milking both in the stalls and in milking rooms. Electromagnetic pulser guarantee control over technological process of machine milking of cows.

Specific constructive and technological properties of structure and running of pulsers influence the parameters of milking units running on the whole. As capabilities of milking units (correlation of cycles, cycles durations, frequency of pulsings, velocity of cycles shifting) are specified by pulsers, the nature of transition processes in pulsers and their influence upon the parameters of milking require more detailed research.

## RECENT RESEARCH AND PUBLICATIONS ANALYSIS

Constructions of pneumomembrane pulsers have been examined and researched many times [1-4], in particular pulsers of the pairwise action [2, 4]. In addition, perspective directions of pulsers construction development were outlined [2]. Regimes of running and the character of modifications of vacuum-gauge pressure in working chambers are described in the main considering pneumatic pulsers of the coincidental and pairwise actions [5, 6] as well as electromagnetic or electrically controlled pulsers [7, 8]. The mentioned above papers, however, have not managed to present a comprehensive definition of interdependences caused by the input of vacuum-gauge or atmospheric pressures in the working chamber and dynamics of elementary compounds of electromagnetic pulsers. The researches [8-10] described in detail the operation of electromagnetic actuating element under the impact of vacuum-gauge pressure on the examples of electromagnetic vacuum-regulator and pulser or some of their constituents [11]. In addition, they presented the milking unit by means of classical methods of the theory of the system of automated regulation [12]. This method, however, requires the preceding determination and proving of quantities of coefficients of magnification.

The presented specific moments of cows milking operations and the requirements to pulsers [13, 14] point to the vital directions of the devices investigation. The construction and running peculiarities of the suggested pneumomagnetic pulser of pairwise action [15] and the milking unit employing it [16] allow to carry out pneumodynamical analysis and to develop analytical dependences for determining parameters of the transition processes.

## OBJECTIVES

The article is aimed at discovering dependences of the electromagnetic pulser functioning in statics and dynamics as a pneumo-mechanical electrically controlled device of converting steady vacuum-gauge pressure into variable which secures simulation of the constant of time for transition processes in electromagnetic pulser of a milking unit.

## MAIN PRESENTATION

When discussing functioning of a pulser one should mention two steady position of equilibrium of movable element of a pulser which alternate with each other in time and, correspondingly, provide both cycles of a milking unit running (sucking and compression).

Let us consider distribution of forces influencing the moving elements of a pulser during the cycle of sucking (Fig. 1).

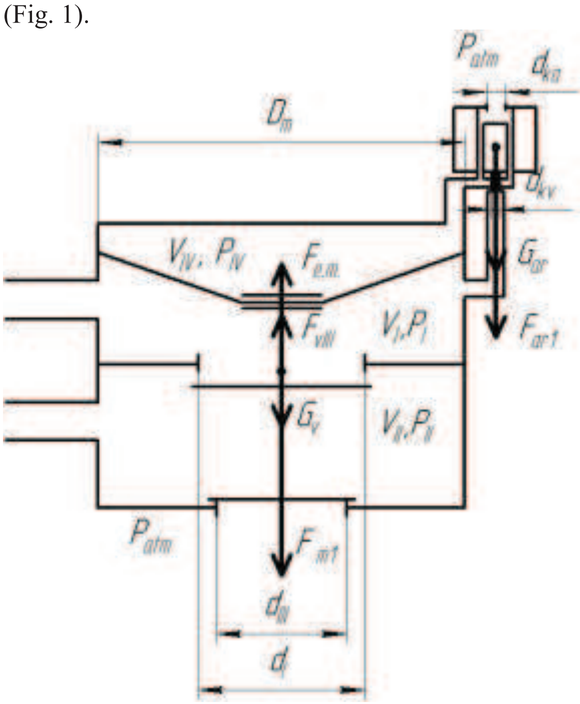


**Fig. 1.** Distribution of forces during the cycle of sucking:

$V_I$ – volume of a chamber with constant vacuum-gauge pressure; $V_{II}$ – volume of the working chamber; $V_{IV}$ – volume of the regulative chamber; $F_{vIII}$ – force formed by the difference of pressures in the chambers III and II influencing the valve; $F_{e.m.}$ – force of elasticity of a membrane; $F_{m1}$ – force formed by the difference of pressures in the chambers IV and II of a pulser; $F_{ar1}$ – force formed by the difference of pressures in gauged hole and above the armature space of electromagnet; $G_v$ – weight of valves and a rod; $G_{ar}$ – weight of an armature valve.

According to the constructive parameters, forces interactions and functional peculiarities of a pulser, it may be divided into two parts (regulative and principal).

The regulative part contains an electromagnet, an armature valve and a gauged hole while the principal part possesses the system of valves, a membrane and chambers of constant and variable pressures.

As the regulative past does not have any serious effect on the pulser time characteristics, we shall further on focus on the principal part functioning.

When considering the principal part of the pulser we shall describe the forces applied to the center of weight of the valve and rod group with a movable rod. The upper end of the movable rod is fixed to the movable membrane while the upper and lower valves are stiffly fixed to the rod.

Forces directed from the membrane across the rod's axis to the lower valves provide the lower valve's shutting up of the hole of atmospheric pressure input to the working chamber and the upper valve's opening of the hole of vacuum gauge pressure input.

The forces of the weight may be calculated by means of the following formula:

$$G_V = m_V \cdot g\ , \tag{1}$$

where: $m_v$ – mass of valves and a rod, kg.

Force effecting the membrane and curving it in the direction of the impact of weight together with a rod and valves is formed by the difference of the pressure $P_I$ and $P_{IV}$ in the chambers I and IV of a pulser. It is determined by means of the formula [18]:

$$F_{m1} = \frac{\pi\cdot(D_m^2 + D_m d_w + d_w^2)}{12}(P_{IV} - P_I), \tag{2}$$

where: $D_m$ – diameter of the membrane, m; $P_{IV}$ – pressure in the regulative chamber of the pulser IV, kPa; $d_w$ – diameter of the washer which fixes the membrane to the rod, m.

The next two forces impact the rod trying to move it upwards. The membrane with an inelastic center is characterized by a slight movement. The force of membrane elasticity is determined by the expression [15]:

$$h = A_Q \cdot \frac{F_{e.m}\cdot R^2}{E\cdot\delta^3}, \tag{3}$$

where: $h$ – motion of membrane, m; $A_Q$ – coefficient of constructive specifications of the membrane; $R$ – radius of the membrane, m; $\delta$ – thickness of the membrane , m.

Coefficient considering constructive dimensions is determined by means of the formula [15]:

$$A_Q = \frac{3\cdot(1-\mu^2)}{\pi}\cdot\left[\frac{c^2-1}{4c^2} - \frac{\ln^2 c}{c^2-1}\right], \tag{4}$$

where: $\mu$ – coefficient of Poisson; $c$ – coefficient of constructive dimensions of the membrane.

$$c = \frac{R}{r_0}, \tag{5}$$

where: $r_0$ – radius of the inelastic center, m.

Then, the force of elasticity is determined by means of the expression:

$$F_{e.m} = \frac{h\cdot E\cdot\delta^3}{A_Q R^2}. \tag{6}$$

Force formed by the difference of pressures in the chambers III and II influence the lower valve with a diameter $d_{III}$. As the chamber III has constant atmospheric pressure, the equation for determining the force will have the following form:

$$F_{vIII} = \frac{\pi\cdot d_{III}^2}{4}\cdot(P_{atm} - P_{II}), \tag{7}$$

where: $d_{III}$ – diameter of the lower valve, m; $P_{II}$ – pressure in the working chamber II of the pulser, kPa.

Thus, to provide the cycle of sucking, the positions of the upper and lower valves should be accurately determined by the following inequity:

$$G_v + F_{m1} > F_{e.m} + F_{vIII}\ . \tag{8}$$

The pulser will be in this state till the electromagnet receives the pressure of power supply. In this case the armature-valve will move upward having opened the gauged hole with a diameter $d_{cv}$. In some time due to the open channel connecting the regulative chamber with the chamber of constant vacuum-gauge pressure, the former will get equilibrium (or close to equilibrium) pressure. The principal part will get redistribution of forces (Fig. 2). Such position of valves correspond to the cycle of compression.

Forces distribution in the principal part and their character will be soon altered. It should be said, the force of membrane elasticity $F_{e.m}$ in such case is opposite-directed and facilitates opening the upper valve. The force of weight stays constant as the amount and of constituents have not been changed. The force directed upward is formed by the difference of pressures in the chambers I and II equals to:

$$F_{vI} = \frac{\pi \cdot d_I^2}{4} \cdot (P_{II} - P_I) \cdot \quad (9)$$

Thus, the condition which guarantees maintaining all parts of the pulser in the situation corresponding to the cycle of compression for the principal part of the pulser will be:

$$F_{vI} > G_v + F_{e.m} \cdot \quad (10)$$

Let us consider specific characteristics of transition process in the pulser and then determine time characteristics.

After the armature valve has moved down and the hole connecting the chamber IV with atmosphere open, this chamber starts to fill with air which alters its pressure and density.

We shall further consider adiabatic process of air movement. Then, we carry out the following ratio [19]:

$$\frac{P}{P_a} = \left(\frac{\rho}{\rho_a}\right)^k, \quad \text{or} \quad \left(\frac{\rho}{\rho_a}\right) = \left(\frac{\mathrm{P}}{P_a}\right)^{\frac{1}{\mathrm{k}}}. \quad (11)$$

According to the Bernoulli theorem:

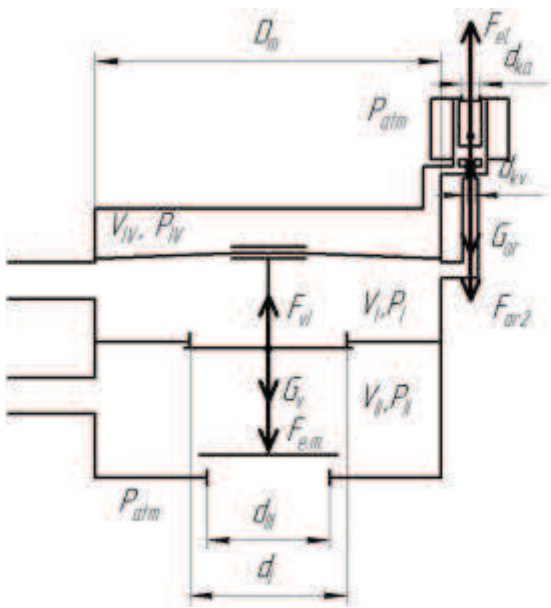


**Fig. 2.** Distribution of forces during the cycle of air compression

$$u^2 = \frac{2k}{k-1}\frac{P_a}{\rho_a}\left\{1 - \left(\frac{P}{P_a}\right)^{\frac{k-1}{k}}\right\}, \quad (12)$$

where: $P_a$ – atmospheric pressure, kPa; $\rho_a$ – air density under standard conditions, kg/m$^3$; $P$, $\rho$ – variable quantities of pressure and density; $k$ – index of polytrope; $u$ – velocity of air, m/s.

Let us take the derivative to time quantities from the equation (12):

$$\frac{\mathrm{d}P}{dt} = \frac{P_a}{\rho_a} k \left(\frac{\rho}{\rho_a}\right)^{k-1} \frac{d\rho}{dt}, \quad \text{or:}$$

$$\frac{\mathrm{d}P}{dt} = \frac{P_a}{\rho_a} k \left(\frac{P}{P_a}\right)^{\frac{k-1}{k}} \frac{d\rho}{dt}. \quad (13)$$

Knowing the quantity of air mass entering the chamber during a certain unit of time and considering the expression (12) for determining velocity quantity and $\frac{\mathrm{d}\rho}{\mathrm{dt}} = \frac{1}{V_0}\frac{\mathrm{dm}}{dt}$, we insert these data into the expression (13) and receive the differential equation:

$$\frac{\mathrm{d}}{dt}\left(\frac{P}{P_a}\right) = K_1 \left(\frac{P}{P_a}\right)^{\frac{k-1}{k}} \sqrt{1 - \left(\frac{P}{P_a}\right)^{\frac{k-1}{k}}}. \quad (14)$$

The differential equation (14) is valid till pressure in the chamber modifies from the initial quantity $P_I$ (vacuum-gauge pressure) to a certain quantity of $P_3$, is calculated by means of the static-equilibrium equation:

$$(\mathrm{P}_3 - P_1)S_1 + G_\mathrm{v} - (\mathrm{P}_\mathrm{a} - P_1)S_2 = 0\,.$$

In the equation (14) we separate the variable quantities and carry out an integration:

$$P_3 = P_1 + \frac{(P_a - P_1)S_2 - G_k}{S_1}. \quad (15)$$

$$\mathrm{t} = \frac{1}{k}\int_{\frac{P_1}{P_a}}^{\frac{P}{P_a}} \frac{dz}{z^{\frac{k-1}{k}}\sqrt{1 - z^{\frac{k-z}{k}}}} \quad (15)$$

where: $\mathrm{z} = \frac{P}{P_a}$.

Duration $\tau_I$ of this stage is determined by means of the expression (15) with pointing out the upper limit: $\frac{P}{P_a} = \frac{P_3}{P_a}$, i.e.

$$\tau_1 = \frac{1}{k_1}\int_{\frac{P_1}{P_a}}^{\frac{P_3}{P_a}} \frac{dz}{z^{\frac{k-1}{k}}\sqrt{1 - z^{\frac{k-z}{k}}}}. \quad (16)$$

After the increase of pressure in chamber ($P > P_3$), the valve begins to move. Its motion may be described by means of the differential equation:

$$\mathrm{m}_\mathrm{k}\frac{d^2x}{dt^2} = (zP_a - P_1)S_1 + G_\mathrm{v} - (P_a - P_1)S_2. \quad (17)$$

Differential equation (14) will be soon altered because of the perspective of enlargement of the chamber IV volume $\mathrm{V} = V_0 + xS_1$. Then:

$$\frac{dz}{dt} = \frac{k_1 V_0}{(V_0 + xS_1)} z^{\frac{k-1}{k}} \sqrt{1 - z^{\frac{k-1}{k}}}. \quad (18)$$

The system of differential equations should be integrated by numerical methods till transitions $0 \le x \le h_1$, under initial conditions: *t=0,*

$$x=0,\ V = \frac{dx}{dt} = 0,\ z = \frac{P_3}{P_a},$$

$$\mathrm{t} = \frac{V_0 + h_1 S_1}{k_1 V_0} \int_{z_5}^{\frac{P}{P_a}} \frac{dz}{z^{\frac{k-1}{k}} \sqrt{1 - z^{\frac{k-z}{k}}}}. \quad (19)$$

Duration of this stage $\tau_3$ is determined by means of the expression (19):

$$\tau_3 = \frac{V_0 + h_1 S_1}{k_1 V_0} \int_{z_5}^{1} \frac{dz}{z^{\frac{k-1}{k}} \sqrt{1 - z^{\frac{k-z}{k}}}}. \quad (20)$$

Effected by electromagnetic force, the armature valve moves upward and opens the hole connecting the chamber IV where $P = P_a$ with the chamber where vacuum-gauge pressure is constantly maintained ($P = P_1$). The air from the chamber IV begins to enter another chamber and we again witness here the adiabatic way of air movement. The correlation:

$$\frac{\mathrm{P}}{P_1} = \left(\frac{\rho}{\rho_1}\right)^k, \text{ or } \left(\frac{\rho}{\rho_1}\right) = \left(\frac{\mathrm{P}}{P_1}\right)^{\frac{1}{\mathrm{k}}}, \quad (21)$$

becomes valid.

And according to the Bernoulli theorem:

$$u^2 = \frac{2k}{k-1} \frac{P_1}{\rho_1} \left(1 - \left(\frac{P}{P_1}\right)^{\frac{k-1}{k}}\right). \quad (22)$$

Let us take the derivative to time quantities from the equation (22):

$$\frac{\mathrm{d}P}{dt} = \frac{P_1}{\rho_1} k \left(\frac{\rho}{\rho_1}\right)^{k-1} \frac{d\rho}{dt}, \quad \text{or:}$$

$$\frac{\mathrm{d}P}{dt} = \frac{P_1}{\rho_1} k \left(\frac{P}{P_1}\right)^{\frac{k-1}{k}} \frac{d\rho}{dt}. \quad (23)$$

Heaving made the transformations analogical to those in case with opening the hole we shall receive the differential equation:

$$\frac{\mathrm{dp}}{\mathrm{dt}} = \frac{1}{V_1} \frac{\mathrm{dm}}{dt} = -\frac{2\pi \mathrm{d}_{\mathrm{cv}} \mathrm{h}_{\mathrm{cv}}}{\mathrm{V}_1} \left(\frac{P}{P_1}\right)^{\frac{1}{k}} \sqrt{\left(\frac{P}{P_1}\right)^{\frac{k-1}{k}} - 1} \quad (24)$$

Having inserted (23) into (24) we shall receive the differential equation:

$$\frac{d\mathrm{y}}{dt} = -K_2 y \sqrt{z^{\frac{k-1}{k}} - 1}, \quad (25)$$

where:

$$K_2 = \frac{k \cdot \pi \cdot d_{\mathrm{cv}} h_{cv}}{V_1} \sqrt{\frac{2k}{k-1} \frac{P_1}{\rho_1}}.$$

The differential equation is valid till pressure in the chamber IV modifies from the initial quantity $P_a$ to a certain quantity of pressure $P_4$. The quantity of $P_4$ is calculated by means of static-equilibrium equation:

$$(\mathrm{P}_4 - P_1) S_1 + G_k - c\mathrm{h}_1 - (\mathrm{P}_a - P_1) S_3 = 0,$$

therefore:

$$\mathrm{P}_4 = P_1 + \frac{c\mathrm{h}_1 + (P_a - P_1) S_3 - G_v}{S_1}, \quad (26)$$

where: $c$ – membrane inelasticity.

In the equation (25) we separate variable quantities and integrate:

$$\mathrm{t} = \frac{1}{k_2} \int_{y}^{y_1} \frac{dz}{z \sqrt{z^{\frac{k-z}{k}} - 1}}. \quad (27)$$

Duration of this stage is determined having put $y = y_4$, i.e.:

$$\tau_2 = \frac{1}{k_2} \int_{y_2}^{y_1} \frac{dz}{z \sqrt{z^{\frac{k-z}{k}} - 1}}. \quad (28)$$

The defined integrals in formulas (27) and (28) are calculated by means of numerical methods.

After the decrease of pressure in chamber IV ($P < P_4$) the valve begins to move upward. Its motion is described by the differential equation:

$$\mathrm{m}_{\mathrm{k}} \frac{d^2 x}{dt^2} = c(h_1 - x) - G_k + (P_a - P_1) S_2 - (y P_1 - P_1) S_1. \quad (29)$$

The differential equation describing pressure modifications will get the form:

$$\frac{dy}{dt} = -\frac{k_2 V_1}{(V_1 - x S_1)} y \sqrt{y^{\frac{k-1}{k}} - 1}. \quad (30)$$

We integrate the system of differential equations till $0 \le \mathrm{x} \le h_1$ under initial conditions: $t=0,\ x=0,$ $\mathrm{V} = \frac{\mathrm{dx}}{\mathrm{dt}} = 0,\ \mathrm{y} = \mathrm{y}_4 = \frac{P_4}{P_1}$.

$$\mathrm{t} = \frac{V_0}{k_2 V_1} \int_{1}^{y_6} \frac{dz}{z \sqrt{z^{\frac{k-z}{k}} - 1}}. \quad (31)$$

Duration of this stage $\tau_5$ is determined from (31), when $\frac{P}{P} = 1$, i.e. :

$$\tau_4 = \frac{V_0}{k_2 V_1} \int_{1}^{y_6} \frac{dz}{z \sqrt{z^{\frac{k-z}{k}} - 1}}. \quad (32)$$

Interdependence of the described above quantities and characteristics of the milking unit is indicated in Fig. 3. which presents the way of determining durations of phases and cycles of pulsations according to the requirements of the standard ISO 5707.1996 "Installation of milking unit. Construction and operating capabilities". In addition, it suggests the way of determining time intervals $\tau_{1'}$ and $\tau_{2'}$, which have a colossal impact upon the efficiency of machine milking of cows and directly depend on the quantities of $\tau_1$, $\tau_3$, and $\tau_2$, $\tau_4$ correspondingly.

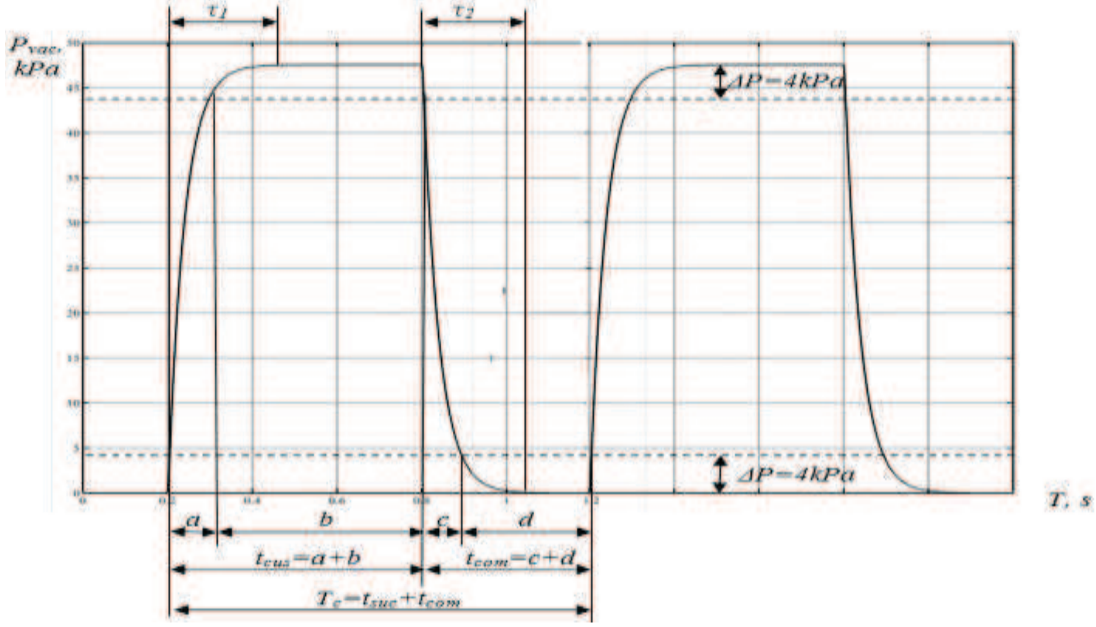


**Fig. 3.** Indicative diagram of the pulser functioning:
*a, b, c, d* – durations of phases of the milking unit functioning, s; $t_{suc}$ – duration of the cycle of sucking, s; $t_{com}$ – duration of the cycle of compression, s; $T_c$ – duration of the cycle of pulsation, s; $\tau_1'$ – duration of the leading edge of a pulse, s; $\tau_2'$ – duration of the trailing edge of a pulse, s.

## CONCLUSIONS

We proved the dependences of constructive parameters of an electromagnetic pulser and the intake vacuum-gauge pressure (15, 19, 27, 31), which allow to determine modifications of pressure in the working chamber of a pulser.

We discovered analytical dependences for determining the constants of time of electromagnetic pulser of a pairwise action (16, 20, 28, 32). These dependences directly determine durations of the leading and trailing edges of pulser of vacuum-gauge pressure of indicatory diagram of the pulser functioning.

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# Argumentation of the parameters of the system of purveyance of milk collected from the private farm-steads within a single administratinve district

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Abstract. The article is focused on the analysis of the current scientific and methodological principles of determining parameters of transport and purveyance infrastructures of enterprises. The research proves the necessity of determining parameters of the system of milk collecting from the private farm-steads of a single administrative district and develops its own methods of such determining based on the simulation modeling. It presents specifications and determines parameters of the system of purveyance of milk collected from the private farm-steads of a single administrative district.

Key words: parameters, system of purveyance, milk, private farm-steads.

## INTRODUCTION

Ukraine is currently faced with an acute problem of effective manufacture of sound dairy products. The people"s private farm-steads make up 76,6% of the branch of dairy production [3; 13].Simultaneously, milk purveyance is in the focus of interest of both business structures and milk processing enterprises. They are enforced to form their own fleets of machinery and equipment for milk purveyance in some specific regions. The purveyance structures, thus, face a number of objectives connected with formation of their own fleets of machinery and equipment able to provide effective milk purveyance, transportation and procession. When solving these problems we have to develop the mechanism of determining parameters of the corresponding system [6, 8, 10]. One of the unsolved problems here is the argumentation of parameters of the system of purveyance of milk collected from the private farm-steads of a single administrative district.

## RECENT RESEARCH AND PUBLICATIONS ANALYSIS

The problem of developing effective systems of milk purveyance is in the focus of a rather intense attention of scholars [4-13]. Quite a number of analysts state their argumentations towards the disposal of objects in different economic projects [4]. In addition, there exists a number of researches on automobile fleets [13, 15].However, the mentioned above developments frequently ignore specifications of the system of purveyance of milk collected from the private farm-steads. They, in particular, do not take into consideration the factor of unsteadiness of the volumes of milk purveyance during the whole purveyance season and, consequently, unsteadiness of the demand in productive capacities. The said above proves the position that the current methods are imperfect for argumentation of parameters of the system of purveyance of milk collected from the farm-steads. Currently we witness spreading of systemic principles of determining parameters of infrastructure of enterprises [1, 2]. Thus, there is an acute demand in developing fresh methods of purveyance of milk collected from the private farm-steads on the basis of systematic approach.

## OBJECTIVES

The article is aimed at developing methods of determining parameters of the system of purveyance of milk collected from the private farm-steads.

## MAIN PRESENTATION

Parameters of the system of milk purveyance are influenced by the forms of milk purveyance and parameters of its further components: 1) primary transport means responsible for transporting raw milk from private farm-steads to purveyance centres; 2) purveyance centres with milk refrigerating facilities; 3) secondary transport means for milk transportation from purveyance centres to milk processing enterprises. We take into consideration here the condition that private farm-steads got their own tare for cows milking and raw milk delievery to primary transport machinery and equipment means. In addition, each of the mentioned above units gets their machinery and equipment whose parameters form a set of potential versions of the system of milk purveyance.

Let us consider the potential versions of the first component of the system of milk purveyance. Collection of raw milk from farm-steads and loading of primary transport means may be carried out in two ways: 1) farm-steads themselves deliver raw milk to primary transport means disposed in the settlements; 2) primary transport means visit all farmsteads and take their raw milk. The process of collecting raw milk from farm-steads should coordinate the factors of multiplicity of operations with their time. Each of the mentioned above ways of collecting raw milk can be carried out with a maintenance of the following primary transport means: 1) trucks with milk cans; 2) special auto-tanks for milk transportation. Each of these primary transport means is able to contain a finite set of its versions which differ from each other by the market structure as well as their physical and functional properties. A version number of one type of primary transport means is dictated by their presence at the market.

Another compornent of the system of milk purveyance is its centres of purveyance. The parameter version of purveyance centres may also be a finite set determined by: 1) the number and disposition of the centres of purveyance; 2) the types of buildings of the centres of purveyance; 3) the types of the market structure of the facilities of milk refrigeration.

When choosing the place of purveyance centres disposition the following criteria must be taken into consideration: 1) it must be disposed within a settlement; 2) it should be connected with a network of roads of a hard covering.

When choosing the versions of purveyance centres disposition within a single administrative district one should study the principal parametes of this district: 1) a number of settlements $(N_{нп})$; 2) farm-steads presence in each of the settlement $\left(N^{n}_{гв}\right)$; 3) cow presence in each the farm-steads $\left(N^{i}_{к}\right)$; 4) the average milk yield per one cow per one day $\left(Q^{i}_{к}\right)$; 5) characteristics of the roads network connecting the settlement of the given administrative district.

The daily capacities of milk purveyance $\left(Q^{n}_{д}\right)$ in the settlement n-y is determined by the following way:

$$Q^{n}_{д} = \sum_{i=1}^{N_{гв}} N^{i}_{к} \cdot Q^{i}_{к} \cdot z_{i} \cdot k_{i} \ , \tag{1}$$

where: $z_i$ – is the multiplicity of cow milkings per one day; $k_i$ – is the coefficient which takes into consideration the portion of raw milk utilized by farm-steads for their own needs.

Characteristics of the roads network connecting the settlements within a single administrative district are described by the model of roads network and territorial disposition of settlements concerning the milk processing enterprises in the form of a symmetrical matrix of the shortest distances from the milk processing enterprises to the settlements as well as between the settlements with the following dimensions $(N_{нп} + 1 \times N_{нп} + 1)$.

The number of potential versions $\left(C^{N_{пз}}_{N_{нп}}\right)$ of the territorial disposition of purveyance centers of the settlements $(N_{пз})$ within a single administrative district is determined by the well known theorem of combinations [4]:

$$C^{N_{пз}}_{N_{нп}} = \frac{N_{нп}\,!}{N_{пз}\,!} \cdot \frac{1}{\left(N_{нп} - N_{пз}\right)!} \ . \tag{2}$$

Nevertheless, sorting out of all potential versions of purveyance centres territorial disposition requires extremely accurate calculations. The majority of them are irrational. Taking into consideration the said above we use a well known method of choosing the rational versions of purveyance centers disposition [4].

The criterion of choosing the rational versions of purveyance centers disposition in a given administrative district will be the minimal transport operation valued by the total freight turnover $\left(\sum W_k\right)$ of milk transportation from farm-steads to milk processing enterprises at the given value of the number of purveyance centres ($k$):

$$\sum W_k = \sum_{i=1}^{n} W_{ПЗПО_i} + \sum_{j=1}^{m} W_{МПП_j} \rightarrow \min \ , \tag{3}$$

where: $\sum_{i=1}^{n} W_{ПЗПО_i}, \sum_{j=1}^{m} W_{МПП_j}$ – is correspondingly, the raw milk freight turnover from purveyance centre to milk processing enterprises, tkm; $n$ – is the number of settlements within the given district, units; $m$ – is the number of purveyance centers within the same administrative district.

Our calculations proved the position that the minimal $\sum W_k$ is at the shortest distance between a purveyance centre and a milk processing enterprise. That means the most preferable settlements for constructing purveyance centres are those situated closer to the milk processing enterprises.

When choosing the place of purveyance centres disposition and determining the settlements for raw milk deliveries one should keep to the condition (3).

Our method of choosing the versions of purveyance centres disposition is based on the said above and foresees the following. First of all, each settlement within a single administrative district is given the numeration in the order of increasing their distances from a closest milk processing enterprise. The distances from one settlement to another within a single administrative district are chosen by means of the matrix of the shortest distances between them. Afterwards, the road network embracing settlements with milk processing enterprises is examined. Then we distinguish branches with chains connecting settlements with the road network. Each of the n-settlement should be related to one of these branches considering the principle of minimization of the distance from the settlement to the branch. Such operations will give the opportunity to construct the chains of settlements related to the road network.

Another stage is choosing territorial disposition of purveyance centers in settlements. Opening of purveyance centers in some settlements might be illogical as it may result in sufficient costs because of the lack of suitable land parcels there as well as supply lines, communications, high quality roads connecting them with other settlements, etc. All settlements are examined concerning their facilities to dislocate purveyance centers. In our research we did not take into account the versions provoking sufficient costs.

Of all admissible versions $\left(C_{N_{нп}}^{N_{пз}}\right)$ of territorial disposition of purveyance centers $(N_{нп})$ in the settlements $Z\left\{\{N_{нп1}, N_{пз1}\}, \{N_{нп2}, N_{пз2}\}, ..., \{N_{нпj}, N_{пзi}\}\right\}$ of a single administrative district we choose the finite set of rational versions. The first version allows to dislocate purveyance centers in every settlement. The next versions are chosen from the chains constructed by us under condition of gradual enlargement of the number of settlements capable to collect raw milk and to deliver it to purveyance centers.

The third component of the system of milk purveyance is the secondary transport means for transporting milk from the farm-steads to the milk processing enterprises. The admissible versions constitute the finite set which is limited by the number of special automobiles for milk transportation available at the market.

The initial data for determining parameters of the system of milk purveyance are: statistical information about functioning and disposition of private farm-steads within a single administrative district; distances from one farm-stead to another; distances from farm-steads to milk-processing enterprises; daily volumes of raw milk purveyance in every purveyance centre.

All information about farm-steads can be taken from the recording documentation of the milk processing enterprises. All the distances are determined with the use of the administrative district topographical maps and the curvometer KU – A (GOST 207 1099 – 74). Taking into consideration these data we formulate symmetrical matrix of the shortest distances between farm-steads with a proportion $n+1 \times n+1$ ($n$ – is a number of farmsteads). The first number in this matrix is given to the milk processing enterprises. Other numbers are connected with farmsteads in the order of increasing distances from farmsteads to milk processing enterprises. The data about these distances are constantly specified on the basis of information given by the milk processing enterprises" controller office.

To determine daily volumes of raw milk purveyance in each purveyance centre one may refer to the accounting documentation of the milk processing enterprise and employ the well-known method [4, 3] of forecasting milk purveyance for all periods of a purveyance season.

First of all, it is necessary to consider the data about milk purveyance in every farm-stead for the previous period of not less than three years. These data are not presented in absolute values, but in the form of the rates of milk delieveries.

Mathematical analysis of these data means determination of the average daily milk delievery for 1 year period at the milk processing enterprise and the rates of milk delieveries for 1 day of the season of purveyance.

Let us consider Ivanychi district Volyn region zone of milk purveyance. This zone has got 21 settlements with milk purveying farm-steads. The choice of versions of purveyance centres disposition here is made with employing the described above methods on the basis of the results of industrial experiments.

To choose the version of purveyance centres in Ivanychi district we construct a graph of territorial disposition of the district settlements. Then we formulate a matrix of the shortest distances between these settlements and analyze the data concerning daily volumes of milk collection from every private farm-stead.

Each settlement of the milk purveying zone gets its number in the order of increasing distances from them to milk processing enterprises, analogically to the graph of territorial disposition of the settlements in the zone of milk purveyance. In the result of the analysis of road network of the zone of milk purveyance we distinguished four branches with chains constructed by us to attach settlements to a road network (Fig. 1).

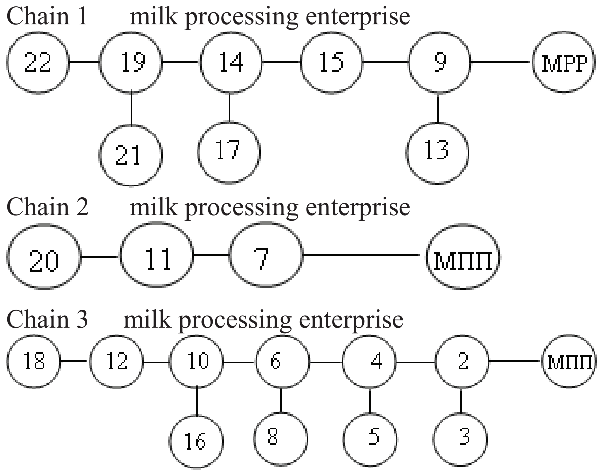


**Fig. 1.** Chains attaching settlements to the road network

Aimed at discovering the impact of purveyance centres territorial disposition, physical and functional characteristics of primary and secondary transport means on their systemic functional and value properties we carried out simulation modeling of the virtual system of milk purveyance by means of the specially developed computer programmes developed at the department of management of projects and safety of production, Lviv national agrarian university.

We were focused there on the modeling of the processes of milk transportation from farm-steads to purveyance centres and from purveyance centres to milk processing enterprises under conditions of Ivanychi district Volyn region.

Coming from the simulation modeling of the processes of milk transportation from farm-steads to purveyance centres and from purveyance centres to milk processing enterprises we determined systemic functional characreristics, I,e. the distances covered by transport means, duration of their operations and the degree of demand in them.

Coming from the determined systemic functional characteristics and the market value of machinery and equipment for the system of milk purveyance we grounded valuable characteristics for each of these versions. Our machine experiments on computers resulted in the modeling of transportation and purveyance processes of the system of milk purveyance. In particular, we foresaw three versions of territorial disposition of the purveyance centres: 1) purveyance centres in all 21 settlements 1,6,9,10,11,14; 3) purveyance centres in the settlements 2,6,7,9,14. We also foresaw two versions of primary transport means: 1) automobiles Daewoo Lanos Pick-up with milk cans; 2) autotanks G6-OTA-12,- and three versions of secondary transport meanns: 1) an auto- tank G6-OTA-39; 2) an auto-tank G6-OPA-4,9; 3) an auto-tank G6-OPA-8,3.

In our calculations we took into consideration all gross current expenditures for milk purveyance (Bn). In addition, we determined the gross value of capital investvemts (Kgr) for functioning of transport and purveyance infrastructures

We determined the overall summary expenditures (3n) for different versions of parameters of the system of milk purveyance (Fig 2) by the numerical method.

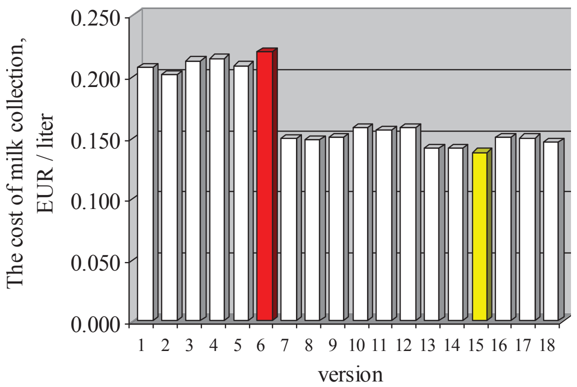


**Fig. 2.** Histogram of the specific expenditures for milk purveyance in dependence with the versions of parameters of the system of milk purveyance

The constructed histogram (Fig 2) gives the opportunity to say that the most rational parameters of the system of milk purveyance is the version No15 which foresees the disposition of 1 unit of a centre of purveyance of primary procession M of P-1000, 2units of the centers MP-1500 and 5units of MP-2000 in 5 settlements.

To transport milk from farm-steads to purveyance centers one should employ 43 automobiles Daewoo Lanos Pick-up and 2 auto-tanks KAMAZ-53215+G6-OPA-8,3 for milk transportation from farm-steads to milk processing enterprises. Thus, for Ivanychi district Volyn region the most rational version of the system of milk purveyance will allow to purvey milk collected from farm-steads with the specific expenditures of 0,138 *€/l.*

## CONCLUSIONS

Our analysis of current methods of developing effective systems of milk purveyance allows to make up a conclusion of their imperfection in determining parameters of the system of purveyance from private farm-steads as they do not take into consideration specific industrial conditions and their components of unsteady character. We suggest the methods of determining parameters of the system of milk purveyance in private farm-steads of a single administrative district which eliminate some drawbacks of current methods and are based on the simulation modeling of milk purveyance and transportation. The suggested methods allow to determine the rational version of the parameters of the system of milk purveyance from private farm-steads of Ivanychi district. This version secures the annual milk purveyance with the minimal gross summary costs of 0,138 *€.*

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# Bioenergetical appraisal of the technology of jerusalem artichokes growing at different systems of fertilization in western forest and steppe regions of Ukraine

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Abstract. The article suggests a bioenergetical analysis of energy content in humus of grey forest soil depending on its fractionally grouped structure. It presents culculations of energetic efficiency of applying mineral, organic and organically – mineral systems of fertilizing jerusalem artichokes, in particular with including multifunctional preparation of phylazonit. The research determines efficiency of applying agrocenosis of the gross energetic resource .

Key words: system of fertiliazation, humus, bioenergetical analysis, coefficients of energetical efficiency.

## INTRODUCTION

A high potencial of productivity and wide consumption of jeraselem artichokes facilitate public interest in growing this crop as a source of biomass. In spite of a high energetic capacity of jerusalem artichokes, the technology of this crop growing needs additional developments of the potential methods of increasing its yielding capacity under conditions of different soils and different climatic zones of Ukraine.

Therefore, the problem of appraising efficiency of various agrotechnical instruments including the systems of fertilization as well as their energetic effects is of an acute importance now.

## RECENT RESEARCH AND PUBLICATIONS ANALYSIS

One of the priority ways of solving the problem of enlarging the share of renewable energy in energetical balance of agriculture is growing bioenergetical crops accumulating the dry substance with concentrated energy received in the result of photosysthesis[1, 3, 22 ].

The problem of delievering renewable sources of energy in agriculture is connected with growing a biomass. The plant biomass, including jerusalem artichokes is able to produce energy by means of the immediate combustion of solid, biofuels and conversions into liquid fuels (biofuels) or the gasform fuels (methane) [7]. Some analysts forcast that the biomass of the plant resources will manage to become one of the major sources of biofuels manufacture [8, 15, 19].

The jerusalem artichoke is a universal crop .It is widely used as a foodstaff as well as an industrial crop, forage and a medical herb. In addition, it is a raw material for phitoenergetics [6]. The jerusalem artichoke is a crop with a potential ability of attaching solar energy [6, 18] and is able to perform a function of a reliable source of renewable types of energy [4, 20]. It may be used for combustion of a dry biomass including the case of its utilization in combination with the coal formed in brickets or pellets for producing biogases [6, 17, 18,20]. The jerusalem artichoke got serious perspectives of becoming a source of bioethanol receiving [14], in particular in Ukraine with colossal facility for its manufacture [12].

## OBJECTIVES

The research is focused on the analysis of bioenergetics efficiency of jerusalemartochokes growing in Western Forest and Steppe regions of Ukraine on grey forest soils at various rates of mineral nutrition.

## MAIN PRESENTATION

The research was carried out under industrial condotions of the branch of the department of soil science , crop – growing and agrochemistry of Lviv national agrarian university. All laboratory experiments were carried out by the standard methods in the research laboratory of agrochemistry of the department (A certificate No RL 1354/09, 24 Apr. 2007).

Field experiments were carried out on grey forest soils of the Western Forest and Steppe regions of Ukraine on the plot of the jerusaleum artichoke at the mineral organic and organically – mineral systems of application with the use of phylazonit which is a multifunctional preparation of bacterial origin.

The versions of the experiment are as follows: 1. Without fertilizers (control); 2. $N_{100}P_{90}K_{160}$; 3. $N_{140}P_{90}K_{160}$ ; 4. A manure 20 l/ha; 5. A manure 20 t/ha + phylazonit 10 l/ha; 6. A manure 10 t/ha + $N_{50}P_{25}K_{60}$; 7. A manure 15 t/ha + $N_{65}P_{53}K_{70}$ ; 8. Amanure 20 t/ha + $N_{40}P_{40}K_{40}$; 9. $N_{100}P_{50}K_{160}$ + Phylazonit 10 l/ha ; 10. $N_{140}P_{90}K_{160}$ + phylazonit 10 l/ha. 11. A manure 15 t/ha + $N_{65}P_{53}K_{70}$ + phylazonit 10 l/ha 12. A manure 20 l/ha + $N_{40}P_{40}K_{40}$ + phylazonit 10 l/ha.

The total area of each of the experimental plot is 85 $m^2$. The accounting area is 50 $m^2$. The repeatedness is thrice repeated. The soils of the experimental plot are grey – forest light – loamy and coarse dusty. Before the experiments the upper layer ( 0-20 cm ) of humus – eluvial ( HE ) horizon got the following agrochemical indices : PH of salt – 5.6; hydrolite acidity – 1.52; sum of absorbed bases – 9.6 mmol/100 gr of a soil; degree of bases saturation – 86.4 %.

Let us consider the jerusaleum artichokes of Lvivskyi variety characterized by its intensive growth of a vegetative mass and a high degree of receiving nutriets from the soil [2].

The value of humus content was determined by the method of Tiurin [5]. Fractionally – grouped content of humus was estimated by the method of Ponomariova – Plotnikova [13]. Calculations of the costs of energetic resources and energetic efficiency of the system of jerusalem artichokes fertilization were carried out according to current methods [5, 9, 23].

The statistical procession of data was carried out by means of the programmes STATISTIKA 6.0 and EXCEL. To appreciate the energetic state of the grey forest soils by means of its energy contentwe employed the equation [16] which considers the quantalive content of humus and heat capacity of its main fractions. The mentioned above equation got the following form (1):

$$Q = (19{,}96HA + 9{,}16FA + 17{,}86HR)\ H\ d\ 10, \qquad (1)$$

where: Q − is the reserve of energy accumulated by the soil humus, Hj/ha; 19,96 − heat of combustion of humidified residue, Kj/g; 9,16 − heat of combustion of fulvoacids, Kj/g; 17,86 − heat of combustion of humificated residue, kj/g; HA − content of humificated acids, %; FA − content of fulvoacids, %; HR content % HR – content of humificated residue, % H – soil layer, m; d – density of soil structure, g/cm$^3$, 10 – coefficient of converting into Hj/ha.

The gross energy accumulated by the yields of Jerusalem artichokers was determined by means of calculation of the content of the total energy of the yield**s** of above - and underground parts by the average indices of 3 years of experiments. The gross energy costs for the period of growing were determined by means of evaluation of energetic costs on the basic of technological charts. Energy of photosynthetically active radiation received for crop rotation in the zone of Western Forest Steppe constituted 18,01 Hj/ha for the period of vegetation.

Coefficient of energetic efficiency $C_{ee}$(2) was introduced as a share of energetic costs for growing from the total energy accumulated by the yields:

$$C_{ee} = E_y/E_a, \qquad (2)$$

where: $E_y$ – total energy accumulated by yields; $E_a$ – total costs of anthropogenic energy for growing Jerusalem arthichokes.

For comprehensive appraisal of efficiency of agrocenosis as an open thermodynamic system closely connected with the currents of solar energy we employed the equation of calculating the coefficient of the use of energetic resources in agrocenosis $C_{na}$ (3) which takes into consideration energy reserves in the humus of soils and photosynthetically active radiation [2]:

$$C_{na} = E_y/E_r + Q + E_a, \qquad (3)$$

where: $E_r$ – reserve of humus of soils (0-40 cm), Hj/ha; $Q$ – gross photosynthetically active radiation for the vegetation period, Hj/ha.

Calculations of the biological coefficient of the use of anthropogenic energy and energy of photosynthetically active radiation by the yields of agrocenosis of Jerusalem artichokes were carried out according to (4):

$$C_b = E_b/Q + E_a. \qquad (4)$$

Our calculations resulted in the position that growing of Jerusalem artichokes is energetically reasonable in all experimental versions except on the version of control. Coefficients of energetic efficiency, nevertheless, were fluctuating rather sufficiently depending on the system of fertilization (See Table)

Depending on the applied fertilizers the average content of the humus compound in the upper layer (0-20 cm) of grey forest soil was ranging in a rather wide diapason (from 1,29 on the control plots to 1,76% on the version of organically-mineral fertilizers application combined with the use of phylazonit).

Such fertilization secured not only increased indices of humus content in soils but also facilitated modification in its fractionally-grouped srtructure. This phenomenon has been already discussed in our previous publications [11].

The results of the content of different fractions of humus compounds showed that the increase of the standards of organic fertilizers caused the increase of the content of humidified acids and decrease of the fulvoacids. This fact effected the correlation $C_{ha}$ :$C_{fa}$ and reflected improvements of indices of humus quality.

The best indices of the correlation $C_{ha}$:$C_{fa}$ were in the versions of organically-mineral systems of fertilization with application of phylazonit. Huminal acids have two times more heat-producing capacity comparing with fulvoacids and 10% more in comparison with an unhumidified residue. Therefore, modifications in fractionally-groupped content of humus provided different indices of the reserve of energy accumulated by humus.

**Table.** Bioenergetics analysis of the fertilizer systems under Jerusalem artichoke in Western Forest Steppe of Ukraine

| No | Version | H % | $E_r$ | $E_y$ | $E_a$ | $C_{ee}$ | $C_{na}$ | $C_b$ |
|---|---|---|---|---|---|---|---|---|
| | | | Hj/ha | | | | | |
| 1 | Without any fertilizer(control) | 1,29 | 26,6 | 354,9 | 169,5 | 2,09 | 1,66 | 1,89 |
| 2 | $N_{100}P_{50}K_{120}$ | 1,42 | 29,5 | 559,7 | 194,5 | 2,88 | 2,31 | 2,63 |
| 3 | $N_{140}P_{90}K_{160}$ | 1,44 | 30,1 | 579,1 | 198,5 | 2,92 | 2,35 | 2,67 |
| 4 | Manure 20 t/ha | 1,55 | 33,3 | 566,0 | 189,5 | 2,99 | 2,35 | 2,73 |
| 5 | Manure 20 t/ha + phylazonit 10l/ha | 1,58 | 34,1 | 594,3 | 190,0 | 3,13 | 2,45 | 2,86 |
| 6 | manure 10 t/ha + $N_{50}P_{25}K_{60}$ | 1,63 | 35,3 | 560,7 | 191,5 | 2,93 | 2,29 | 2,68 |
| 7 | Manure 15 t/ha + $N_{65}P_{53}K_{70}$ | 1,68 | 36,2 | 590,4 | 200,5 | 2,94 | 2,32 | 2,70 |
| 8 | Manure 20 t/ha + $N_{40}P_{40}K_{40}$ | 1,70 | 37,2 | 596,4 | 205,5 | 2,90 | 2,29 | 2,67 |
| 9 | $N_{100}P_{50}K_{120}$+ phylazonit10 l/ha | 1,45 | 30,4 | 593,2 | 195,0 | 3,04 | 2,44 | 2,78 |
| 10 | $N1_{40}P_{90}K_{160}$+ phylazonit10 l/ha | 1,48 | 31,2 | 615,5 | 197,0 | 3,12 | 2,50 | 2,86 |
| 11 | Manure 15 t/ha + $N_{65}P_{53}K_{70}$ + phylazonit10 l/ha | 1,72 | 38,0 | 654,6 | 203,0 | 3,22 | 2,53 | 2,96 |
| 12 | Manure 20 t/ha + $N_{40}P_{40}K_{40}$ + phylazonit10 l/ha | 1,76 | 38,9 | 709,8 | 206,0 | 3,44 | 2,70 | 3,17 |

The best indices of the total energy accomulated by humus in the upper layer (0-20 cm) of the grey forest soil was provided by organically-mineral system of fertilization with application of phylazonit which facilitated accumulation of humus content on the level of 1,72 – 1,76%. The indices of the total energy, then were on the level of 38,0 – 38,9 Hj/ha. These indices prevailed the analogical data of the control version in 11,4 – 12,3 Hj/ha.

Organically-mineral system of fertilization without application of phylazonit provided somewhat lower indices of the reserve of accumulated energy (35,3-37,2 Hj/ha).

The lowest indices (29,5-31,2 Hj/ha) were received from the mineral system of fertilization, including the versions with application of phylazonit.

The value of the net reserves of energy in the yields of Jerusalem artichokes were determined by the indices of productivity of the green mass and tubers [10,21] and their energy capacities which constituted on the average 16,8 Mj/kg of the dry biomass [6].

Determination of the index of the content of accumulated energy in Jerusalem artichokes biomass proved that application of fertilizers sufficiently raise this index even in the versions of mineral systems of fertilization which has much lower positive effect on the increase of indices of energy accumulated by humus. The yield gross reserve of energy on the plots No 2-3 prevailed in 58-65% analogical indices of unfertilized plots. Practically the same values of the reserves of energy accumulated by yields were received on the plots manured with a standard of 20 t/ha.

Organically-mineral system of fertilization provided the highest indices of the total energy accumulated by the yields which prevailed the indices of the control version in 85-100%.

Such a dependence provided the highest indices of energetic efficiency in spite of the increase of costs of anthropogenic energy ($E_a$) with application of organic and mineral fertilizers.

The integral index of the reason for application of energetic resources in agrocenosis is the coefficient of energetic efficiency. The index of this coefficient ranges in a sufficient diapason and is much depended upon the system of fertilization. In the version of control the index $C_{ee}$constituted 2,1. This proves the position that Jerusalem artichokes even without any agrochemical instrumnts are able to accumulate much energy in the yields.

Application of fertilizers provokes the increase of the coefficients of energetic efficiency. This index increased from 2,9 in the versions with mineral system of fertilization to 3,4 on the plots of organically-mineral systems of fertilization. Such a tendency reflects a high payback of the energetic costs put into a technology of the crop growing. As a perennial plant Jerusalem artichokes output high yields without sufficient costs for fertilization. Therefore, the value of energetic efficiency have the tendency to increase only. According to the data [2] in 3-4 years of growing Jerusalem artichokes on the same plantation causes the dramatic decrease of agrocenosis productivity. Therefore, the high payback of energetic resources for these several years facilitates the increase of the indices of energetic efficiency coefficient.

Coefficient of agrocenosis productivity Cpa refleets the efficiency of the use of natural resources by the crop, i.e. the reserves of soils energy and photosynthetically active radiation.

In our research this index was also sufficiently fluctuating and depended much on the system of ferliliza-tion. In our control version it constituted 1,7 and in the versions of organically-mineral system with application of phylazonit it achieved the level of 2,5-2,7.

Mineral system of fertilization provided the sufficient increase of the coefficient of agrocenosis productivity in comparison with the version of control. But its value were much less than in the versions of organically-mineral system. This means, the versions of mineral system of fertilization get their yields due to the reserves of energetic resources of soils. In other words, the increase of productivity of agrocenosis is secured due to dehumification which facilitates the risk of negative anthropogenic loading on the soil.

Biological coefficient of energy utilization by agrocenosis $C_b$ reflects the general trend of the increase of energetic efficiency under conditions of the combined application of organical and mineral fertilizers.

One should confess, the calculations of coefficients of energetic efficiencies pointed to the tendency of their increase due to both increase of energetic costs for growing of biomass and the improvement of the state of the soil humus, in particular its content enlarging and the increase of humid acids share. On the other hand, high energetical costs do not secure higher energy liberation under conditions of soils degradation which was reflected in the versions with mineral system of fertilization.

The correlation $C_{ha}:C_{fa}$0,83 and the quantity of energy accumulated by humus (Er) carry out a mutual influence on the coefficient of energetic efficiency (Fig 1).

At correlation $C_{ha}:C_{fa}$ 0,83 and Er 38,9 the maximum value of $C_{ee}$ will constitute 3,4. Nevertheless, the value of $C_{ee}$ is under the greater impact of the quantity of energy accumulated by the yield ($E_y$) (Fig 2). When the value of index of energy accumulated by the yields of Jerusalem artichokes (Ey) is 709 Hj/ha, the maximum value of $C_{ee}$ will constitute 3,6.

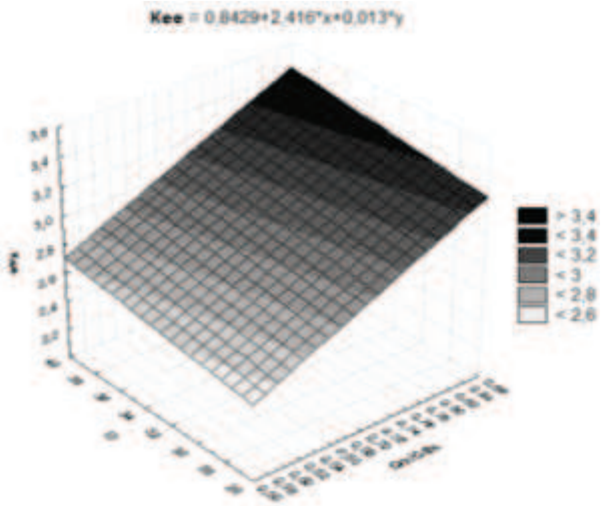


**Fig 1.** Dependence of the coefficient of energetic efficiency on the quality and reserves of energy in humus

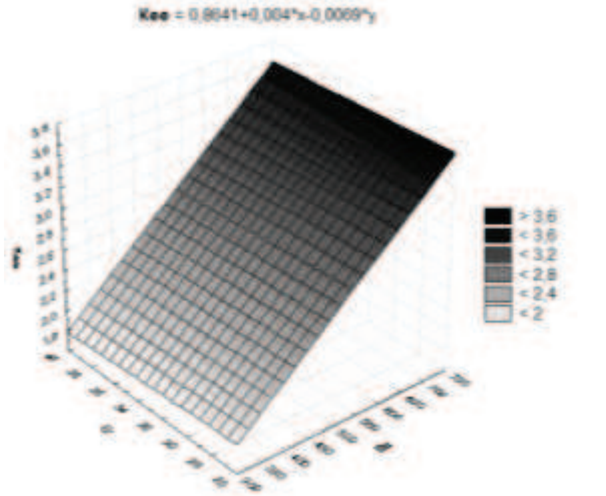


**Fig 2.** Dependence of the coefficient of energetic efficiency on the energy accumulated by the yields and humus

The results of dispersial analysis proved the position that the coefficient of energetic efficiency is under a sufficient impact of the correlation $C_{ha}:C_{fa}$ and the index of energy accumulated by the yields ($E_y$) because the multivariate coefficient of determination $R^2$=0,96 reflects very tight connection according to the scale of Cheddock. The value of F is steady and constitutes 110,17. The regection zone is described by the right-hand interval (4,69; +∞). As $F^A$=110,17 gets into the regection zone, one may state of the absolute reproducibility of the experiment.

## CONCLUSIONS

1. Jerusalem artichoke is a highly productive energetic crop which is able to accumulate a sufficient quantity of a dry substance by its tubers and overground mass. When growing in Western Forest and Steppe of Ukraine the crop's energetic potential achieves 355 Hj/ha . Under conditions of rational standards of fertilization the crop grows two times more intensive.

2. Application of the systems of fertilization both influence the increase of productivity of agrocenosis of Jerusalem artichokes and improves the state of humus of the grey forest soils which effects positively the reserve of energy accumulated by humus. In the upper layer of soil (0-20 cm) the reserves of energy in humus effected by organically-mineral system of fertilization together with the microbiological preparation of Phylazonit achieves 38-39 Hj/ha and 1,4 times prevails the indices of the version of control.

3. The highest indices of energetical efficiency of Jerusalem artichokes growing were received due to organically-mineral system of fertilization with a standard of manure 10 l/ha. Such a system secured the highest indices of the coefficient of energetical efficiency ($C_{ee}$), the coefficient of the use of energetical resources of agrocenosis ($C_{na}$) and biological coefficient of the use of anthropogenic energy ($C_b$) which constituted 3,44; 2,70 and 3,17 correspondingly.

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# Impact of meteorogical conditions on the need in adaptive perfoming of technological operations of soil tillage and crop sowing

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Abstract. The article discusses the impact of the agrarometeorological conditions on the state of soil and the processes connected with soil tillage and crop sowing. It determines agrotechnological reasons of technological adapting of these operations to enviromental conditions. It sets the terms of qualitative modifications in soil under the impact of agrometeorological conditions within spring and summer-autumn periods

Key words: soil, sowing, agrometeorological conditions, fund of time, variability, technological operation, simulation, indices, complexes of machines, efficiency.

## SETTING OF THE PROBLEM

Agrometeorological conditions infuence the fields soils and hence, cause modifications of the terms of perfoming soils tillage and crop sowing operations. This phenomenon objectively predetermines the need in technological adaptation to the state of objects of labour both in spring and in summer-autumn periods. Therefore, to perform crop sowing operations in time one should employ the adaptive complex of specific machines. Current methods and models of studying efficiency of such complex, unfortunantely, do not allow to calculate systemic and event peculiarities of their functioning and, hence, they need some improvements.

## RECENT RESEARCH AND PUBLICATIONS ANALYSIS

Our research established the fact that the current methods and models of determining parameters of machine complexes at agrarian enterprises are based upon the standard needs in machinery [7, 12, 19] unich, unfortunately, do not allow to estimate adequately the efficiency of adaptive technological systems employed in crop growing [6].

## OBJECTIVES

The article is aimed at generalization of the results of studing the influence of agrometeorological conditions on physical and mechanical state of soils and terms of performing soil tillage and sowing operations.

## MAIN PRESENTATION

A vital requirement for efficient mechanized growing of crops is their timely providing with sound soil conditions for germination and young growth [8, 10]. One may guarantee such conditions by means of mechanized operations influencing the soil structure, density, weeds, hymidity, etc. A particular function here is performed by the natural (physical, chemical and biological) processes which have a serious effect on the agrometeorological conditions of a sigle season. Coming from the said above, agrarian enterprises have to monitor the objects of operations [1] and agrometeorological conditions. They also have to forecast their development to be able to take reasonable decisions concerning mechanized operations and modifying soil state – from one to another. The soil humidity is known to influence the qualitative indices of some field operations, in particlular, soil tillage and sowing. The mentioned above operations should be performed when soil is in the state of physical maturity and (embrittlement and mixing of soils) [2].

On the other hand, crops also have their specific requirements to quantative indices of performing sowing layer, sowing operations[10] and terms of preparing these operations[2, 4, 6]. In case these objective requirements are not satisfied because of the unqualitative and ill-timed operations, the crops will get low yields and, hence, the total output will suffer of technological losses.

Winter finishing and soils drying up provoke the need in starting spring field operations of soil tillage and sowing [4] which should be completed till the moment of formulating necessary hydrothermical conditions within the sowing layer to start crop sowing [10, 11]. The time period between the mentioned above events determines the naturally established fund of time ($t^{в}_{пз}$) for spring field operations. For summer-autumn period fund of time ($t^{о}_{пз}$) is caused by the terms of finishing harvesting operatins of the predecessor and finishing physical maturity of soil in the early winter period. In additon, rainfalls lead to extra-humidity which causes stopping field operations and cutting the fund of time $t_{пз}$. Because of variability of agrometeorological conditions , time of the pointed out operations proved to be a probable quantity within the calendar period and causes stochasticity of the fund of time $t_{пз}$.

The soil state (its moisture, plants remains in structure, etc) and duration of the fund of time $t_{пз}$ influence the content of operations within spring and summer-autumn periods.In particular, the early spring dictates the need in performing the additional operation called "moisture blocking".

Under conditions of medium and late terms of spring it is mostly unreasonable to perform this operation in growing early and medium spring crops because in such situation it is preferable to carry out presowing tillage of soil and not to be late with crop sowing. Under conditions of early spring one must repeat weeding operation( cultivation with harrowing ) when planning to sow late spring crops. In the case of late spring one should prepare the soil for such crops growing by means of pre-saw tillage. Long intervals of rainy weather during summer-autumn season and early winter cause incompletion of field jobs and dictate the needs in correcting the content of spring field operations of the next year.

The agrarian enterprises, thus, should possess complexes of machines giving the opportunity to be adapted to the variability of the state of the objects of labour (the sowing layer of soil) and , in particular, to the fund of time $t_{пз}$. Such adaptive complex of machines is aimed at timely sowing of crops into sound soils both in spring and summer-autumn periods.

However, to illustrate the specific characteristics of adaptive technological systems of agrarian enterprises in the corresponding simulation models and to study the parameters of the systemic efficiency of adoptive complex of machines one should employ specific methods and models [3, 18, 20] allowing to points out the specific impact of the enviromental conditions on the content and course of jobs. One of the stages of carrying out this task is studying and formalization of characteristics of the influence of agrometeorological conditions on the soil state which, in its turn, influences the terms of accompanied performing soil tillage and sowing operations.

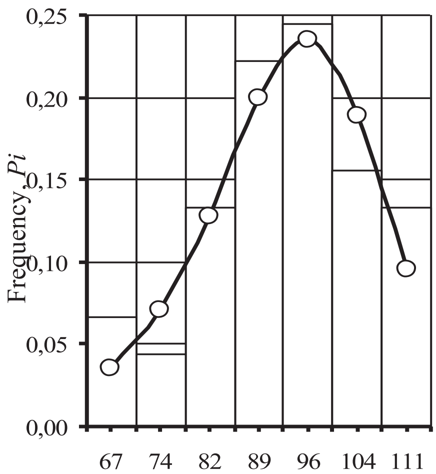
System and event analysis of the mentioned above processes prove that these characteristics can be accompanied by the following parameters: 1) time of the start of physical maturity of soils in spring period; 2) time of completion of this maturing in autumn period; 3) duration of fine and rainy weather intervals for each of the periods.

Thus, having the retrospective data base of meteorological stations concerning the terms of the mentioned above events, we get the possibility of constucting variational series of empirical quantities.

Their procession by means of methods of mathematical statistics gives the opportunity to ground the theoretical laws of distributing corresponding indices and, in such a way, to reflect their time characteristics in statistical simulation model of functional technological systems of soils tillage and sowing.

The terms of mentioned above events were determined coming from the data of Volodymyr-Volynskyi meteorological station (Vohlyn region). Having used the information from the accounts (TSH-1, KM-1) of daily observation of atmospherical phenomena and the state of moistering of the upper soil layer (on the depth of 0-2, 2-10sm) [5, 6, 9] we formulated the base of initial data of observation (for the period of 45 years) – 1963-2008.

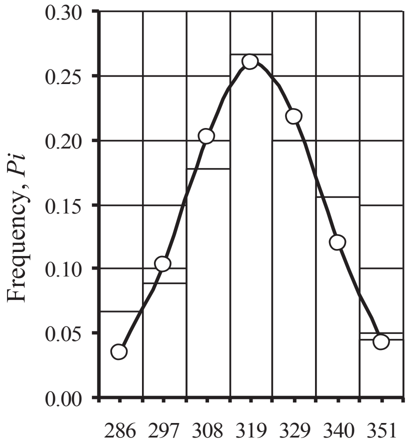
Having used methods of mathematical statistics we made up the following distributions [13, 14]: 1) time ($\tau_{\varphi}^{п}$) of the start of physical soil maturity in spring period (Fig. 1); (Fig. 2) duration of fine ($t_{пп}$) (Table) and rainy ($t_{нн}$) (Table) intervals for spring (March1-June 5) and summer-autumn periods (Sept.1 - Dec.20); 3) time ($\tau_{\varphi}^{з}$) of comletition of physical maturity of soil in autumn period (Fig. 2).




*Time of the start of physical maturity of soil $\tau_{\varphi}^{п}$, a day.*

**Fig. 1.** Histogram and theoretic curve of distributing time of physical maturity of soil in spring period

We found, in particular, that the distribution $\tau_{\varphi}^{п}$ (Table) is coordinated with the law of Laplas-Charlier. The confidance interval $\tau_{\varphi}^{п}$ – 63…115 a day. Distribution $\tau_{\varphi}^{з}$ (Table) is coordinated with the normal distribution law [13], the confidence interval – 281…256 a day. Distribution $t_{пп}$, $t_{нн}$ (Table) for spring and summer-autumn periods are coordinated with the law of Welbull [14]. In particular, the confidence interval for the spring period is 1…114 days and for the autumn season is 1…21 days. The confidence interval $t_{нн}$ for the spring season is 1-10 days and for the autumn season – 1…14 days.




*Time of the start of physical maturity of soil $\tau_{\varphi}^{з}$, a day.*

**Fig. 2.** Histogram and theoretic curve of distributing time of completion of time of physical maturity of soil in summer-autumn period

Thus, development of methods and models giving the opportunity to consider specific impact of agrometeorological conditions on the soil state and formulating naturally allowed fund of time for soil tillage and sowing operations is a vital stage in constructing specific simulation models of these operations.

Then, coming from the grounding of the algorith of taking decisions concerning the rationality of performing technological operations under diffirent agrometeorological conditions and unruled trends of their influence on the soil state and formulating duration of naturally allowed fund of time we get the opportunity to carry out computer experiments and to determine a set of integrated functional indices.

The valuable estimates of these indices and their regularities under conditions of various production programmes of agrarian enterprises, variable subjective and agro meteorological conditions as well as indices of adaptive complex of machines give the opportunity to find the correlation allowing to achieve extremum of the functional efficiency.

**Table.** Diffirental functions and estimates of statistical characteristicas of distributions of random quantities.

| Calendar intervals | Differential function of distribution |
|---|---|
| | *Spring period* |
| Time of the start of physical maturity of soils in spring time | $\varphi(t) = 0,033 \cdot e^{-\frac{t^2}{2}} \left\{ 1 + \frac{A_s}{6} \cdot t \cdot (t^2 - 3) + \frac{E_s}{24} \left[ t \cdot (t^2 - 2) - 3 \cdot (t^2 - 1) \right] \right\}$, $t = \frac{x_i - 92,962}{12,191}$, $A_s = -0,514$, $E_s = -0,1$ |
| Fine weather intervals | $f\left(t_{\text{ïï}}\right) = 0,044 \cdot \left( \frac{t_{\text{ïï}} - 1}{24,057} \right)^{0,068} \cdot \exp\left[ -\left( \frac{t_{\text{ïï}} - 1}{24,057} \right)^{1,068} \right]$ |
| Rainy weather intervals | $f\left(t_{\text{ïï}}\right) = 0,506 \cdot \left( \frac{t_{\text{ïï}} - 1}{2,375} \right)^{0,202} \cdot \exp\left[ -\left( \frac{t_{\text{ïï}} - 1}{2,375} \right)^{1,202} \right]$ |
| | *Summer-autumn period* |
| Fine weather intervals | $f\left(t_{\text{ïï}}\right) = 0,203 \cdot \left( \frac{t_{\text{ïï}} - 1}{5,665} \right)^{0,148} \cdot \exp\left[ -\left( \frac{t_{\text{ïï}} - 1}{5,665} \right)^{1,148} \right]$ |
| Rainy weather intervals | $f\left(t_{\text{íï}}\right) = 0,427 \cdot \left( \frac{t_{\text{íï}} - 1}{2,531} \right)^{0,08} \cdot \exp\left[ -\left( \frac{t_{\text{íï}} - 1}{2,531} \right)^{1,08} \right]$ |
| Time of completition of physical maturity of soils in autumn periods | $f(\tau_{\hat{o}}^{ç}) = 0,024 \cdot \exp\left[ -\frac{(\tau_{\hat{o}}^{ç} - 319,452)^2}{539,002} \right]$ |

## CONCLUSIONS

Stochasticity of agrometeorological conditions and their impact on the soil state cause variability of naturally allowed fund of time and the way of performing soil tillage and crop sowing operations. Analysis of the results of observing the upper layer of soil at Volodymyr Volynskyi meteorological station by means of methods of mathematical statistics gave the opportunities to make a quantitive estimation of characteristics of the influence of agrometeorological conditions on the terms of soil tillage and sowing operations of the corresponding period. Development of methods and models considering influence of agrometeorological conditions on the calendar terms of the mentioned above jobs allows to investigate characteristics and trends of variability of the parameters of efficiency of adaptive technological complexes of machines.

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# Innovative approaches towards the analysis of the dependence of production efficiency on the parameters of agricultural enterprises land use

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Abstract. The efficiency of production of agricultural enterprise in the Carpathian region of Ukraine is provided in the article. The main indicators of agricultural enterprises efficiency in the Carpathian region of Ukraine and in Ukraine are done. The evaluation of the efficiency of land use by the enterprises is separately analyzed on the basis of the analysis of gross output per unit of agricultural land. With the help of software the efficiency dependence from the parameters of land use by agricultural enterprises of Carpathian region is analyzed. Proved that the cause of the low efficiency of agricultural enterprises activity is their lack of land.

Key words: agricultural enterprises, agrarian sector of economy, the efficiency, the land use, statistic analysis.

## INTRODUCTION

Land reforming in Ukraine and in the Carpathian region at this stage of development of land relations foresees their implementation on the basis of new approaches towards ensuring effective economic use of land resources of agricultural enterprises. The analysis of key indices of land use of business entities shows that reforms in the agricultural sector practically have no positive production results and the basic problem for today has not been solved – the provision of effective and rational use of land resources and the improvement of the efficiency of production of agricultural enterprises both at the national level and at the level of a particular region.

## THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

It should be mentioned that the problems of rational land use are increasingly becoming the subject of scientific research, the results of which are being implemented in the practice of agricultural production. A significant contribution to the theory and methodology of the research of problems connected with more efficient use of land resources of agricultural enterprises was made by A.S. Danilenko [3], I.G. Kirilenko [5], M.I. Malik [6], V.J. Mesel-Veselyak [7], I.P. Mikhasyuk [8], L.Y. Nowakowski [11], V.I. Pasternak [13], P.T. Sabluk [14] and others.

However, it should be noted that the new economic conditions determine the need for research in order to improve the efficiency of land use by agricultural enterprises in the direction of improving the efficiency of agricultural production at the level of certain regions. Therefore, the assessment of land use of agricultural enterprises aimed at increasing the efficiency of land use and improving the results of entrepreneurs' production is extremely important at the regional level.

## UNSOLVED PARTS OF THE PROBLEM

The efficiency of production of agricultural enterprises is the resulting and generalizing indicator of its farming and land use, since the regulation of the efficiency of agricultural production is difficult, but necessary process. Due to the goal to hold comprehensive and objective assessment of land use by agricultural enterprises of the Carpathian region it is necessary to consider main economic performances of the enterprises concerning the farming and analyze the impact of land use parameters on the production efficiency of agricultural enterprises.

The goal of the research is to evaluate the dependence of the production efficiency on the parameters of land use of agricultural enterprises at the level of the Carpathian region of Ukraine aimed at finding ways to increase the efficiency of enterprises functioning of agrarian sector.

Object of study is economic land relations in agriculture enterprises in the Carpathian region of Ukraine.

Research methodology. Study was conducted during 2010-2012 years. Number of respondents was the four areas of the Carpathian region. The sample size is 12 observations. The statistic method is the main used in the article. Stages of statistic research presented as a correlation and regression analysis are implemented on a personal computer by means of an integrated system of statistical analysis and data processing STATISTICA v.6.0. Results of the research are presented in the form of formalized dependencies resulting from input variables (explanatory).

## THE MAIN RESULTS OF THE RESEARCH

The land issue has always been the focus of researchers. "Land issues, land management – proves Academy L.Y. Nowakowski – in terms of state regulation of the market economy have always been the most important" [11].

First of all it is necessary to define what the land relations – is multifaceted problem that covers a wide range of issues: ownership and management, land, land market, rents, land tax, rent, land management, public lands, play it performance and so on [10].

They are characterized by social relations between people related to the ownership and use of land, and is a component of the entire system of relations of each historical era [2].

By their nature land relations are categorized as economic, because the land has a certain economic value as a result of its relationship with the means of production, commodities and other products of human labor [15]. We can say that they are at the heart of agriculture policy, including land ownership, tenure, by nature, its use [16].

I must say that land relations directed to land management, and at different levels - national, commercial and internal business, but also as an object of management and the means of production in agriculture [4].

In order to evaluate how currently operating land relations, we must consider them as an example of the area. In the article the Carpathian region as a striking example of the implementation of specific land relations and land use in the production process.

The Carpathian region is malozemelnym and it determines the nature of land area farmers. The implementation of land reform in the region had a number of regional differences. The need for agricultural producers to keep production in the highlands;

- The destruction of a relatively large agricultural sector;
- Limitation of land holdings of farmers.
- Simultaneity and complexity of reform.
- In the Carpathian reform was characterized by higher than in other regions, the pace [17].

It is known that better company operates large, particularly with large plots of land. Thus, according to researchers, the effect of large agricultural production is manifested in the possibility of better use of fixed assets, labor force, they have the option of processing products, but most importantly - these businesses more efficient in terms of rational the use of land [9].

It should be noted that the world has emerged a trend toward larger farms due to the liquidation and bankruptcy of small farms. This contributes to the expansion of productive capacity of farm families due to technological progress. For example, in the United States for 100 years, the number of farms decreased from 6 to 2 million, and the average farm size increased from 56 to 175 hectares [12].

But the effectiveness of management on land depends not only on the size of land holdings, but the results of management of agricultural enterprises.

The effectiveness of the implementation of business processes is a complex concept that includes an analysis of the effectiveness of management conducted by the producers, and comparing the results of this activity with indicators of the global production system [6]. Therefore, in order to assess the economic efficiency of agricultural producers in the Carpathian region, in our opinion it is necessary to compare the main economic performance of it functioning effectiveness as compared to the state performance (Table 1).

According to the data provided in Table 1, it could be concluded that the place of researched region is not very important in the production of gross agricultural output for state performance. Concerning the production of gross crop output, three out of four areas of the region occupy the last places in Ukraine. Slightly better situation with the production of gross output of livestock – the Lviv region occupies the 6$^{th}$ place and Ivano-Frankivsk region occupies the 10$^{th}$ place. In general, the relative share of gross agricultural output in the region concerning Ukraine is about 10 %, which is the average result of the functioning of its producers.

**Table 1.** Basic performance of economic management efficiency of agricultural enterprises of Carpathian region and Ukraine in 2012*

*The source [20, 214, 217, 219, 232]

| Region | Gross output of agriculture, mln. UAH | Place of the region in the gross agricultural output for Ukraine | Profits, losses from the sales of agricultural products, mln. UAH |
|---|---|---|---|
| Transcarpathian region | 4044.8 | 25 | -0.6 |
| Ivano-Frankivsk region | 5176.2 | 23 | 311.9 |
| Lviv region | 8400.9 | 14 | 343.7 |
| Chernivtsi region | 4318.6 | 24 | 124.2 |
| Total for Carpathian region | 21940.5 | x | 779.2 |
| Total for Ukraine | 233696.3 | x | 19926.0 |
| The region in % for Ukraine | 9.4 | x | 3.9 |

**Table 2.** The dynamics of gross agricultural output * * Calculated according to [20, 214, 236]

| Region | Per 100 hectares of agricultural land, thsd. UAH | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2005 | 2009 | 2010 | 2011 | 2012 |
| Ukraine | 683 | 393 | 485 | 551 | 541 | 534 | 641 |
| Transcarpathian region | 1009 | 755 | 904 | 934 | 972 | 947 | 999 |
| Ivano-Frankivsk region | 1103 | 769 | 852 | 851 | 925 | 932 | 1057 |
| Lviv region | 820 | 616 | 676 | 727 | 745 | 714 | 814 |
| Chernivtsi region | 1016 | 664 | 750 | 814 | 843 | 868 | 962 |
| Carpathian region | 938 | 680 | 765 | 804 | 839 | 828 | 924 |

Regarding the profitability of business processes of agricultural enterprises in the Carpathians region, their relative share in the state performance is only 3.9 %, which is too little. In particular, the producers of Transcarpathian region ended with a loss in 2012. This performance should be improved.

The general tendency of existing agricultural enterprises in the researched region is to reduce the production of gross agricultural output of during 1990 and 2012 and increase the production in households of the population. This is a striking reflection of the economic impact of land reform in the region and the economic performance of agricultural producers.

Speaking about the effective functioning of commodity producers of agrarian sector in the Carpathian region, it is necessary to analyze the impact of land use. One of the indicators that characterizes the efficiency of land use of agricultural enterprises is the production of gross output per unit of agricultural land (Table 2). As it is seen from the table 2, the agriculture of the Carpathian region is characterized by a much more intensive use of agricultural land compared to Ukraine. In particular, in 2012 the production of agricultural products was in 1.44 times more than in Ukraine in the region of 100 hectares of agricultural land.

However, the gross output per unit of land area does not show a complete picture of the effectiveness of land use in the Carpathian region. Therefore, while analyzing the efficiency of agrarian land use in agriculture it is necessary to use advanced mathematical methods of statistical data processing. In this case, the appropriate software for personal computers should be used, especially the software STATISTICA v.6.0, which will allow identifying and describing the existing relationships between results on the basis of partial results of statistical observation of events or indicators that are analyzed. Thus, by means of the software it is possible to analyze the dependence level of production efficiency on the parameters of land use by the agricultural enterprises in the Carpathian region.

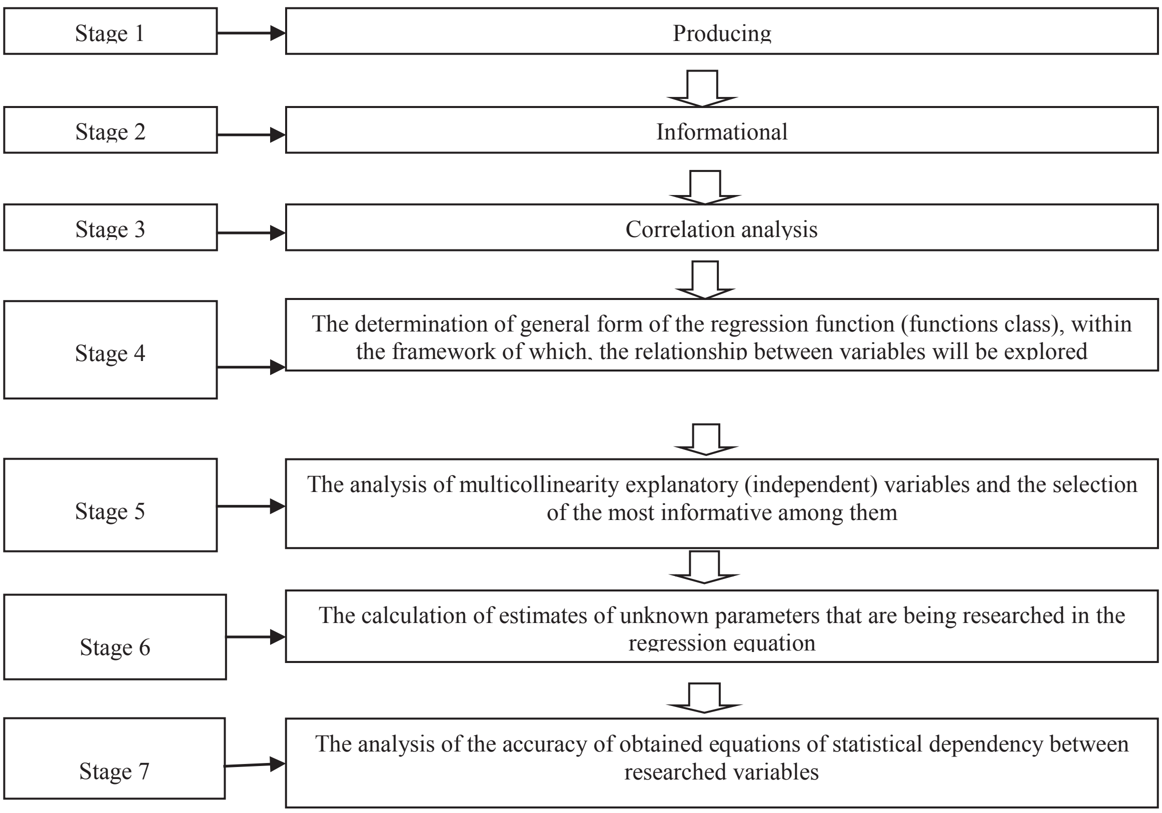


**Fig.** Stages of statistical analysis of dependency between efficiency performance indices of agricultural production and land use *. *the source [1]

**Table 3.** The list of "input" (explanatory) and "output" (resulting) variables*
* Suggested by the author.

| Variable | Type of variable | Symbol |
|---|---|---|
| The area of agricultural land per enterprise in the Carpathian region, ha | $X^{(1)}$ | *X1_PSU* |
| Crops capacity of agricultural enterprises in the Carpathian region, c / ha | $X^{(2)}$ | *X2_UZK* |
| The cattle stock in the enterprises of agricultural areas of the Carpathian region per 1 ha of agricultural land, head | $X^{(3)}$ | *X3_PVH* |
| The usage of mineral fertilizers of areas of agricultural enterprises in the Carpathian regions per 1 ha of agricultural lands, kg | $X^{(4)}$ | *X4_MIN* |
| The usage of organic fertilizers of areas of agricultural enterprises in the Carpathian region per 1 ha of agricultural land, tons | $X^{(5)}$ | *X5_ORG* |
| Net income (receipts) from sales of agricultural products in the areas of agricultural enterprise in the Carpathian region per 1 ha of agricultural land, thsd. UAH | $Y^{(1)}$ | *Y1_CHD* |
| Income (loss) from sales of agricultural products in the areas of agricultural enterprise in the Carpathian region per 1 ha of agricultural land, thsd UAH | $Y^{(2)}$ | *Y2_PSG* |
| The level of profitability of agricultural activities of agricultural enterprises of the areas in the Carpathian region, % | $Y^{(3)}$ | *Y3_REN* |

The analysis of literature shows that the use of statistical software and the process of statistical analysis of dependency between indicators of efficiency of agricultural production and land use can be divided into the following interrelated stages (Figure).

Let us start the process of statistical analysis of the dependency of efficiency performance indices of agricultural production and land use from the step 1 - producing. In this case, it is necessary to define the objects of study Oi (i=1,2,3,4). These will be the areas of the Carpathian region. For each object of the research $O_i$ let us put into conformity the list for "input" (explanatory) and "output" (resulting) variables (Table 3). As it is seen, in the first equation on the indicator of net income from the sales of agricultural products the cattle population negatively affects (H3_PVH), and in the third - of the level of crops productivity negatively affects the profitability (H2_UZK). It affirms the need for measures to increase the crops capacity and cattle population in the researched region.

## CONCLUSIONS

Therefore, based on the conducted analysis, it can be concluded that due to distortion of economic relations in agriculture in the Carpathian region the increase of the concentration level of agricultural production, which is expressed by means of crops capacity and cattle population per unit of land area. It appears to be a negative factor that affects the performance of net income from the sale of agricultural products per 1 ha of land and profitability of agricultural enterprises. It is obvious that the current structure of land use in agriculture in the Carpathian region is unable to provide effective agricultural production. In our opinion, the basis of this is a number of reasons and one of them is a shortage of arable land in the region, which causes the small size of land of commodity producers, which does not allow to introduce modern technologies of land cultivation. As a result, smallholders carry out the process of manufacturing processes mainly by means of primitive, natural methods.

Therefore, in order to improve land use for agricultural commodity producers in the Carpathian region it is necessary to consolidate effectively and develop positive achievements of land reform. That is to ensure the efficient use of land with the usage of restrictions concerning the deecolization. It is important to create the conditions for medium-sized landowners, ensuring a relatively high social security of rather small and very small owners. In this case the land lease should play an important role, especially by raising lease payment and payments for land revocation.

Toward further research regarding this problem, it is necessary to prove mechanism by means of which the increase the efficiency of agricultural production and the profitability of land use will be ensured. The levers of state regulation of land relations, aimed at the establishment and development of market relations in agricultural land use, improvement of tax and price policies on land markets and taking measures in order to improve the rational use of land and its protection should play an important role.

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# Development of mathematical model of duration of filling the finite-dimensional space with air at vacuum-gauge pressure

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Abstract. The article presents analytical dependences for simulating the process of filling the chambers of variable vacuum-gauge pressure of the system of pulser-teat cup with air. The simulation is carried out with an account of the law of mass saving for controlled volumes of gases by means of equation of mechanical energy of air transportation. The paper calculates the time of filling chambers of milking units with air to the conditions of atmospheric pressure.

Key words: milking unit, velocity coefficient, vacuum-gauge pressure, time of filling.

## INTRODUCTION

Developments of new constructions of milking units pulsers require theoretical grounding of technical characteristics of their operation, i. e. air expenditure at preassigned geometrical dimensions of the construction which determine the very regime of the work of pulser, its energetical parameters and time characteristics of the derivative processes when coming from the cycle of sucking to the compression cycle. Therefore, in modeling constructive and technological parameters of the milking units pulser there exists a need in models of air expenditures caused by both separate elements and the whole milking units [22].

Air expenditures caused by a milking units is calculated under conditions of reaching normal atmospheric pressure taking into consideration the volumes of chambers of variable vacuum-gauge pressure, vacuum-gauge pressure, frequency of pulsations [1,2]. The given methods of calculation guarantee only average results and ignore specific properties of the pulser's construction. The character of pressure variation is accepted here by the exponencial law.

Experimental data on air expenditures caused by the milking unit and methods of research are presented in the works [3,4] which may be used in determining air expenditures caused by the existing now pulsers of conventional structures.

The average value of air expenditure may be calculated considering the air motion velocity in vacuum conductor of the milking unit, the lapse of vacuum-gauge pressure, constructive dimensions of vacuum drive and coefficient of pneumatic voltage of friction [5].

Model of calculating air expenditures with an account of the equation of the state of gas is closely approached to the solution of the predetermined problem [6].

To simulate air expenditures in displacement of condensed gas from the finite-dimensional space through the nozzle, the equation of Saint-Venant Wentzel is employed. The mentioned equation describes the process of filling space through a short attachment from the infinite-dimensional space [7].

When learning the impact of the pulser construction parameters on technological parameters of its functioning, the analysts are usually focused on the experimental study of the impact of pressure and the transmission hole diameter on the frequency of pulsation [8, 9].

In the dynamic analysis of pneumodrives thermodynamic processes are considered. The part of energy here is directed to the gas thermal extension taking into account initial and finite temperatures of extension [10-15].

The discussed above models get a number of drawbacks. They do not consider the regime of milking units operation and, as a result, the nature of variations of vacuum-gauge pressure. In addition, the aquation lacks the parameter of the losses of vacuum-gauge pressure and, therefore, it does not give the opportunity of calculating the amount of air for the preassigned time period.

Having developed the model of filling the finite-dimensional space with air, we shall further on consider the process of filling air considering only mechanical energy of air movement in the system of the teat cup – pulser [16, 19, 22].

## OBJECTIVES

The article is aimed at the development of mathematical model for simulating time of filling the finite dimensional space with air depending upon the geometrical dimensions and technological parameters of the pulser functioning.

## MAIN PRESENTATION

Let us consider the process of variation of pressure in the following system: interwall space of teat cup-pulser which formulates the volume of the space with variable vacuum-gauge pressure as a single system filled with air. Let the volume of the system equals $V$. Its vacuum gauge pressure is $P_V$. It is important to determine in the finite dimensional space the duration of pressure increase from $P_V$ to $P_A$. At an arbitrary moment $t$ pressure in the system will be $P_i$ and, consequently, density of air stream $\rho$ and its velocity $\upsilon$.

We shall set up a differential equation for filling the space $V$ with air within the system “teat cup-pulser” considering the fact that air mass $M$ which will arrive in some time may be calculated by the equation [17]:

$$dM = m \cdot dt\ , \tag{1}$$

where: $m$ – mass of air expenditure according to the equation [22], kg/s,

$$m = \upsilon \cdot S_{cross} \cdot \rho_A\ , \tag{2}$$

where: $\upsilon$ – velocity of air motion during filling of the volume $V$.

According to the equation [22] with corrections, the velocity of motion is calculated by the formula:

$$\upsilon = \sqrt{\frac{2g}{1+\xi} \cdot \frac{P_i}{\rho_i} \cdot \left(1 - \left(\frac{P_i}{P_A}\right)^{\frac{n-1}{n}}\right)} \cdot dt\ , \tag{3}$$

where: $P_i$ – running value of pressure in the space of vacuum-gauge pressure ($P_i$ varies from $P_V$ to $P_A$); $P_A$ – atmospheric pressure; $\rho_i$ – air density at the running value of pressure $P_i$.

Let us substitute the equation (3) into the equation (2) and get:

$$m = S_{cross} \cdot \rho_A \cdot \sqrt{\frac{2g}{1+\xi} \cdot \frac{P_i}{\rho_i} \cdot \left(1 - \frac{P_i}{P_A}\right)^{\frac{n-1}{n}}}\ . \tag{4}$$

We shall accept:

$$x_i = \frac{P_A}{P_i}\ . \tag{5}$$

Then the value of mass of air expenditure during filling the chamber of variable vacuum-gauge pressure and its getting the conditions of atmospheric pressure will be:

$$m_\Delta = S_{cross} \cdot \sqrt{\frac{2g}{1+\xi} \cdot P_i \rho_i \cdot \left(x_i^{\frac{2}{n}} - x_i^{\frac{3-n}{n}}\right)}\ . \tag{6}$$

Variation of air mass in chambers of variable vacuum-gauge pressure will equal:

$$dM_A = S_{cross} \cdot \psi_i \cdot \sqrt{P_i \rho_i} \cdot dt\ , \tag{7}$$

where:

$$\psi_i = \sqrt{\frac{2g}{1+\xi} \cdot \left(x_i^{\frac{2}{n}} - x_i^{\frac{3-n}{n}}\right)} \cdot \frac{м^{\frac{1}{2}}}{s}\ , \tag{8}$$

- coefficient of velocity.

Then considering the equations (6), (8) the equation (7) will get the from:

$$dM_A = S_{cross} \psi_i \cdot \sqrt{P_i \rho_A \left(\frac{P_i}{P_A}\right)^{\frac{1}{n}}} \cdot dt = $$
$$= S_{cross} \cdot \psi_i \sqrt{P_A \rho_A \cdot \frac{P_i}{P_A} \cdot \left(\frac{P_i}{P_A}\right)^{\frac{1}{n}}} \cdot dt = . \tag{9}$$
$$= f_{cross} \cdot \psi_i \sqrt{P_A \rho_A} \cdot \sqrt{\left(\frac{P_i}{P_A}\right)^{\frac{n+1}{n}}} \cdot dt$$

When filling the volume $V$, with air, its mass will vary with simultaneous variation of its density. Variation of the air mass may be described in the following way:

$$dM = V \cdot d\rho_i\ . \tag{10}$$

We shall insert expression for $\rho_i$ (4), to the equation (10) and get:

$$dM = V \cdot \rho_A \cdot d\left(\left(\frac{P_i}{P_A}\right)^{\frac{1}{n}}\right) = $$
$$= \frac{V}{n} \cdot \rho_A \cdot \left(\frac{P_i}{P_A}\right)^{\frac{1-n}{n}} \cdot d\left(\frac{P_i}{P_A}\right) \tag{11}$$

Let us match the equations (11) and (9):

$$\rho_A \cdot \frac{V}{n}\left[\frac{P_i}{P_A}\right]^{\frac{1-n}{n}} \cdot d\left(\frac{P_i}{P_A}\right) = $$
$$= S_{cross} \psi_i \sqrt{P_A \rho_A} \cdot \sqrt{\left(\frac{P_i}{P_A}\right)^{\frac{n+1}{n}}}\, dt\ . \tag{12}$$

let us shorten the equation (12) to the expression $\left(\frac{P_i}{P_A}\right)^{\frac{1}{n}}$.

$$\rho_A \cdot \frac{V}{n}\left(\frac{P_i}{P_A}\right)^{-1} \cdot d\left(\frac{P_i}{P_A}\right) = $$
$$= S_{cross} \psi_i \sqrt{P_A \rho_A} \cdot \sqrt{\left(\frac{P_i}{P_A}\right)^{\frac{n-1}{n}}}\, dt\ . \tag{13}$$

Let us make transformation in the equation (13):

$$\frac{1}{n} \cdot \frac{1}{\frac{P_i}{P_A} \cdot \left(\frac{P_i}{P_A}\right)^{\frac{n-1}{2n}}} \cdot d\left(\frac{P_i}{P_A}\right) = \frac{S_{cross} \psi_i}{V} \cdot \sqrt{\frac{P_A}{\rho_A}} \cdot dt\ .$$

or:

$$\frac{1}{n}\cdot\left(\frac{P_i}{P_A}\right)^{\frac{1-3n}{2n}}\cdot d\left(\frac{P_i}{P_A}\right)=\frac{S_{cross}\psi_i}{V}\cdot\sqrt{\frac{P_A}{\rho_A}}\cdot dt\ . \quad (14)$$

Let us integrate the equation (14) having set the limits of integration from $\frac{P_i}{P_A}$ to *1* and from *0* to *t*:

$$\frac{1}{n}\int_{\frac{P_i}{P_A}}^{1}\left(\frac{P_i}{P_A}\right)^{\frac{1-3n}{2n}}\cdot d\left(\frac{P_i}{P_A}\right)=\frac{S_{cross}\psi_i}{V}\cdot\sqrt{\frac{P_A}{\rho_A}}\int_0^t dt\ .$$

$$\frac{1}{n}\cdot\frac{\left(\frac{P_i}{P_A}\right)^{\frac{1-n}{2n}}\Big|_{P_i/P_A}^{1}}{\frac{1-n}{2n}}=\frac{S_{nep}\psi_i}{V}\cdot\sqrt{\frac{P_A}{\rho_A}}\cdot t\Big|_0^t\ . \quad (15)$$

Let us substitute the limits of integration into the equation (15):

$$\frac{1}{n}\cdot\frac{1-\left(\frac{P_i}{P_A}\right)^{\frac{1-n}{2n}}}{\frac{1-n}{2n}}=\frac{S_{cross}\psi_i}{V}\cdot\sqrt{\frac{P_A}{\rho_A}}\cdot t\ . \quad (16)$$

Coming from the equation (16) we determine duration of filling chambers of variable vacuum gauge pressure of the system “teat cup-pulser” with air to the conditions of atmospheric pressure:

$$t=\frac{1}{n}\cdot\frac{2n}{1-n}\left(1-\sqrt{\left(\frac{P_i}{P_A}\right)^{\frac{1-n}{n}}}\right)\cdot\frac{V}{S_{cross}\psi_i}\cdot\sqrt{\frac{\rho_A}{P_A}}\ ,$$

or:

$$t=\frac{2}{1-n}\cdot\frac{V}{S_{cross}\psi_i}\cdot\sqrt{\frac{\rho_A}{P_A}}\cdot\left[1-\sqrt{\left(\frac{P_i}{P_A}\right)^{\frac{1-n}{n}}}\right]. \quad (17)$$

where $V$– volume of chambers of variable vacuum-gauge pressure of the system “teat cup-pulser”, м$^3$; $S_{cross}$ – area of crossing the transmission channel “pulser – teat cup”, м$^2$; $\psi_i$ – coefficient of velocity characterizing pressures relations, м$^{1/2}$/s; $\rho_A$ – density of air at atmospheric pressure, kg/м$^3$; $P_F$ – atmospheric pressure of air, kg/м$^2$; $n$ – parameter of polytropy.

In approbating the received equation we calculated the time of filling the system “teat cup-pulser” with air using the following initial data: $V$ – 0,00005; 0,0001; 0,00015; 0,0002 м$^3$; $d_{cross}$ – diameter of the permitting channel of the pulser, $d_{cross}$ – 0,002; 0,003; 0,004 м; $\rho_V$ = 1,25 kg/м$^3$; $P_V$ = 10000 kg/м$^2$; $n$ = 1,4.

The calculation results are presented in fig. 1-2.

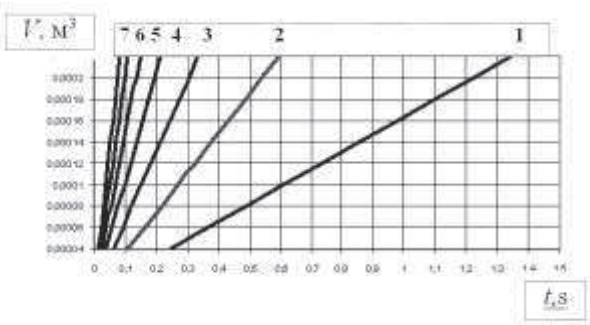


**Fig. 1.** Dependence of time filling with air $t$ on the volume of space V “teat cup-pulser” at preassigned diameter of the transmission chanel of the pulser: 1,2,3,4,5,6,7 - $d_{cross}$ = 0,001; 0,0015; 0,002; 0,0025; 0,003; 0,0035; 0,004 м

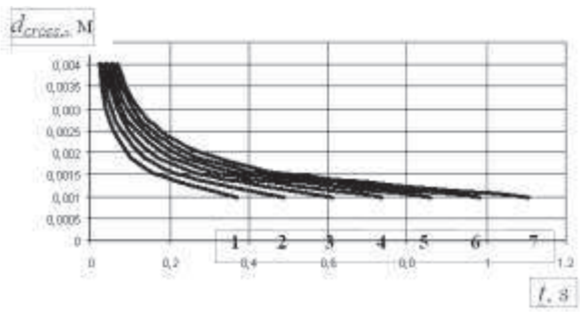


**Fig. 2.** Dependence of time filling with air $t$ on the diameter of transmission hole $d_{cross}$ of the pulser at the preassigned volume of space “teat cup-pulser”: 1,2,3,4,5,6,7 - $V$ = 0,00006; 0,00008; 0,0001; 0,00012; 0,00014; 0,00016; 0,00018 м$^3$

## CONCLUSIONS

The suggested mathematical dependences allow to simulate velocity and expenditure of air, time of filling depending on the volumes of chambers of variable vacuum-gauge pressure of the milking unit, constructive dimensions of air-conductors, regime of variation of pressure which allow to determine theoretically constructive and dynamical characteristics of the system “pulser – milking unit”.

Calculations proved the position that optimal diameters of permissing hole of the pulser are within 0,002…0,003 м at the volumes of variable pressures from 0,00005 м$^3$ to 0,0002 м$^3$.

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# Verilog – ams model of comb-drive sensing element of integrated capacitive microaccelerometer for behavioral level of computer aid design

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Abstract. The article presents Verilog – AMS model of the comb-drive sensing element of the integrated capacitive microaccelerometer. The suggested model allows to simulate the reaction of the sensing element effected by the applied force of acceleration, changes of its comb-drive capacities, output voltages and currents for determining its constructive parameters and for analysis of the mechanical module of the integrated device at the behavioral level of computer-aided design.

Key words: micro-electro-mechanical systems (MEMS), micromachining technologies, micromechanical comb-drive sensing element, integrated capacitive microaccelerometer, acceleration, SMASH, Verilog – AMS hardware description language, computer-aided design.

## INTRODUCTION

We face now a remarkable progress in developing new technologies accompanied by their more advanced parameters comparing with the present day practice. One of them is the technology of micro electromechanical systems (MEMS) [1-3] These systems allow to manufacture the devices which proved to be cheaper, lighter and more delicate then their analogues in the macro world. In addition, such devices are more reliable as they are manufactured with the use of integrated technologies. They are also given the perspective of growing their functionality and quite a number of other advantages [4-7].

MEMS technologies are used in various fields of science and engineering as well as in developing different mechanisms [3, 8, 9] for improving their output parameters. Such technologies are used in realization of sensors of different functional purposes, actuators, medical micro instruments. MEMS technologies are in particularly wide use when realizing inertial sensors. Such MEMS inertial sensors as accelerometers [10] and gyroscopes [11] are widely used in many fields of engineering: automobiles (systems of controlling safety backs, antiblocking ABS systems, antislipping systems, systems of active suspension, etc.), medical service and consumer electronics (smartphones, hand-held computers, notebooks, video-playing consoles, systems of stabilization in photo and video cameras, systems of monitoring engineering structures (machines and bridges), inertial and navigation systems, determining concentration of harmful gases, etc. [1-3, 5, 6, 12-16].

To make an effective design of such sensors, to provide them with the necessary technical and operating characteristics, to improve their reliability, the behavioral models are made up in the hardware – description language (VHDL-AMS, Verilog-AMS) with the use of the following software: Cadence, MATLAB, hAMSter, SMASH (Dolphin integration) and others [17] therefore, operations connected with developing behavioral models and automation of their design in the languages VHDL-AMS, Verilog-AMS aimed at description of such compound heterogeneous systems as MEMS are of a particular importance now. There exists quite a number of various constructions of accelerometers [3, 18-20] but in case with microaccelerometers the most common type of constructions is the comb one. The mentioned above constructions have VHDL-AMS models [21-24] However, most of them do not consider in a satisfactory way constructively – technological parameters which have a sufficient effect on the initial parameters of a microaccelerometer.

## MAIN PRESENTATION

We suggest a typical structure (Fig 1) of the comb-constructioned sensing element of the integrated capaci tive microaccelerometer [25]. The sensing element comprises the operational mass suspended on the elastical elements fixed to the pad of an integrated device; movable comb electrodes suspended to the operational mass and immovable comb electrodes suspended to the pad of an integrated device. Movable and immovable comb electrodes make up a comb drive. At the moment of external acceleration starting, the operating mass accompanied by movable comb electrons begins to move under the impact of the force of inertia with the simultaneous alteration of the distance between the movable and immovable electrodes of the comb drive. As comb drive electrodes compose differential capacit couple of $C_1$ and $C_2$, any changes made within the mentioned above capacity will provoke changing of these capacity.

We shall start our analysis of the integrated capacitive microaccelerometer from the equation describing its sensing element movement:

$$M\frac{d^2x(t)}{dt^2}+D_y\frac{dx(t)}{dt}+K_x x(t)=-F_{ext}, \quad (1)$$

where: $M$ – mass of the sensing element, $D_y$ – coefficient of attenuation, $K_y$ – coefficient of elasticity, $x(t)$ – movement of the sensing element across the axis x. $F_{ext} = M{\cdot}a_{ext}$, where $aext$ – external acceleration.

Mass $M$ of the sensing element may be calculated by means of the formula:

$$M=\rho\left(V_{mass}+V_{fingers}\right)=\rho\left(W_{pm}L_{pm}+(N_s+N_f)L_{sf}W_{sf}\right)T, \quad (2)$$

where: $\rho$ – specific density of the material (for polysilicon $\rho$ = 2330 kg/m³), $V_{mass}$ and $V_{fingers}$ – volumes of the operating mass and movable comb electrodes correspondingly.

System of suspension of mechanically sensing elements comprises four curved elastic paralelly connected elements (Fig 1). Coefficient of inelasticity connected elements (Fig 1). Coefficient of inelasticity of one section of elastic elements is calculated by means of formula [26, 27]:

$$K_{beam}=\frac{12EI_s}{L_s^3}, \quad (3)$$

where: $E$ = 170×10 H/m² – poly-silicon module of Ewing; $L_s$ – inertial moment of the elastic element which is calculated on the basis of the formula $\frac{W_sT^3}{12}$; $W_s$, $L_s$, and $T$ – width, length and thickness of one section of the elastic element correspondingly.

As two sections of the curved elastic elements possess similar lengthes and are connected successionally, the elasticity coefficient of one curved elastic element is determined by the formula:

$$K_{fold}=\frac{1}{2}K_{beam}=\frac{EW_sT^3}{2L_s^3}. \quad (4)$$

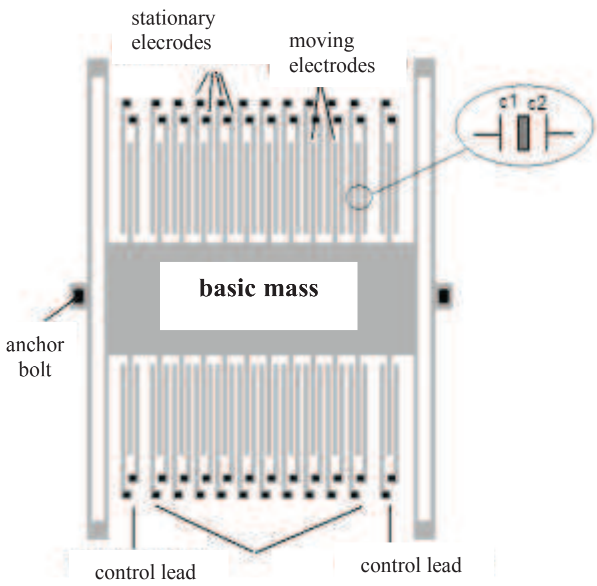


**Fig. 1.** Schematic representation of the comb structure of MEMS capacitive micro accelerometer sensing element

As the operational mass is suspended on four elastic elements of the single length, each elastic element receives 1/4 of the total force of loading. Therefore, the total coefficient of elasticity equals $4\times K_{fold}$:

$$K_{mechanical}=4\times K_{fold}=\frac{2EW_sT^3}{L_s^3}. \quad (5)$$

The suggested above formula for calculating coefficients of inelasticity does not take into consideration the effect of electrostatic moderation of elasticity. After application of simulating voltage of high frequency $V_m(t)$ to immovable comb electrodes, electrostatic forces are generated in metering drive. These forces cause modifications in mechanical inelasticity of elastic elements of suspension. This phenomenon is called moderation and is observed in the model of mechanical sensing element. The resulting force effecting the comb electrode ($F_s$) may be calculated by means of the following formula:

$$F_e=F_{e1}-F_{e2}=\frac{\varepsilon_0AV_m^2}{2}\left[\frac{1}{(d_0-x)^2}-\frac{1}{(d_0+x)^2}\right], \quad (6)$$

where: $F_{e1}$ and $F_{e2}$ – electrostatic forces; $d_0$ – initial distance between movable and immovable electrodes of the comb drive; $x$ – replacement of the movable electrode; $A$ – side area of metering comb electrode ($A=L_{sf}T$); $\varepsilon\varepsilon_0$ – dielectric constant (8,85×10⁻12 F/m) and $V_m$ – amplitude of voltage of modulation.

Suppose, $x<<d_0$ and $N_s$ – number of comb electrodes. Then electrostatic coefficient of elasticity may be calculated by means of the formula:

$$K_e=N_s\left(\frac{d(F_e)}{dx}\right)=-N_s\left(\frac{2\varepsilon_0L_{sf}TV_m^2}{d_0^3}\right). \quad (7)$$

Accordingly, effective coefficient of elasticity equals:

$$K=K_{mechanical}+K_e. \quad (8)$$

During replacement of movable structure air flow crosses the clearance between movable and immovable structures. For capacitive mechanical sensing element dumping of the condensed layer of air between comb electrodes is dominative over all the rest forms of dumping. Effect of dumping between comb electrodes may be simulated by the low of Hagen – Poiseuille [28]. Thus, we get the following formula for calculating coefficient of attenuations:

$$D = 14{,}4(N_f + N_s)\mu L_{sf}\left(\frac{T}{d_0}\right)^3, \tag{9}$$

where: $N_s$ and $N_f$ – number of metering and controlling comb electrodes, correspondingly; $L_{sf}$ and $T$ – length and thickness of movable comb electrodes; $d_0$ – initial distance between immovable and movable comb electrodes; and $\mu$ – coefficient of aid viscosity (1,1839×10$^{-5}$ Pa·s).

The received parameters may help in determining operational parameters. The resonant frequency ($f_0$) may be calculated considering mass ($M$) and the effective coefficient of elasticity ($K$):

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{K}{M}}. \tag{10}$$

Coefficient of quality ($Q$) of mechanical sensing element may be received considering the following parameters: operational mass ($M$), coefficient of elasticity ($K$) and coefficient of attenuation ($D$):

$$Q = \frac{\sqrt{KM}}{D} = \frac{M\omega_0}{D}. \tag{11}$$

Dynamic response of mechanically sensing element may fall into three types according to the value of the coefficient of quality $Q$: if $Q < 0{,}5$, the sensing element is sufficiently dumping; if $Q = 0{,}5$ the sensing element is critically dumping. In other case we get weakly dumping.

Electrodes of comb drive make up differential condenser (Fig 2). When the external acceleration is absent, static capacity of such differential condenser may be calculated by means of the formula:

$$C_1 = C_2 = C_0 = \frac{\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0}. \tag{12}$$

When external acceleration appears, the operational mass begins to move under the impact of inertial force in the direction of axis x and causes changes of $C_1$ and $C_2$ of differential condenser which may be calculated by formula:

$$C_1 = \frac{\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0 + x} = \frac{\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0(1 + x/d_0)} \approx \frac{\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0}\cdot\left(1 - \frac{x}{d_0}\right). \tag{13}$$

$$C_2 = \frac{\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0 - x} = \frac{\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0(1 - x/d_0)} \approx \frac{\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0}\cdot\left(1 + \frac{x}{d_0}\right), \tag{14}$$

where: $\varepsilon_0$ – dielectric constant; $\varepsilon_r$ – relative dielectric environmental penetrability between the plates of condenser; $d_0$ – distance between the plates of condenser at $a_{ext} = 0$; $x$ – replacement of the sensing element.

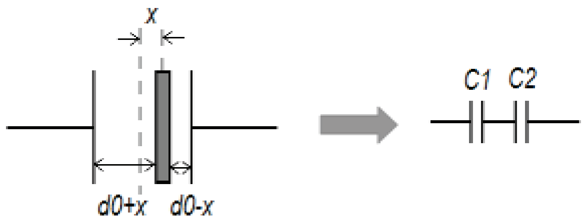


**Fig. 2.** Differential capacitor formed by the interdigitated electrodes with capacitors $C_1$ and $C_2$.

The initial signal is proportional to the oscillations of the carrier frequency and the changes of capacitors of differential condenser, and, thus, to external acceleration $a_{ext}$. As:

$$C_2 - C_1 = \frac{2\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0}\cdot\left(\frac{x}{d_0}\right) = 2C_0\cdot\left(\frac{x}{d_0}\right), \tag{15}$$

$$C_1 + C_2 = \frac{2\varepsilon_0\varepsilon_r N_s L_{sf} T}{d_0} = 2C_0. \tag{16}$$

The value of initial signal $V_{out}$ is directly proportional to the carrier frequency and movement of the sensing element. It is inverse proportional to the initial distance between the movable and immovable electrodes of the comb drive (distances between covers of differential capacitors couple at $a_{ext} = 0$):

$$V_{out} = \frac{C_2 - C_1}{C_1 + C_2}\cdot V_{sample} = V_{sample}\left(\frac{x}{d_0}\right). \tag{17}$$

When designing MEMS at the schemotechnical level the construction of behavioral models are foreseen. The specific feature of such models is their ability to contain data of various fields of science and engineering. For example, models of integrated capacitive microaccelerometer contains the quantities of mechanics, electricity and electronics. The language describing facilities of Verilog-AMS (Verilog Hardware Description Language Analog-Mixed Signals) allows to develop digital, analogue and mixed behavioral models which use both electrical and mechanical signals [28, 29]. Parameters of Verilog-AMS behavioral model of the sensing element of comb construction of integrated capacitive microaccelerometer are presented in the tab. 1

**Table 1.** Parameters of comb structuews of integrated capacitive microaccelerometer sensing element used in Verilog-AMS model

| Symbols | Constructional parameter of a sensing element | Value |
|---|---|---|
| $W_{pm}$ | Width of operational mass | 120 Mkm |
| $L_{pm}$ | Length of operational mass | 450 Mkm |
| $T$ | Thickness of elastic elements, comb electrodes and operational mass | 20 Mkm |
| $L_s$ | Length of elastic element | 176 Mkm |
| $W_s$ | Width of elastic element | 20 Mkm |
| $W_{sanchor}$ | Width of anchor of an elastic element | 10,0 Mkm |
| $L_{sf}$ | Length of comb electrode | 150 Mkm |
| $W_{sf}$ | Initial distance between movable and immovable electrodes of a comb drive | 1,5 Mkm |
| $G$ | Number of metrical comb electrodes | 54 |
| $N_s$ | Number of controlling electrodes | 4 |
| $N_f$ | Width of the anchor of comb electrode | 5,0 <k, |

The developed behavioral models made possible simulation using SNASH software [17]. The results are graphically presented in Fig 3. at the synosoidal change of external acceleration of 5g. The received results prove that the initial voltage takes place in the antiphase with the frequency 1MHz and the amplitude of 200pV-1nV. Thus, having such constructive parameters of sensing elements of the microaccelerometer we need precision amplifiers and highly sensing schemes for processing such signals.

## CONCLUSIONS

We developed Verilog-AMS model of the sensing comb construction of integrated capacitive microaccelerometer which allows to simulate reaction of the sensing element to the applied force of inertia, i.e. change of capacitors of its comb drive, initial voltage and currents for the given initial quantities of its constructional parameters. This system also gives the opportunity to analyze mechanical components of integral device at the behavioral level of automated design.

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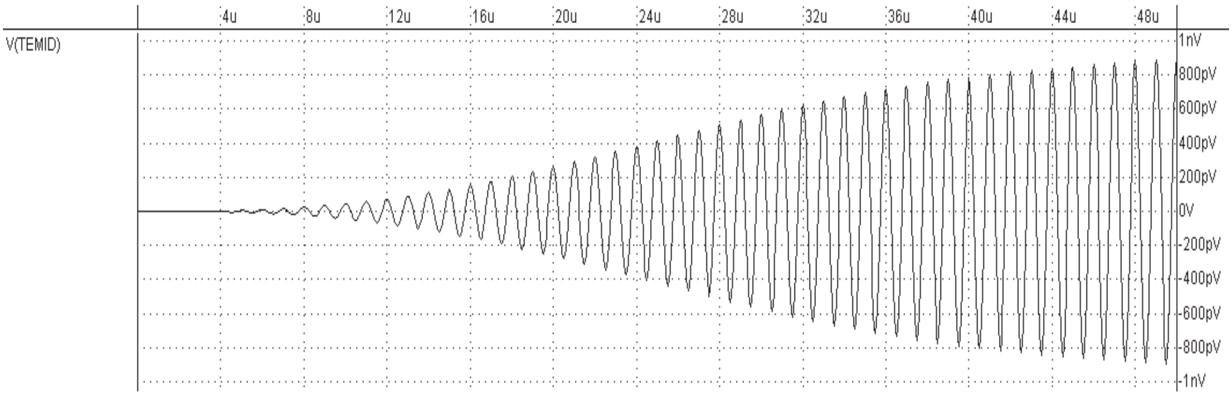


**Fig.3.** Changing of output voltage $V_{out}$

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# Prediction of losses in agricultural production output

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Abstract. The research presents the method of predicting the output losses in the two-staged project of agricultural production which takes into consideration the volumes of production; technological requirements concerning directory temps of carrying out operations; properties of technical resources; interdependence of operations.

This method also allows to determine the expected losses of the output connected with violating directory terms of performing technological operations of the project.

Key words: project, output, losses, directory terms, method.

## INTRODUCTION

Projects connected with criop production in agriculture have quite a number of specifie characteristics and, therefore, traditional network and calendar types of planning frequantly cannot be effectively employed there. In particular, such projects foresee performing of a lot of agricultural operations only within optimal agrotechnical terms because of the biological properties of crops, their specific phases of vegetation and agrometeorogical conditions of environment.

The given terms should be considered as directory. Their violation will provoke irreversible losses in crop yields ( the output of the project ) and , therefore, predictions of losses at the stage of planning the project and developing the corresponding managerial decisions proved to be a serious scientifically – practical objective aimed at minimizing such losses.

## RECENT RESEARCH AND PUBLICATIONS ANALYSIS

Manager's activity may be sufficiently relieved at each stage if he managed to get a model of calendar planning of performing predetermined operations and their biasing [2, 3]. In the projects connected with agrarian production any moving away of directory terms cause losses of yields (outputs).

Current methods of predicting yields losses caused by ill-timing of technological operations [4, 5, 6] are based on the biological specifications of crop vegetation. The analysts possess different views in predicting such losses . The reseach [4] suggests to employ a linear model of losses under conditions of velatively short periods of time (no more 20 days):

$$U_t = U_{\max}\left(1 - k_l t\right), \tag{1}$$

where: $U_t$ –current value of the yielding capacity, c/ha; $U_{max}$ – the yielding capacity of the crop which corresponds to performing operations in optimal terms, c/ha; $k_l$ – coefficient of the yield losses when directory terms of performing an operation are prolonged in one unit of time (a day); $t$ – duration of ill – timed operation carried out with violation of optimal moments, days.

The research [5] suggested the method of determining losses of crop yields caused by ill-timed performing of each technological operation. The given method, however, ignores the impact of neigbouring technological operations within a single project on the volumes of crops yields losses.

## OBJECTIVES

The article is focused on developing the method of predicting losses of the project's output under conditions of violation of directory terms of performing operations.

## MAIN PRESENTATION

Our project connected with crop growing is implemented on the single field or the group of fields. It faces, therefore, the necessity of performing major operations in one field in succession only. This approach excludes performing of different operations simultaneously there.

In addition, the results of the projects dealing with crop growing frequently face the risks of natural calamities, bad weather, etc which should be taken into consideration when making up models.

The project dealing with crop growing production can be considered as a set of well – organized operations over soils, a plant or a material in accordance with the given agrotechnical requirements:

$$P = \{O_i\}. \quad (2)$$

Each technological operation $O_i$, is given a finite sequence with the following attributes: type of operation $VO_i$, (ploughing, cultivation, chemical protection, etc.); a set of agrotechnical requirement to operations $\{AV_i\}$ (depth of procession, rate of application, etc.); directory time of starting $[\tau_i]$ and duration of fulfillment of an operation $[t_i]$:

$$O_i = \langle VO_i, \{AV_i\}, [\tau_i], [t_i] \rangle. \quad (3)$$

When performing major and additional technological operations within a single project one uses a limited number of industrial and technical resources of agrarian enterprises. We may distinguish there a set of farm machines $\{M_i\}$ and energetic instruments $\{T_i\}$ for their drive. The given resources make up the resource pool which may also be used in some other projects of the portfolio of agrarian enterprises. Because of the resources scarcity it is reasonable, therefore, to simulate these resources utilization under conditions of variable volumes of jobs $Q$ within the project and limitation of the admissible terms of performing operations.

Calendar schedule of technological operations dealing with crop growing production is planned at three stages. The first stage foresees constructing the model of technology demonstrates orderable by time and content set of operations and vectors of directory calendar terms of their performing. The coordinate of the vector origin of the calendar terms of operation in the model of technology is given the directoty time of the operation starting $[\tau_s]$. The coordinate of completion $[\tau_{e_i}]$ is determined by the formula:

$$[\tau_{e_i}] = [\tau_{s_i}] + [t_i]. \quad (4)$$

The model of the products output technology sets the ideal calendar schedule of the project. Performing of all technological operations within the directory calendar terms guarantees maximum output.

The second stage foresees selecting for each a-operation farm machines of the set $\{M_i\}$ of machinery available at the enterprise. The selected machines should secure the successful performing of the predetermined types of operations $VO_i$, and observing a set of agrotechnical requirements $\{AV_i\}$. In case with nonautomotive machines one should select specific energetic tool from the set $\{T_i\}$ of energetic means for these machines drive to secure the most efficient fulfillment of the predetermined technological operation. In this way we, thus, get the technical resource (machine and tractor aggregate) needed for performing the predetermined operation.Coming from technical characteristics of the given technological resource and environmental factors (specific resistance of the soil, the average angle of the field incline, length of the field gon and state of the object of conversion – a plant or material) we determine the veriable productivity $w_v$ of the technical resource and its specific fuel costs $g_p$.

Coming from the determined variable productivity of technical resources we can determine the real duration of each technological operation $O_i$, taking into consideration the quality of all available technical resources:

$$t_i = \frac{q}{w_v \cdot k_v \cdot n}, \quad (5)$$

where: $q$ – the volume of jobs, ha, t, m$^3$; $w_v$ – productivity of the aggregate for a shift (standard of the aggregate output) ha/shift; $k_v$ – coefficient of variability; $n$ – number of aggregates involved onto the given operation from the available set $\{M_i\}$ and $\{Ti\}$.

As only a single operation may be carried out in one single field at the given time, one must determine coordinates of the vector of both origin $\tau_{s_i}$ and completion $\tau_{e_i}$ for each single technological operation. In the case with the first operation of the project coordinates of the vectors origin will be equal to its directory calendar time $[\tau_{s_1}]$, i.e. $\tau_{s1} = [\tau_{s_1}]$.

For all further 1-x operations coordinates of their vectors of starting are determined with consideration of directory time of their starting $[\tau_{s_i}]$ after finishing the previous field operation $\tau_{e_{i-1}}$, i.e:

$$\tau_{s_i} = \begin{cases} [\tau_{si}], \text{ if } [\tau_{si}] > \tau_{e_{i-1}} \\ \tau_{e_{i-1}}, \text{ if } [\tau_{si}] \le \tau_{e_{i-1}} \end{cases}. \quad (6)$$

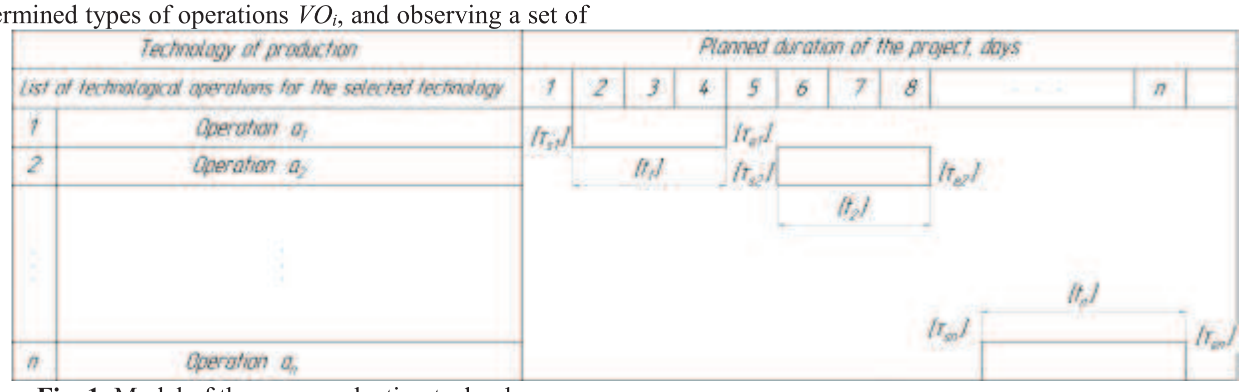


**Fig. 1.** Model of the crop production technology

Coordinate of completion of the vector of technological operation is determined by addition of the value of duration $\tau_{s_i}$ of the operation to the coordinate of its starting $t_i$:

$$\tau_{e_i} = \tau_{s_i} + t_i . \qquad (7)$$

When performing technological operations in the predetermined volumes one may face the searcity of farm machines $\{M_i\}$ and energetic means $\{T_i\}$, and, hence, the problems of violation of directory terms of operations may arise. The value of duration of performing operations prevailing the directory terms $t_u$ (Fig. 2) is determined under the following condition:

$$t_u = \begin{cases} \tau_{e_i} - [\tau_{e_i}], \text{ if } \tau_{e_i} > [\tau_{e_i}] \\ 0, \text{ if } \tau_{e_i} \le [\tau_{e_i}] \end{cases} . \qquad (8)$$

In case the time of completion of technological operation prevails its directory calendar time of completion $\tau_{e_i} > [\tau_{e_i}]$ (Fig. 2*b*), the problem of the losses of the output may arise.

To avoid such situations one must modify the duration of one day working time (the coefficient of variability) or the number of machine and tractor aggregates involved into jobs.

If both measures are not able to prevent the duration of operations beyond the directory terms , one must determine the value of losses caused by ill-timed performing of such operations:

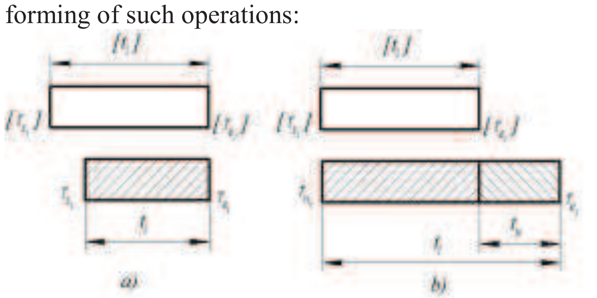

**Fig. 2.** The technological operation which does not prevail (*a*) and prevails (*b*) the directory terms of its carrying out

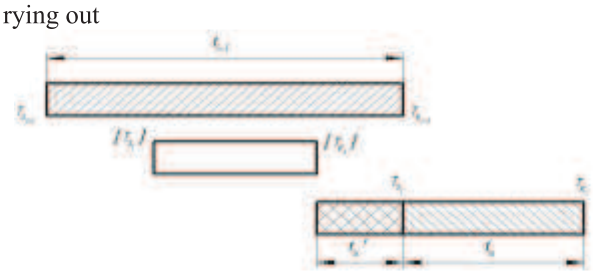

**Fig. 3.** The technological operation with the starting lagged behind the directory term of carrying out jobs

$$Z_i = 0{,}5 \cdot U_{\max_i} \cdot q_{u_i} \cdot t_{u_i} \cdot \kappa_l , \qquad (9)$$

$$q_{u_i} = q - W_{d_i} \cdot ([\tau_{ei}] - \tau_{si}) , \qquad (10)$$

where: $U_{max}$ – maximum yielding capacity of a crop (the project output), c/ha; $q_{ui}$ – the area of the field where the operation is performed with violations of directory terms, ha; $t_u$ – duration of performing the operation beyond the directory terms, days; $k_l$ – coefficient of the crop losses caused by 1 day delay of the technological operation; $W_{di}$ – the delay standard of the aggregate output when performing the given operation, ha/day.

When field or technical resources are employed in the previous operation may, the time of starting of the next technological operation, may be lagged behind the directory terms predetermined for it (Fig. 3). The output losses caused by ill – timed starting of the operation $t_n$, then, are calculated by maens of the formula:

$$Z_i' = q_u \cdot t_u' \cdot U_{\max_i} \cdot \kappa_{l_i} , \qquad (11)$$

$$t_{u'} = \begin{cases} \tau_{s_i} - [\tau_{e_i}], \text{ if } \tau_{s_i} \ge [\tau_{e_i}] \\ 0, \text{ if } \tau_{s_i} < [\tau_{e_i}] \end{cases} . \qquad (12)$$

The next step is determining the total output losses for each operation of the project caused by its ill – timed performing:

$$\sum Z_{S\,i} = Z_i' + Z_i . \qquad (13)$$

Coming from the construction of the calendar schedule we determine the expected losses of the output for all operations of the project *P*, and their gross expected losses of the output by means $Z_{P\,i}$ of the formula:

$$Z_{P\,i} = \sum_{i=1}^{n} Z_{S_i} . \qquad (14)$$

The received results give grounds for motivating organizationally technical decisions on realization of the project.

Analysis of the technical operations give the apportunity to determine the critical operations of the project causing the most dramatical output losses as well as to determine such technical resources whose scarcity provokes these losses. Managers supervising the project should constantly take into consideration the said above and feel their personal responsibilities for satisfactory supply of technical resources through cooperation, rent and additional purchase of the given type of resources.

If it is impossible or unreasonable to employ the additional resources one should think about the opportunities of diminishing the range of the project which, in its turn, will lead to diminishing demands in technical resources and, hence, minimal losses of the output.

## CONCLUSIONS

1. Projects connected with agrarian production have their specific characteristics caused by limitation of calendar terms of performing operations. This phenomenon needs further developments or improvements of the current methods of constructing calendar schedules and supervision of the projects.

2. The suggested method of constructing calendar schedule considers optimal versions of interdependence of technological operations conserving both the timely realization of the project and violation of directory terms which allows to determine the expected losses of the project caused by the violation of directory terms of performing operations within the project.

3. The developed method of predicting the output losses proved to be a reason for grounding the needs in

additional resources and the change of the range of the project for preventing irreversive losses of the output.

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# Current aspects of mathematical modelling of evaluating quality of agricultural products

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Abstract. The paper presents mathematical model of complex evaluation of the quality of production with optimizing indicators of crop growing. Multicriterion model is reduced to the problem of optimizing with the predetermined target function which considers almost all parameters of the prodution quality. The model takes into account limits of modifications of quality characteristics of production by introducing the indistinct description of the quality characteristics of productions. The model was developed on the example of evaluating quality of the barley grain.

Key words: target function, fuzzy restriction, vector-optimizing model.

## INTRODUCTION

After signing the political part of Association Agreement with Ukraine, the European Union unilaterally opened the Ukrainian commodities access to the European markets. This gives our country unprecedental conditions supplying of our commodities at the European markets. The best opportunities are possessed by agricultural producers because of cancelling import duties for agricultural products. However, the quality and safety of products they produce and supply should correspond to the requirements of consumers. The described above situation gave birth to the acute demand in developing complex system of quantative evaluation of agricultural production.

## ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The given problem of systemic evaluation of the quality of agrarian production is in the budding stage now. The work [8] presents the theoretically generalized concept of a virtual measure of quality and of its basis developed structural system of determining the level of the quality of production. The work [9] highlights theoretical foundations of the use of methods of its multidimensional scaling to combine several single parameters of quality of production to the single scale. Developing such a scale is a rather complicated objective. We believe it would be more expedient to apply calculating methods of evaluating quality of production with setting a functional dependence of a complex indicator of quality from a number of single quality indicators or input parameters of manufacturing (growing) agricultural products.

Prof. A. Dolzhanskyi [5] suggests a mathematical model of quality evaluation where the single quality indicators are presented in rows. The rows are formed on the basis of experimental data focused on the problem of influence of technical, technological and organization parameters on a single quality characteristic of production. Complex indicator of quality is presented by the functional (the average value of functions of the single quality indicators). The suggested mathematical model is studied on the example of calculating complex quality indicators of a steel wire after dragging two single indicators of quality. The work determined maximum value of the composite indicator of quality, but this value is reached by the functional at unrealistic values of input parameters. Thus, the suggested mathematical model of complex evaluation of quality ignores the restriction of real values of input parameters.

To create a general system of obtaining flax fibers with predictable properties, the work [4] developed a mathematical model of predicted properties of the production and quality control in the technological process. Using the developed mathematical model you can optimize the properties of the resulting product. However, the paper presents only the results of optimization flax fibers and ignores the mathematical mechanism of this model.

Safety and quality of agricultural products are studied in various aspects. The work [13] analyzes regional and national food staff safety at the state level in Ukraine and Russia. The work [14] offers economically-mathematical modeling of factors influencing the formulation of competitiveness of milk production and procession. One of the factors influencing the competitiveness of milk is its quality. Thus the problem of quality of agricultural production is important in terms of the improving competitiveness of enterprises.

Research in the area of quality evaluation of production is carried out in the direction of complex evaluation of quality and evaluation of quality characteristics of production. In particular, the problem of quality of water is discussed in the work [15].

In our opinion, the problem of complex evaluation of quality of production is advisable to reduce to optimizing with application of the theory of fuzzy sets. This idea has been suggested in the work [3]. The author has restricted his analysis to studying optimal indices of quality of production under conditions of certainty. However, the production may be of a high quality in case it does not necessarily reach a certain specified value and stays within the predetermined limits. To account the admissible modifications of some separate characteristics of quality at mathematical modeling of the complex indicator of the production quality it is advisable to apply the theory of fuzzy sets. It is also advisable to work out some recommendations on providing progressive norms of the quality of production on the basis of its mathematical model.

## OBJECTIVES

The given research is aimed at the development and studies of mathematical model of complex avaluation of the quality of agricultural production.

## MAIN PRESENTATION

Quality of production depends on many characteristics. In mathematical modeling of complex evaluation of quality we shall take into account the most essential features. The irrelevant features will not be introduced into the mathematical model. But their influence will be taken into consideration by means of approximation of non-linear problems by linear problems with fuzzy coefficients. Thus, we shall accepts the decision based on the mathematical model building where purposes and restrictions are formulated undistinctly. Analysis of difficult qualimetric systems built with the use of fuzzy set theory can correctly describe the status of the product and compare it with the basic product. A fuzzy set $\tilde{A}$ is defined by the base scale X and the belonging function $\mu_{\tilde{A}}(x)$. Functions of belonging accept values in the interval [0, 1]. A fuzzy set $\tilde{A}$ - is a totality of pairs of the form [12]:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)), x \in X\}. \qquad (1)$$

If the basic scale is discrete and finite, that is $X = \{x_i\}_{i=1}^{n}$. Then the fuzzy set can be written as:

$$\tilde{A} = \sum_{i=1}^{n} \frac{x_i}{\mu_{\tilde{A}}(x_i)}, \qquad (2)$$

where: $x_i$ - i-meaning of the base scale.

Functions of belonging $\mu_{\tilde{A}}(x)$ determines the degree of the expert confidence that the given base value of the scale corresponds to the fuzzy set.

If the functions of belonging is continuous, it can be presented in the bell, triangular or trapezoidal form.

In addition, for producers is important both to evaluate the production and to receive recommendations of getting sufficient output and the highest quality of the products. Thus, we put two objectives of reaching maximum results in quality and quantity of production. Sometimes they are contradictionary. One should, therefore, find a compromising decision. In such case it is advisable to apply the vector-optimizing model [11]:

$$Z(x) = \begin{pmatrix} z_1(x) \\ \vdots \\ z_n(x) \end{pmatrix} = \begin{pmatrix} C_1 \cdot x \\ \vdots \\ C_n \cdot x \end{pmatrix} \to \max, \qquad (3)$$

under conditions:

$$g_i(x) \equiv a_i \cdot x \tilde{\le} b_i, b_i + d_i \;\; i = \overline{1, m_1}$$

$$g_i(x) \equiv a_i \cdot x \le b_i,_i \;\; i = \overline{m_1 + 1, m}. \qquad (4)$$

Vectors:

$x = (x_1;...;\ x_n)$.

$C_K=(c_{1K};\ \ldots;c_{nK})$; $k = \overline{1, K}$.

$a_i = (a_{i1};\ \ldots;\ a_{in})$, $i = \overline{1, m}$.

and numbers

$b_i$ $i = \overline{1, m}$, $d_i > 0$ $i = \overline{1, m_1}$.

are real:

Let us formulate a multicriterion linear optimizing model of evaluation of quality of agricultural production with the simultaneous optimizing parameters of growing.

$$Z(x_1, x_2, ...., x_n) = \begin{pmatrix} z_1(x_1, x_2, ...., x_n) \\ \vdots \\ z_r(x_1, x_2, ...., x_n) \end{pmatrix} =$$

$$= \begin{pmatrix} 1 - \sqrt{\sum_{j=1}^{p} w_j^2 (\sum_{i=0}^{n} a_i x_i - \mu_j(x_1, x_2, ...., x_n))^2} \\ \vdots \\ \sum_{i=0}^{n} a_i x_i \end{pmatrix} \to \max, \qquad (5)$$

where $\mu_j(x_1, x_2, ...., x_n)$ - functions of belonging, which may have a triangular, a trapezoidal, a bell-shaped and other forms. The function of belonging determines the rate of assurance of an expert in the position, that the given value of the basic scale corresponds to the fuzzy sets,

$w_j$ - coefficient of the weightiness of the j-index of quality.

In such situation the conditions (4) and $x_0=1$ should be valid.

When functions of belonging have a trapezoidal form, then in (5) $\mu_j(x_1, x_2, ...., x_n)$ is determined by the kernel $[\underline{q_1}, \overline{q_1}]$ and carrier $[\underline{q_0}, \overline{q_0}]$.

To solve this problem we use the position of Bellman-Zadeh. According to the mentioned idea the solution means the crossing objectives and restrictions.

Here we shall compare various objectives:

$$\max_{x \in X_U}( Z_1(x);....;\ Z_k(x);\ \mu_1(x);....;\ \mu_{m_1}(x)) \ . \quad (6)$$

Let us construct the optimization model:

$$\begin{aligned} &\lambda \to \max \\ &\lambda \le \mu_z(x) \\ &\lambda \le \mu_i(x) \qquad \forall i = \overline{1, m_1} \\ &0 \le \lambda \le 1 \quad 0 \le \lambda \le 1 \quad x \in \bigcup \end{aligned} \quad , \qquad (7)$$

$\mu_z(x)\mu_i(x)$ - functions of belonging of targets and limitation:

$$\lambda = \min( \mu_z(x), \mu_1(x),..., \mu_{m_1}(x)) \ .$$

Each target value $Z_k=Z_k(x)$ will be compared with the measure $\tilde{\mu}_{z_k}(z_k)$:

The optimal solution $X_k^{**} = \max\limits_{x \in X}$ $Z_k(x)$, (8)

where:

$$\overline{X} = \left\{ \begin{matrix} x \in X^n \mid & g_i(x) = a_i \cdot x \le b_i + d_i \forall i = \overline{1, m_1} \\ & g_i(x) = a_i \cdot x \le b_{ii} \forall i = \overline{m_1 + 1, m} \end{matrix} \right\}.$$

Maximum value:

$$\overline{Z_k} = Z_k(x_k^{**})$$

All functions of belonging are linear and the fuzzy problem of optimization will be reduced to the determined form:

$$\begin{aligned} &\lambda \to \max \\ &d_0\lambda - c \cdot x \le -(w_0 - d_0) \\ &\lambda d_i + a_i \cdot x \le b_i + d_i \forall i = \overline{1, m_1} \\ &a_i \cdot x \le b_i \forall i = \overline{m_1 + 1, m} \\ &x \ge 0; \lambda \ge 0. \end{aligned} \qquad (9)$$

$\underline{w} = \max\ z(x)$,

$$a_i \cdot x \le b_i \forall i = \overline{1, m} \ .$$

$x \ge 0$,

$\overline{w} = \max\ z(x)$

$$a_i \cdot x \le b_i + d_i \forall i = \overline{1, m_i} \ .$$

$$a_i \cdot x \le b_i \forall i = \overline{m_1 + 1, m} \ .$$

$x \ge 0$

Studies of the model are carried out on the example of evaluating quality of the brewery barley with maximization of the grains mass depending upon the applied mineral fertilizers in crop growing. One should give some recommendations on the amount of fertilizers applied during the brewery barley growing to get 8% of protein in a grain but less than 9-12%. The starch content should be more than the 60-70% [2]. The barley grain should get the maximum value of the mass of each grains.

Let us formulate the mathematical model:

$$Z(x_1, x_2, x_3) = \left( \begin{matrix} 1 - \sqrt{\begin{matrix} w_1^2 \cdot (2{,}47 x_1 + 2{,}47 x_2 - 2{,}07 x_3 + 7{,}7 - [9;11])^2 + \\ w_2^2 \cdot (-0{,}8 x_1 - 0{,}8 x_2 - 0{,}54 x_3 + 67{,}83 - [60;75])^2 \end{matrix}}, \\ 2{,}93 x_1 + 2{,}93 x_2 - 2{,}33 x_3 + 37{,}23 \end{matrix} \right) \quad (10)$$

$\to \max$

At the conditions:

$$\begin{aligned} &g_1(x) = -0{,}247 \cdot x_1 - 0{,}247 \cdot x_2 + 0{,}207 \cdot x_3 \le -0{,}03 \\ &g_2(x) = 0{,}247 \cdot x_1 + 0{,}247 \cdot x_2 - 0{,}207 \cdot x_3 \le 0{,}13; 0{,}13 + 0{,}3 \\ &g_3(x) = 0{,}08 \cdot x_1 + 0{,}08 \cdot x_2 + 0{,}054 \cdot x_3 \le 0{,}78 \quad (11) \end{aligned}$$

$$\begin{aligned} &g_4(x) = x_1 \ge 0{,}1 \\ &g_5(x) = x_1 \le 0{,}3 \qquad (12) \\ &g_6(x) = x_2 \ge 0{,}1 \\ &g_7(x) = x_2 \le 0{,}3 \\ &g_8(x) = x_3 \ge 0{,}15 \\ &g_9(x) = x_3 \le 0{,}4 \\ &x \ge 0. \end{aligned}$$

Flexible ratios are composed on the basis of the structural matrix:

$$A = \begin{pmatrix} -0{,}247 & -0{,}247 & 0{,}207 \\ 0{,}247 & 0{,}247 & -0{,}207 \\ 0{,}08 & 0{,}08 & 0{,}054 \end{pmatrix}, \qquad (13)$$

received from the experimental data of the influence of fertilizers on the brewery quality of the spring barley grain and conditions corresponding to the indices of brewery barley grain.

$w_1$ and $w_2$ - coefficients of the weightness of the percent content of the protein and the starch are determined by the method of experts.

We shall receive the value:

$\underline{w} = z(x_1, x_2, x_3) = z(1;1;1{,}5) = 3{,}5$, and

$\overline{w} = z(x_1, x_2, x_3) = z(1;1;1{,}75) = 3{,}75$ .

Let us put down the functions of belonging:

$$\mu_z(x) = \begin{cases} 0 & w = z(x) < \underline{w} \\ \dfrac{z(x) - \underline{w}}{\overline{w} - w} & \underline{w} \le w = z(x) < \overline{w} \\ 1 & w = z(x) \ge \overline{w} \end{cases}$$

$$\mu_z(x_1, x_2, x_3) =$$

$$= \begin{cases} 0 & x_1 + x_2 + x_3 < 3{,}5 \\ \dfrac{x_1 + x_2 + x_3}{0{,}25} & 3{,}5 \le x_1 + x_2 + x_3 < 3{,}75 \\ 1 & x_1 + x_2 + x_3 \ge 3{,}75 \end{cases},$$

$$\mu_z(x_1, x_2, x_3) =$$

$$= \begin{cases} 1 & aa \le 0{,}13 \\ 1 - \dfrac{aa - 0{,}13}{0{,}3} & 0{,}13 < aa \le 0{,}43 \\ 0 & aa > 0{,}43 \end{cases}$$

Where:

$$aa = 0{,}247\ x_1 + 0{,}247\ x_2 - 0{,}207\ x_3$$

Having solved the problem (11) - (12), we shall find the maximum value:

$$\overline{Z_k} = Z_k(x_k^{**})$$

$$\overline{Z}_1 = Z_1(1;1;1{,}5) = 1 \quad \text{for } x_1^{**}=(1;1;1{,}5),$$

$$Z_1(x_1^{*}) = Z_1(3;2;4) = 0{,}99 \quad \text{for } x_1^{*}(3;2;4).$$

$Z_2(x_1, x_2, x_3) = 2{,}93x_1 + 2{,}93x_2 - 2{,}33x_3 + 37{,}23 \rightarrow \max$ under conditions (11)-(12) we shall get optimal solution $(x_1, x_2, x_3) = (3;2;4)$ with the maximum value of the target function:

$Z_2^{*}=Z_2^{*}(x_1^{*}, x_2^{*}, x_3^{*}) = Z_2(3;2;4)= 42{,}84.$

$Z_2^{*}=Z_2^{*}(x_1^{*}, x_2^{*}, x_3^{*}) = Z_2(1;1;1{,}5)= 39.$

Thus, we shall get the determined quality of production having applied the fertilizers $N_{60}\ P_{45}\ K_{120}$. We may also apply the fertilizers $N_{30}\ P_{30}\ K_{45}$. But the mass of grain in such a can will be less.

## CONCLUSIONS

1. The problem of evaluating quality of agricultural production with the simultaneous optimization of parameters of growing can be solved by constructing mathematical multicriterion model of the evaluation of quality.
2. We presented the dual-purpose optimizing model of evaluating quality of production with the simultaneous optimizing the indices of growing. The model takes into account the limits of modifications of quality characteristics of production by means of introduction of fuzzy descriptions of characteristics of the production quality.
3. To find the solution of the suggested model we used the multi-purpose approach of Bellman-Zadeh.
4. The approbation of the suggested model of evaluating quality of agricultural production with the simultaneous optimization of the grains mass and the ammounts of mineral fertilizers is carried out on the basis of the analysis of the influence of mineral fertilizers on the quality and mass of brewery barley grain.

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# Calculation of discrete states probability of the system with four units of harvesting machines

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Abstract. The model example is considered. In particular, the system composed of four units of harvesting techniques is considered. The states of the corresponding system are being analyzed. The probability of state i is the probability of the fact that the system will be in the state $S_i$ in the instant t. The state probabilities can be found as time functions. For this the system of differential equations with unknown functions is obtained. The intensities of events flow appear in the system. They cause the rejection of unit i of harvesting machines and the intensities of events flow after "finishing of repairing" of unit i of harvesting techniques. The intensities of rejections as time function are considered. The system is solved using numerical methods. The probabilities of finding the system in the discrete states are calculated. The tabulated solution functions and their graphs are given. It is shown how the probabilities of states depending on time change.

Key words: project management, configuration, discrete states, intensities of rejections.

## INTRODUCTION

It is necessary to apply methods and models that allow increasing the efficiency of technical potential use of harvesting machines for solving the problem of optimal technical support of agricultural production processes.

## ANALYSIS OF THE LATEST RESEARCHES AND PUBLICATIONS

The application of mathematical methods and models in agro-industrial projects management aimed at the increase of the number harvesting machines is the topical scientific and practical problem [1]. In the latest researches [1, 2, 3, 4, 5] and others models of productivity indicators of harvesting t machines are considered. However, similar models do not take into consideration the probable character of the factors which affect the agricultural goods harvesting process and it declines the modeling accuracy.

## MATERIALS AND METHODS

In [6, 7, 8] it is grounded the advisability and methodology of applying accidental processes in models of harvesting machines productivity determination in the management of agricultural goods harvesting projects. Such approach takes into consideration the probabilistic nature of the factors influencing the activity of physical systems.

The productivity of harvesting machines during the operations of agricultural production harvesting projects is of probabilistic nature. That is why it is relevant to apply the stochastic tasks involving the usage of random markovian processes in the models of definition of agricultural machines productivity; the optimization of their quantity for certain projects and the calculation of their economic efficiency.

The model example for the system created of four units of harvesting techniques is considered [8; 9; 10]. The probability of machinery failure is taken into consideration. We have to deal with undeterminate factors of machinery failure. These factors are random quantities. The probabilistic characteristics of these quantities can be obtained empirically (using statistical methods). The process under study is a process with discrete states and permanent time. It means that
1) the given physical system can be in different states, that can be enumerated in advance; the states are characterized by failure resulting from machinery breakage and unplanned repairs of a certain number of harvesting equipment units; the transition from the state of functionality into the state of failure occurs suddenly; 2) the transitions from one state into another are indeterminate that is why they are possible in any moment.

The states of the corresponding system were analyzed. Later the graph was made up [8; 9].

On its basis the mathematical model of the systems with discrete states has been built. In this case system $S$ has been considered, that has sixteen possible states: $S_i$ ($i$ = 1, …, 16). The probability of $i$-state is the probability of the fact that the system will be in the state $S_i$ in the instant t. For every instant of time the sum of all state probabilities equals unit. The state probabilities can be found as time functions.

The possible discrete states of this system: $S_1$ – all four units are serviceable; $S_2$ – the first unit is being repaired, the second, the third and the fourth ones are serviceable; $S_3$ - the second unit is being repaired, the first, the third and the fourth ones are serviceable; $S_4$ - the third unit is being repaired, the first, the second and the fourth ones are serviceable; $S_5$ - the fourth unit is being repaired, the first, the second and the third ones are serviceable; $S_6$ - the first and the second units are being repaired, the third and fourth ones are serviceable; $S_7$ - the first and the third units are being repaired, the second and fourth ones are serviceable; $S_8$ - the first and the fourth units are being repaired, the second and third ones are serviceable; $S_9$ - the second and the third units are being repaired, the first and fourth ones are serviceable; $S_{10}$ – the second and the fourth units are being repaired, the first and third ones are serviceable; $S_{11}$ – the third and the fourth units are being repaired, the first and second ones are serviceable; $S_{12}$ – the first, the second and the third units are being repaired, the fourth one is serviceable; $S_{13}$ – the first, the second and the fourth units are being repaired, the third one is serviceable; $S_{14}$ – the second, the third and the fourth units are being repaired, the first one is serviceable; $S_{15}$ – the first, the third and fourth units are being repaired, the second one is serviceable; $S_{16}$ – all four units are being repaired.

We suppose that the average time of repairing harvesting machines unit does not depend on the fact whether one unit is being repaired or several units are being repaired at once. We also believe that the transition of the system from the state $S_1$ in the state $S_6$ is possible only through the states $S_2$, $S_3$ and $S_{12}$. That is why we consider that all units can fail independently, we neglect that it can be simultaneously.

Let the system is in the state $S_1$. It is obvious that events which promote the rejection of the first unit of harvesting machines transfer it into the state $S_2$. Its intensity $\lambda_1$ is equal to the unit that is divided into the average time of infallible work of the first machinery unit. In the reverse direction the system is transferred from the state $S_2$ in the state $S_1$ due to the flow of "finishing of repairing" of the first unit of harvesting technique. Its intensity $\mu_1$ is equal to the unit that is divided into the average time of repairing of the first technique unit. The intensities of events flows that transfer the system from the state into the state are similarly calculated. The system transfers in different states are represented by the appropriate graph of states [8, 9]. Having marked graph of states one can find probabilities of states $p_i$ ($i$ = 1, …, 16) as the function of time. For this reason it is compiled the system of Kolmogorov equations in order to search probabilities $p_i$ ($i$ = 1, …, 16) of system stay in every state $S_n$ ($n$ = 1, …, 16) [10] (1).

Here $\lambda_i$ ($i$ = 1, …, 4) - intensities of events flow that promote the rejection of $i$ ($i$ = 1, …, 4) harvesting technique unit; $\mu_i$ ($i$ = 1, …, 4) - intensities of events flow of "finishing of repairing" of $i$ ($i$ = 1, …, 4) harvesting technique unit.

## MAIN PRESENTATION

It is necessary to set the initial conditions in order to solve Kolmogorov equation and find states probabilities. If the initial state of the system $S_1$ is known then we can suppose, for example, that in time moment $t$ = 0,1 $p_1(0,1) = 1$ all other initial probabilities are equal to zero. In our case we can assume that in time moment $t$ = 0,1 all four machinery units are serviceable that is we solve the system (1) under such initial conditions:

$$\begin{aligned} &p_1(0{,}1) = 1\, p_2(0{,}1) = p_3(0{,}1) = p_4(0{,}1) = \\ &= p_5(0{,}1) = p_6(0{,}1) = p_7(0{,}1) = p_7(0{,}1) = \\ &p_8(0{,}1) = p_9(0{,}1) = p_{10}(0{,}1) = p_{11}(0{,}1) = \\ &= p_{12}(0{,}1) = p_{13}(0{,}1) = p_{14}(0{,}1) = p_{15}(0{,}1) = \\ &= p_{16}(0{,}1) = 0. \end{aligned} \tag{2}$$

We will consider the rejection intensities $\lambda_1(t)$, $\lambda_2(t)$, $\lambda_3(t)$, $\lambda_4(t)$ as functions from time. It is confirmed by observations data [11; 12; 13; 14]. The functions of intensities are modeled as:

$$\lambda(t) = \lambda_0\, \alpha\, t^{\alpha - 1},$$

where: $\lambda_0$ and $\alpha$ are some numerical parameters [15].

We use mathematically processed statistical data [14] and method of least squares for determining parameters $\lambda_0$ and $\alpha$ of the function $\lambda(t)$. After finding parameters the functions $\lambda_1(t)$, $\lambda_2(t)$, $\lambda_3(t)$, $\lambda_4(t)$ will be as following:

$$\begin{aligned} \lambda_1(t) &= 877{,}964 \cdot t^{-1{,}88193}, \\ \lambda_2(t) &= 816{,}84 \cdot t^{-1{,}85615}, \\ \lambda_3(t) &= 838{,}6609 \cdot t^{-1{,}91494}, \\ \lambda_4(t) &= 838{,}6609 \cdot t^{-1{,}91494}. \end{aligned} \tag{3}$$

$$\left.\begin{aligned}
\frac{dp_1}{dt} &= \mu_1 p_2 + \mu_2 p_3 + \mu_3 p_4 + \mu_4 p_5 - (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4) p_1, \\
\frac{dp_2}{dt} &= \lambda_1 p_1 + \mu_2 p_6 + \mu_3 p_7 + \mu_4 p_8 - (\lambda_2 + \lambda_3 + \lambda_4 + \mu_1) p_2, \\
\frac{dp_3}{dt} &= \lambda_2 p_1 + \mu_1 p_6 + \mu_3 p_9 + \mu_4 p_{10} - (\lambda_1 + \lambda_3 + \lambda_4 + \mu_2) p_3, \\
\frac{dp_4}{dt} &= \lambda_3 p_1 + \mu_1 p_7 + \mu_2 p_9 + \mu_4 p_{11} - (\lambda_1 + \lambda_2 + \lambda_4 + \mu_3) p_4, \\
\frac{dp_5}{dt} &= \lambda_4 p_1 + \mu_1 p_8 + \mu_2 p_{10} + \mu_3 p_{11} - (\lambda_1 + \lambda_2 + \lambda_3 + \mu_4) p_5, \\
\frac{dp_6}{dt} &= \lambda_2 p_2 + \lambda_1 p_3 + \mu_3 p_{12} + \mu_4 p_{13} - (\lambda_3 + \lambda_4 + \mu_1 + \mu_2) p_6, \\
\frac{dp_7}{dt} &= \lambda_3 p_2 + \lambda_1 p_4 + \mu_2 p_{12} + \mu_4 p_{14} - (\lambda_2 + \lambda_4 + \mu_1 + \mu_3) p_7, \\
\frac{dp_8}{dt} &= \lambda_4 p_2 + \lambda_1 p_5 + \mu_2 p_{13} + \mu_3 p_{14} - (\lambda_2 + \lambda_3 + \mu_1 + \mu_4) p_8 \\
\frac{dp_9}{dt} &= \lambda_3 p_3 + \lambda_2 p_4 + \mu_1 p_{12} + \mu_4 p_{15} - (\lambda_1 + \lambda_4 + \mu_2 + \mu_3) p_9, \\
\frac{dp_{10}}{dt} &= \lambda_4 p_3 + \lambda_2 p_5 + \mu_1 p_{13} + \mu_3 p_{15} - (\lambda_1 + \lambda_3 + \mu_2 + \mu_4) p_{10}, \\
\frac{dp_{11}}{dt} &= \lambda_4 p_4 + \lambda_3 p_5 + \mu_1 p_{14} + \mu_2 p_{15} - (\lambda_1 + \lambda_2 + \mu_3 + \mu_4) p_{11}, \\
\frac{dp_{12}}{dt} &= \lambda_3 p_6 + \lambda_2 p_7 + \lambda_1 p_9 + \mu_4 p_{16} - (\lambda_4 + \mu_1 + \mu_2 + \mu_3) p_{12}, \\
\frac{dp_{13}}{dt} &= \lambda_4 p_6 + \lambda_2 p_8 + \lambda_1 p_{10} + \mu_3 p_{16} - (\lambda_3 + \mu_1 + \mu_2 + \mu_4) p_{13}, \\
\frac{dp_{14}}{dt} &= \lambda_4 p_7 + \lambda_3 p_8 + \lambda_1 p_{11} + \mu_2 p_{16} - (\lambda_2 + \mu_1 + \mu_3 + \mu_4) p_{14}, \\
\frac{dp_{15}}{dt} &= \lambda_4 p_9 + \lambda_3 p_{10} + \lambda_2 p_{11} + \mu_1 p_{16} - (\lambda_1 + \mu_2 + \mu_3 + \mu_4) p_{15}, \\
\frac{dp_{16}}{dt} &= \lambda_4 p_{12} + \lambda_3 p_{13} + \lambda_2 p_{14} + \lambda_1 p_{15} - (\mu_1 + \mu_2 + \mu_3 + \mu_4) p_{16}
\end{aligned}\right\} \qquad (1)$$

Let we make model assumption that events flow intensity promoting exit from the state of breaking does not depend on time that is we find the significance $\mu_1$, $\mu_2$, $\mu_3$, $\mu_4$. For this reason we consider the specific brand of combine harvesters. At today's market of Ukraine there is a great number of combine harvesters which differ by technical and value indicators [11, 12, 13, 14].

Statistical data on the particular indicators of harvesters (removal of technological rejections) are collected and mathematically processed on the basis of chronometric observations after the work of combine harvesters under conditions of agricultural enterprises of Lviv region [11, 12, 13, 14]. In particular

$$\mu_1 = 1{,}75\ ,\ \mu_2 = 2,\ \mu_3 = 2{,}25,\ \mu_3 = 2{,}5. \qquad (4)$$

We get the system (1) – the system of differential equations with non-linear coefficients $\lambda_1(t)$, $\lambda_2(t)$, $\lambda_3(t)$, $\lambda_4(t)$.

So, under the initial conditions (2) and appropriate meanings of technological indicators $\lambda_1(t)$, $\lambda_2(t)$, $\lambda_3(t)$, $\lambda_4(t)$, $\mu_1$, $\mu_2$, $\mu_3$, $\mu_4$ (3) and (4) we solve the system (1).

The system (1) is solved by numerical methods with the help of the program package Maple. We present the tabulated functions of solution (Table) and their graphs (Fig. 1).

**Table.** Tabulated functions of solution

| *t* | **0,1** | **10,1** | **20,1** | **30,1** | **40,1** | **50,1** | **60,1** | **70,1** | **80,1** | **90,1** | **100,1** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $p_1$ | 1 | 0,001 | 0,028 | 0,129 | 0,270 | 0,405 | 0,5172 | 0,6055 | 0,6741 | 0,7275 | 0,7694 |
| $p_2$ | 0 | 0,017 | 0,054 | 0,052 | 0,036 | 0,023 | 0,0145 | 0,0094 | 0,0062 | 0,0043 | 0,0030 |
| $p_3$ | 0 | 0,013 | 0,042 | 0,039 | 0,027 | 0,017 | 0,0104 | 0,0067 | 0,0044 | 0,0030 | 0,0021 |
| $p_4$ | 0 | 0,105 | 0,098 | 0,046 | 0,019 | 0,008 | 0,0036 | 0,0018 | 0,0009 | 0,0005 | 0,0003 |
| $p_5$ | 0 | 0,111 | 0,098 | 0,044 | 0,018 | 0,007 | 0,0033 | 0,0016 | 0,0008 | 0,0005 | 0,0003 |
| $p_6$ | 0 | 0,088 | 0,075 | 0,033 | 0,013 | 0,005 | 0,0024 | 0,0011 | 0,0006 | 0,0003 | 0,0002 |
| $p_7$ | 0 | 0,076 | 0,066 | 0,029 | 0,012 | 0,005 | 0,0022 | 0,0010 | 0,0005 | 0,0003 | 0,0002 |
| $p_8$ | 0 | 0,004 | 0,051 | 0,109 | 0,133 | 0,131 | 0,1182 | 0,1035 | 0,0895 | 0,0773 | 0,0670 |
| $p_9$ | 0 | 0,004 | 0,045 | 0,096 | 0,118 | 0,117 | 0,1068 | 0,0938 | 0,0815 | 0,0706 | 0,0614 |
| $p_{10}$ | 0 | 0,003 | 0,034 | 0,072 | 0,087 | 0,085 | 0,0766 | 0,0667 | 0,0574 | 0,0494 | 0,0427 |
| $p_{11}$ | 0 | 0,003 | 0,034 | 0,070 | 0,083 | 0,079 | 0,0705 | 0,0606 | 0,0517 | 0,0441 | 0,0378 |
| $p_{12}$ | 0 | 0,023 | 0,080 | 0,081 | 0,058 | 0,038 | 0,0244 | 0,0160 | 0,0108 | 0,0075 | 0,0053 |
| $p_{13}$ | 0 | 0,018 | 0,062 | 0,061 | 0,043 | 0,027 | 0,0175 | 0,0114 | 0,0076 | 0,0053 | 0,0037 |
| $p_{14}$ | 0 | 0,020 | 0,062 | 0,059 | 0,041 | 0,026 | 0,0161 | 0,0104 | 0,0069 | 0,0047 | 0,0033 |
| $p_{15}$ | 0 | 0,016 | 0,054 | 0,054 | 0,038 | 0,025 | 0,0158 | 0,0103 | 0,0069 | 0,0048 | 0,0034 |
| $p_{16}$ | 0 | 0,499 | 0,119 | 0,025 | 0,006 | 0,002 | 0,0005 | 0,0002 | 0,0001 | 0,0000 | 0,0000 |

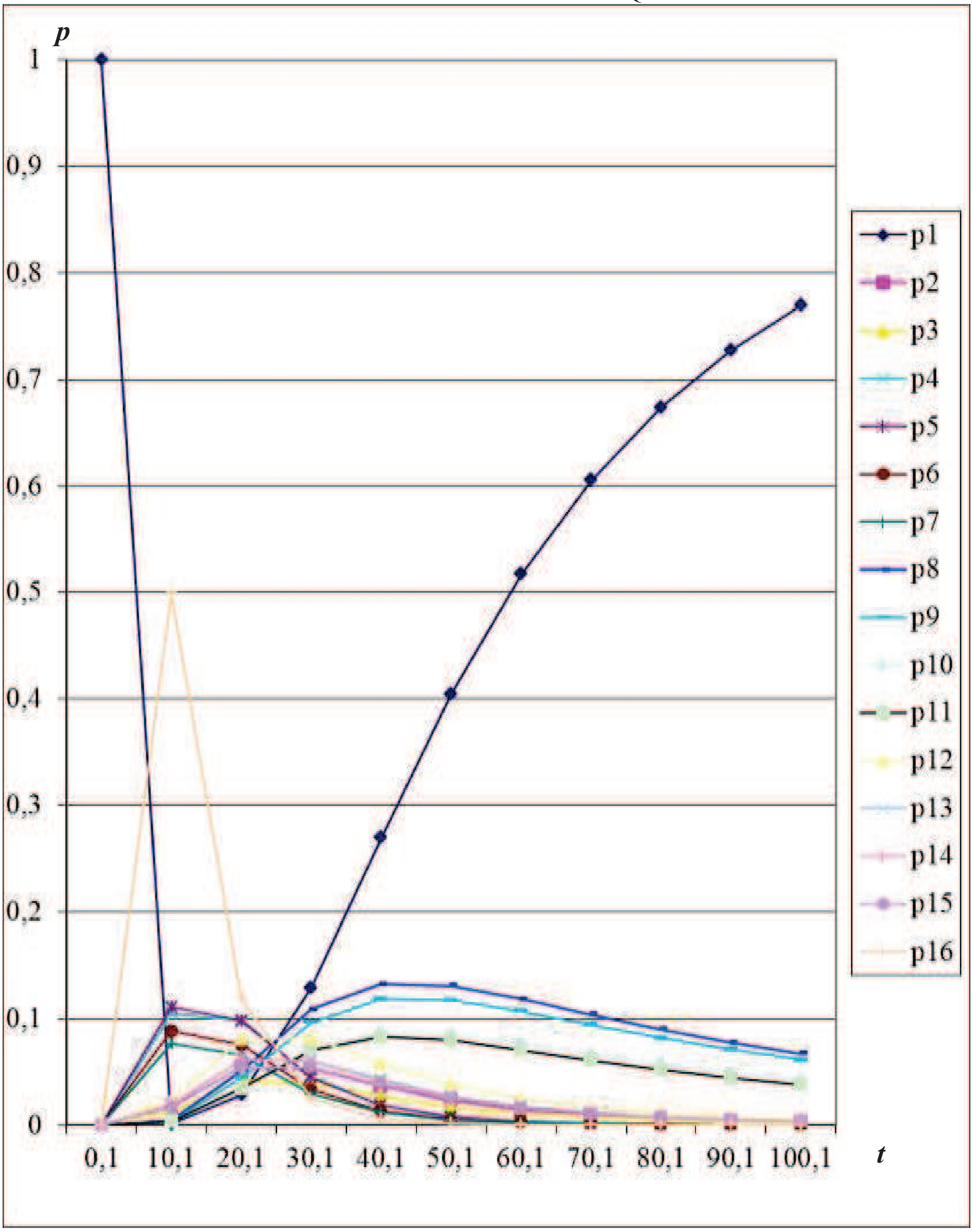


**Fig. 1.** The graph of system states probabilities

On the basis of interrelation of probabilities the picture 2 it is determined how system states probabilities $p_i$ ($i$ = 1, …, 16) differ over time of the system work during 100 hours. The received solutions allow collecting agricultural goods, to evaluate the average efficiency of harvesting machines system work, to optimize the number of units, to determine productivity indicators, to calculate economic efficiency.

## CONCLUSIONS

It is shown that during different periods of time the probabilities of stay of three units system in appropriate discrete states differ significantly. In particular it is determined that $p_1$ – the probability of the fact that all three units of harvesting machines will be serviceable is the biggest one however it decreases rapidly, during the first 10 hours of the system work. During next 20 hours of the work the significance of this probability reaches its minimum. After 30 hours of the system work, $p_1$ increases fast, exceeding probabilities of other states. The probabilities of other states have increasing character during the first 20-40 hours of the system work, then they decrease gradually.

Model solutions may be applied in certain circumstances of agricultural production harvesting, during the optimization of the quantity of machinery units for the certain conditions of agricultural production harvesting, the definition of the productivity indicators, the calculation of economic efficiency etc.

The designed mathematical model may be used for the development and realization of management projects. Nowadays it opens up the possibility of prediction of the development of the systems with discrete states and provides efficient functioning of such systems.

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# Construction of the approximate stability equations of motion for an elastic cylindrical body under axial compressive load

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Abstract. A method of constructing nonlinear motion stability equations for isotropic elastic bodies is developed for cylindrical bodies of standard material of the 2nd order subjected to the action of "dead" axial compressive forces. The perturbation of the displacement vector is given by its approximate decomposition with respect to the base of tensor functions of the 1st, 2nd and 3d valences. The time-dependent tensor coefficients of the decomposition satisfy the system of ordinary differential equations. Based on the obtained equations one can investigate the balance stability of cylindrical bodies under various fixing conditions.

Key words: elastic body, stress tensor, the perturbation of the displacement vector, stability equations of motion, standard material of the 2nd order, compresive load.

## INTRODUCTION

Mathematical models of mechanics of a deformable elastic body is a scientific basis for the development of engineering methods for design and technologies of manufacturing modern structures and devices. The most common model of the mechanical system is the classical mechanics model for an elastic (thermoelastic) body [7, 12, 14]. A number of works are devoted to constructing the mathematical models, development and generalization of the methods for solving spatial boundary value problems in the theory of elasticity and thermoelasticity for bodies of finite size e.g. [9, 15].

Cylindrical bodies often serve as bases of structures used in modern machine building, instrument ingeneering, civil ingeneering [1, 13]. In operational process effects undesirable in sense of strength and reliability of machinery, equipment, and buildings occur. Therefore problems of dynamical stability of structures, especially in nonlinear formulation, are among the most important in elasticity theory [10, 11].

As a rule, to construct the mathematical models of equations of motion (equilibrium) stability of elastic bodies one needs to know the basic (unperturbed) solution. It is usually found out by methods of quasi-static linear elasticity theory [4, 5, 6, 16].

We use the mathematical model [17] for solving spatial problems of nonlinear dynamic elasticity theory applying the method of expansion in tensor functions developed in [8]. In [2] and [3], based on the proposed mathematical model, we have constructed the equations for investigation of motion (balance) stability of elastic systems and, in particular, the linearized equations of motion stability for a body of Murnagan's material. Next, we have derived (in a certain approximation) the system of ordinary differential equations of motion stability for a straight circular cylinder of Murnagan's material and standard material of the 2nd order subjected to the action of the complex surface load.

In the present work on the basis of the technique, proposed in these works, we obtain the system of equations for investigation of motion stability of an elastic cylinder of standard material of the 2nd order subjected to the action of axial compressive forces.

## MATHEMATICAL MODEL AND RESEARCH TECHNIQUE

In the mathematical model introduced in [17] we consider two configurations of an isotropic elastic body K. The reference $\gamma_0$ configuration is natural (undeformed), there are no stresses and deformations in the body. The actual $\gamma_\tau$ configuration is basic (unperturbed), it arises as a result of the action of body and surface forces on the body K starting from the moment $\tau = \tau_0$.

The vector $\vec{u}$ and the tensor $P$ denote the perturbations of the displacement vector and the Piola-Kirchhoff stress tensor, respectively, in $\gamma_\tau$ -configuration. The vector $\vec{u}$ is given by its decomposition with respect to the base of tensor functions $\{\Phi^{(i-1)}(\vec{R}_0)\}$, where $\vec{R}_0 = \vec{r}_0 - \vec{r}_{30}$, $\vec{r}_0$ and $\vec{r}_{30}$ stand for the radius vector of an arbitrary point of the body K and the radius vector of some fixed point (e.g., the center of mass of the body K) in the actual configuration:

$$\vec{u} = \sum_{i=1}^{N} \Phi^{(i-1)}(\vec{R}_0) \overset{i-1}{\cdot} u^{(i)}(\tau) \ , \tag{1}$$

where: the coefficients $u^{(i)}(\tau)$ are time-dependent tensor functions.

In [3] we formulate the problem of motion stability of a homogeneous elastic body K with the density ρ:

$$\int_{X_0} [\rho_0 \frac{d^2\vec{u}}{d\tau^2} \otimes \hat{\Phi}^{(i-1)} + \vec{\ni}_0^k \cdot \hat{P} \otimes \frac{\partial \hat{\Phi}^{(i-1)}}{\partial \xi^k}] dV_0 =$$
$$= \int_{X_0} \rho_0 \vec{f} \otimes \hat{\Phi}^{(i-1)} dV_0 + \int_{\partial X_0} \vec{n}_0 \cdot \hat{P} \otimes \hat{\Phi}^{(i-1)}] d\Sigma_0,$$
$$i = \overline{1, N}, \tag{2}$$

with the boundary conditions:

$$\vec{n}_0 \cdot \hat{P}\Big|_{\partial X_0} = (\vec{q}_* \frac{d\Sigma_*}{d\Sigma_0} - \vec{q}\frac{d\Sigma}{d\Sigma_0})\Big|_{\partial X_0}. \tag{3}$$

Here $\otimes$ denotes the operation of tensor product, $\{\xi^i\}$ are the Lagrange coordinates, $\{\vec{\ni}_i^0\}, \{\vec{\ni}_0^j\}$ are the vector basis in the reference configuration and the biorthogonal vector basis, respectively (for the Cartesian coordinate system they coincide), $X_0$, $\partial X_0$ are the domain of the body K and its boundary surface in the reference configuration, $\vec{f}$ is the perturbation of the vector of mass forces, $\vec{n}_0$ is the vector of outer normal to the surface $\partial X_0$, $\vec{q}$ is the vector of surface forces per unit area of the $\gamma_\tau$-configuration, $\vec{q}_*$ is its value in the $\gamma_\tau^*$-configuration, $d\Sigma_0, d\Sigma, d\Sigma_*$ are the surface area elements, respectively, in the $\gamma_0$, $\gamma_\tau$, and $\gamma_\tau^*$-configurations ($\gamma_\tau^*$ is the actual configuration, which corresponds to a perturbation of the initial conditions in the $\gamma_\tau$–configuration).

The dynamic boundary conditions (3) are taken into account in the surface integral in the right-hand side of the relation (2). Note that, if the mass and the surface loads are "dead", then $\vec{q}_* d\Sigma_* = \vec{q} d\Sigma$, $\vec{f}_* = \vec{f}$ and, therefore, the right-hand side of (2) is equal to zero.

While investigating the stability of a straight circular cylinder of standard material of the 2nd order with the radius $r$ and the height $h$, we remain three summands in the decomposition of the perturbation of the displacement vector (1) and take $\{\vec{R}_0^N\}$, where $\vec{R}_0^k$ is k-multiple tensor product of the vector $\vec{R}_0$ by itself, as the base of the decomposition, namely, we suppose that

$$\vec{u} = u^{(1)} + \vec{R}_0 \cdot u^{(2)} + \vec{R}_0 \otimes \vec{R}_0 \cdot\cdot u^{(3)}. \tag{4}$$

We assume that the axis of the cylinder coincides with the axis $O\xi^3 (-\frac{h}{2} \le \xi^3 \le \frac{h}{2})$.

The Piola-Kirchhoff stress tensor for standard material of the 2nd order up to the second-order terms with respect to the gradient $\vec{\nabla}_0 \otimes \vec{u}_0$ has the following form [17]:

$$P_0(\vec{\nabla}_0 \otimes \vec{r}) = (I + \vec{\nabla}_0 \otimes \vec{u}_0) \cdot T(\vec{u}_0) +$$
$$+ \frac{1}{2}\lambda \vec{\nabla}_0 \otimes \vec{u}_0 \cdot\cdot \vec{\nabla}_0 \otimes \vec{u}_0^T I + \mu \vec{\nabla}_0 \otimes \vec{u}_0^T \cdot \vec{\nabla}_0 \otimes \vec{u}_0, \tag{5}$$

where:

$$T(\vec{u}_0) = \lambda \vec{\nabla}_0 \cdot \vec{u}_0 I + 2\mu\varepsilon(\vec{u}_0),$$
$$\hat{\varepsilon}(\vec{u}_0) = \frac{1}{2}(\vec{\nabla}_0 \otimes \vec{u}_0 + \vec{\nabla}_0 \otimes \vec{u}_0{}^T), \tag{6}$$

are the Cauchy stress tensor and the strain tensor in the linear elasticity theory, $\vec{\nabla}_0 = \vec{\ni}_0^i \frac{\partial}{\partial \xi^i}$ is the Hamilton nabla-operator in the reference configuration, $\hat{I}$ is the unit tensor, λ, μ are the Lame parameters, the index "T" denotes the transposition operation. Then the perturbation of the Piola-Kirchhoff stress tensor takes the form:

$$P = \vec{\nabla}_0 \otimes \vec{u}_0 \cdot T(\vec{u}_0) + \vec{\nabla}_0 \otimes \vec{u} \cdot T(\vec{u}_0) +$$
$$+ \lambda \vec{\nabla}_0 \otimes \vec{u}_0 \cdot\cdot \vec{\nabla}_0 \otimes \vec{u}^T I + \mu(\vec{\nabla}_0 \otimes \vec{u}_0{}^T \cdot \vec{\nabla}_0 \otimes \vec{u} +$$
$$+ \vec{\nabla}_0 \otimes \vec{u}^T \cdot \vec{\nabla}_0 \otimes \vec{u}_0) + (I + \vec{\nabla}_0 \otimes \vec{u}) \cdot T(\vec{u}) + \tag{7}$$
$$+ \frac{1}{2}\lambda \vec{\nabla}_0 \otimes \vec{u} \cdot\cdot \vec{\nabla}_0 \otimes \vec{u}_0^T I + \mu \vec{\nabla}_0 \otimes \vec{u}^T \cdot \vec{\nabla}_0 \otimes \vec{u}.$$

Substituting (4) and (7) into (2) and taking some transforms we obtain the system of three tensor ordinary differential equations of the motion stability for a given cylinder of standard material of the 2nd order. Neglecting nonlinear summands we obtain the approximate linearized system of the motion stability for such cylindrical body [2]:

$$\sum_{\beta=1}^{3} [\rho_0 \hat{M}^{(i+\beta)} \overset{\beta}{\cdot} \frac{d^2\hat{u}^{(\beta)}}{d\tau^2} + \hat{J}^{(i+\beta)} \overset{\beta}{\cdot} \hat{u}^{(\beta)}] = \hat{F}^{(i)}, i = \overline{1,3}, \tag{8}$$

where:

$$M^{(i+\beta)} = \int_{X_0} \vec{\ni}_0^s \otimes \Phi^{(i-1)} \otimes \vec{\ni}_s^0 \otimes \Phi^{(\beta-1)} dV_0,$$
$$J^{(i+\beta)} = \delta^{kt} \int_{X_0} A_{ts}^{qj} \vec{\ni}_0^s \otimes \frac{\partial \Phi^{(i-1)}}{\partial \xi^k} \otimes \vec{\ni}_q^0 \otimes \frac{\partial \Phi^{(\beta-1)}}{\partial \xi^j} dV_0, \tag{9}$$
$$F^{(i)} = \int_{X_0} \rho_0 \vec{f} \otimes \Phi^{(i-1)} dV_0 + \int_{\partial X_0} \vec{n}_0 \cdot P \otimes \Phi^{(i-1)} d\Sigma_0,$$
$$A_{ts}^{qj} = \lambda \delta^{qj} \delta_{st} + \lambda a_{ts} \delta^{qj} + \lambda a^{jq} \delta_{st} + \mu(\delta_t^i \delta_s^q +$$
$$+ \delta_t^q \delta_s^j) + 2\mu\varepsilon_{t\cdot}^{\cdot j} \delta_s^q + t_{\cdot s}^{q\cdot} \delta_t^j + \mu a_{t\cdot}^{\cdot q} \delta_s^j + \mu a_{\cdot s}^{j\cdot} \delta_t^q,$$
$$\vec{\nabla}_0 \otimes \vec{u}_0 = a^{ij} \vec{\ni}_i^0 \otimes \vec{\ni}_j^0 = a_{ij} \vec{\ni}_0^i \otimes \vec{\ni}_0^j = a_{\cdot j}^{i\cdot} \vec{\ni}_i^0 \otimes \vec{\ni}_0^j =$$
$$= a_{i\cdot}^{\cdot j} \vec{\ni}_0^i \otimes \vec{\ni}_j^0,$$

$$T(\vec{u}_0) = t^{ij}\ \vec{\ni}_i^{\,0} \otimes \vec{\ni}_j^{\,0} = t_{ij}\ \vec{\ni}_0^{\,i} \otimes \vec{\ni}_0^{\,j} = t^{i.}_{.j}\ \vec{\ni}_i^{\,0} \otimes \vec{\ni}_0^{\,j} = t_{i.}^{.j}\ \vec{\ni}_0^{\,i} \otimes \vec{\ni}_j^{\,0},$$

$$\varepsilon(\vec{u}_0) = \varepsilon^{ij}\ \vec{\ni}_i^{\,0} \otimes \vec{\ni}_j^{\,0} = \varepsilon_{ij}\ \vec{\ni}_0^{\,i} \otimes \vec{\ni}_0^{\,j} = \varepsilon^{i.}_{.j}\ \vec{\ni}_i^{\,0} \otimes \vec{\ni}_0^{\,j} = \varepsilon_{i.}^{.j}\ \vec{\ni}_0^{\,i} \otimes \vec{\ni}_j^{\,0}, \tag{10}$$

$\delta^{ij} = \delta_{ij} = \delta^i_j$ are the Kronecker symbols.

## APPROXIMATE LINEARIZED EQUATIONS OF THE MOTION STABILITY FOR A CYLINDRICAL BODY OF STANDARD MATERIAL OF THE 2ND ORDER UNDER AXIAL COMPRESSIVE LOADS

Let a given cylindrical body be subjected to the action of axial compressive forces which in the actual configuration are specified by the stress vector:

$$\vec{q} = \begin{cases} -N_0\overrightarrow{n_0}, & (\xi^1,\xi^2,\xi^3) \in \Sigma_1 \cup \Sigma_2, \\ 0, & (\xi^1,\xi^2,\xi^3) \in \Sigma_3 \end{cases}, \tag{11}$$

where: $\Sigma_1$, $\Sigma_2$ are the upper and the lower bases of the cylinder, and $\Sigma_3$ is its lateral surface, $N_0$ is the density of axial compressive forces uniformly distributed along $\Sigma_1$ and $\Sigma_2$. The mass load is assumed to be "dead". As a base solution we take the solution of a corresponding problem formulated within the framework of the stationary linear elasticity theory [12]

$$\vec{u}_0 = \nu Q(\xi^1\ \vec{\ni}_1^{\,0} + \xi^2\ \vec{\ni}_2^{\,0}) - Q\xi^3\ \vec{\ni}_3^{\,0}, \tag{12}$$

where: $Q = \dfrac{N_0}{E}, \nu = \dfrac{\lambda}{2(\lambda+\mu)}$ is the Poisson coefficient, and $E = 2\mu(1+\nu)$ is the Young's elastic modulus.

We obtain from (12):

$$\vec{\nabla}_0 \otimes \vec{u}_0 = \nu Q\ \vec{\ni}_\alpha^{\,0} \otimes \vec{\ni}_0^{\,\alpha} - Q\ \vec{\ni}_3^{\,0} \otimes \vec{\ni}_3^{\,0},$$

$$\varepsilon(\vec{u}_0) = \nu Q\ \vec{\ni}_\alpha^{\,0} \otimes \vec{\ni}_0^{\,\alpha} - Q\ \vec{\ni}_3^{\,0} \otimes \vec{\ni}_3^{\,0},$$

$$\vec{\nabla}_0 \cdot \vec{u}_0 = (2\nu - 1)Q,\ T(\vec{u}_0) = -EQ\ \vec{\ni}_3^{\,0} \otimes \vec{\ni}_3^{\,0},$$

whence, we have

$$a^{ij} = \varepsilon^{ij} = \begin{cases} \nu Q, & i = j = \overline{1,2}, \\ -Q, & i = j = 3, \\ 0, & i \neq j, \end{cases} \tag{13}$$

$$t^{ij} = \begin{cases} -EQ, & i = j = 3 \\ 0, & \mathit{otherwise} \end{cases}.$$

Calculating coefficients (9) with regard for (13), substituting them into linearized system (8) and performing appropriate convolutions, we obtain the approximate linearized system of the motion stability for the problem in coordinate form:

$$8\frac{d^2u_m}{d\tau^2} + \tau^2\left(\frac{d^2u_{11m}}{d\tau^2} + \frac{d^2u_{22m}}{d\tau^2}\right) + \frac{h^2}{3}\frac{d^2u_{33m}}{d\tau^2} = \frac{8F_m}{\rho_0 V}\ (m = 1,2,3),$$

$$3\rho_0 r^2\frac{d^2u_{11}}{d\tau^2} + 12(1+2\nu Q)((\lambda+2\mu)u_{11} + \lambda u_{22}) + 12\lambda(1+Q(\nu-1))u_{33} = \frac{12F_{11}}{V},$$

$$\rho_0 h^2\frac{d^2u_{33}}{d\tau^2} + 12(1+Q(\nu-1))(u_{11}+u_{22}) + 12((\lambda+2\mu)(1-2Q) - EQ)u_{33} = \frac{12F_{33}}{V},$$

$$3\rho_0 r^2\frac{d^2u_{12}}{d\tau^2} + 12\mu(1+2\nu Q)(u_{12}+u_{21}) = \frac{12F_{21}}{V},$$

$$3\rho_0 r^2\frac{d^2u_{21}}{d\tau^2} + 12\mu(1+2\nu Q)(u_{12}+u_{21}) = \frac{12F_{12}}{V},$$

$$3\rho_0 r^2\frac{d^2u_{13}}{d\tau^2} + 12\mu((1-2Q)u_{13} + (1+Q(\nu-1))u_{31}) = \frac{12F_{31}}{V},$$

$$\rho_0 h^2\frac{d^2u_{31}}{d\tau^2} + 12\mu(1+Q(\nu-1))u_{13} + (1-2Q)u_{31}) = \frac{12F_{13}}{V},$$

$$3\rho_0 r^2\frac{d^2u_{23}}{d\tau^2} + 12\mu((1-2Q)u_{23} + (1+Q(\nu-1))u_{32}) = \frac{12F_{32}}{V},$$

$$\rho_0 h^2\frac{d^2u_{32}}{d\tau^2} + 12\mu((1+Q(\nu-1))u_{23} + (1-2Q)u_{32}) = \frac{12F_{23}}{V},$$

$$\rho_0[12\frac{d^2u_1}{d\tau^2}+r^2(3\frac{d^2u_{111}}{d\tau^2}+\frac{d^2u_{221}}{d\tau^2})+\frac{h^2}{2}\frac{d^2u_{331}}{d\tau^2}]++24[(1+2\nu Q)((\lambda+2\mu)u_{111}+\lambda u_{122})+$$

$$+\lambda(1+Q(\nu-1))u_{133}]=\frac{48F_{111}}{Vr^2},$$

$$\rho_0[12\frac{d^2u_2}{d\tau^2}+r^2(3\frac{d^2u_{112}}{d\tau^2}+\frac{d^2u_{222}}{d\tau^2})+\frac{h^2}{2}\frac{d^2u_{332}}{d\tau^2}]+24\mu(1+2\nu Q)(u_{112}+u_{211})=\frac{48F_{211}}{Vr^2},$$

$$\rho_0[12\frac{d^2u_3}{d\tau^2}+r^2(3\frac{d^2u_{113}}{d\tau^2}+\frac{d^2u_{223}}{d\tau^2})+\frac{h^2}{2}\frac{d^2u_{333}}{d\tau^2}]+24\mu[(1-2Q)u_{113}+(1+Q(\nu-1))u_{311}]=\frac{48F_{311}}{Vr^2},$$

$$\rho_0[12\frac{d^2u_1}{d\tau^2}+r^2(3\frac{d^2u_{111}}{d\tau^2}+\frac{d^2u_{221}}{d\tau^2})+\frac{h^2}{2}\frac{d^2u_{331}}{d\tau^2}]+24\mu(1+2\nu Q)(u_{122}+u_{221})=\frac{48F_{122}}{Vr^2},$$

$$\rho_0[12\frac{d^2u_2}{d\tau^2}+r^2(\frac{d^2u_{112}}{d\tau^2}+3\frac{d^2u_{222}}{d\tau^2})+\frac{h^2}{2}\frac{d^2u_{332}}{d\tau^2}]+24[(1+2\nu Q)(\lambda u_{211}+(\lambda+2\mu)u_{222})+$$

$$+\lambda(1+Q(\nu-1))u_{233}]=\frac{48F_{222}}{Vr^2},$$

$$\rho_0[12\frac{d^2u_3}{d\tau^2}+r^2(\frac{d^2u_{113}}{d\tau^2}+\frac{d^2u_{223}}{d\tau^2})+\frac{h^2}{2}\frac{d^2u_{333}}{d\tau^2}]+24\mu[(1-2Q)u_{223}+(1+Q(\nu-1))u_{322}]=\frac{48F_{322}}{Vr^2},$$

$$\rho_0[4\frac{d^2u_1}{d\tau^2}+\frac{r^2}{2}(\frac{d^2u_{111}}{d\tau^2}+\frac{d^2u_{221}}{d\tau^2})+\frac{3h^2}{10}\frac{d^2u_{331}}{d\tau^2}]+8\mu[(1+Q(\nu-1))u_{133}+(1-2Q)u_{331}]=\frac{48F_{133}}{Vh^2},$$

$$\rho_0[4\frac{d^2u_2}{d\tau^2}+\frac{r^2}{2}(\frac{d^2u_{112}}{d\tau^2}+\frac{d^2u_{222}}{d\tau^2})+\frac{3h^2}{10}\frac{d^2u_{332}}{d\tau^2}]+8\mu[(1+Q(\nu-1))u_{233}+(1-2Q)u_{332}]=\frac{48F_{233}}{Vh^2},$$

$$\rho_0[4\frac{d^2u_3}{d\tau^2}+\frac{r^2}{2}(\frac{d^2u_{113}}{d\tau^2}+\frac{d^2u_{223}}{d\tau^2})+\frac{3h^2}{10}\frac{d^2u_{333}}{d\tau^2}]+$$

$$+8[\lambda(1+Q(\nu-1))(u_{311}+u_{322})+((\lambda+2\nu)(1-2Q)-EQ)u_{333}]=\frac{48F_{333}}{Vh^2},$$

$$\rho_0r^2\frac{d^2u_{211}}{d\tau^2}+6[\lambda(1+Q(\nu-1))u_{233}+(1+2\nu Q)((\lambda+3\mu)u_{211}+\lambda u_{222}+\mu u_{112})]=\frac{24F_{112}}{Vr^2},$$

$$\rho_0r^2\frac{d^2u_{122}}{d\tau^2}+6[(1+2\nu Q)(\lambda u_{111}+(\lambda+3\mu)u_{122}+\mu u_{221})+\lambda(1+Q(\nu-1))u_{133}]=\frac{24F_{212}}{Vr^2},$$

$$\rho_0r^2\frac{d^2u_{123}}{d\tau^2}+6\mu[(1+Q(\nu-1))(u_{231}+u_{132})+2(1-2Q)u_{123}]=\frac{24F_{312}}{Vr^2},$$

$$\rho_0r^2h^2\frac{d^2u_{311}}{d\tau^2}+4h^2[(1+2\nu Q)(\lambda+2\mu)u_{311}+\lambda u_{322})+\lambda(1+Q(\nu-1))u_{333}]+$$

$$+12\mu r^2[(1+Q(\nu-1))u_{113}+(1-2Q)u_{311}]=\frac{48F_{113}}{V},$$

$$\rho_0r^2h^2\frac{d^2u_{231}}{d\tau^2}+4\mu h^2(1+2\nu Q)(u_{312}+u_{231})+12\mu r^2[(1+Q(\nu-1))u_{123}+(1-2Q)u_{231}]=\frac{48F_{123}}{V},$$

$$\rho_0r^2h^2\frac{d^2u_{132}}{d\tau^2}+4\mu h^2(1+2\nu Q)(u_{312}+u_{231})+12\mu r^2[(1+Q(\nu-1))u_{123}+(1-2Q)u_{231}]=\frac{48F_{213}}{V},$$

$$\rho_0r^2h^2\frac{d^2u_{322}}{d\tau^2}+4h^2[(1+2\nu Q)(\lambda u_{311}+(\lambda+2\mu)u_{322})+\lambda(1+Q(\nu-1))u_{333}]+$$

$$+12\mu r^2[(1+Q(\nu-1))u_{223}+(1-2Q)u_{322}]=\frac{48F_{223}}{V},$$

$$\rho_0 r^2 h^2 \frac{d^2 u_{133}}{d\tau^2} + 4\mu h^2 [(1+Q(\nu-1))u_{331} + (1-2Q)u_{133}] + 12 r^2 [2(\lambda+2\mu)+E)u_{33} +$$

$$+ \lambda(1+Q(\nu-1))(u_{111}+u_{122}) + ((\lambda+2\mu)(1-2Q)-EQ)u_{133}] = \frac{48 F_{313}}{V},$$

$$\rho_0 r^2 h^2 \frac{d^2 u_{233}}{d\tau^2} + 4\mu h^2 [(1+Q(\nu-1))u_{332} + (1-2Q)u_{233}] + 12 r^2$$

$$[\lambda(1+Q(\nu-1))(u_{211}+u_{222}) + ((\lambda+2\mu)(1-2Q)-EQ)u_{233}] = \frac{48 F_{323}}{V}. \quad (14)$$

Since:

$$\vec{q}\,\frac{d\Sigma}{d\Sigma_0}\Big|_{\Sigma_1\cup\Sigma_2} = -N_0\vec{n}_0\,\frac{d\Sigma}{d\Sigma_0}\Big|_{\Sigma_1\cup\Sigma_2} \text{ and}$$

$$\vec{q}_*\,\frac{d\Sigma_*}{d\Sigma_0}\Big|_{\Sigma_1\cup\Sigma_2} = -N_0\vec{n}_0\,\frac{d\Sigma_*}{d\Sigma_0}\Big|_{\Sigma_1\cup\Sigma_2},$$

the boundary conditions (3) for the problem are of the form:

$$\vec{n}_0 \cdot P\Big|_{\Sigma_1\cup\Sigma_2\cup\Sigma_3} = 0. \quad (15)$$

Hence, if the mass and the surface loads are “dead”, then the right-hand sides of the equations (14) are equal to zero.

## CONCLUSIONS

On the basis of constructed in [Ban-Kol-2003] equations for the investigation of motion (balance) stability of elastic systems we have obtained the system of ordinary differential equations of the motion stability for a straight circular elastic cylinder of standard material of the 2nd order subjected to the action of axial compressive forces. The obtained equations enables us to investigate the balance stability of the cylinder under various fixing conditions.

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# Conceptlion of simulating the processes of innovative projects initialization for agro-industrial production in Ukraine

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Abstract. The article is focused on preconditions and general conception of simulating the processes of innovative projects initialization with establishing production and processing complexes on the industrial facilities and material and technical basis of agricultural enterprises. The paper suggests the conceptual model of the processes of initialization of introducing innovative projects of production and processing complexes for agribusiness of Ukraine. The suggested conceptual model reveals the sequential and mutual dependence of the processes of initialization of the determined innovative projects.

The received results allow to start the construction of algorithm and mathematical program of simulating the processes of initialization of innovative projects of introducing production and processing complex.

The further research is aimed at the development of methods and instruments of effective management of the processes of initialization of innovative projects of introducing production and processing complexes to improve agribusiness production in Ukraine.

Key words: innovative project, management of project, conceptual model, initialization processes, agricultural enterprise, production and processing complex.

## STATEMENT OF THE PROBLEMS

One of the freshest and the most advanced ways of achieving high-effective modern agricultural production in Ukraine capable to put it at the new technically-technological and socially-economical level is the integrated approach in running of agricultural enterprises (AE) - from crops growing and conservation to their complete processing and getting the forms of finished goods. Therefore the theoretical argumentation of the expediency and realization of the projects of production and processing complexes (PPC) formed on production facilities and material and technical basis of AE proved to be a vital scientific and technical problem in the field of management of projects.

Improvement of agribusiness production in Ukraine needs innovative projects of production and processing complexes (IP of PPC) which will be formed on the production facilities and material and technical basis of the valid or new-formed AE. Investment attractiveness of such innovative projects with introducing production and processing complexes in agrarian sector of the country should secure a rapid and successful search of the interest of investors and the successful realization of their financials facilities.

The investment interests in the innovative projects of PPC are formed with consideration of the results of identification of each of the projects on the stage of their initialization. Therefore, the problem of management of the projects and initialization of IP of PPC is important both in theoretical approach in the practice of agrarian management of planning of the country.

## THE ANALYSIS OF SCIENTIFIC RESEARCHES AND PUBLICATIONS

Methods and instruments of management of production have been staying in the focus of attention of many analysts for a very long time and are examined comprehensively in the earlier and current scientific literature, e.g. [1, 2]. As far as the management of projects and programs is concerned, its theoretical principles are developed in the works of many famous scholars including a group of our contemporaries: H. Tanaka, S. Bushuev [3] V. Hohunskyy [4], A. Rybak [5], V. Rach [6] and others. A large group of researchers in the field of management of projects and programs (S. Chernov and K. Koshkin [7], Yu. Teslja [8], E. Druzhynin [9], Yu. Rak [10], I. Kononenko [11] and others) work at the practical application of management instruments of introducing innovative projects and programs in various areas of production and social activities in Ukraine.

The problem of raising efficiency of agrarian production by means of the of development of theory of management of projects is in the focus of attention of such scholars as: O. Sydorchuk [12, 13, 14], A. Truhuba [14, 15], P. Lub [14] A. Sharybura [15] and others. They develop new and improve the valid methods and models of management of projects aimed at raising efficiency and competitiveness of agrarian production in Ukraine.

The researchers discuss scientific and methodological problems of management of innovative projects of production and processing complexes formed on the basis of AE. They also carried out theoretical argumentation of expediency and realization of such projects [16, 17]. They distinguished characteristics of the product of innovative projects focused on formation of PPC and carried out scientifically-practical studies of their influence upon the processes of initialization of the mentioned above projects in the practice of functioning of agro-industrial complex (AIC) of Ukraine [18].

Nevertheless, in our opinion, introduction of IP of PPC into AIC of our country, which is capable to effect considerably the development of our rural settlements and their neighboring territories is restricted by the fact that the theory of management of projects lacks correct scientific argumentation of the methods of management of processes of initialization of such projects.

## AIM AND TASK OF THE RESEARCH

The aim of the given research is to make argumentation of the conception and to suggest the conceptual model of the development of the processes of initialization of innovation projects with forming production and processing complexes of agricultural enterprises of Ukraine on the production facilities and material and technical basis of the valid or new-formed AE for the balanced development of rural settlements and their neighboring territories.

The objective of the given research is to analyze the succession and interdependence of the processes of initialization of IP of PPC as well as interrelations between them.

## THE RESULTS OF THE RESEARCH AND THEIR ANALYSIS

Current agrarian production is influenced by the considerable risks of both objective (agro-technical and weather conditions) and subjective (the human factor) character. Therefore, potential abilities of AE in their achieving higher production results are often restricted by either incompletely controlled or incompletely forecasted factors.

This leads to the unprofitability of production and sufficient financial losses. The process of getting agricultural raw material starting from the stage of crops growing to their sale is long (9-12 months) and causes the potential sufficient financial losses at all stages of production. In our opinion, one of the possible ways of overcoming the risks or decreasing their results and, in addition, of suggesting the chance of additional profits at rather small capital investment is the idea of forming IP of PPC on the basis of production facilities of the valid AE.

The main aim of PPC is not only growing and realization of agricultural products in maximum possible volumes, but also production and sales of finished goods manufactured on their own raw materials. We believe, such a model of PPC functioning has the chance to get much higher index of profitability of agrarian production of the given AE, i.e. to create additional value.

The result of every PPC agrarian production is the function of such indexes [16]:

$$V = f(K_T, P_S, F_G, A_g, G_Z, R_S), \qquad (1)$$

where: $K_T$ - the traditional sowing of cultures in the economies of the region; $P_S$ - an area of agricultural lands; $F_G$ - physical and mechanical properties of soils; $A_G$ - agro-technical properties of soils; $G_Z$ - configuration of fields; $R_S$ - the demand on this raw material at the market:

$$Q = f(N_M, U_K, P_T, G_K, O_P, Z_P), \qquad (2)$$

where $N_M$ - the quality of seminal material; $U_K$ - the productivity of cultures; $R_T$ - the productivity of animal husbandry; $G_K$ - soils and climatic terms; $O_P$ - the organization of mechanized processes in a crop-growing and husbandry; $Z_P$ - the storage of raw material.

The efficiency of processing production also depends on such factors:

$$S = f(C_P, C_S, W_P, Q_S), \qquad (3)$$

where: $C_P$, $C_S$ - a realized price, according to finished goods and its raw material; $W_P$ - finished goods volumes of every PPC; $Q_S$ - the amount of the grown raw material for a given of finished goods:

$$W = f(V_P, B_P, T_P, K_P), \qquad (4)$$

where: $V_P$ - a commodity unit cost; $B_P$ - the losses of products in raw material up to the moment of reprocessing; $T_P$ - transport charges; $K_P$ - capital investments on creation of PPC.

Production-processing complex is an agro-industrial enterprise established for growing agricultural raw materials and procession of their sufficient part for the output of finished goods (Fig. 1).

Functional structure of PPC should comprise: agricultural lands, animal farms with facilities and high-productive animals, machine and tractor fleet (MTF), warehouses and storehouses with their technological equipment, and a number of small-sized processing enterprises (SPE) with their premises and technological equipment for processing agricultural raw materials, as well as, production infrastructure, system of energy- and resources provision, transport, communication, etc. and system of controlling the given complex. The conception of simulating the processes of innovative projects initialization with establishing production-processing complex, formed on the industrial facilities and material and technical basis of agricultural enterprises considers the following theoretical preconditions.

Processes of initialization of IP of PPC need, primarily, generating the very idea of such a project, i.e., the previous initialization (initialization of initialization), and identification which means the technically-economic argumentation of the vital capacity of PPC as an agro-industrial unit. These factors prove the efficiency of functioning of such complex. The process of identification of the project will be explained by means of the scheme (Fig.2).

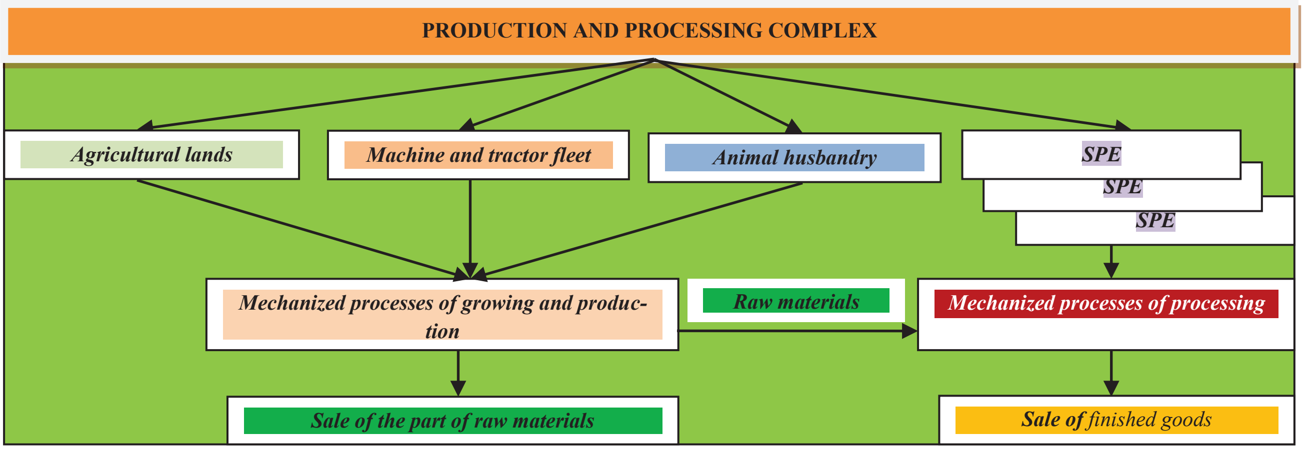


**Fig. 1.** Scheme of production and processing complex formed on the basis of AE

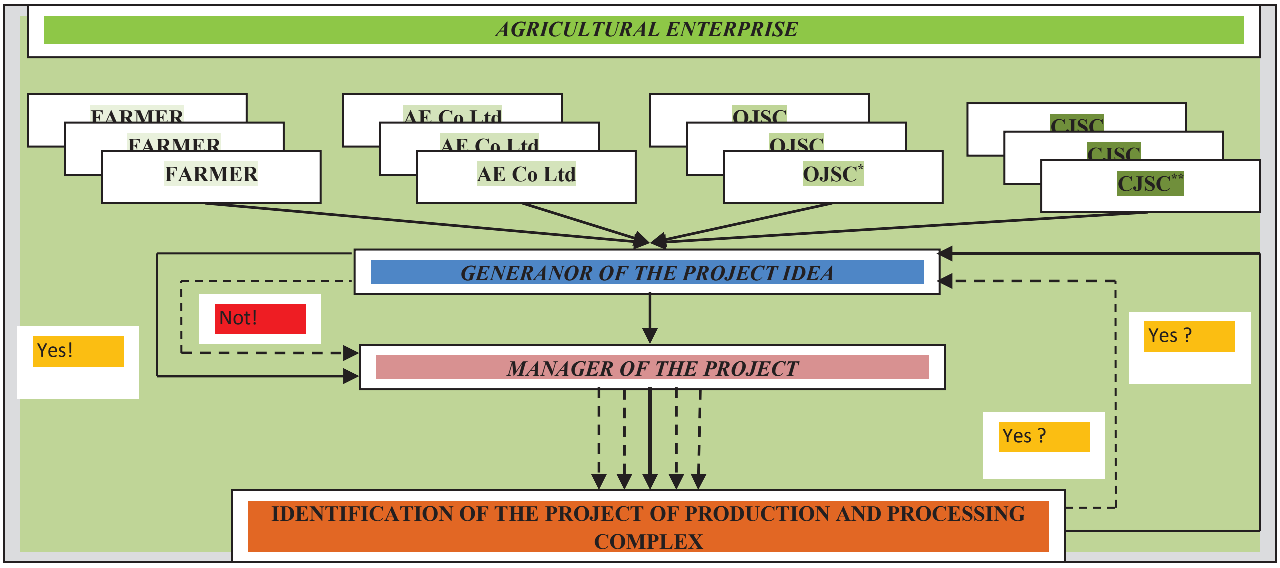


**Fig. 2.** Process of identification of the project of the production and processing complex OJSC* - Opened Joint-Stock Company; CJSCA** - Closed Joint-Stock Company

The generator of the idea of innovative project PPC is a physical or juridical person interested in the project and in fact the user of the given product in the future. The generator of the project idea should consider and be able to explain the manager of the project the need in the product, evaluate adequately the financial situation and opportunities for investments. Taking all these factors into consideration the generator of the idea of PPC project must be able to formulate the order for identification of the project. The manager of the project and the generator of the idea (in the main he is the customer of the project and the user of its product in the future) hold conceptual negotiations about the configuration of the project, its aims and ways of achieving them. The project manager carries out initial technically-economic argumentation and coordination with the previous configuration of the project of PPC with the interested persons to clarify its actuality. In our opinion, the initiators (customers and (or) users of the product of IP of PPC) may be [18]:

- managers of valid AE in order to increase profitability of agrarian production;
- managers of food (processing) enterprises in order receive their own sources of agricultural raw materials (sugar, brewery, fruit- and vegetable processing enterprises, etc.) to decrease the cost of production;
- interested investors (juridical and physical persons) for effective investments of their capital and getting the additional profits or, if they want, to expand the sphere of commercial activity;
- managers of rural (territorial) or district councils of deputies, administrative district, region or Ministry of agrarian policy and food staff of Ukraine to realize fresh opportunities (financially- economic, material and technical, social and cultural, ecological, etc.).

**1.** Processes of initialization of innovative projects with establishing production-processing complex on the basis of AE as other processes of management of such projects depend sufficiently on their product, to be more exact - on its properties. The product of such a project may be considered as:

- solving of the existing problem;
- amount of the received new products and services after achieving the mission of the project;
- production-processing complex, established on the basis of the existing AE or new-formed enterprises.

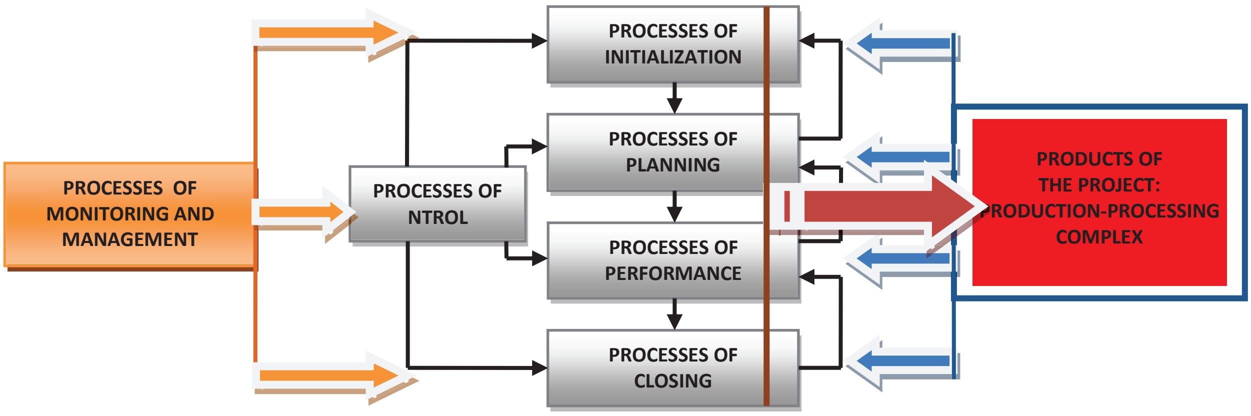


**Fig. 3.** Influence of the product of IP of PPC on the interrelations in number of processes of management of its elements

Solution of the main problem of AIC of Ukraine concerning the increase of effective current agricultural production opens new perspectives: financially-economic, material and technical, social and cultural, ecological, etc. Realization of these new possibilities proved to mean the amount of received new products and services caused by introduction of IP of PPC. All of them are received after achieving the mission of the product of PPC. Coming from the said above we arrived at the position that the product of IP of PPC is the production-processing complex itself. Let us analyze the position and function of the product of IP of PPC in the number of the processes of management of the projects (Fig. 3). As we see, the product of IP of PPC (more exactly: its properties) perform the reverse influence on all groups of the processes of management of the elements of the given project. Nevertheless, the product of the project is a the main result and its mission the reason of its initial. Thus we may confirm the dialectical unity, interconnection and interdependence of the process and its result: the project is supervised process of creation a unique product, i.e. PPC. However, the properties of this product conduct a sufficient reverse influence on all processes of management of elements of this innovative project.

The properties of the product of IP of PPC fall into quantitative and qualitative ones [18].

The quantitative properties are considered to be the following:

1) production program: the project specialization (types of the grown or received production) and power (quality of production) of agricultural and processing production in the given production-processing complex;

2) capital investment: necessary single-action money expenditures for introduction of innovative project of establishing PPC;

3) level of profitability: determining of efficiency of production after launching PPC, considering only agricultural operations innovation project, i.e. getting of value added;

4) term of payability: the term denoting investment sums returning into innovative project of establishing the production-processing complex based on the given AE.

The qualitative properties of the product of PPC are:

1) innovation: the level of application of nanotechnologies in the project of PPC and the most advanced facilities, methods and means of management of its functioning,

2) investment efficiency: the interest and attraction for involving and investing money into innovative project of forming PPC for juridical or physical person,

3) value: causing sufficient economic, social, cultural and ecological changes in the given territory after opening the PCC,

4) motivation: adaptivity, ability of the innovative project of PPC to initiate and introduce.

Let us analyze the influence of quantitative and qualitative properties of the product of innovative projects of establishing PPC on the processes of initialization of such projects which is obligatory for starting any project (Fig. 4).

3. As a result of the first two preconditions of the conception of simulation the processes of initialization of IP of PPC directly depend on the level of identification of each of these projects, its configuration, conception and content, and, first of all, on the properties of the product of every project.

Quantitative properties of the product influence directly the identification and configuration of the project (the expediency and need in it), types and volumes of operations for its introduction, terms of their performance as well as the expenditures of resources and money and indirectly its conception and content (mission of the project, its aims, amount of the received products and services).

Qualitative properties of the product conduct the influence in the reversal form: they determine conception and content of the project and indirectly influence the configuration and it’s identify. Impact of quantitative and qualitative properties of the product, however, is complex and interrelated and, therefore, one must reveal and evaluate quantitatively the weight of every component.

Let us show the development of the processes of initialization of the innovative project of establishing PPC in the form of the following model suggested by us in [19] (Fig 5).

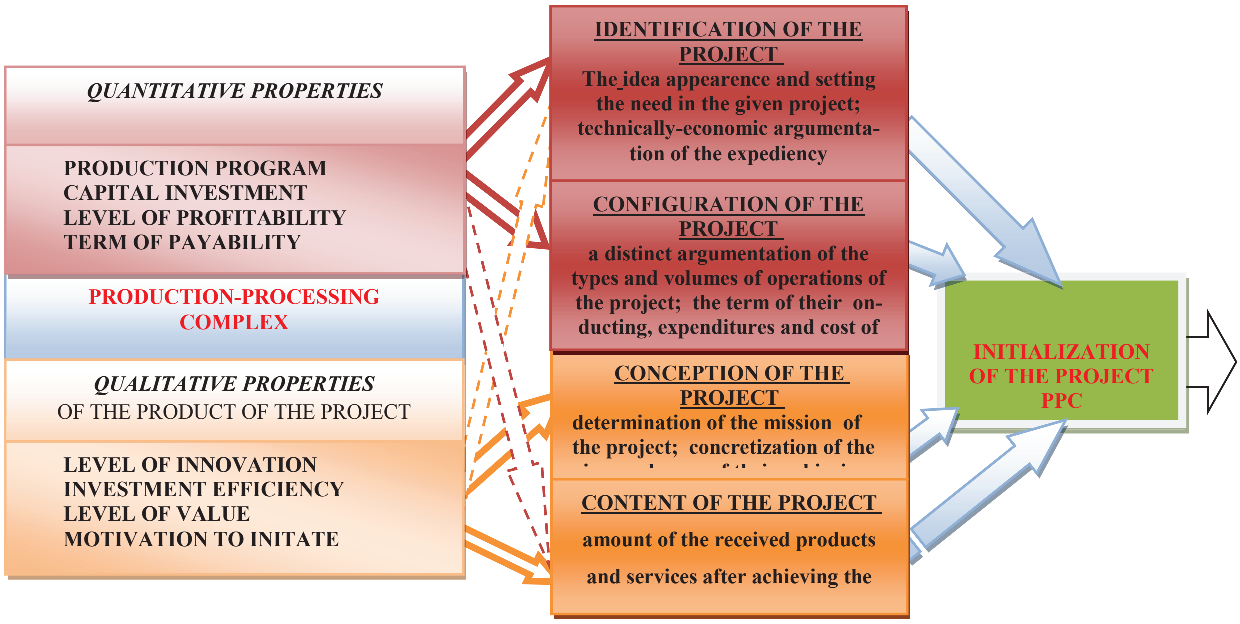


Fig. 4. Model of the influence of quantitative and qualitative properties of the product of **IP of PPC** on processes of initialization of the projects

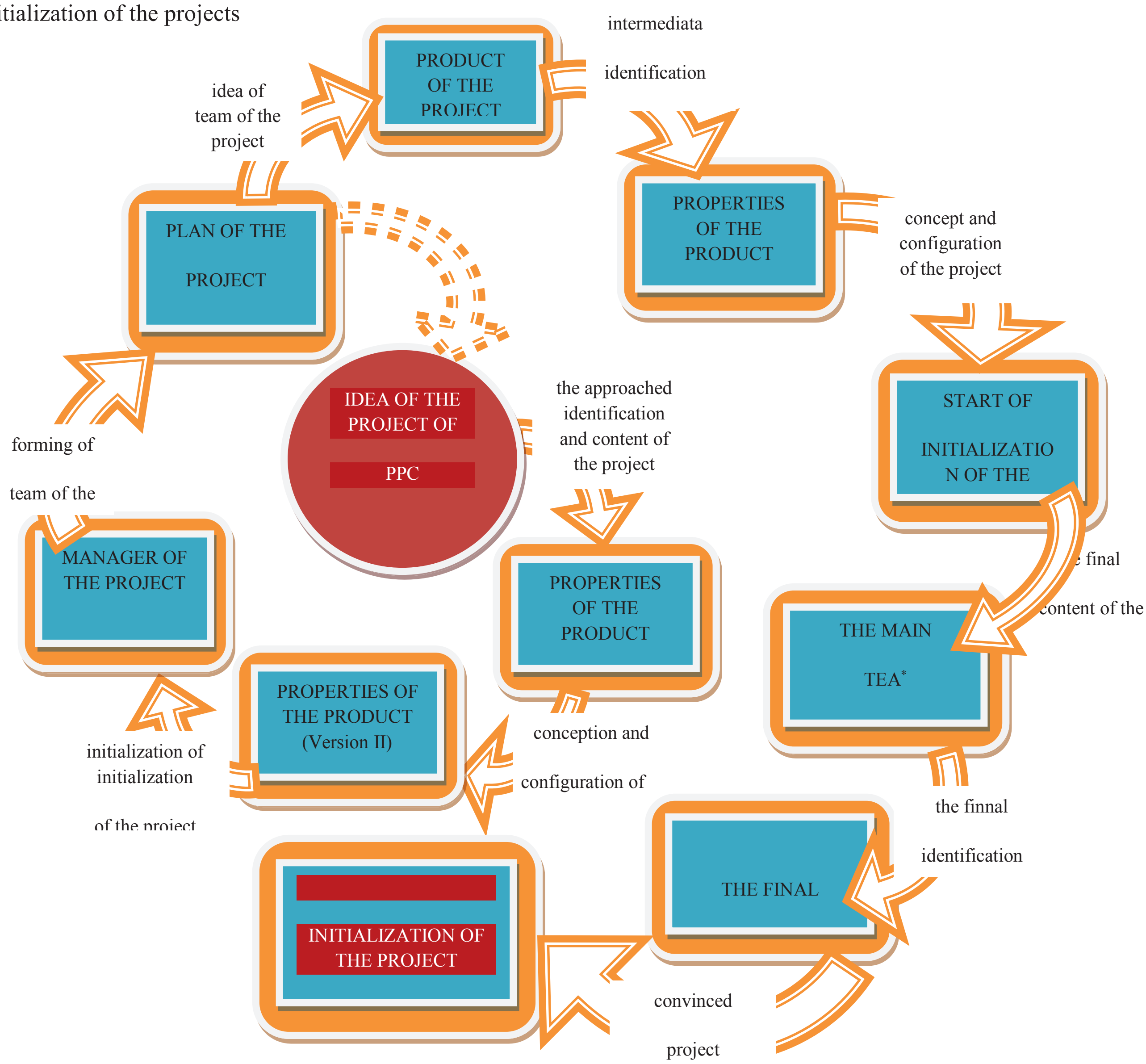


**Fig. 5.** Conceptual model of the development of the processes of initialization of IP of PPC TEA* – technically-economic argumentation of the IP of PPC

The idea of introduction of the IP of PPC in the processes of initialization is of a great impotence for starting every project. Motivation of initialization and introduction of innovative projects of PPC should be dominant. Any of the projects cannot do without it (it cannot stop or be completed at any moment of its life cycle). The project should be motivated at the very start of its idea. Therefore, when dealing with the processes of initialization of IP of PPC, one should consider the level of interest in such projects of every its participants. One should also identify all possible risks and develop methods of their overcoming or diminishing their negative results.

Processes of initialization of innovative project of establishing PPC, which are conducted by iterative steps can fall into three stages depending on the stages of formulating properties of the product of IP of production-processing complex (Fig. 5):

I-st stage - defining properties of the product (version I) after approached identification of the idea and content of the project;

II-nd stage – initial evaluation of the properties of the product (version II) after distinguishing conception and configuration of the project;

III-rd stage – project team's understanding of the essence of a target manufactured commodity and its potential properties (version III).

The pointed out stages of the development of the processes of initialization of innovative project of establishing PPC, according to the stages of concretization of the product properties of every each project are conducted during the pre-investment phase of the it life cycle.

Processes of formalized start of initialization of IP of PPC take place already at the investment phase, when the main technically-economic argumentation (TEA) and development of the final plan of the project are conducted.

## CONCLUSIONS

The suggested conception of simulating processes of initialization of innovative projects (IP) with establishing production-processing complex (PPC) formed on the industrial facilities and material and technical basis of agricultural enterprises (AE) formulates the preconditions for the successful management of practical realization of these processes.

The suggested conceptual model discusses the concession of the development of the processes of initialization of IP of PRC formed on the basis of AE. The developed conceptual model allows to understand better the peculiarities of appearance and development of the processes of initialization of innovative projects.

The received results allow to develop algorithm and mathematical program of simulation of processes of initialization of innovative projects of establishing production-processing complexes.

The further perspectives of our research will be connected with setting and evaluating interrelations within the processes of initialization of the project and getting the instruments for effective management of these processes.

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

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Abstract. 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: ellipsoid-shape seeds, pneumo-electric channel, modelling.

## FORMULATION OF THE PROBLEM

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 purificatory machines.

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

## REVIEW OF RECENT PUBLICATIONS

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 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.

## STATEMENT OF THE PROBLEM

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 STUFF

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 effect 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:

$$G = mg, \tag{1}$$

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 O2:

$$F_e = E\,q, \tag{2}$$

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:

$$F_a = KV_aA_m, \tag{3}$$

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*.

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:

$$\sum_{\hat{e}=1}^{\ddot{\imath}} M_e(F_{\ddot{\imath}}) = 0\,. \tag{4}$$

Expand the condition (4):

$$F_{\ddot{\imath}} \cdot Y_c \cdot \cos\varphi - F_e \cdot L \cdot \sin\varphi = 0\,. \tag{5}$$

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

$$tg\,\varphi = \frac{G \cdot Y_c}{F_e \cdot L}\,. \tag{6}$$

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

$$V_a = \frac{G}{K \cdot A_m}\,, \tag{7}$$

where: $A_m$ - midship area of the particle.

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 - 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 semiaxes *a* and *b* (Figure 2).

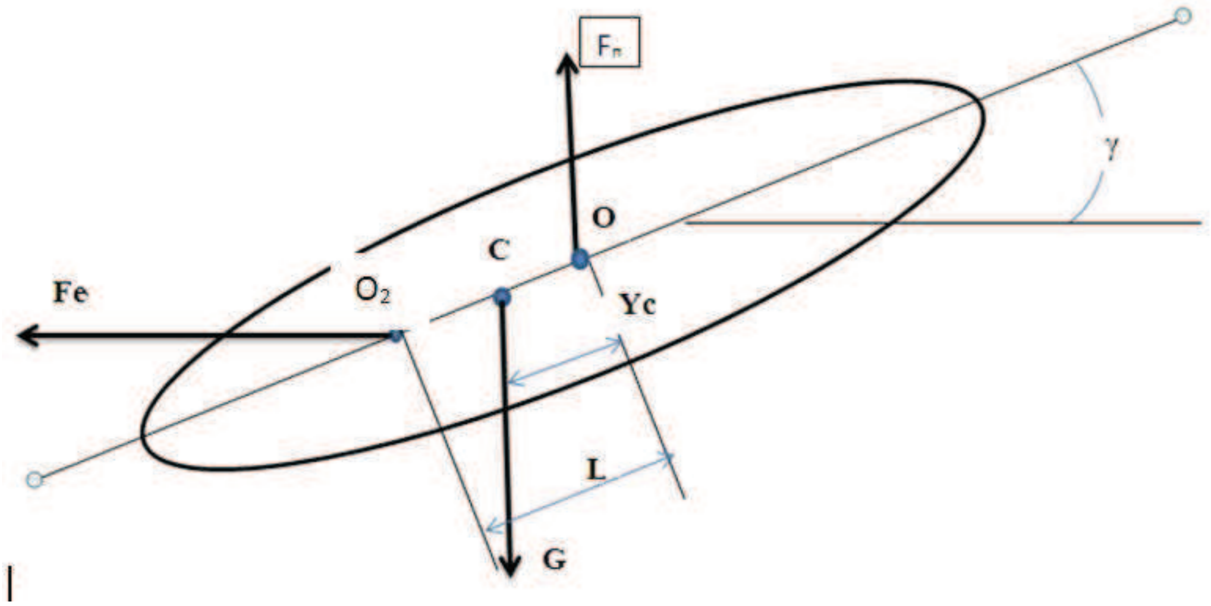


**Fig. 1.** Forces' effect on a particle of a seed mixture in pneumo-electric channel

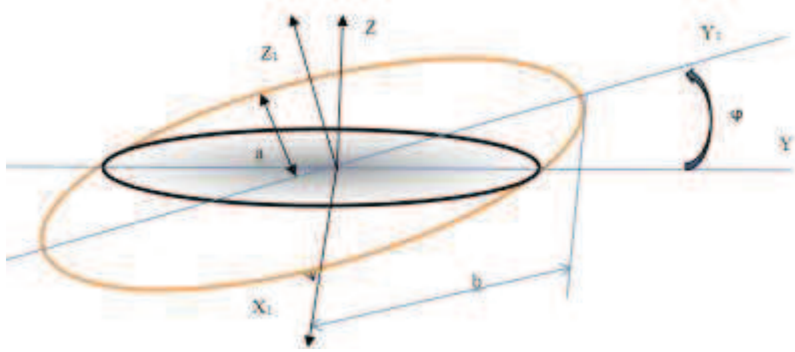


**Fig. 2.** Figure to determine a midship section of an ellipsoid-shaped particles

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

$$\frac{X_1^2}{a^2}+\frac{Y_1^2}{b^2}+\frac{Z_1^2}{c^2}=1. \qquad (8)$$

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

$$Y_1 = y\cdot\cos\varphi + z\cdot\sin\varphi,$$
$$Z_1 = z\cdot\cos\varphi + y\cdot\sin\varphi. \qquad (9)$$

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

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

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

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

with semiaxes $a$ and $b=\dfrac{ab}{\sqrt{a^2\cos^2\varphi+b^2\sin^2\varphi}}$.

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

$$A_m=\pi\frac{a^2b}{\sqrt{a^2\cos\varphi+b^2\sin\varphi}}. \qquad (12)$$

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):

$$V_a=\frac{G}{\pi\cdot K\cdot a^2b}\sqrt{\frac{(a\cdot F_e\cdot L)^2+(b\cdot G\cdot Y_c)^2}{(F_e\cdot L)^2+(G\cdot Y_c)}}. \qquad (13)$$

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

$$G > K\cdot V_a\cdot A_m. \qquad (14)$$

This inequality is right for any $\varphi$, if:

$$V_a<\frac{G}{K\cdot\pi\cdot a\cdot b}. \qquad (15)$$

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

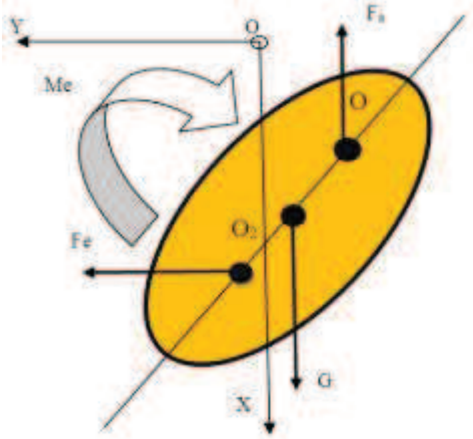


**Fig. 3.** Scheme of seed movement in pneumo-electric separator channel

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

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

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

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

$$A_2\frac{\pi a^2b}{\sqrt{a^2\sin^2\varphi+b^2\cos^2\varphi}}$$
$$\int_0^b y^2\sqrt{1-\frac{y^2}{b^2}}dy=b^3\frac{\pi}{16}. \qquad (17).$$

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

$$t=0; X_c=0; Y_c=0; \varphi=0, \qquad (18)$$
$$\frac{dy}{dt}=0; \frac{dx_c}{dt}=0; \frac{dy_c}{dt}=0.$$

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.

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 *xc* 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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# Development of a management systems model of automatic control by using fuzzy logic

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Abstract. Performing control in complex technical systems frequently becomes complex task, especially at the absence of a deterministic model of the system functioning or in conditions of incomplete system information. Often control efficiency under these conditions is not satisfactory. The paper describes control quality improvement approach based on using of fuzzy logic mechanisms on the example of fyzzy-system for controlling diesel engine fuel feed.

Key words: fuzzy logic, fuzzy controllers, diesel engine control, fuel feed control.

## STATEMENT OF THE PROBLEM

Management of complex systems is fundamentally different from the optimal (software) control, i.e. the transfer of the system to the desired state in some optimal way. This is because the behavior of complex systems is difficult to predict that is why it is almost impossible to identify and the more "impose" the "best" way of transition to the desired state [1, 3].

The management of complex systems is often carried out under conditions of uncertainty (lack of complete information necessary for the correct control action, lack of adequate mathematical models of operation, several alternatives, etc.).

The uncertainty of the system leads to increased risk due to poor management, which can bring fruit in negative economic, technical and social consequences.

Tools, that allow to provide an efficient system control under conditions of uncertainty, are methods built on the principles of an artificial intelligence using fuzzy logic rules [4,5]. They are based on fuzzy sets and use linguistic notions and expressions for the process control based on fuzzy, incomplete or subjective data, without the need for formalization as it goes in classical mathematical systems.

It is experimentally shown that fuzzy control gives better results compared with those obtained by conventional control algorithms. Fuzzy logic mainly provides effective means of uncertainties and inaccuracies of the real world depiction. With the help of fuzzy logic we solve the problems of harmonization of conflicting criteria of decision making, create logic controls systems.

An important application of fuzzy set theory is fuzzy logic controllers used in various control systems. These controllers use the integrated experts' knowledge that by the structure of representation approach to speaking and are described with linguistic variables and fuzzy sets.

The aim is to increase the efficiency of automatic control systems by using fuzzy logic.

## THE MAIN STUFF

One of the main methods of knowledge representation in fuzzy logic systems are production rules that allow to get closer to the style of human thinking.

Usually, these production rules are given as "IF logical expression THEN operator", where the rule's condition (logical expression) is a statement about the content of the knowledge base, and the consequence (operator) suggests what we should do when this production rule is activated.

Summarizing the above said we can make a statement that the system of fuzzy logic is a system of following descriptions:

- fuzzy specification of parameters,
- fuzzy description of the input and output variables of the syst,
- fuzzy description of the system's functioning based on production rules "if-then".

The most important class of fuzzy systems are fuzzy control systems (fuzzy logic controllers).

The overall structure of fuzzy logic controllers (fuzzi-controllers) consists of:

- fuzzification block,
- knowledge base,
- fuzzy conclusion block,
- defuzzification block.

Graphically, this structure is shown in Figure 1.

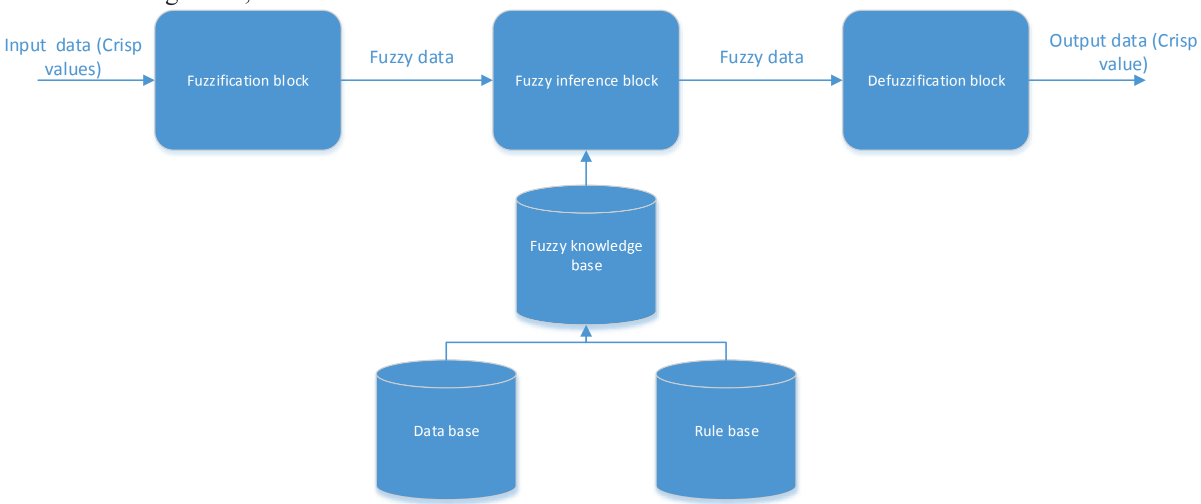


**Fig. 1.** The general structure of a fuzzi-controller

Fuzzification block turns precise values, measured at the output of control object, onto the fuzzy values, described by the linguistic variables in the knowledge base.

Fuzzy conclusion block uses fuzzy conditional (IF-then) rules incorporated in the knowledge base in order to convert fuzzy input data into the necessary control actions that are also unclear.

Defuzzification block converts the fuzzy output data block making a clear value that is directed to the execution unit to control the object.

The database contains functions of affiliation of fuzzy sets used in the fuzzy rules.

The rules base contains a set of fuzzy rules such as "if-then".

Due to that, the process of fuzzy logic controller can be determined by the following steps:

- fuzzification (transformation of clear input variables to fuzzy form, i.e. determining the coincidence grade of the inputs to each of the fuzzy sets),
- the proper logical conclusion (calculated value of truth for each rule condition),
- composition (combining of fuzzy rules outputs in the common notion),
- defuzzification (transformation of fuzzy rules output in a clear exit notion).

Fuzzy logic systems use linguistic variables to describe their own parameters of input and output variables. They reflect the experts' experiences, facts, qualitative information etc. and are expressed in terms of normative language.

Each linguistic variable is characterized by a set of terms that denote the set of qualitative states of a variable.

Suppose that a system which needs to improve the quality of management is characterized by a linguistic variable X that displays, for example, temperature and is characterized by a set of terms. Let X be defined m of linguistic terms:

$$X = \{A_j \mid j = 1..m\}, \qquad (1)$$

where: $A_j$ – term of fuzzy linguistic variable; m - total number of terms of fuzzy linguistic variable.

Each of the terms is a fuzzy set:

$$A_j = \{x, \mu_{Aj}(x) \mid x \varepsilon X,) \le \mu_{Aj}(x) \le 1\}, \qquad (2)$$

where x – value of space of the input parameters of the system X; $\mu_{Aj}(x)$ - function (grade) of affiliation of each x set (terms) $A_j$.

Affiliation functions $\mu_{Aj}(x)$ of a linguistic variable X are defined in one measurement space X and put each real number x on the line segment [0,1]. In fact, this is a subjective measure of how an element x corresponds to the concept, the essence of which is formalized by a fuzzy set.

Inputs $x = (x_i$ ┤ $\mid i = 1..n)$ and output y are clear controlled values. Each value $x_i$, i = 1..n possess a fuzzy match as a linguistic variable $X = \{A_i \mid j = 1..m_j\}$.

Rules $R_k$, k = 1..N check the meaning of each linguistic variable. Therefore, the maximum possible number of rules is: $N_{max} = \prod_{i=1}^{n} m_j$. In practice, the number of rules is not always necessary. The real number of rules $N \le N_{max}$.

Statement of a rule - a linguistic variable $Y = \{B_j \mid j = 1..m\}$, which takes the value of one of the terms $B_j$.

Generalizing of the rules is a composition of their fuzzy outputs into a single fuzzy set with its subsequent conversion to a precise output value y.

Fuzzification lies in convertion of precise input values $x = (x_1, x_2, ..., x_n)$ to the fuzzy set A '= (A', A ', ..., A').

During the fuzzification of precise input $x_i$ grades of its compliance with each linguistic term are determined $A_i$, j along with the affiliation functions $\mu_{Ai}$, j, j = $1..m_i$. These degrees are the values of affiliation functions $\mu_{Ai}$, j at the point $x = x_i$.

Fuzzy input values are transformed into output ones based on fuzzy logic rules.

Suppose that the control system performs conversion of values n input linguistic variables x = ($x_i$ ┤ | i = 1..n) in output linguistic variable y = R (x) under the rules base R = {$R_k$ ┤ | k = 1..N }.

Rules R represent menagement laws in the form of fuzzy implication R = A → B, which can be regarded as a fuzzy set in the Cartesian product of bearers of input and output fuzzy sets. The process of accumulation fuzzy result B` ¢ out of fuzzy input sets A` based on the knowledge A → B can be represented as follows:

$$B` = A` \cdot R = A` \cdot (A \rightarrow B), \quad (2)$$

where: - compositional rule of fuzzy inference.

In practice, for fuzzy inference a maximand composition is used, fuzzy implication is realized by finding the minimum affiliation functions. For the simulation of an expert system work according to the scheme of implication a fuzzy set of production rules is used, each of which is constructed as a conditional operator:

If - logical expression then - operator

where the logical expression - statements that are based on the basic logical operations over fuzzy values;

operator - the resulting solution.

Rules can determine the ratio of compliance (E) between the input linguistic variables X and their fuzzy terms {$A_{i,\ j}$ ┤ | i = 1, .., n; j = 1..$m_j$}. In general, a rule may include all possible combinations of linguistic terms for all input variables, combined by logical operations. In order to determine the fuzzy conjunction the defining of minimum can be used, and for fuzzy disjunction – defining of maximum of two affiliation functions.

Defuzzification output is used when fuzzy set of values of output linguistic variables is useful to convert into the precise ones.

There are a lot of methods of transition into the precise values: the method of the average center; first maximum; average maximum; altitudial defuzzification [7].

The method the average center or centroid method is to find the center of gravity (centroid) which is chosen as the output result:

$$Y = \frac{\sum_{j=1}^{m} y_j B^{/}(y_j)}{\sum_{j=1}^{m} y_j B^{/}(y_j)}, \quad (3)$$

where: B` ($y_j$) - the aggregate value of the system output after phase of logical inference, Y - the resulting value (the result of defuzzification).

In control systems resulting precise output value is used in a feedback loop to generate control actions.

The system can be used to control the operation of a diesel engine using electronic-controlled system [6]. The input values of the system are: engine temperature, engine rotation speed, accelerator pedal position, opacity of exhaust gases, pressure and temperature of the incoming air. The output value is the fuel supply of the engine (actually the fuel pump handle position). Simultaneously, the output value is used for feedback.

Let us construct a fuzzy model of functioning of the proposed system.

First of all, we have to define the input and output fuzzy linguistic variables:

- fuel supply: none, the minimum possible, reduced, optimal, increased, the maximum possible.
- engine rotation speed: starting, minimum, idling, high idling, speed of maximum torque, nominal, maximum.
- accelerator pedal: released, the minimally clicked, clicked, clicked the most. (Note, the same as for the speed).
- engine temperature: not heated, nominal (optimal), overheating, critical.

Let us create a rules base:

- If it is not heated enough and turns are higher than high idling then fuel supply is reduced.
- If it is not heated enough and the engine rotation is starting then fuel supply is increased.
- If the temperature is critical then the fuel supply is minimum possible.
- If the temperature is the most critical then the fuel supply is absent.
- If the accelerator pedal is released and turns are more than high idling then the fuel supply is absent.
- If the accelerator pedal is released and turns are high idling then fuel supply is minimum possible.
- If the accelerator pedal is maximum pressed and turns are minimum then fuel supply is maximum possible.

To calculate the output, the system step by step goes through the following stages: takes the results of measurements of engine monitoring devices, their fuzzification, actual logical conclusion, defuzzification of output fuzzy value and transfering it to the control circuit.

For hardware implementation of fuzzy logic, it is appropriate to use the motherboard of input\ output Arduino Mega 2560, which has its own programming environment and are fairly easy to reprogramme. The above-mentioned motherboard we use C-like language: Arduino Programming Language.

It is expected to improve technical and economic values of diesel engine using fuzzy logic methods by optimizing its fuel supply.

## CONCLUSIONS

1. The model of fuzzy logic as a fuel supply system of diesel is presented, hardware and a list of inputs are specified.
2. The authors of this article didn't use fuzzy logic to optimize the fuel supply.

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# Lubrication impact on the value of friction coefficient of coffee beans sliding ever the steel surfaces of various roughness

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Abstract. The article analyzes the influence of steel surfaces processing quality on the value of sliding friction coefficient of Robusta and Arabica coffee beans at dry and lubricated fricbica. The research obtained coffee dry and lubrication functions and parameters of sliding friction coefficients distributions and mathematical models for determining the index which depends on the roughness of steel surfaces.

Key words: coffee beans, steel surfaces, roughness, dry friction, sliding friction coefficient, lubrication.

## INTRODUCTION

Advanced technologies of procession, transportation and storage of agricultural production as well as planning of new production operations and designing of new machines and tools are impossible without studies of physical and mechanical properties of agricultural materials serving the functions of structural and technological parameters of machines and equipment.

The research of friction coefficient is especially important [28]. In fact the working surfaces of machines are made mainly of steel or cast-iron of different grades with the use of various technological methods, and that is why their surfaces are characterized by the different processing quality. Inaccuracies in friction coefficient determination result in the increasing of energy and material consumption of equipment, and also result in machines breakage.

A lot of articles are devoted to the method of physical properties investigation of agricultural materials [6, 9, 14, 25, 26]. It is established [3, 12, 16, 19] that relative humidity of seeds and beans has a significant impact on their physical and mechanical properties. Varieties in differences are also essential.

Researches pay a particular attention to the study of friction coefficients of different agricultural materials [10; 11; 15; 16; 19] and to the development of the special means of index measuring [2; 27]. As to coefficients of static friction and sliding it is known that the values of these indexes depend on the sizes of seeds or beans, and value on the relative humidity, and on the friction surfaces material [4; 10; 11; 15; 16; 19]. However, the conducted researches concerned the values of friction coefficients of seeds of different crops in pairs with various materials (steel, aluminum, concrete, glass, etc.) not taking into account the roughness of friction surfaces. At the same time the first researches of friction coefficient concerning the seed of oil-bearing flax [13] showed the necessity to take into account this important index of surfaces processing quality.

As to the coffee beans, the size of seeds [21, 22], coefficients of external and internal friction [20, 23, 24], aerodynamic [1] and thermal properties [7, 17] are determined. At the same time, the published results contain mainly average values and also values range of physical and mechanical properties for different varieties of coffee beans without specifying the nature of the distribution of these random values.

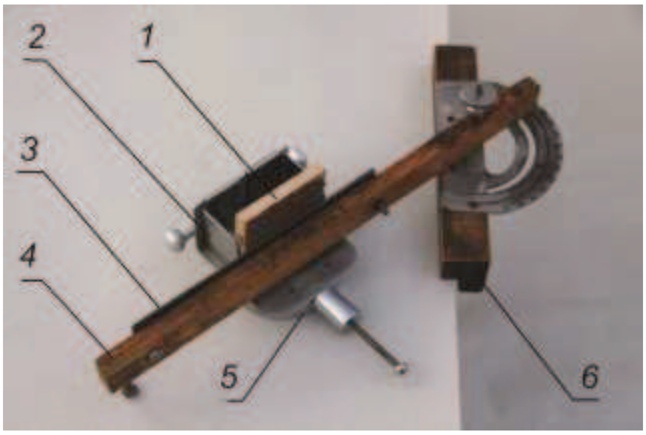
Thus, there is a need for clarification of values of sliding friction coefficients of coffee beans taking into accounts not only their relative humidity and varietal differences, but also surface roughness of sliding and lubrication.

## OBJECTIVE OF RESEARCHES

The objective of researches was to determine the sliding friction coefficient of coffee beans of different varieties on the steel surfaces of different roughness under conditions of dry friction and under the presence of lubrication.

## METHODOLOGY OF RESEARCHES

The research used Arabica and Robusta coffee beans. The value of relative humidity was obtained with the help of drying preliminary moistened coffee beans in the heat chamber at 100 $^{o}$C by changing the drying period.




*a*

*b*

**Fig. 1.** Device for determination of sliding friction coefficient (*a*) and bar with coffee beans (*b*): 1 – bar of the research material, 2 – carriage 3 – sliding surface, 4 – ruler, 5 – automatic recorder 6 – guide block

Determination of the angle φ and sliding friction coefficient f was conducted using well-known structures (Fig 1) [26, 27]. As sliding surfaces the flat surface of steel parts, processed to a roughness Ra = 12,5 mcm, $R_a$ = 6,3 mcm, $R_a$ = 2,5 mcm, Ra = 1,25 mcm are used. Different roughness values that were determined according to the models of roughness are obtained due to changing the surface processing mode (milling and grinding).

The results of experimental researches were obtained up using the methods of mathematical statistics [5, 18] calculated the mathematical expectation M[f], average quadratic deviation σ[*f*] and variation coefficient *υ*[*f*] of values of sliding friction f, matched the distribution law, application of which was checked using Pearson and Kolmohorov-Smirnov statistic fitting test.

The significance of the difference of obtained results of the sliding friction coefficient and geometrical parameters for the different varieties of coffee beans were checked using the Wilcoxon signed-rank test [5, 18].

The method of regression analysis [8] for obtaining the dependencies of values of mathematical expectation of sliding friction coefficient M[*f*] of different varieties of coffee beans on steel surface roughness Ra in the presence of lubrication was used. Checking of obtained regression dependencies was conducted using the F-test.

## RESULTS OF RESEARCHES

According to the results of determination of sliding friction coefficient *f* the distribution of this random variable for Arabica and Robusta coffee beans for different values of steel surface roughness Ra under conditions of lubrication are obtained. (Fig 2).

The distribution parameters of obtained values of sliding friction coefficient of coffee beans of these two varieties on steel surfaces of different roughness under condition of lubrication, namely the mathematical expectation M[*f*], average quadratic deviation [*f*] and variation coefficient [*f*] are defined.

Checking of received results according to the Wilcoxon signed-rank test showed that the difference of values of sliding friction coefficient under condition of dry friction and $f_c$ and under condition of lubrication $f_{\text{м}}$ on steel surfaces of different roughness (1 – *Ra* = 1,25 mcm, 2 – *Ra* = 6,3 mcm, 3 – *Ra* = 12,5 mcm, 4 – *Ra* = 2,5 mcm.) is statistically significant for both varieties of Arabica coffee beans (Fig. 3) and for Robusta coffee beans (Fig 4).

With the help of regression analysis [8] dependencies of mathematical expectation of sliding friction coefficient M[*f*] of Arabica and Robusta coffee beans under condition of lubrication of steel surfaces roughness Ra are obtained:

$$\mathrm{M}[f] = c_0 + c_1 \cdot Ra + c_2 Ra^2, \qquad (1)$$

where: $c_0$, $c_1$ i $c_2$ – regression coefficient; *Ra* – surface roughness, mcm.

Checking of the regression model (1) according to the F-test [5, 8, 18] did not give reasons for its rejection.

As we can see (Fig 5), at the same relative humidity *φ* = 23-26 % for coffee beans of both varieties in case of steel surfaces roughness decreasing starting with Ra = 12,5 mcm (turning) and to Ra = 1,25 mcm (grinding) the values M [*f*] are reducing nonlinear.

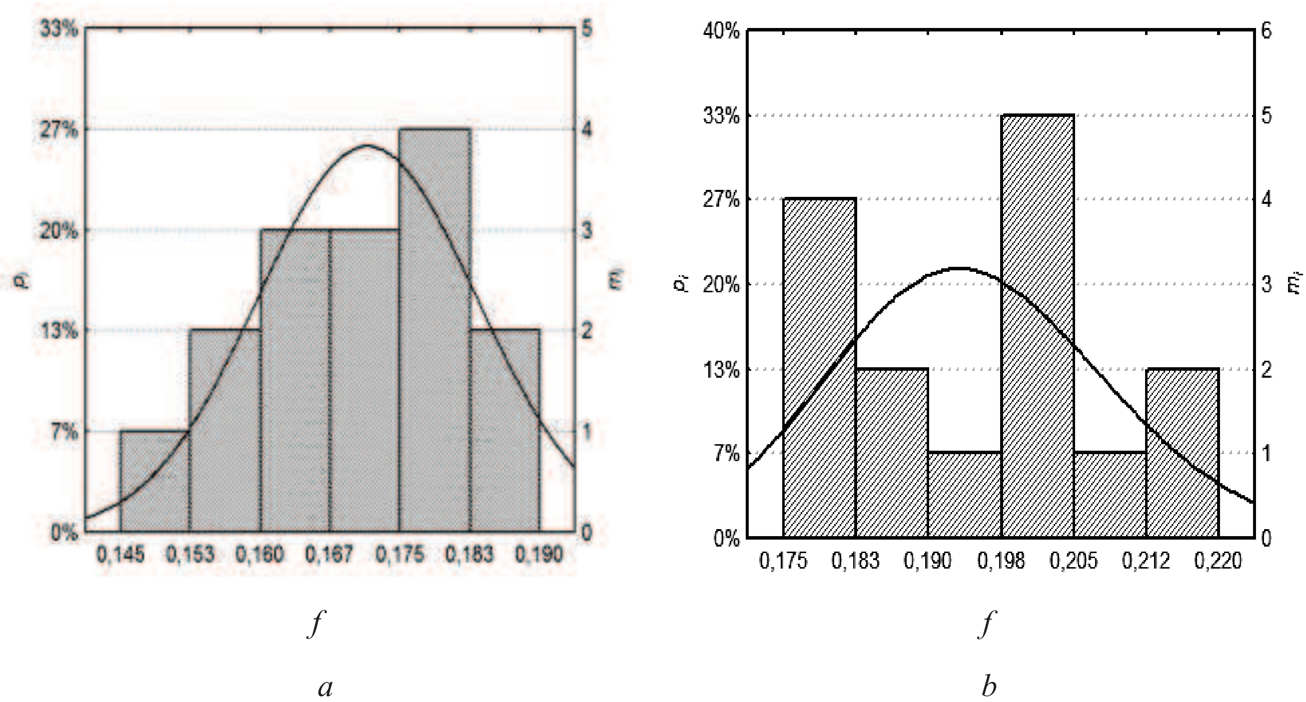



**Fig. 2.** The results of determination of distribution of values of the sliding friction coefficient of Arabica (*a*) and Robusta (*b*) coffee beans of relative humidity $\varphi$ = 23-26 % on steel surface roughness Ra = 6,3 mcm under condition of lubrication

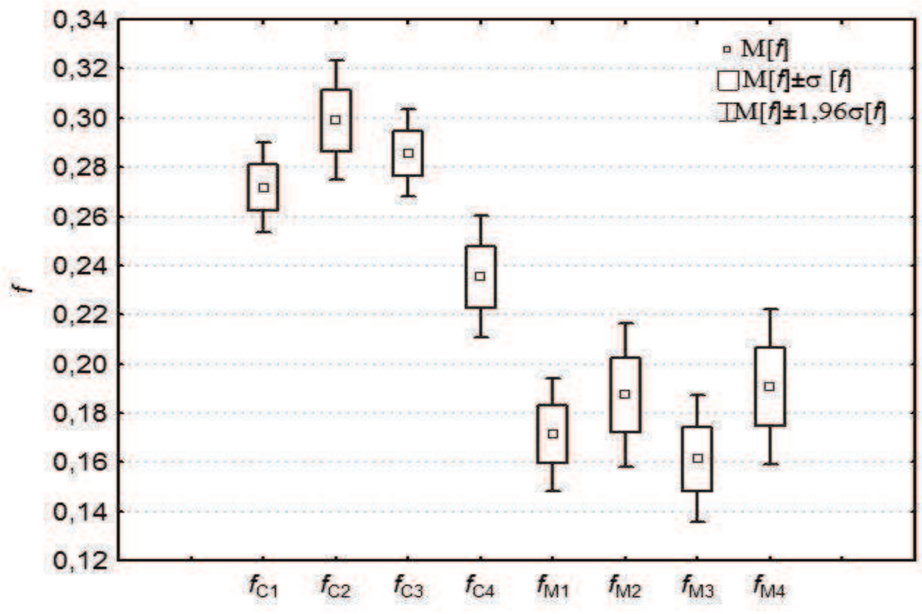



**Fig. 3.** The results of checking of sampling values of sliding friction coefficient of Arabica coffee beans under condition of lubrication ($f_{M1}$, $f_{M2}$, $f_{M3}$, $f_{M4}$) and dry friction ($f_{C1}$, $f_{C2}$, $f_{C3}$, $f_{C4}$)on steel surfaces of different roughness according to the Wilcoxon signed-rank test:1 – *Ra* = 1,25 mcm 2 – *Ra* = 6,3 mcm, 3 – *Ra* = 12,5 mcm, 4 – *Ra* = 2,5 mcm

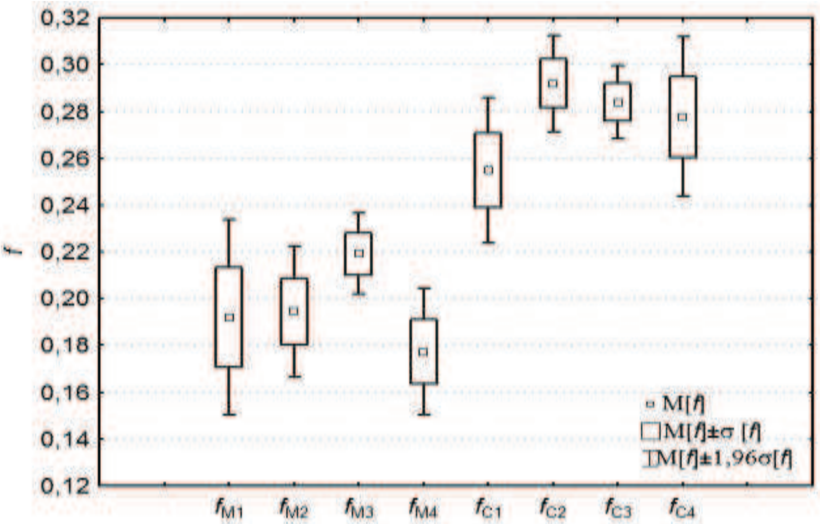
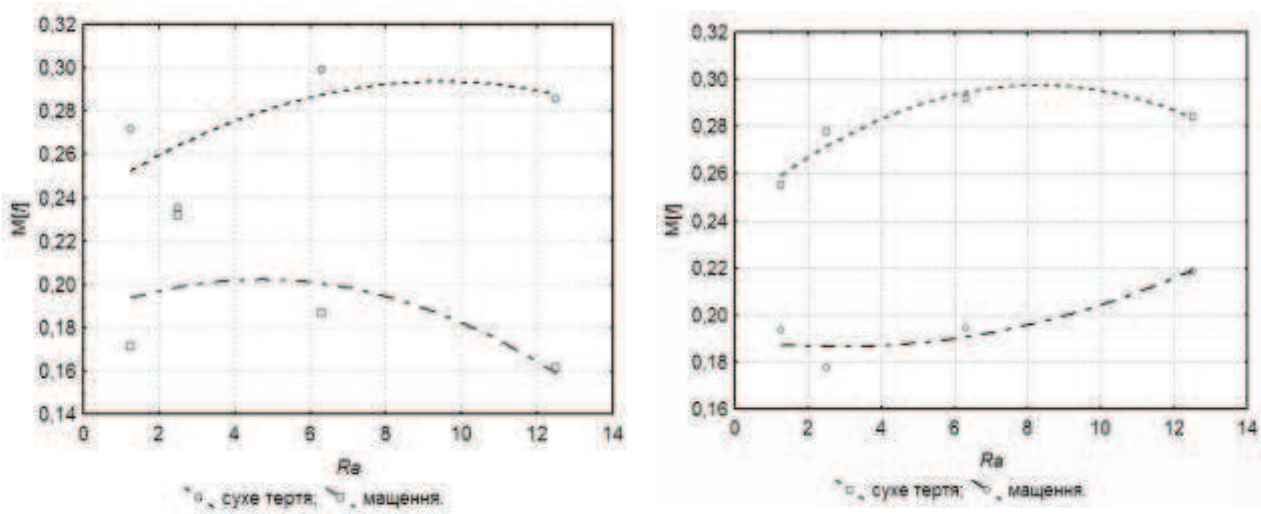



**Fig. 4.** The results of checking of sampling values of sliding friction coefficient of Robusta coffee beans under condition of lubrication ($f_{M1}$, $f_{M2}$, $f_{M3}$, $f_{M4}$) and dry friction ($f_{C1}$, $f_{C2}$, $f_{C3}$, $f_{C4}$)on steel surfaces of different roughness according to the Wilcoxon signed-rank test:1 – *Ra* = 1,25 mcm 2 – *Ra* = 6,3 mcm, 3 – *Ra* = 12,5 mcm, 4 – *Ra* = 2,5 mcm




*a* *b*

**Fig. 5.** Dependencies of mathematical expectation of sliding friction coefficient M [*f*] of coffee beans on steel surface roughness Ra: *a* – Arabica variety *b* – Robusta variety

## CONCLUSIONS

1. The value of sliding friction coefficient of coffee beans on steel surfaces should be considered as random variables distributed according to normal or logarithmic normal laws, the parameters of which significantly depend on the roughness of the processed steel surfaces and the factor of lubrication that should be considered during the project calculations of machines and equipment.

2. Under dry friction the increase of relative humidity of coffee beans influences the values change of sliding friction coefficient more significantly than the increasing of steel surface roughness.

3. The sliding friction coefficient of Arabica coffee beans is much more sensitive to changes of frictional surfaces roughness than for Robusta coffee beans, because of the differences of geometrical parameters of different varieties of beans.

4. Lubrication significantly reduces the value of sliding friction coefficient of coffee beans on steel surfaces with different processing quality.

5. Since the differences of obtained sampling values of sliding friction coefficient for coffee beans of different varieties on steel surfaces with the same processing quality were statistically significant, this index should be given in the reference data taking into account the sorts differences.

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# Analysis of methodological approaches to evaluation of land quality in Ukraine

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Abstract. The paper analyzes methodological approaches to evaluation of the quality of land in Ukraine. It was determined that, depending on the purpose and methods of assessment there are several types of land evaluation in Ukraine: soil rating (bonitet), economic and pecuniary evaluation, where the quality of the land affects the results of evaluation. There are many methodological approaches to qualitative assessment of the land. It was highlighted both many individual and integrated indicators, but there is no uniform system of their evaluation.

Works on soil rating of agricultural lands in Ukraine have been carried out in accordance with "Methods of soil rating in Ukraine." Under the present conditions of the regulation of land relations, the question as for more precise specification of limits of agro-industrial groups of soils has arisen.

On the basis of experimental researches, it was found that using a variety of methodological approaches to qualitative assessment of soil, there is inexactitude in the formation of soil maps, and hence in soil rating. Thus, it is necessary to adopt and uphold a single methodology for the qualitative assessment of land.

Key words: soil rating (bonitet), land evaluation, environmental and agrochemical certification of fields, agrochemical passport of a land plot, agro-industrial group of soils.

## PROBLEM STATEMENT

The issues of land quality at all stages of society were particularly relevant. Because of the diversity of functions of land its quality is evaluated by different criteria. The quality of the land affects the results of land assessments.

Depending on the purpose and methods there are several types of land evaluation in Ukraine: soil rating (bonitet), economic and pecuniary evaluation which is divided into normative and expert. Each of them has its practical application and each uses appraisal that reflects the natural properties of soil oriented on criteria for potential fertility as well as for crop yield. In these conditions the value of reliability of bonitet data is growing, since it is the basis for the definition of :indices of economic evaluation of soil used in the analysis of the efficiency of land use, economic suitability of land for growing crops; normative pecuniary evaluation of a particular land plot, which is the basis for determining the amount of land tax and rent; peer review of land plots during the alienation, insurance, mortgage and determining the investment contribution to the implementation of the investment project on land improvement.

## ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The famous soil scientist V.V. Dokuchaiev is considered to be the founder of soil rating. In Ukraine, the first attempts to solve issues of soil rating related to researches of V.P. Kuzmychov, S.S. Soboliev, A.I. Zrazhevsky, I.I. Karmanov, then it was much improved by A.I. Siryi, V.V. Medvediev, T.M. Laktionova, L. Ya. Nowakowski, O.P. Kanash, etc. However, in existing methods of soil rating physical parameters were used not enough and not impartially. Since the physical properties is an important component of soil fertility, their indices are gaining popularity in foreign concepts of soil quality and evaluation of agricultural lands: Russia (I.I. Karmanov and joint authors, 2002), France (D. De la Rosa, 1982), USA (F. Steiner, 1987; B.P. Warkentin, 1995), Canada (D.E. Romig and oth., 1995), India (D.P.S. Divakar, R.N. Sing, 1993), Bulgaria (B. Heorhiyev, 1994), New Zealand (G.P. Sparting, L.A. Schipper, 2002), etc.

A significant number of methodological approaches to qualitative assessment of the land can be found in the literature. It has been highlighted both many individual and integrated indexes, but there is no unified system.

## STATEMENT OF THE PROBLEM

To analyze the methodological approaches to qualitative land evaluation.

## THE MAIN MATERIAL

Since 1993, all agricultural lands in Ukraine have been embraced by soil rating, which is based on materials of large-scale soil surveys or selective surveys.

According to Article 199 of the Land Code of Ukraine [10] and Article 1 of the Law of Ukraine "On Land Valuation" [11] soil rating is the comparative evaluation of quality of soils based on their key natural characteristics that have stable character and substantially affect yields of agricultural crops grown in specific geographic and climatic zones.

The object of soil rating were accepted the units of the soil cover, which were distinguished on the maps of soils and combined into agro-industrial groups of soils in accordance with the "Classification of agro-industrial groups of soils Ukrainian SSR" (Kyiv, 1978).

The criterion of soil rating is soil qualitative indicators obtained in soil surveys that are sustainable and have a significant impact on the yield of crops grown in specific climatic conditions, and fully reflect the fertility of the soil.

Evaluation of soil quality is given in relative values – soil is rated on a 100-point scale worked out for some crops, which include winter wheat, winter rye, barley, oats, corn and grain, sunflower, sugar beet, potatoes and flax. Scales of soil bonitet are calculated for each natural agricultural area. The highest rating is given to soils that have the better characteristics and the highest natural productivity.

Works on soil rating of agricultural lands of Ukraine have been carried out in accordance with "Methods of soil rating in Ukraine", which was considered and approved at the meeting of the Department of Agriculture of the Ukrainian Academy of Agrarian Sciences 10.03.1992 (protocol number 2) and "Methodological guidelines on soil rating" [9], which were reviewed and approved by the scientific methodical Council on the soil rating in Ukraine on 21.01.1993.

In Ukraine the soil rating is conducted following three main natural features like depth of humus horizons, humus content and the content of physical clay.

Calculation of the score of soil rating ($B_i$) is based on a formula (1):

$$B_i = \frac{y_i}{y_e} * 100 , \qquad (1)$$

where: $y_i$ - the value of the soil characteristic, for which the score is determined, $y_e$ - the value of the soil characteristic, taking by 100points.

Thus within the land area estimated for each of these characteristics, their share impact on crop yield is determined, taking into account the determination coefficient ($K_d$) calculated by the formula (2):

$$K_{dij} = r_{ij}^2, \qquad (2)$$

where: $r_{ij}^2$ - the correlation coefficient between the yield of j-crop and individual i coefficient of soils properties in scores.

Taking into account a share impact of each characteristic on crop yield in each agro-industrial group of soils of land-estimated area it was defined the total score of soil rating (bonitet) by the formula (3):

$$B_{zj} = \frac{B_{1ij} * B_{d1ij} + B_{2ij} * B_{d2ij} + ... + B_{nij} * B_{dnij}}{K_{d1ij} + K_{d2ij} + ... + K_{dnij}}, \qquad (3)$$

where: $B_{zj}$ - total score of bonitet of i's agro-group of soils, $B_{1ij}, B_{2ij}, ... B_{nij}$ - score of bonitet of soils by individual properties of i's group, $K_{d1ij}, K_{d2ij}, ... K_{dnij}$ - coefficients of determination by individual properties of soils of i's crop.

As correction coefficients such indicators like soil acidity, content of sodium, salinity, gleying are used.

The main purpose of soil rating is to determine the relative quality of soils by their fertility, that is, establishing how many times each soil is better or worse than the other one in its natural and sustainably acquired properties.

Since the last soil rating of agricultural lands according to mentioned methods more than twenty years have passed. Despite the fact that the Law of Ukraine "On Land Valuation" [11] soil rating must be conducted at least once every 7 years.

Under the present conditions of regulation of land relations there is the question as for specification of limits of agro-industrial groups based on the Law of Ukraine "On Land Protection", "On state control over land use and protection", the Decree of the President of Ukraine of December 2, 1995 , №1118 "On complete agrochemical certification of agricultural lands", the Decree of the Ministry of Agrarian Policy and Food of Ukraine "On Approval of the Order of keeping of agrochemical passports on a field and a land plot" of October 11, 2011, №536 [10], which define the procedure for obtaining qualitative soil characteristics, with the help of which specification of limits of agro-industrial groups of soils is conducted.

Methods for environmental and agrochemical certification of fields and land plots have been considered and approved by the Academic Council of the Institute of Agroecology and Biotechnology UAAN on December 28, 1994 and by the Technical Council of the Ukrainian public association on execution of agrochemical works "Ukragrohim» on January 24, 1995 [3].

In Ukraine, there are many scientific and practical institutions operating in the field of agrochemical certification, but, unfortunately, the results of their performance are not coordinated. These are regional production engineering centers dealing with the protection of soil fertility of the Ministry of Agrarian Policy, a system of observation stations of the State Committee for Hydrometeorology; hydrogeology and reclamation expeditions, regional sanitary-and-epidemiological stations etc. Basic indicators of soil fertility, which given institutions use, belong to the category of individual ones:

1. pHsaline - potentiometrically (DSTU ISO 10390-2001).
2. The humus content – according to Tiurin (GOST 26213-91).
3. The content of alkali and hydrolyzed nitrogen - according to Cornfield.
4. The content of physical clay - according to Kaczynski (DSTU ISO 11277: 2005).
5. Mobile forms of phosphorus and exchangeable potassium - according to Kirsanov (DSTU 4405-2005) and Machyhin (DSTU 4114-2002).
6. The sum of absorbed bases - according to Kappen-Hilkovits (GOST 27821-88).
7. The content of calcium and magnesium –by the trylonometrical method (GOST 26487-85).
8. Hydrolytic acidity - according to Kappen in modification of ЦІНАО (GOST 26212-91).
9. Trace elements – atomic and absorption spectrophotometer method C - 115 M1.
10. Salts of heavy metals - according to RD 52.18.289-90.
11. DDT and its metabolites - according to the "Methodical reference on level control and studying of dynamics of pesticides content in soils and plants. - M.: Agropromizdat, 1985."

Following a given set of indicators, we can adequately assess the current state of the soil, diagnose all kinds of degradation and predict changes for the near or even distant future. However, a large amount of data gained by various organizations, often without following unified standardized (certified) techniques, and especially not in accredited laboratories, cannot provide a complete picture of the quality of land in different regions in particular and the country as a whole.

Well-founded algorithm of calculation of qualitative soil evaluation is described in the Methods of ecological and agrochemical certification of agricultural lands [3]. However, the number of correction coefficients in establishing this evaluation also is not clearly stipulated, that greatly affects the final result. Furthermore, among the indicators included in the agrochemical passport of a field and a land plot, parameters characterizing physical and chemical properties of soils, and their nutrient regime and pollution were dominant, but almost no physical parameters are taken into account [15].

According to indices of qualitative assessment of land soil maps of the area are formed. Soil maps of Ukraine of different scales, which were made on the basis of large-scale soil survey during 1957 - 1961, are significantly outdated and many of them have the low-quality information for the following reasons: 1) taking the prescription of soil maps; 2) materials were processed in the absence of topographic maps or aerial photographs; 3) there was a change of soil cover due to its radical reclamation or intensive erosion processes, etc.; 4) changes in the boundaries of land use and so on.

Experimental data obtained by the State institution "Oblderzhrodyuchist" indicate significant differences between boundaries of agro-industrial groups of soils with different methodological approaches. For example, let's consider how to change the boundaries of agro-industrial soils groups of the land plot of 24.4371 hectares, which belongs to Borschovychi (03) natural and agricultural region of the western steppe zone.

Figure 1 shows the boundaries of agro-industrial soils groups of the given area, which have been formed according to the data of the large-scale soil survey during 1957 - 1961.

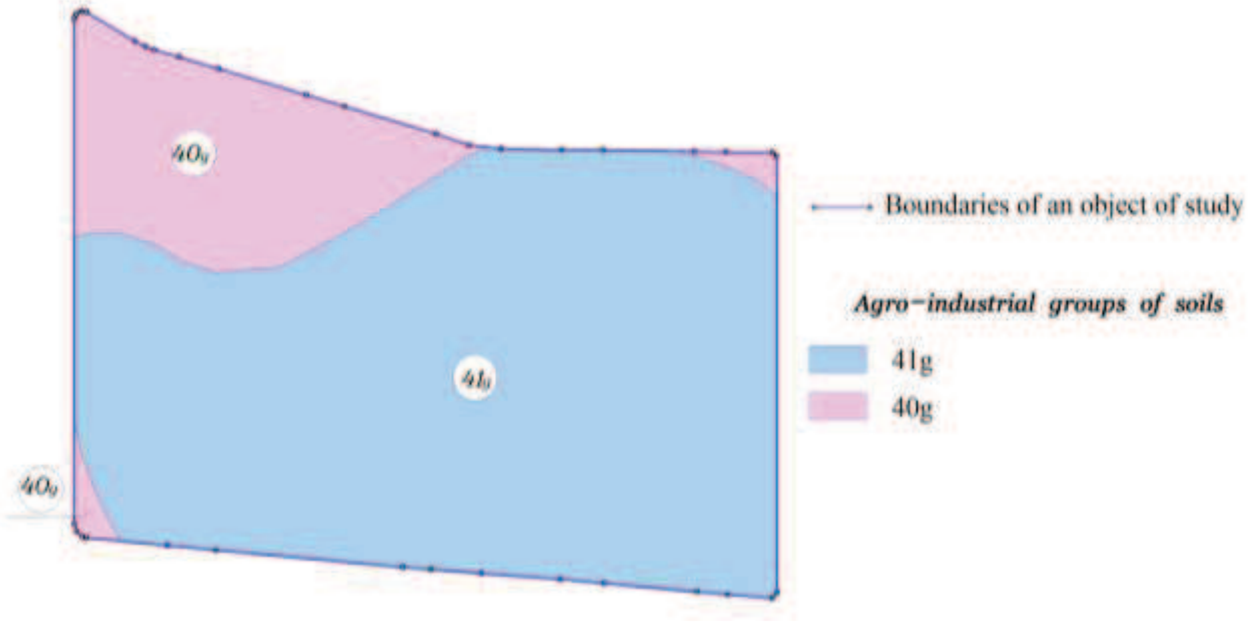


**Fig. 1.** Soil map of the investigated area, which is formed according to the data of the large-scale soil survey since 1957 till 1961

It has been determined that within the survey area the following types of soils prevail: 40g - dark gray podzolic light loamy soils on loess loams, occupying an area of 4.8479 hectares and 41g – black earth podzolic light loamy soils on loess loams, occupying an area of 19.5892 hectares.

According to the results of soil agrophysical and agrochemical properties investigation on the investigated area by the Methods of ecological and agrochemical certification of agricultural lands, we obtained data presented in Table 1.

On the basis of field and analytical investigations and in accordance with the nomenclature list of agro-industrial groups in Ukraine and the scale of soil rating in Lviv region we revealed that within the investigated area following soils prevail:

1. Dark gray podzolic light loamy soils on loess deposits that cover an area of 6.1235 hectares of arable land, and belong to 40g agro-group, the score of soil rating is 66.
2. Black earth-meadow gley of medium-depth soils on loess diluvium that cover an area of 1.9164 hectares of arable land, and belong to 134g agro-group , the score of soil rating is 61.
3. Dark gray podzolic gley light loamy soils on loess deposits that cover an area of 16.3972 hectares of arable land, and belong to 46g agro-group , the score of soil rating is 27.

Figure 2 shows the soil map of the investigated area, which is formed on the basis of Methods of ecological and agrochemical certification of agricultural lands.

**Table 1.** The results of soil agrophysical and agrochemical properties investigation

| № of a sample | Code of an agro-group | Depth of sampling | Results of investigation | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Humus, % | pH saline | The amount of fraction of physical clay less 0,01 mm, % | Nitrogen alkaline mg / kg | Phosphorus, mg / kg | Potassium, mg / kg |
| 1-1 | 40g | 0-28 | 2,61 | 4,81 | 25,52 | 112,9 | 60,0 | 32,0 |
| 2-1 | 134g | 0-44 | 2,51 | 5,73 | 27,07 | 102,7 | 205,3 | 63,7 |
| 3-1 | 46g | 0-34 | 2,54 | 5,62 | 25,97 | 132,9 | 156,7 | 45,0 |

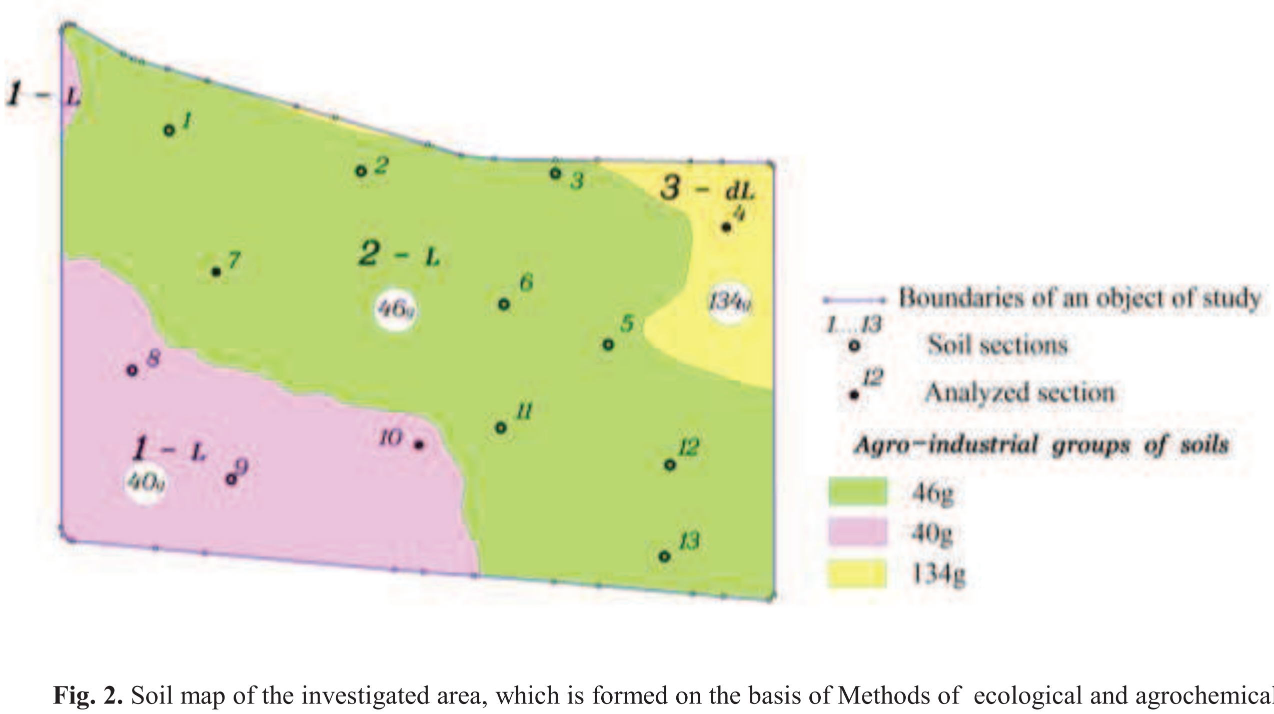


**Fig. 2.** Soil map of the investigated area, which is formed on the basis of Methods of ecological and agrochemical certification of fields and land plots

According to the data of two methodological approaches for the qualitative assessment of land we have formed a comparative explication of agro-industrial groups of soils (Table 2).

**Table 2.** Comparative explication of agro-industrial groups of soils on the investigated area

| *Name of the methodological approach to evaluation of the land quality* | *Agro-industrial groups of soils prevailing on a plot* | *Area of agro-industrial group of soils,* |
|---|---|---|
| *Large-scale soil survey during 1957 -1961* | *40g* | *4,8479* |
| | *41g* | *19,5892* |
| *Methods of agrochemical certification of agricultural lands* | *40g* | *6,1235* |
| | *134g* | *1,9164* |
| | *46g* | *16,3972* |

Thus, using a variety of methodological approaches to qualitative assessment of soil, there is inexactitude in making soil maps, and hence in determination of the score of soil rating.

Today soil rating is important for the SLC because it provides information about the qualitative assessment of soil, which in turn is the basis for the economic valuation of land and thus - normative pecuniary evaluation of land. However, the legislation governing the procedure for this type of evaluation is very limited; even there is no normative act that would define such a procedure.

Therefore, we can conclude that at the present stage of development of land relations legal regulation of soil rating needs to be improved.

## CONCLUSIONS

Thus, in general terms, the problem is to define a common methodology and a set of indicators to assess soil quality adequately. Development of a system of indicators should be done taking into consideration the possibility of information use from existing services that control the state of the soil cover, soil fertility and health of soil. We also should take into account the need in spreading information from researches based on the modern technical base and advanced techniques.

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# Mathematical model of interaction of milk thistle seed with grooved working surfaces

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Abstract. The interaction of milk thistle seed with grooved working surfaces is revealed. The dependences of curvature of the ellipse of contact on the step between grooves and pressure distribution on the area of contact of normal force of compression are identified. The achieved dependences make it possible to justify optimal geometrical parameters of grooved working surfaces required for peeling milk thistle seed coat.

Key words: seeds of milk thistle grooved working surface, area of contact.

## SETTING OF THE PROBLEM

Under contemporary market conditions small farms should grow and process minor oilseeds (flax, mustard, milk thistle, and radish) and avoid competition from powerful agricultural producers. To obtain high-quality oil, meal and oilcake it is necessary to introduce new technology and processing equipment, their adaptation to small production volumes. The task will include milk thistle to one of the most profitable crops [14, 2].

Depending on the physical and mechanical properties and morphological structure of the seed we use peeling method that provides the best technological effect. The initial condition for the justification of technical parameters of means for peeling the seeds of milk thistle are such mechanical indications of seeds as their tangential and normal stress and deformation in which the elastic deformation develops in the plastic one and shell of seeds is peeled [13].

## LAST PUBLICATIONS

Analysis of published works [1, 3–6] showed that at this stage there is a need for equipment and implementation of complex processing technologies of minor oilseeds.

In industry, the most widely used are such machines that use a blow, compression, shift, friction and more rarely - cut, shear and combinations of them. The existing shelling equipment should not be used for thistle seeds as thistle seed coat is much stronger than the core, with almost complete absence of space between the shell and the core. Usage of such machines would lead to the destruction of not only fetal membranes but also the core of milk thistle, which is highly undesirable effect.

Theoretical studies of membrane destruction process of oilseeds presented in published papers [8−12] are devoted to the main oilseeds - sunflower, canola, soybean, mustard, radish. Therefore, the justification of parameters of shelling equipment for milk thistle seeds processing need to be theoretically explored: the nature of the interaction of milk thistle seed with grooved working surfaces, set the value of the normal force and tangential load on fruit shell in which it suffers its destruction.

## OBJECTIVES

Create a mathematical model of the interaction of milk thistle seed with grooved working surfaces. Justify the grooves' parameters that ensure the destruction of fetal membranes in the longitudinal area of the seed and prevent from cranking around its axis. This will ensure the stability of the peeling process, while maintaining the integrity of the core and increase the quality indicators of milk thistle meal [7].

## MAIN PRESENTATION

We believe that the seeds of milk thistle has the shape of an ellipsoid of revolution. Then the equation of the surface of the ellipsoid in the principal central axes of inertia can be written [15–16]:

$$\frac{x^2}{b^2}+\frac{y^2}{a^2}+\frac{z^2}{a^2}=1, \tag{1}$$

where: $b$ and $a$ – semiaxis of ellipsoid of revolution. As a result of the force $F$ seed turns at an angle $\alpha$ and will contact with protrusion at points $B$ and $B_1$ (Fig. 1). The equation of the surface of the turned seed will be:

$$\frac{(x\cos\alpha + z\sin\alpha)^2}{b^2}+\frac{y^2}{a^2}+\frac{(z\cos\alpha - x\sin\alpha)^2}{a^2}=1\,. \quad (2)$$

We will find the angle $\alpha$ substituting in equation (2) coordinate of point B *(t, 0, a)*:

$$\frac{(t\cos\alpha + a\sin\alpha)^2}{b^2}+\frac{(a\cos\alpha - t\sin\alpha)^2}{a^2}=1. \quad (3)$$

The squaring:

$$\frac{t^2}{b^2}\cos^2\alpha + 2\frac{at}{b^2}\cos\alpha\sin\alpha + \frac{a^2}{b^2}\sin^2\alpha + $$
$$+\cos^2\alpha - 2\frac{at}{a^2}\cos\alpha\sin\alpha + \frac{t^2}{a^2}\sin^2\alpha = 1.$$

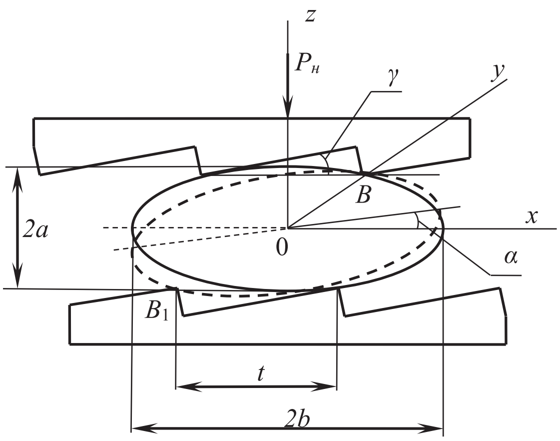


**Fig. 1.** Scheme of thistle seed orientation in space when interacting with the working surfaces

After transformations we obtain a quadratic equation for *tga*:

$$\left(1-\frac{a^2}{b^2}-\frac{t^2}{a^2}\right)tg^2\alpha + 2at\left(\frac{1}{a^2}-\frac{1}{b^2}\right)tg\,\alpha - \frac{t^2}{b^2}=0. \quad (4)$$

Hence we find:

$$tg\,\alpha = \frac{-2at\left(\frac{1}{a^2}-\frac{1}{b^2}\right)+\sqrt{4a^2t^2\left(\frac{1}{a^2}-\frac{1}{b^2}\right)^2 + 4\frac{t^2}{b^2}\left(1-\frac{a^2}{b^2}-\frac{t^2}{a^2}\right)}}{2\left(1-\frac{a^2}{b^2}-\frac{t^2}{a^2}\right)}. \quad (5)$$

Then:

$$\sin\alpha = \frac{tg\,\alpha}{\sqrt{1+tg^2\alpha}}, \quad \cos\alpha = \frac{1}{\sqrt{1+tg^2\alpha}}. \quad (6)$$

Find the slope of the tangent to the ellipse ($y = 0$) at point B in the area ($x\ 0\ z$). To do this, find the derivative $\frac{dz}{dx}$ of equation (2) at $y = 0$:

$$\frac{2}{b^2}(x\cos\alpha + z\sin\alpha)\left(\cos\alpha + \frac{dz}{dx}\sin\alpha\right) + $$
$$+\frac{2}{a^2}(z\cos\alpha - x\sin\alpha)\left(\frac{dz}{dx}\cos\alpha - \sin\alpha\right)=0 \quad (7)$$

Hence, solving relatively $\frac{dz}{dx}$, we obtain:

$$\frac{dz}{dx}=\frac{-\left[x\left(\frac{\cos^2\alpha}{b^2}+\frac{\sin^2\alpha}{a^2}\right)-z\sin\alpha\cos\alpha\left(\frac{1}{a^2}-\frac{1}{b^2}\right)\right]}{z\left(\frac{\sin^2\alpha}{b^2}+\frac{\cos^2\alpha}{a^2}\right)-x\cos\alpha\sin\alpha\left(\frac{1}{a^2}-\frac{1}{b^2}\right)}. \quad (8)$$

Then the tangent of the slope at point $B$ equals:

$$tg\gamma = -\left(\frac{dz}{dx}\right)_{\substack{z=a\\x=h}} = \frac{t\left(\frac{\cos^2\alpha}{b^2}+\frac{\sin^2\alpha}{a^2}\right) - a\sin\alpha\cos\alpha\left(\frac{1}{a^2}-\frac{1}{b^2}\right)}{a\left(\frac{\sin^2\alpha}{b^2}+\frac{\cos^2\alpha}{a^2}\right) - t\cos\alpha\sin\alpha\left(\frac{1}{a^2}-\frac{1}{b^2}\right)}. \quad (9)$$

Accordingly:

$$\sin\gamma = \frac{tg\gamma}{\sqrt{1+tg^2\gamma}}, \quad \cos\gamma = \frac{1}{\sqrt{1+tg^2\gamma}}. \quad (10)$$

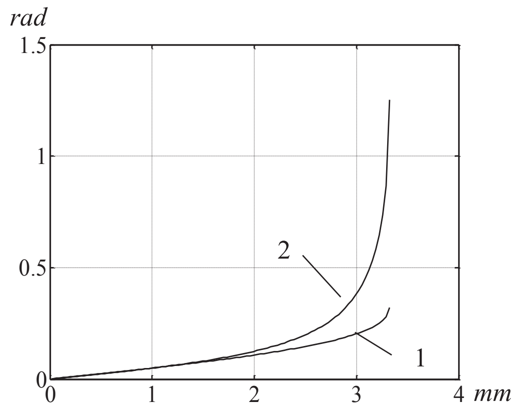


**Fig. 2.** Dependence of the angle γ (1) The slope of the tangent at the point of contact and angle of rotation of seed α (2) the step between the grooves $t$

Figure 2 shows that an increase of step between grooves $t$ ranging from 0 to 2 mm, a twist of ellipsoidshape seed will not exceed 11º, it will enable us to stabilize its position at the moment of contact with the groove.

Let us identify the main ellipsoid surface curvatures at the point of contact. To do this, again take the derivative of equation (7) and solve relatively $\frac{d^2z}{dx^2}$, that is:

$$\frac{d^2z}{dx^2}=-\frac{\frac{1}{b^2}\left(\cos\alpha+\frac{dz}{dx}\sin\alpha\right)^2+\left(\frac{dz}{dx}\cos\alpha-\sin\alpha\right)\cdot\frac{1}{a^2}}{z\left(\frac{\sin^2\alpha}{b^2}+\frac{\cos^2\alpha}{a^2}\right)-x\cos\alpha\sin\alpha\left(\frac{1}{a^2}-\frac{1}{b^2}\right)}. \quad (11)$$

Then find the main curvature at the point of contact in the area $xOz$:

$$K_1 = \left. \frac{\left| \dfrac{d^2 z}{dx^2} \right|}{\left(1 + \left(\dfrac{dz}{dx}\right)^2\right)^{3/2}} \right|_{\substack{z=a \\ x=t}} . \tag{12}$$

Similarly, we find the main curvature in the perpendicular direction. To do this, we calculate the derivatives $\dfrac{dz}{dy}$ and $\dfrac{d^2 z}{dy^2}$ using equation (2):

$$\frac{dz}{dy} = -\frac{y}{(z\cos\alpha - x\sin\alpha)\cos\alpha}$$

$$\frac{d^2 z}{dy^2} = -\frac{1 + \left(\dfrac{dz}{dy}\right)^2 \cos^2\alpha}{(z\cos\alpha - x\sin\alpha)\cos\alpha} . \tag{13}$$

Then the main curvature $K_2$ equals:

$$K_2 = \left. \frac{\left| \dfrac{d^2 z}{dy^2} \right|}{\left(1 + \left(\dfrac{dz}{dy}\right)^2\right)^{3/2} \cdot \cos\alpha} \right|_{\substack{y=0 \\ x=0 \\ z=t}} . \tag{14}$$

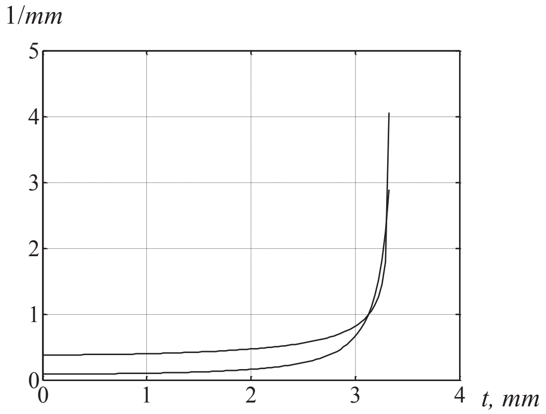


**Fig. 3.** Dependence of curvature 1 – $K_1$, 2 – $K_2$ of contact ellipse on the step between grooves *t*

Formulas (12, 14) and a graph of the curvature of contact ellipse between steps of grooves *t* (Fig. 3) indicate that with an increase of step between the grooves to 2 mm the contact ellipse curvature is in constant range.

Force P is acting on the edge and presses it into the seed. We can investigate the defomational state of seeds using the solution of the problem from Hertz's monograph.

If you choose to start a new coordinate system at the point of the edge and the seed contact on the *x* and *y*-axis and they are situated in a common area, then in the circle of points of contact surfaces equation can be represented as:

$$\begin{aligned} z_3 &= a_{23}x^2 + a_{32}xy + a_{22}y^2, \\ z_2 &= -\left(d_{22}x^2 + b_{32}xy + b_{22}y^2\right). \end{aligned} \tag{15}$$

Then the distance between corresponding points before deformation:

$$z_3 - z_2 = (a_{33} + b_{22})x^2 + (a_{32} + b_{32})xy + (a_{22} + b_{22})y^2 . \tag{16}$$

The coordinate system can be selected so that $(a_{32} + b_{32}) = 0$ and then:

$$z_3 - z_2 = Ax^2 + By^2 . \tag{17}$$

Axis are marked so that $A \geq B$.

Further, we believe that the edge has a shape of a parabolic cylinder:

$$z_3 = \frac{k}{x} x^2 . \tag{18}$$

Then A and B can be expressed due to previously defined curvatures:

$$A = k_3 + k; \; b = k_2 . \tag{19}$$

According to Hertz theory after applying to the edge force *N* the area of contact occurs, which has the shape of an ellipse:

$$\frac{x^2}{a_3^2} + \frac{y^2}{b_3^2} = 1 , \tag{20}$$

where: $(a_1 \leq b_1)$.

Pressure distribution in the contact area can be calculated by the formula:

$$p = (x, y) = \frac{3P}{2\pi a_3 b_3} \sqrt{1 - \frac{x^2}{a_3^2} - \frac{y^2}{b_3^2}} . \tag{21}$$

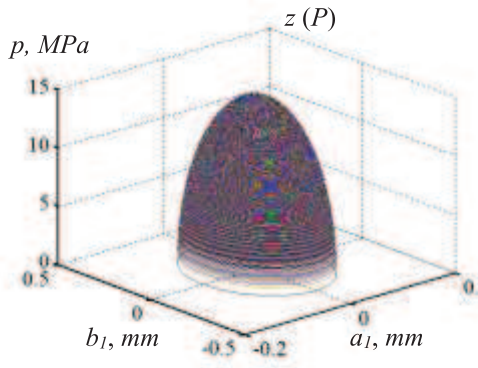


**Fig. 4.** Graph of pressure distribution on the contact area

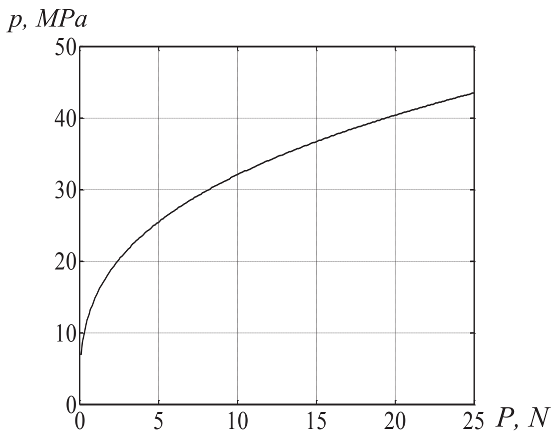


**Fig. 5.** Graph of pressure dependence on the area of contact *p* according to normal force of compression *P*

It is significant that seed and groove form an ellipse of contact with semiaxes $a_1$, $b_1$, reduction of mechanical stress and pressure *p* decreases with more distance from the contact area (Figure 4). With increasing normal force *P* (Figure 5), groove's pressure on the seed will also increase, and contact stresses occurring in fruit shell will be transmitted to the core and this can lead to its destruction.

## CONCLUSIONS

We revealed geometric relationship between an ellipsoidshaped seed and grooved working surfaces parameters that make it impossible to turn the seed on its axis. Mathematical formulas of curvatures $K_1$, $K_2$ of ellipse of contact between grooves with step *t* are obtained , as well as the dependences of the contact pressure *p* with respect to compressive normal force *P*.

A mathematical model of the interaction of milk thistle seed with grooved working surfaces allows us to substantiate the basic parameters of means for peeling the seeds of milk thistle - the height of the working surfaces grooves, the gap between the working surfaces.

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