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Optimization the Start-up Mode of Bucket Elevator by Criterion of Mean Rate of Change Efforts in Traction Body During Clash on Drive Drum

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Summary. The oscillations of the structural elements, the drive mechanism and the traction body are minimized by optimizing the movement modes of the grain elevator during transient processes, which made it possible to increase its efficiency. Based on the chosen dynamic model, a mathematical model was created using the d'Alamber's principle. The optimization process of the start-up mode of the bucket elevator was considered by the criterion of mean rate of change efforts in the traction body during clash on the drive drum. Found laws of motion for working branch, the tensioning drum and the drive drum which correspond to the optimal mode of movement of the bucket elevator. Based on the discovered laws of motion were built kinematical characteristics of the main parts of the elevator which are presented in the form of graphical dependencies for the optimal motion mode. The graphical dependencies of the effort changes in the traction body during clash on the drive drum and shrinkage from the tensioning drum also received. Based on the graphical dependencies established that during start-up bucket elevator at the optimal mode of motion there are small oscillating processes that are the smallest just in the optimization by the criterion of mean rate of change efforts in the traction body during clash on the drive drum.

Key words: bucket elevator, dynamic model, mathematical model, motion mode, dynamic load, effort, oscillation.

INTRODUCTION

To improve the technological of processing and transportation of grain is advisable to increase the efficiency of work the bucket elevator. During the motion oscillations occur in the elements of the drive mechanism, traction body and supporting structures, which lead to increasing dynamic loads [1]. These loads are most significant during transition processes (start, braking or locking, switch from one speed to another), which leads to the accumulation of fatigue stresses in the construction of the elevator. This in turn leads to premature destruction of it, and complicates the technological process of transportation of grain material (rashes and damage the grain), which negatively affects the safe operation of the elevator as a whole.

The minimize oscillations of structural elements, drive mechanism and traction body can be through optimization of movement grain elevator during transition processes that will improve its efficiency.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Works Khorolsky I. M., Kondrahin V. P., Spivakovsky A. O. and others [2-6] were devoted to simulation of working process elevator as multimass system with closed loop. In work [7] the optimization of mode start-up is reduced to finding the minimum time start conveyor under different conditions (strength ribbon, no slip ribbon on the drum, and the maximum moment of the motor). But at the calculation are used statistical indicators of conveyor, which do not fully reflect dynamic processes of vertical belt bucket elevators.

In [8] the mathematical model of the motion of the bucket elevator where accepted statistical mechanical characteristic of the drive motor is not fully reflects the movement of the elevator. Therefore there is a need to use the dynamic characteristics of the drive motor, which is enough to reflect the dynamic processes at the time of launch.

For optimization the modes of motion of the lifting machines used the methods of dynamic programming [9], the maximum principle [10] and the calculus of variations [11-14].

The most appropriate method to eliminate of oscillations in the elements of the bucket elevator is the calculus of variations, because at the decision of problems in the final result will getting smooth functions of changes kinematics characteristics.

The traction body (ribbon) is the main element of grain elevator, that's why the modes of motion for optimization appropriate to use criteria that reflect the dynamic load in the traction body.

OBJECTIVE

Improve the efficiency of the bucket elevator by optimizing the mode of motion of drive mechanism.

THE MAIN RESULTS OF THE RESEARCH

For optimization the modes of motion of the bucket elevator selected the dynamic model. We will consider that all elements of the bucket elevator are absolutely rigid bodies besides ribbon and drive mechanism. All inertial masses are reduced to axis of rotation of the drive drum. The rigidity of drive mechanism reduces to this axis too. We consider that slip between the ribbon and the drive and tension drums are absent. Such assumption is provided the necessary preloading ribbon and enough clutches between drive and tension drums with ribbon. Mass of buckets and areas between ribbons is replaced one weight, which is concentrated in their center of mass at the working and non-working branches of the conveyor. Rigidity of the ribbon on the working and non-working branches of the conveyor consider the same.

Ignored the transverse vibrations of the buckets and ribbon, because they are minor compared to the main movement and they are more dependent on design features of the elevator but not from the mode of movement.

The chain contour of ribbon with buckets and drums are represented as chain open-circuited contour in the dynamic model of the bucket elevator (Fig.1). Conditional cut of ribbon made at the point of clash the ribbon on the tension drum. This is accepted that the tension of the ribbon at this point is equal to pre-loading ribbon with device tensioning with a force F_0. Such assumption is accepted and used by many authors for the study of ribbon and chain conveyors [2].

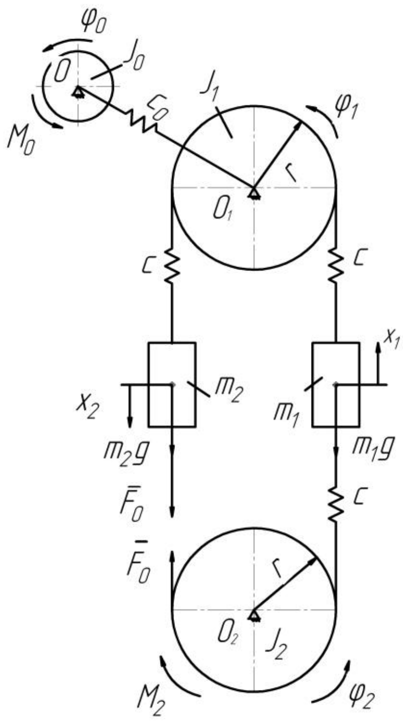


Fig. 1. Dynamic model of the bucket elevator

As a result of the accepted assumptions the bucket elevator consider as mechanical system with five degrees of freedom, which is presented as a dynamic model, shown in Fig. 1. For generalized coordinates was taken the angular coordinates of rotor of the electric motor, which are reduced to the axis of the drive drum φ_0 , drive drum $\varphi 1$ and tension drum φ_2 and also longitudinal the linear coordinates of the center of mass of the working and non-working branches of the bucket elevator.

For the purpose of differential equations of motion bucket elevator, dynamic model is presented in fig.1, we use the principle of dynamic equilibrium of d'Alembert. According to this principle the equations of motion have the form:

$$\begin{cases} J_0\ddot{\varphi}_0 = M_0 - c_0(\varphi_0 - \varphi_1), \\ J_1\ddot{\varphi}_1 = c_0(\varphi_0 - \varphi_1) - cr(\varphi_1 r - x_1) + cr(x_2 - \varphi_1 r), \\ m_1\ddot{x}_1 = c(\varphi_1 r - x_1) - c(x_1 - \varphi_2 r) - m_1 g, \\ m_2\ddot{x}_2 = F_0 + m_2 g - c(x_2 - \varphi_1 r), \\ J_2\ddot{\varphi}_2 = cr(x_1 - \varphi_2 r) - M_2 - F_0 r, \end{cases} \quad (1)$$

where: J_0 , J_1 , J_2 – moments of inertia relative to their axes of rotation of the drive mechanism, which was erected to the axis of rotation of the drive drum, drive and tension drum to accordance,

m_1, m_2, – the total masses of the working and non-working branches of the elevator to accordance,

c_0 – stiffness of elastic elements of the drive mechanism that reduced to the axis of rotation of the drive drum,

c – stiffness of half the length of ribbon on the working (non-working) branch of the conveyor,

M_0 – the driving moment on shaft of the motor that reduced to the axis of rotation of the drive drum,

M_2 – the moment of resistance from loading buckets that reduced to the axis of rotation of the tension drum,

r – the radius of the drive drum and tension drum, which were adopted equal,

g – acceleration of free fall.

Consider the optimization process the start-up mode of the bucket elevator by the criterion of mean rate of change efforts in the traction body during clash on the drive drum.

We will define the efforts in the traction body during clash on the drive drum from the third equation of the system (1):

$$R_{11} = c(\varphi_1 r - x_1) = m_1\ddot{x}_1 + c(x_1 - \varphi_2 r) + m_1 g. \quad (2)$$

From the last equation of the system (1) will find the coordinate x_1 through φ_2 and it second derivative for time:

$$x_1 = \varphi_2 r + \frac{J_2}{cr}\ddot{\varphi}_2 + \frac{M_2/r + F_0}{c}. \quad (3)$$

We will differentiate expression (3) for time, as a result we receive:

$$\begin{aligned} &\dot{x}_1 = \dot{\varphi}_2 r + \frac{J_2}{cr}\dddot{\varphi}_2,\ \ddot{x}_1 = \ddot{\varphi}_2 r + \frac{J_2}{cr}\overset{IV}{\varphi}_2, \\ &\dddot{x}_1 = \dddot{\varphi}_2 r + \frac{J_2}{cr}\overset{V}{\varphi}_2,\ \overset{IV}{x}_1 = \overset{IV}{\varphi}_2 r + \frac{J_2}{cr}\overset{VI}{\varphi}_2, \\ &\overset{V}{x}_1 = \overset{V}{\varphi}_2 r + \frac{J_2}{cr}\overset{VII}{\varphi}_2,\ \overset{VI}{x}_1 = \overset{VI}{\varphi}_2 r + \frac{J_2}{cr}\overset{VII}{\varphi}_2. \end{aligned} \quad (4)$$

Substituting the expressions (3) and (4) in depending (2), then we have:

$$R_{11} = \frac{m_1 J_2}{cr} \overset{IV}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right) r \ddot{\varphi}_2 + \frac{M_2}{r} + F_0 + m_1 g. \quad (5)$$

We will differentiate expression (5) for time, as a result we receive the depending of speed changes efforts in the traction body during clash on the drive drum:

$$\dot{R}_{11} = \frac{m_1 J_2}{cr} \overset{V}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right) r \dddot{\varphi}_2. \quad (6)$$

The mean rate of change efforts in the traction body during clash on the drive drum defined as an integrated functional:

$$\dot{R}_{11ск} = \left[\frac{1}{t_1} \int_0^{t_1} \dot{R}_{11}^2 dt \right]^{\frac{1}{2}}, \quad (7)$$

where: t – time,

t_1 – the duration of the transition process (start, braking, speed change, reverse).

The integrand expression of functional (7) is:

$$f = \dot{R}_{11}^2 = \left[\frac{m_1 J_2}{cr} \overset{V}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right) r \dddot{\varphi}_2 \right]^2. \quad (8)$$

Differentiating the expression (8) in compliance with the equation (9), we have:

$$\frac{\partial f}{\partial \varphi} = \frac{\partial f}{\partial \dot{\varphi}_2} = \frac{\partial f}{\partial \ddot{\varphi}_2} = \frac{\partial f}{\partial \overset{IV}{\varphi_2}} = 0,$$

$$\frac{\partial f}{\partial \dddot{\varphi}_2} = 2\left(m_1 + \frac{J_2}{r^2} \right) r \left[\frac{m_1 J_2}{cr} \overset{V}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right) r \dddot{\varphi}_2 \right],$$

$$\frac{\partial f}{\partial \overset{V}{\varphi_2}} = 2\frac{m_1 J_2}{cr} \left[\frac{m_1 J_2}{cr} \overset{V}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right) r \dddot{\varphi}_2 \right], \quad (10)$$

$$\frac{d^3}{dt^3} \frac{\partial f}{\partial \dddot{\varphi}_2} = 2\left(m_1 + \frac{J_2}{r^2} \right) r \left[\frac{m_1 J_2}{cr} \overset{VIII}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right) r \overset{IV}{\varphi_2} \right],$$

$$\frac{d^5}{dt^5} \frac{\partial f}{\partial \overset{V}{\varphi_2}} = 2\frac{m_1 J_2}{cr} \left[\frac{m_1 J_2}{cr} \overset{X}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right) r \overset{VIII}{\varphi_2} \right].$$

After substituting expression (10) in equation (9) we obtain the differential equation tenth order:

$$\left(\frac{m_1 J_2}{cr} \right)^2 \overset{X}{\varphi_2} + 2\frac{m_1 J_2}{cr} \left(m_1 + \frac{J_2}{r^2} \right) \cdot r \cdot \overset{VIII}{\varphi_2} + \left(m_1 + \frac{J_2}{r^2} \right)^2 r^2 \overset{VI}{\varphi_2} = 0. \quad (11)$$

Divide all the members of (11) on the coefficient near oldest derivative and will made a substitution:

$$k = \sqrt{\frac{m_1 + J_2/r^2}{m_1 J_2} cr^2} = \sqrt{\frac{m_1 r^2 + J_2}{m_1 J_2} c}, \quad (12)$$

we got

$$\overset{X}{\varphi_2} + 2k^2 \overset{VIII}{\varphi_2} + k^4 \overset{VI}{\varphi_2} = 0. \quad (13)$$

Equation (13) is a homogeneous differential equation tenth order with constant coefficients. For it solution will make the characteristic equation $r^{10} + 2k^2 r^8 + k^4 r^6 = 0,$ which can be written in this form:

$$r^6 \left(r^4 + 2k^2 r^2 + k^4 \right) = 0. \quad (14)$$

Solution of equation (14) gives:

$$r^6 = 0, \quad (15)$$

$$r^4 + 2k^2 r^2 + k^4 = 0. \quad (16)$$

From equation (15) we'll have six roots:

$$r_1 = r_2 = r_3 = r_4 = r_5 = r_6 = 0, \quad (17)$$

and the equation (16) is biquadrate equation which after the replacement $p = r^2$, have a form $p^2 + 2k^2 p + k^4 = 0.$

Solution of this equation gives:

$$p_{1,2} = -k^2 \pm \sqrt{k^4 - k^4} = -k^2,$$

$$p_1 = p_2 = -k^2.$$

Then

$$r_{7,8} = \sqrt{p_1} = \sqrt{-k^2} = \pm k_i,$$
$$r_{9,10} = \sqrt{p_2} = \sqrt{-k^2} = \pm k_i. \quad (18)$$

As a result, the general solution of equation (13), based on the roots (17) and (18) of the characteristic equation (14), has the form:

$$
\begin{gathered}
\varphi_2 = C_1 + C_2 t + C_3 t^2 + C_4 t^3 + C_5 t^4 + C_6 t^5 + \\
+ (C_7 + C_8 t)\sin kt + (C_9 + C_{10} t)\cos kt
\end{gathered},
$$

$$
\begin{gathered}
\dot{\varphi}_2 = C_2 + 2C_3 t + 3C_4 t^2 + 4C_5 t^3 + \\
+ 5C_6 t^4 + (C_8 - C_9 k - C_{10} kt)\sin kt + \\
+ (C_{10} + C_7 k + C_8 kt)\cos kt
\end{gathered},
$$

$$
\begin{gathered}
\ddot{\varphi}_2 = 2C_3 + 6C_4 t + 12C_5 t^2 + 20C_6 t^3 - \\
- (2C_{10} + C_7 k + C_8 kt)k\sin kt + \\
+ (2C_8 - C_9 k - C_{10} kt)k\cos kt
\end{gathered},
$$

$$
\begin{gathered}
\dddot{\varphi}_2 = 6C_4 + 24C_5 t + 60C_6 t^2 - \\
- (3C_8 - C_9 k - C_{10} kt)k^2 \sin kt - \\
- (3C_{10} + C_7 k + C_8 kt)k^2 \cos kt
\end{gathered}, \quad (19)
$$

$$
\begin{gathered}
\overset{IV}{\varphi}_2 = 24C_5 + 120C_6 t + \\
+ (4C_{10} + C_7 k + C_8 kt)k^3 \sin kt - \\
- (4C_8 - C_9 k - C_{10} kt)k^3 \cos kt,
\end{gathered}
$$

$$
\begin{gathered}
\overset{V}{\varphi}_2 = 120C_6 + (5C_8 - C_9 k - C_{10} kt)k^4 \sin kt - \\
- (5C_{10} + C_7 k + C_8 kt)k^4 \cos kt,
\end{gathered}
$$

where: $C_1, C_2, \ldots, C_{10}$ – constant of integration which found from the boundary conditions of motion:

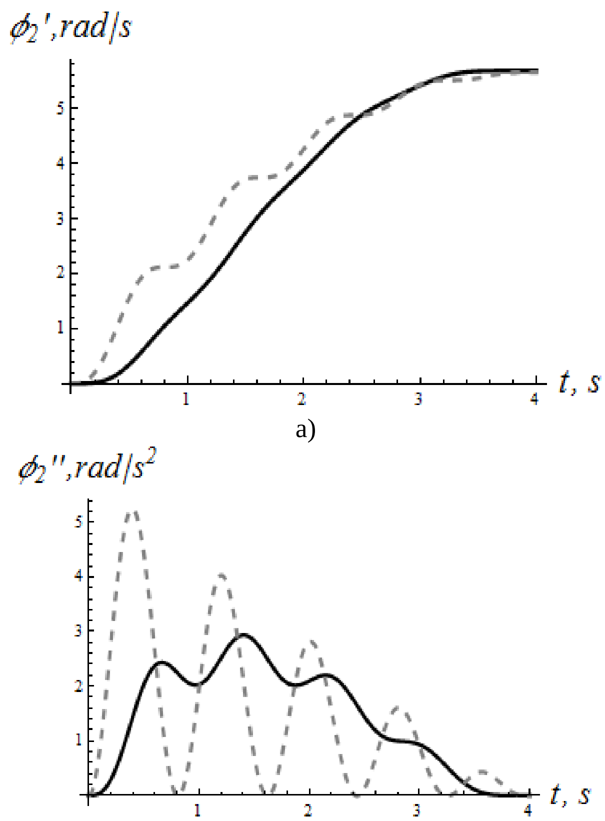
$$
\begin{cases}
t = 0 : \varphi_2 = 0, \dot{\varphi}_2 = 0, \ddot{\varphi}_2 = 0, \dddot{\varphi}_2 = 0, \overset{IV}{\varphi}_2 = 0, \\
t = t_1 : \dot{\varphi}_2 = \omega_y, \ddot{\varphi}_2 = 0, \dddot{\varphi}_2 = 0, \overset{IV}{\varphi}_2 = 0, \overset{V}{\varphi}_2 = 0.
\end{cases} \quad (20)
$$

where: ω_y – the established angular velocity of the tensioning drum,

t_1 – the duration of the transition process (start-up).

Substituting the boundary conditions (20) in the system of dependencies of kinematic characteristics of the tensioning drum (19), we obtain a system of linear equations to determine the constants C_i $(i=1, 2, \ldots, 10)$:

$$
\begin{cases}
C_1 + C_9 = 0, \\
C_2 + C_{10} + C_7 k = 0, \\
2C_3 + 2C_8 k - C_9 k^2 = 0, \\
6C_4 - 3C_{10} k^2 - C_7 k^3 = 0, \\
24C_5 - 4C_8 k^3 + C_9 k^4 = 0, \\
C_2 + 2C_3 t_1 + 3C_4 t_1^2 + 4C_5 t_1^3 + \\
+ 5C_6 t_1^4 + (C_8 - C_9 k - C_{10} kt_1)\sin kt_1 + \\
+ (C_{10} + C_7 k + C_8 kt_1)\cos kt_1 = \omega_y, \\
2C_3 + 6C_4 t_1 + 12C_5 t_1^2 + 20C_6 t_1^3 - \\
- (2C_{10} + C_7 k + C_8 kt_1)k\sin kt_1 + \\
+ (2C_8 - C_9 k - C_{10} kt_1)k\cos kt_1 = 0, \\
6C_4 + 24C_5 t_1 + 60C_6 t_1^2 - \\
- (3C_8 - C_9 k - C_{10} kt_1)k^2 \sin kt_1 - \\
- (3C_{10} + C_7 k + C_8 kt_1)k^2 \cos kt_1 = 0, \\
24C_5 + 120C_6 t_1 + \\
+ (4C_{10} + C_7 k + C_8 kt_1)k^3 \sin kt_1 - \\
- (4C_8 - C_9 k - C_{10} kt_1)k^3 \cos kt_1 = 0, \\
120C_6 + (5C_8 - C_9 k - C_{10} kt_1)k^4 \sin kt_1 + \\
+ (5C_{10} + C_7 k + C_8 kt_1)k^4 \cos kt_1 = 0.
\end{cases} \quad (21)
$$



b)

Fig. 2. Graphs of changes kinematic characteristics of the tensioning drum: a) speed, b) acceleration

As a result of solving the system of equations (21) we find the constants of integration C_i *(i=1,2,...,10)* and substitute the depending (19).

The (19) is the optimization the mode of motion of the bucket elevator by criterion of mean rate of change efforts in the traction body during clash on the drive drum during start-up.

For the bucket elevator with parameters that were calculated [15]: $J_o=65\ kg{\cdot}m^2$, $J_1=78{,}4\ kg{\cdot}m^2$, $J_2=78{,}4\ kg{\cdot}m^2$, $\omega_y=5{,}7\ rad/s$, $R=0{,}315\ m$, $c_0=2000\ N{\cdot}m/rad$, $c=330000\ N/m$, $n_1=32$, $n_2=32$, $m_в=9\ kg$, $m_к=9\ kg$ in the program of the *Mathematica 9.0* [16] were calculated kinematic characteristics that are represented as graphs which are shown in the Fig. 2.

These graphs show characteristics for optimal mode of motion by the criterion of mean efforts in the traction body – the dotted line, and by the criterion of mean rate of change efforts – a solid line.

Knowing the law of motion of the tensioning drum, which corresponds to the optimal mode of motion of the bucket elevator by a system of differential equations (1) we find the laws of motion of other parts.

Law of motion of the working branch is defined from dependencies (3) and (4) and represented as graphs on the Fig. 3.

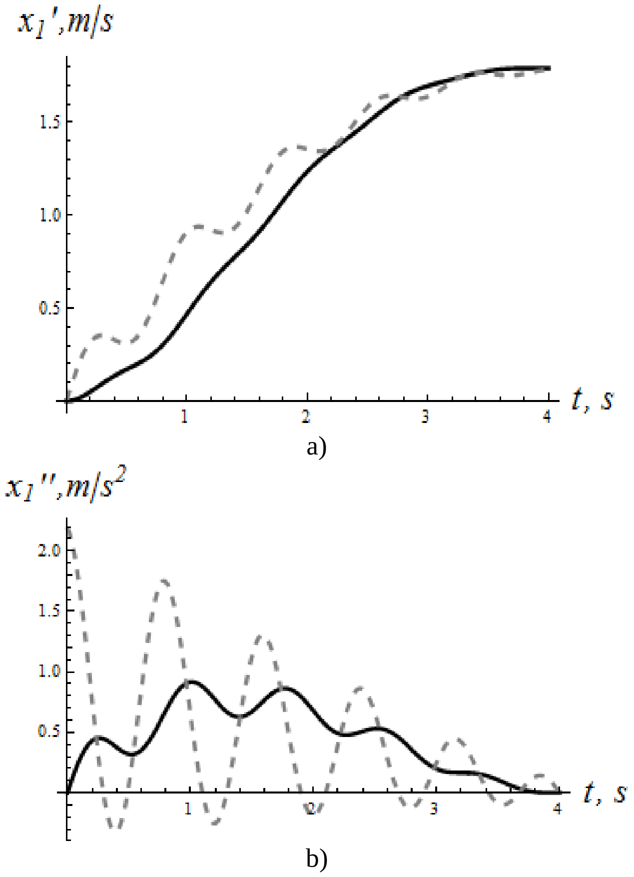


Fig. 3. Graphs of changes kinematic characteristics of the working branch: a) speed, b) acceleration

And the law of motion of the drive drum will defined from the third equation (1) and represented as graphs on the Fig. 4:

$$
\begin{gathered}
\varphi_1=-\varphi_2+2\frac{x_1}{r}+\frac{m_1}{cr}\left(\ddot{x}_1+g\right),\\
\dot{\varphi}_1=-\dot{\varphi}_2+2\frac{\dot{x}_1}{r}+\frac{m_1}{cr}\dddot{x}_1,\ \ddot{\varphi}_1=-\ddot{\varphi}_2+2\frac{\ddot{x}_1}{r}+\frac{m_1}{cr}\overset{IV}{x}_1, \qquad (22)\\
\dddot{\varphi}_1=-\dddot{\varphi}_2+2\frac{\dddot{x}_1}{r}+\frac{m_1}{cr}\overset{V}{x}_1,\ \overset{IV}{\varphi}_1=-\overset{IV}{\varphi}_2+2\frac{\overset{IV}{x}_1}{r}+\frac{m_1}{cr}\overset{VI}{x}_1.
\end{gathered}
$$

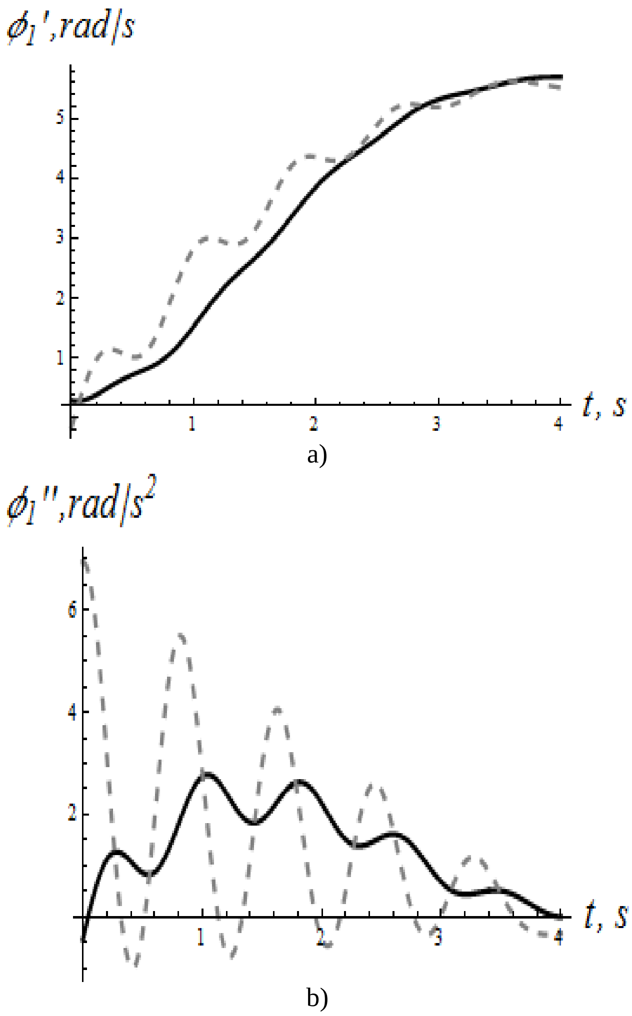


Fig. 4. Graphs of changes kinematic characteristics of the drive drum: a) speed, b) acceleration

Solving the penultimate equation of system (1), we found the law of motion non-working branch of elevator:

$$m_2\ddot{x}_2+cx_2=cr\varphi_1+m_2g+F_0. \qquad (23)$$

Substitute into the equation (26) the expression φ_1 from the system (22) considering of expressions x_1 and $\ddot{x}_1$ at (3) and (4), resulting we have:

$$
\begin{gathered}
m_2\ddot{x}_2+cx_2=cr\varphi_2+\left(2\frac{J_2}{r^2}+m_1\right)r\ddot{\varphi}_2+\\
+\frac{m_1J_2}{cr}\overset{IV}{\varphi}_2+m_2g+2\frac{M_2}{r}+3F_0.
\end{gathered} \qquad (24)
$$

Then substitute into the equation (24) expressions φ_2, $\ddot{\varphi}_2$ and $\overset{IV}{\varphi_2}$ from the system (19), so we have:

$$m_2\ddot{x}_2 + cx_2 = cr\begin{bmatrix} C_1 + C_2t + C_3t^2 + C_4t^3 + \\ (C_5 + C_6t)\sin kt + \\ +(C_7 + C_8t)\cos kt \end{bmatrix} +$$
$$+\left(m_1 + 2\frac{J_2}{r^2}\right)r\begin{bmatrix} 2C_3 + 6C_4t - \\ -(2C_8 + C_5k + C_6kt)k\sin kt + \\ +(2C_6 - C_7k - C_8kt)k\cos kt \end{bmatrix} +$$
$$+\frac{m_1J_2}{cr}\begin{bmatrix} (4C_8 + C_5k + C_6kt)k^3\sin kt - \\ -(4C_6 - C_7k - C_8kt)k^3\cos kt \end{bmatrix} +$$
$$+m_2g + 2\frac{M_2}{r} + 3F_0$$

$$m_2\ddot{x}_2 + cx_2 = \begin{bmatrix} crC_1 + \\ +2C_3\left(m_1 + 2\frac{J_2}{r^2}\right)r + \\ +m_2g + 2\frac{M_2}{r} + 3F_0 \end{bmatrix} +$$
$$+\left[crC_2 + 6C_4r\left(m_1 + 2\frac{J_2}{r^2}\right)\right]t +$$
$$+crC_3t^2 + crC_4t^3 +$$
$$+\left\{\begin{bmatrix} crC_5 - (2C_8 + C_5k)kr\left(m_1 + 2\frac{J_2}{r^2}\right) + \\ +(4C_8 + C_5k)k^3\frac{m_1J_2}{cr} \end{bmatrix} + \right.$$
$$\left. +\begin{bmatrix} crC_6 - C_6k^2r\left(m_1 + 2\frac{J_2}{r^2}\right) + \\ +C_6k^4\frac{m_1J_2}{cr} \end{bmatrix}t\right\}\sin kt +$$
$$+\left\{\begin{bmatrix} crC_7 + (2C_6 - C_7k)kr\left(m_1 + 2\frac{J_2}{r^2}\right) - \\ -(4C_6 - C_7k)k^3\frac{m_1J_2}{cr} \end{bmatrix} + \right.$$
$$\left. +\begin{bmatrix} crC_8 - C_8k^2r\left(m_1 + 2\frac{J_2}{r^2}\right) + \\ +C_8k^4\frac{m_1J_2}{cr} \end{bmatrix}t\right\}\cos kt$$

$$\begin{aligned} m_2\ddot{x}_2 + cx_2 &= a_0 + a_1t + a_2t^2 + a_3t^3 + \\ &+(a_4 + a_5t)\sin kt + (a_6 + a_7t)\cos kt \end{aligned} \tag{25}$$

We write the equation (25) in this form:

$$\begin{aligned} \ddot{x}_2 + k_1^2x_2 &= a_0 + a_1t + a_2t^2 + a_3t^3 + \\ &+(a_4 + a_5t)\sin kt + (a_6 + a_7t)\cos kt \end{aligned} \tag{26}$$

Here $$k_1 = \sqrt{m_2/c}\,. \tag{27}$$

The general solution of (29) we looking as the sum of a full solution of the homogeneous equation and a partial solution of the full equation, so:

$$x_2 = x_2^* + x_2^{**} \tag{28}$$

The homogeneous equation $\ddot{x}_2^* + k_1^2x_2^* = 0$. We write to him the characteristic equation $r^2 + k^2 = 0$, whence $r_{1,2} = \pm k_i$. Then the general solution of the homogeneous equation is:

$$x_2^* = A_1\sin k_1t + A_2\cos k_1t, \tag{29}$$

where: A_1 i A_2 – constants which determined from initial conditions of movements.

Based on the type of the right side of the equation (29), his partial solution has the form:

$$\begin{aligned} x_2^{**} &= B_0 + B_1t + B_2t^2 + B_3t^3 + \\ &+(B_4 + B_5t)\sin kt + (B_6 + B_7t)\cos kt \end{aligned} \tag{30}$$

We will differentiate expression (5) for time twice, as a result we receive:

$$\begin{aligned} \ddot{x}_2^{**} &= 2B_2 + 6B_3t - \left(2B_7k + B_4k^2 + B_5k^2t\right)\sin kt + \\ &+\left(2B_5k - B_6k^2 - B_7k^2t\right)\cos kt \end{aligned} \tag{31}$$

Substituting expressions (33) and (34) in equation (29), then we have:

$$\begin{aligned} &2B_2 + 6B_3t - \begin{pmatrix} 2B_7k + \\ +B_4k^2 + B_5k^2t \end{pmatrix}\sin kt + \\ &+\left(2B_5k - B_6k^2 - B_7k^2t\right)\cos kt + \\ &+k_1^2\begin{bmatrix} B_0 + B_1t + B_2t^2 + B_3t^3 + \\ +(B_4 + B_5t)\sin kt + \\ +(B_6 + B_7t)\cos kt \end{bmatrix} = \\ &= a_0 + a_1t + a_2t^2 + a_3t^3 + \\ &+(a_4 + a_5t)\sin kt + \\ &+(a_6 + a_7t)\cos kt. \end{aligned} \tag{32}$$

We group the components of the left side of the equation (32) according to the components of the right side of the equation and then obtain:

$$\begin{cases} 2B_2 + B_0 k_1^2 = a_0, \\ 6B_3 + B_1 k_1^2 = a_1, \\ B_2 k_1^2 = a_2,\ B_3 k_1^2 = a_3, \\ -\left(2B_7 k + B_4 k^2\right) + B_4 k_1^2 = a_4, \\ -B_5 k^2 + B_5 k_1^2 = a_5, \\ \left(2B_5 k - B_6 k^2\right) + B_6 k_1^2 = a_6, \\ -B_7 k^2 + B_7 k_1^2 = a_7. \end{cases} \tag{33}$$

Having solved a system of linear equations, we find:

$$\begin{aligned} B_0 &= \frac{a_0 - 2a_2/k_1^2}{k_1^2}, \\ B_1 &= \frac{a_1 - 6a_3/k_1^2}{k_1^2}, \\ B_2 &= \frac{a_2}{k_1^2},\ B_3 = \frac{a_3}{k_1^2}, \\ B_4 &= \frac{2ka_7/\left(k_1^2 - k^2\right) + a_4}{k_1^2 - k^2}, \\ B_5 &= \frac{a_5}{k_1^2 - k^2}, \\ B_6 &= \frac{a_6 - 2ka_7/\left(k_1^2 - k^2\right)}{k_1^2 - k^2}, \\ B_7 &= \frac{a_7}{k_1^2 - k^2}. \end{aligned} \tag{34}$$

Then the general solution of equation (26) has the form:

$$\begin{aligned} x_2 &= A_1 \sin k_1 t + A_2 \cos k_1 t + B_0 + B_1 t + B_2 t^2 + \\ &+ B_3 t^3 + \left(B_4 + B_5 t\right)\sin kt + \left(B_6 + B_7 t\right)\cos kt \end{aligned} \tag{35}$$

Take the time derivative of the expression (35):

$$\begin{aligned} \dot{x}_2 &= A_1 k_1 \cos k_1 t - A_2 k_1 \sin k_1 t + B_1 + 2B_2 t + 3B_3 t^2 + \\ &+ \left(B_5 - B_6 k - B_7 kt\right)\sin kt + \left(B_7 + B_4 k + B_5 kt\right)\cos kt; \\ \ddot{x}_2 &= -A_1 k_1^2 \sin k_1 t - A_2 k_1^2 \cos k_1 t + 2B_2 + 6B_3 t - \\ &- \left(2B_7 + B_4 k + B_5 kt\right)k \sin kt + \left(2B_5 - B_6 k - B_7 kt\right)k \cos kt. \end{aligned} \tag{36}$$

The unknown constants A_1 and A_2 determined from initial conditions of motion:

$$t = 0 : x_2 = \dot{x}_2 = 0. \tag{37}$$

Having substituted the initial conditions (40) in the depending (38) and (39) we get:

$$\begin{cases} A_2 + B_0 + B_6 = 0; \\ A_1 k_1 + B_1 + B_7 + B_4 k = 0. \end{cases} \tag{38}$$

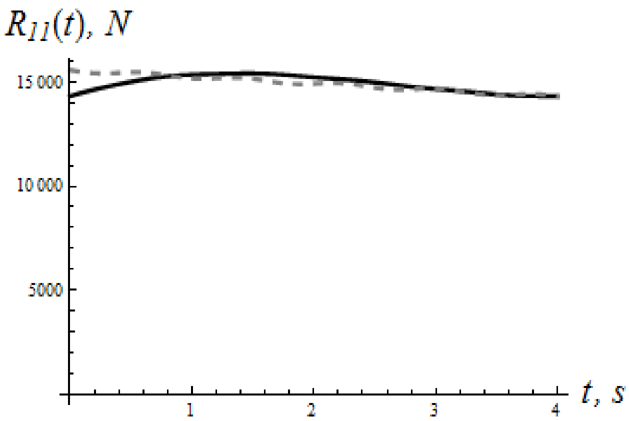
From the system (41) we have:

$$\begin{aligned} A_1 &= -\left(B_1 + B_7 + B_4 k\right)/k_1; \\ A_2 &= -B_0 - B_6. \end{aligned} \tag{39}$$

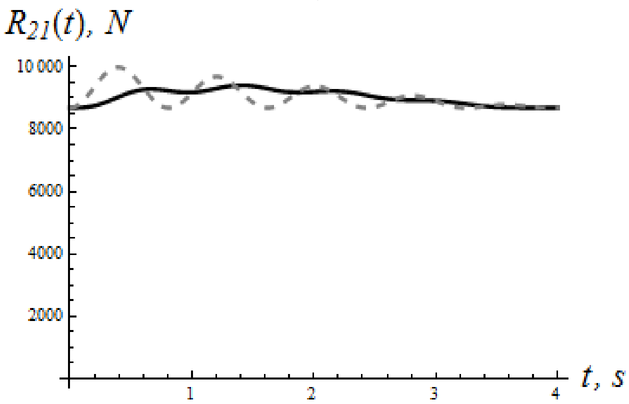
After finding the law of motion the non-working branch of elevator we can define the law of motion of the rotor of the electric motor that reduced to the axis of the drive drum.

For this we use the second equation of (1):

$$\begin{aligned} \varphi_0 &= \varphi_1\left(1 + 2\frac{cr^2}{c_0}\right) + \frac{J_1}{c_0}\ddot{\varphi}_1 - \frac{cr}{c_0}\left(x_1 + x_2\right), \\ \dot{\varphi}_0 &= \dot{\varphi}_1\left(1 + 2\frac{cr^2}{c_0}\right) + \frac{J_1}{c_0}\dddot{\varphi}_1 - \frac{cr}{c_0}\left(\dot{x}_1 + \dot{x}_2\right), \\ \ddot{\varphi}_0 &= \ddot{\varphi}_1\left(1 + 2\frac{cr^2}{c_0}\right) + \frac{J_1}{c_0}\overset{IV}{\varphi}_1 - \frac{cr}{c_0}\left(\ddot{x}_1 + \ddot{x}_2\right). \end{aligned} \tag{40}$$



a)



b)

Fig. 5. Graphs of change of efforts in the traction body: a) during clash on the drive drum, b) at shrinkage of the tensioning drum

Table 1. The mean and maximum values for optimal regimes

Indexes	Criteria for evaluation			
	The mean efforts in the traction body		The mean rate of change efforts in traction body	
	The mean value	The maximum value	The mean value	The maximum value
$\dot{x}_1$, *m/s*	1.311	1.784	1.246	1.793
$\ddot{x}_1$, *m/s²*	0.733	2.184	0.525	0.918
$\dot{\varphi}_1$, *rad/s*	4.116	5.622	3.909	5.693
$\ddot{\varphi}_1$, *rad/s²*	2.365	6.941	1.575	2.777
$\dot{\varphi}_2$, *rad/s*	4.184	5.664	3.983	5.693
$\ddot{\varphi}_2$, *rad/s²*	2.029	5.246	1.712	2.935
R_{11}, *N*	14944	15586	14947	15425
R_{21}, *N*	9042	9988	9039	9413

Now can find dependences of changes of resilient and driving moments of the drive mechanism from using the first equation of the system (1):

$$M_{01} = c_0(\varphi_0 - \varphi_1), \tag{41}$$

$$M_0 = M_{01} + J_0\ddot{\varphi}_0. \tag{42}$$

Effort in the traction body during clash on the drive drum is defined by the following expression (Fig. 5. a):

$$R_{11} = c(\varphi_1 r - x_1). \tag{23}$$

Efforts in traction body at shrinkage of the tensioning drum (Fig. 5. b):

$$R_{21} = c(x_1 - \varphi_2 r). \tag{24}$$

In the program Mathematica 9.0 for optimal mode of motion was calculated the mean and the maximum values of the following indicators:

- angular velocity and acceleration of the drive and tensioning drums,
- linear velocity and acceleration consolidated mass of working branches,
- efforts in the traction body during clash on the drive drum and at shrinkage of the tensioning drum.

As a result of the calculations obtained data are presented in the Table 1.

From the graphic of dependencies can see that at start-up of the bucket elevator in its moving parts there are oscillatory processes.

The magnitude of these oscillations depends on the accuracy of modelling parts of the conveyor.

To simplify the optimization mode of motion by criterion of mean rate of change efforts in the traction body during clash on the drive drum is used a dynamic model with one mass on the working and non-working branches in accordance.

After analysing the graphs can see that oscillatory processes occurring during optimization the mode of start-up by the criterion of mean efforts in the traction body is greater than during optimization by the criterion of mean rate of change efforts.

The maximum value of acceleration on the working branch and on the drive drum during optimization effort in the traction body is 2.5 times higher than the same value at optimization of rate of change efforts.

Also, the maximum value of efforts in the traction body at shrinkage of the tensioning drum at the first criterion is 4% higher than in the second.

It should be noted that the graphs of change efforts in the traction body during clash on the drive drum have smaller fluctuations than at the shrinkage of the tensioning drum.

CONCLUSIONS

1. The dynamic model the mode of motion of the bucket elevator was constructed as mechanical system with five degrees of freedom. For optimization the mode of motion of the bucket elevator by the criterion of mean rate of change efforts in the traction body during clash on the drive drum was created a mathematical model, which based on the chosen dynamic model. Using the developed mathematical model obtained dependences of kinematic and force characteristics of parts for this optimal mode. Analyzing the results can see that optimization for both criteria of evaluation leads to oscillations, but in the second case (rate of change), these oscillations are much smaller.
2. In order to get rid of these oscillations is recommended to optimize the mode of motion by the criterion of mean acceleration the rate of change efforts in the traction body during clash on the drive drum.
3. Also it is necessary be noted that during conducted research was obtained optimal mode of motion at a constant force of resistance downloading the grain. It would be advisable to consider the impact of variable resistance downloading the grain, as is done for scraper conveyors in [17-20].

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ОПТИМИЗАЦИЯ РЕЖИМА ЗАПУСКА КОВШОВОГО ЭЛЕВАТОРА ПО КРИТЕРИЮ СРЕДНЕЙ СКОРОСТИ ИЗМЕНЕНИЯ УСИЛИЯ В ТЯГЕ ТЕЛА ВО ВРЕМЯ СТОЛКНОВЕНИЯ НА ПРИВОДНОЙ БАРАБАН

Вячеслав Ловейкин, Юрий Ловейкин, Леся Ткачук

Аннотация. Колебания структурных элементов, механизма привода и тягового органа сведены к минимуму путем оптимизации режимов движения на элеватор во время переходных процессов, что позволило повысить его эффективность. В зависимости от выбранной динамическая модель, математическая модель была создана с помощью принципа д'Аламбера. Процесс оптимизации пускового режима ковшового элеватора был рассмотрен критерий Средняя скорость изменения усилия на тяговый орган во время столкновения на приводном барабане. Найдены законы движения рабочей ветви, натяжной барабан и приводной барабан, который соответствует оптимальному режиму движения в ковшовый элеватор. На основе обнаруженных законов движения были построены кинематические характеристики основных частей лифта, которые представлены в виде графических зависимостей для оптимального режима движения. Графические зависимости изменения усилий на тяговый орган в ходе столкновения на приводном барабане и усадка из натяжного барабана также получил. На основе графических зависимостей установлено, что при пуске ковшового элеватора при оптимальном режиме движения есть небольшие колебательные процессы, которые являются самыми маленькими, всего в оптимизации по критерию средней скорости изменения усилия на тяговый орган в ходе боестолкновения на приводном барабане.

Ключевые слова: ковшовый элеватор, динамическая модель, математическая модель, режим движения, динамических нагрузок, усилий, колебаний.

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Construction of Minimal Surfaces Using Flat Curves with Constant Complex Curvature

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Summary. Analytical description of isotropic lines and minimal surfaces by means of functions of complex variable is made. To find the isotropic lines analytical description parametric equations of a flat curve given by functions of natural parameter with constant complex curvature are used. Isotropic lines parametric equations are obtained from the condition of spatial curve differential arc equality to zero. Analytical description of minimal surfaces and associated minimal surfaces are made in complex space with isotropic lines of a transferring grid.

Demanding performing Cauchy-Riemann's conditions of differentiation for isotropic lines equations with constant complex curvature, analytical description of isotropic lines with real and imaginary parts of the complex variable was found. For stated isotropic lines analytical description of minimal surfaces and associated minimal surfaces was made. It was investigated that minimal surfaces and associated minimal surfaces formed from isotropic line with help of real part of complex variable is catenoid and right helicoid. Expressions of the first and second quadratic forms coefficients of generated minimal surfaces were found. It is shown that the mean of formed surfaces curvatures is zero at all points. Analytical description of one-parameter set of a associated minimal surfaces formed under their continuous bending, was made.

The proposed method of parametric equations of isotropic curves based on flat curves with constant complex curvature ($a \in R,\ b \in R,\ i -$ imaginary unit) allows to determine analytical description of flat lines defined by natural parameter functions of a in complex space.

Minimal surfaces parametric equations were found in the form of elementary functions, allowing to explore their geometric properties and differential characteristics to optimize the engineering methods of technical forms and architectural constructions design.

Key words: isotropic line, minimal surface, function of complex variable, constant complex curvature, Cauchy–Riemann equations, catenoid, right helicoid.

INTRODUCTION

Development of methods for geometric modeling is an important challenge to find the optimum solution to problems of transport logistics and design of surfaces of technical forms and architectural constructions according to postulated conditions. In particular, the graphs are used to study patterns of traffic [1] and for modeling parameters of technological solutions in construction [2]. Differential curves and surfaces characteristics were taken into account when designing technical surfaces forms in works [3-5]. Ability to find parameters of geometric models by means of computer-aided design is shown in the study [6].

Geometric models described by minimal surfaces can be used in CAD systems, while designing surfaces of technical forms and architectural constructions to solve the problems of finding the smallest surface area, which pass through a given flat or spatial curve.

Geometrical shape of a minimal surface, the mean curvature at all its points is equal to zero, ensures even distribution of efforts in the shell of surface and extra rigidity [7].

Setting minimum surface by the function $z = z(x;\ y)$, J. Lagrange was one of the first who concluded that the function $z = z(x;\ y)$ must satisfy the differential equation of Euler-Lagrange [8, p. 683] in partial derivatives, which generally are not integrated.

Therefore, one of the modern ways of minimal surfaces description is improvement of numerical methods for solving Euler-Lagrange differential equations [9, 10] and learning applications of designing of architectural structures surfaces [11, 12].

Analytical description of minimal surfaces can be obtained using complex variable in form of elementary functions, simplifying the research of geometrical and differential properties of formed minimal surfaces.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

In works [13, 14] in some cases parametric equations for isotropic lines according to Schwartz and Weierstrass formulas were found and corresponding minimal surfaces using the properties of complex variable were built.

Modeling of minimal surfaces with the help of Bezier curves of the third order were reviewed in the work [15].

The method of analytical description of minimal surfaces using isotropic curves that lie on the surfaces of revolution assigned to isometric grid lines were represented in the works [16-18].

In the work [19] for analytical description of isotropic lines parametric equations of logarithmic spiral defined by natural parameter functions with real values of the curvature was used.

It is necessary to research an opportunity to study analytical description of isotropic lines and corresponding minimal surfaces using flat curves with constant complex curvature.

OBJECTIVE

Find analytical description of isotropic lines using parametric equations of flat curve given by functions of a natural parameter with constant complex curvature value $a+bi$ ($a \in R,\ b \in R,\ i -$ imaginary unit). With the help of found isotropic lines find analytical description of minimal surfaces.

THE MAIN RESULTS OF THE RESEARCH

Consider a plane curve, given by constant complex value of the curvature: $k(s)=a+bi,$ де $a \in R, b \in R,$ $i -$ imaginary unit, $s -$ length of the arc curve.

Then the curvature of the flat curve $k(s)$ is defined by the formula [20, p. 39]:

$$k(s)=\frac{d\varphi}{ds}, \qquad (1)$$

where: $\varphi -$ angle between the tangent to the curve and the abscissa.

Demanding meeting the condition $\varphi(0)=0,$ get parametric equations of a flat curve [20, p. 48] from the natural parameter s:

$$\begin{aligned} x(s) &= x(0)+\int_0^s \cos\left[\int_0^s k(s)ds\right]\cdot ds, \\ y(s) &= y(0)+\int_0^s \sin\left[\int_0^s k(s)ds\right]\cdot ds. \end{aligned} \qquad (2)$$

Substitute the value of complex curvature $k(s)=a+bi$ in (2), then under meeting the conditions $x(0)=0$ and $y(0)=0,$ obtain:

$$\begin{aligned} x(s) &= \frac{1}{a+bi}\cdot\sin[(a+bi)\cdot s], \\ y(s) &= -\frac{1}{a+bi}\cdot\cos[(a+bi)\cdot s]. \end{aligned} \qquad (3)$$

From condition [21, p. 14] $(x')^2+(y')^2+(z')^2=0$ define the expression $z(s)=i\cdot s$ and write the parametric equations of a spatial isotropic line:

$$\begin{aligned} x(s) &= \frac{1}{a+bi}\cdot\sin[(a+bi)\cdot s], \\ y(s) &= -\frac{1}{a+bi}\cdot\cos[(a+bi)\cdot s], \\ z(s) &= i\cdot s. \end{aligned} \qquad (4)$$

To find the equations of minimal and associated minimal surface it is necessary to change parametric equations of isotropic curve (4) [19]: $s=u+i\cdot v.$

Then, demanding meeting the conditions of Cauchy-Riemann equations [22, p. 22], we will obtain a parametric equations of minimal surfaces $X(u,v),\ Y(u,v), Z(u,v)$:

$$\begin{aligned} X(u,v) &= \mathrm{Re}\{x(u+i\cdot v)\}, \\ Y(u,v) &= \mathrm{Re}\{y(u+i\cdot v)\}, \\ Z(u,v) &= \mathrm{Re}\{i\cdot(u+i\cdot v)\}, \end{aligned} \qquad (5)$$

and associated minimal surface $X^*(u,v), Y^*(u,v),$ $Z^*(u,v)$:

$$\begin{aligned} X^*(u,v) &= \mathrm{Im}\{x(u+i\cdot v)\}, \\ Y^*(u,v) &= \mathrm{Im}\{y(u+i\cdot v)\}, \\ Z^*(u,v) &= \mathrm{Im}\{i\cdot(u+i\cdot v)\}. \end{aligned} \qquad (6)$$

Separating real and imaginary parts for each function (4), according to (5), (6) we obtain the minimal surface equations:

$$\begin{aligned} X(u,v) &= \frac{1}{a^2+b^2}\cdot(a\cdot \mathrm{ch}(bu+av)\cdot\sin(au-bv)+ \\ &\qquad +b\cdot\cos(au-bv)\cdot \mathrm{sh}(bu+av)), \\ Y(u,v) &= \frac{1}{a^2+b^2}\cdot(-a\cdot\cos(au-bv)\cdot \mathrm{ch}(bu+av)+ \\ &\qquad +b\cdot\sin(au-bv)\cdot \mathrm{sh}(bu+av)), \\ Z(u,v) &= -v, \end{aligned} \qquad (7)$$

and associated minimal surface equation:

$$\begin{aligned} X^*(u,v) &= \frac{1}{a^2+b^2}\cdot(-b\cdot \mathrm{ch}(bu+av)\cdot\sin(au-bv)+ \\ &\qquad +a\cdot\cos(au-bv)\cdot \mathrm{sh}(bu+av)), \\ Y^*(u,v) &= \frac{1}{a^2+b^2}\cdot(b\cdot\cos(au-bv)\cdot \mathrm{ch}(bu+av)+ \\ &\qquad +a\cdot\sin(au-bv)\cdot \mathrm{sh}(bu+av)), \\ Z^*(u,v) &= u. \end{aligned} \qquad (8)$$

In Fig. 1 a minimal surface is shown, Fig. 2 shows profile projection of this surface that is built on equations (7).

In Fig. 3 the associate minimal surface is shown, Fig. 2 shows the horizontal projection of this surface that is built on equations (8).

In Fig. 1, 2, 3, 4 images minimal surfaces and their projections built on equations (7), (8) in accordance with $a=0{,}8,\ b=0{,}1,\ u\in[-4;...4],\ v\in[-2;...2].$

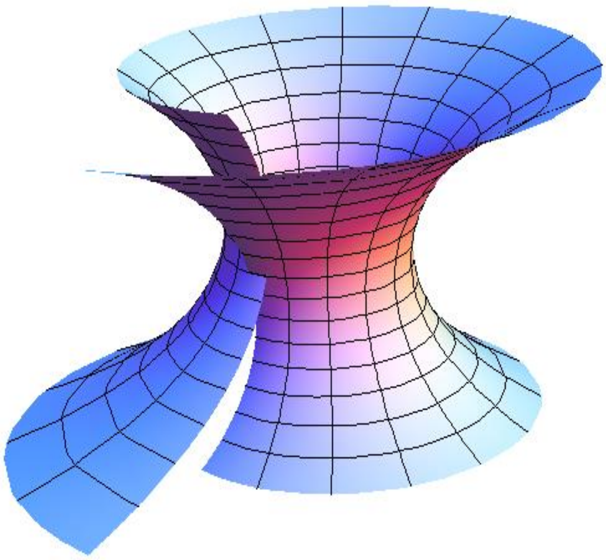

Fig. 1. Minimal surface built on equations (7)

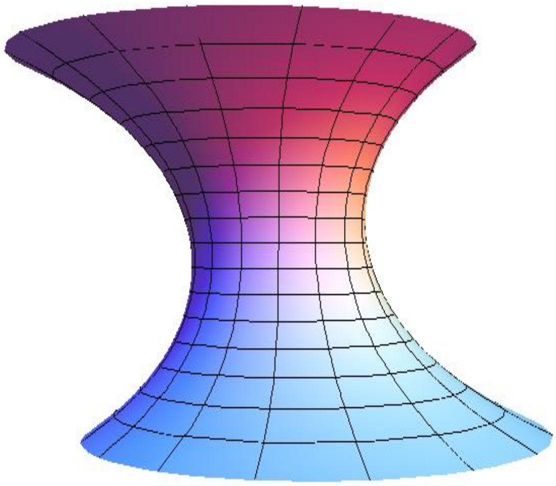

Fig. 2. Profile projection of the minimal surface built on equations (7)

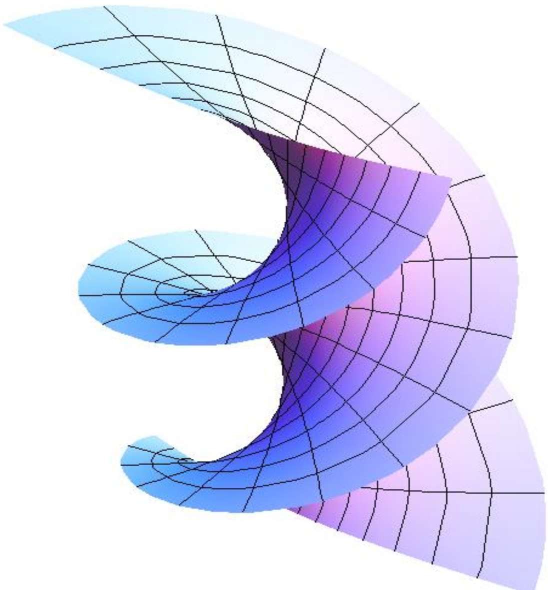

Fig. 3. Associated minimal surface built on equations (8)

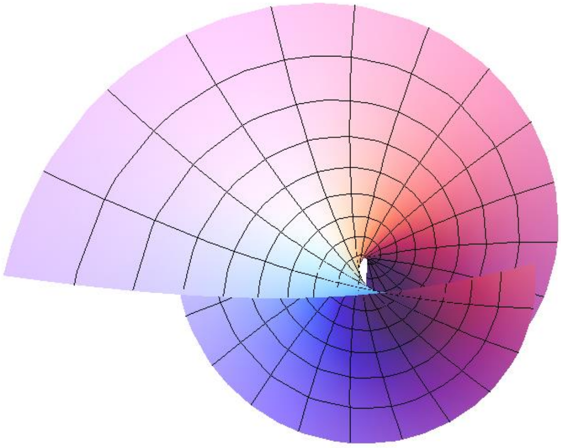

Fig. 4. Horizontal projection of the associated minimal surface built on equations (8)

We find coefficients expressions of the first quadratic surface form $X(u,v)$, $Y(u,v), Z(u,v)$ which define metric properties of the surface according to the formulas [20, p.183]:

$$\begin{aligned} E &= (X'_u)^2 + (Y'_u)^2 + (Z'_u)^2, \\ F &= X'_u \cdot X'_v + Y'_u \cdot Y'_v + Z'_u \cdot Z'_v, \\ G &= (X'_v)^2 + (Y'_v)^2 + (Z'_v)^2. \end{aligned} \tag{9}$$

The coefficients of the first quadratic form of minimal surface (7) and the associated surface (8) equal to: $E = G = [\mathrm{ch}(bu + av)]^2$, $F = 0$.

Minimal surfaces built on equations (7) and (8) have the same expression of coefficients of the first quadratic form, that's why they allow continuous bending one above the other.

Equations of one-parameter set of associated minimal surfaces formed with continuous bending are of the form [19]:

$$\begin{aligned} X_\varphi(u,v) &= X(u,v)\cos\varphi + X^*(u,v)\sin\varphi, \\ Y_\varphi(u,v) &= Y(u,v)\cos\varphi + Y^*(u,v)\sin\varphi, \\ Z_\varphi(u,v) &= Z(u,v)\cos\varphi + Z^*(u,v)\sin\varphi, \end{aligned} \tag{10}$$

where: $X(u,v); Y(u,v); Z(u,v) -$ parametric equations of minimal surface (7),

$X^*(u,v); Y^*(u,v); Z^*(u,v) -$ parametric equations of associated minimal surface (8),

$\varphi -$ bending parameter of surfaces, $\varphi \in \left[0; \dfrac{\pi}{2}\right]$.

It is obviously that $\varphi = 0$ equations (10) define the minimal surface (7), at $\varphi = \dfrac{\pi}{2}$ equations (10) define the associated minimal surface (8), for other values

$\varphi \in \left(0; \frac{\pi}{2}\right)$ equations (10) define associated minimal surfaces [19].

In Fig. 5, 6, 7, 8 images associated minimal surfaces built on equations (10) in accordance for $a = 0{,}8;$ $b = 0{,}1;$ $u \in [-4;...4];$ $v \in [-2;...2]$, at $\varphi = \frac{\pi}{8};$ $\varphi = \frac{\pi}{6};$ $\varphi = \frac{\pi}{4};$ $\varphi = \frac{3\pi}{8}$ respectively are built. These minimal surfaces are formed under continuous bending of a minimal surface (7) to associated minimal surface (8).

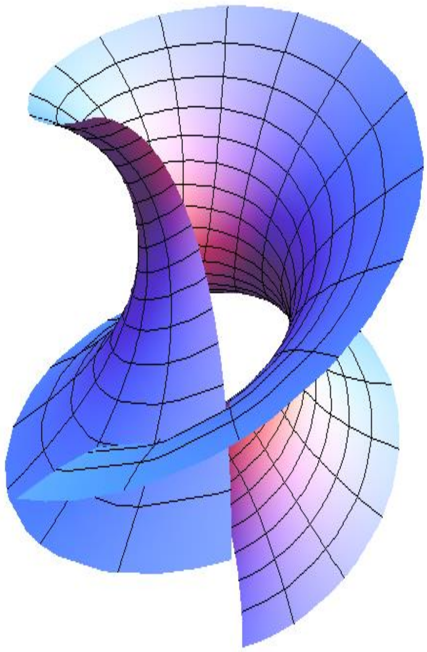

Fig. 5. Associated minimal surface built at $\varphi = \frac{\pi}{8}$

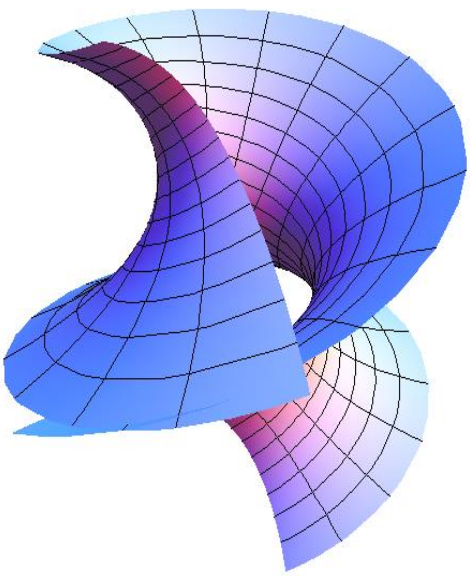

Fig. 6. Associated minimal surface built at $\varphi = \frac{\pi}{6}$

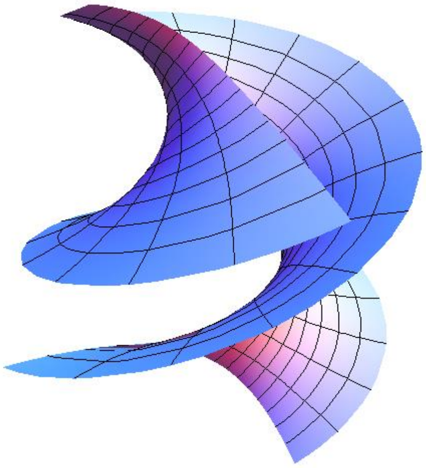

Fig. 7. Associated minimal surface built at $\varphi = \frac{\pi}{4}$

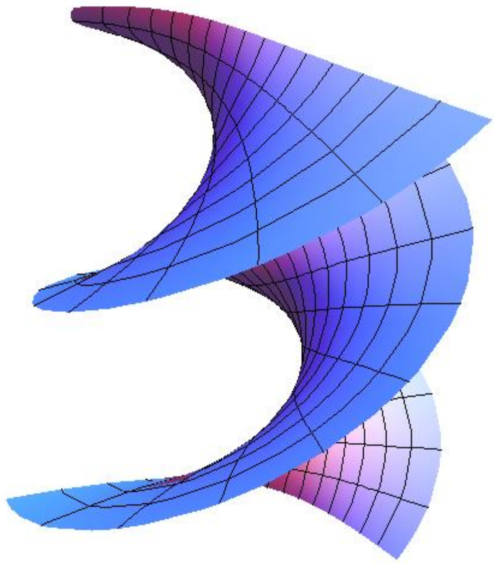

Fig. 8. Associated minimal surface built at $\varphi = \frac{3\pi}{8}$

We find expressions of a second surface quadratic form $X(u,v),\ Y(u,v), Z(u,v)$, that define the properties of surface curvature according to the formulas [20, p.192]:

$$L = \frac{1}{\sqrt{EG - F^2}} \cdot \begin{vmatrix} X''_{uu} & Y''_{uu} & Z''_{uu} \\ X'_u & Y'_u & Z'_u \\ X'_v & Y'_v & Z'_v \end{vmatrix},$$

$$M = \frac{1}{\sqrt{EG - F^2}} \cdot \begin{vmatrix} X''_{uv} & Y''_{uv} & Z''_{uv} \\ X'_u & Y'_u & Z'_u \\ X'_v & Y'_v & Z'_v \end{vmatrix}, \qquad (11)$$

$$N = \frac{1}{\sqrt{EG - F^2}} \cdot \begin{vmatrix} X''_{vv} & Y''_{vv} & Z''_{vv} \\ X'_u & Y'_u & Z'_u \\ X'_v & Y'_v & Z'_v \end{vmatrix},$$

The coefficients of the second quadratic form of minimal surface (7) equal to: $L = -N = a, \quad M = -b.$

The coefficients of the second quadratic form of associated minimal surface (8) equal to: $L^* = -N^* = b,$ $M^* = a.$

The coefficients of the first and second quadratic forms of the constructed minimal surfaces (7) and (8), turn the expression of mean curvature $H = \dfrac{E\cdot N - 2\cdot F\cdot M + G\cdot L}{2\left(E\cdot G - F^2\right)}$ for each of the specified surfaces to zero.

It should be noted that for isotropic line (4) a minimal surface was built (7) – "broken" catenoid, which in $a \neq 0, b = 0$ is an ordinary catenoid. Associated minimal surface (8) is a right helicoid, an only minimal ruled surface.

Separate the real and imaginary parts of complex variable functions (3) performing Cauchy-Riemann conditions [22, p. 22]. For real functions (3) we get:

$$x_1(s) = \mathrm{Re}\{x(s)\} = \frac{a\,\mathrm{ch}(bs)\sin(as) + b\cos(as)\mathrm{sh}(bs)}{a^2+b^2}, \qquad y_1(s) = \mathrm{Re}\{y(s)\} = \frac{b\,\mathrm{sh}(bs)\sin(as) - a\cos(as)\mathrm{ch}(bs)}{a^2+b^2}. \tag{12}$$

From the conditions [21, p. 14] $(x_1')^2 + (y_1')^2 + (z_1')^2 = 0$ define the expression $z_1(s) = i\cdot\dfrac{\mathrm{sh}(bs)}{b}$ and write the spatial isotropic line parametric equations from arbitrary parameter t:

$$x_1(t) = \frac{a\,\mathrm{ch}(bt)\sin(at) + b\cos(at)\mathrm{sh}(bt)}{a^2+b^2}, \quad y_1(t) = \frac{b\,\mathrm{sh}(bt)\sin(at) - a\cos(at)\mathrm{ch}(bt)}{a^2+b^2}, \quad z_1(t) = i\cdot\frac{\mathrm{sh}(bt)}{b}. \tag{13}$$

Enter the replacement in isotropic curve parametric equations (13) [19]: $t = u + i\cdot v.$

Separating real and imaginary parts for each function (13), according to (5), (6) we obtain the minimal surface equations $X_1(u,v),\ Y_1(u,v), Z_1(u,v)$:

$$\begin{aligned}
X_1 &= \frac{\mathrm{ch}(bu)\sin(au)}{a^2+b^2}\left[a\cos(bv)\mathrm{ch}(av) + b\sin(bv)\mathrm{sh}(av)\right] + \\
&\quad + \frac{\mathrm{sh}(bu)\cos(au)}{a^2+b^2}\left[b\cos(bv)\mathrm{ch}(av) - a\sin(bv)\mathrm{sh}(av)\right], \\
Y_1 &= \frac{\mathrm{ch}(bu)\cos(au)}{a^2+b^2}\left[-a\cos(bv)\mathrm{ch}(av) - b\sin(bv)\mathrm{sh}(av)\right] + \\
&\quad + \frac{\mathrm{sh}(bu)\sin(au)}{a^2+b^2}\left[b\cos(bv)\mathrm{ch}(av) - a\sin(bv)\mathrm{sh}(av)\right], \\
Z_1 &= -\frac{\mathrm{ch}(bu)\cdot\sin(bv)}{b},
\end{aligned} \tag{14}$$

and the associated minimal surface equations $X_1^*(u,v),$ $Y_1^*(u,v),\ Z_1^*(u,v)$:

$$\begin{aligned}
X_1^* &= \frac{\mathrm{ch}(bu)\cos(au)}{a^2+b^2}\left[b\sin(bv)\mathrm{ch}(av) + a\cos(bv)\mathrm{sh}(av)\right] + \\
&\quad + \frac{\mathrm{sh}(bu)\sin(au)}{a^2+b^2}\left[a\sin(bv)\mathrm{ch}(av) - b\cos(bv)\mathrm{sh}(av)\right], \\
Y_1^* &= \frac{\mathrm{ch}(bu)\sin(au)}{a^2+b^2}\left[b\sin(bv)\mathrm{ch}(av) + a\cos(bv)\mathrm{sh}(av)\right] - \\
&\quad - \frac{\mathrm{sh}(bu)\cos(au)}{a^2+b^2}\left[a\sin(bv)\mathrm{ch}(av) - b\cos(bv)\mathrm{sh}(av)\right], \\
Z_1^* &= \frac{\cos(bv)\cdot\mathrm{sh}(bu)}{b}.
\end{aligned} \tag{15}$$

The coefficients of the first quadratic form of the minimal surface (13) and the associated minimal surface (14), found according to formulas (9), equal to:

$$E = G = \frac{1}{2}\left(\cos(2bv) + \mathrm{ch}(2bu)\right)\cdot\left[\mathrm{ch}(bu+av)\right]^2,\ F = 0.$$

The coefficients of the second quadratic form of the minimal surface (13), found according to formulas (11), equal to:

$$L = -N = a\cos(bv)\mathrm{ch}(bu),\ M = -a\sin(bv)\cdot\mathrm{sh}(bu).$$

The coefficients of the second quadratic form of associated minimal surface (14) equal to:

$$L^* = -N^* = -a\sin(bv)\cdot\mathrm{sh}(bu),\ M^* = a\cos(bv)\cdot\mathrm{ch}(bu).$$

The coefficients of the first and second quadratic forms of minimal surfaces (13) and (14), transform the mean curvature expression to zero.

Minimal surface built on equations (13), is Catenoid and associated minimal surface (14) is right helicoid which has common geometric properties with the surface shown in Fig. 3. Consider the imaginary part of the complex variable functions (3):

$$x_2(s) = \mathrm{Im}\{x(s)\} = \frac{a\cos(as)\mathrm{sh}(bs) - b\,\mathrm{ch}(bs)\sin(as)}{a^2+b^2}, \qquad y_2(s) = \mathrm{Im}\{y(s)\} = \frac{a\,\mathrm{sh}(bs)\sin(as) + b\cos(as)\mathrm{ch}(bs)}{a^2+b^2}. \tag{16}$$

From condition [21, p. 14] $(x_1')^2 + (y_1')^2 + (z_1')^2 = 0$ define the expression $z_2(s) = i\cdot\dfrac{\mathrm{ch}(bs)}{b}$ and write the spatial isotropic line parametric equations from arbitrary parameter t:

$$x_2(t) = \mathrm{Im}\{x(t)\} = \frac{a\cos(at)\mathrm{sh}(bt) - b\,\mathrm{ch}(bt)\sin(at)}{a^2+b^2}, \quad y_2(t) = \mathrm{Im}\{y(t)\} = \frac{a\,\mathrm{sh}(bt)\sin(at) + b\cos(at)\mathrm{ch}(bt)}{a^2+b^2}, \quad z_2(t) = i\cdot\frac{\mathrm{ch}(bt)}{b}. \tag{17}$$

In isotropic curve parametric equations (17) enter the replacement [19]: $t = u + i \cdot v$. Separating real and imaginary parts for each function (17), according to (5), (6) we obtain the minimal surface equations $X_2(u,v),\ Y_2(u,v), Z_2(u,v)$:

$$\begin{aligned} X_2 &= \frac{\operatorname{ch}(bu)\sin au}{a^2+b^2}\left[-b\cos(bv)\operatorname{ch}(av) + a\sin(bv)\operatorname{sh}(av)\right] + \\ &\quad + \frac{\operatorname{sh}(bu)\cos au}{a^2+b^2}\left[a\cos(bv)\operatorname{ch}(av) + b\sin(bv)\operatorname{sh}(av)\right], \\ Y_2 &= \frac{\operatorname{ch}(bu)\cos au}{a^2+b^2}\left[b\cos(bv)\operatorname{ch}(av) - a\sin(bv)\operatorname{sh}(av)\right] + \\ &\quad + \frac{\operatorname{sh}(bu)\sin au}{a^2+b^2}\left[a\cos(bv)\operatorname{ch}(av) + b\sin(bv)\operatorname{sh}(av)\right], \\ Z_2 &= -\frac{\sin(bv)\cdot\operatorname{sh}(bu)}{b}. \end{aligned} \tag{18}$$

and the associated minimal surface equations $X_2^{\,*}(u,v)$, $Y_2^{\,*}(u,v),\ Z_2^{\,*}(u,v)$:

$$\begin{aligned} X_2^{\,*} &= \frac{\operatorname{ch}(bu)\cos au}{a^2+b^2}\left[a\sin(bv)\operatorname{ch}(av) - b\cos(bv)\operatorname{sh}(av)\right] + \\ &\quad - \frac{\operatorname{sh}(bu)\sin au}{a^2+b^2}\left[b\sin(bv)\operatorname{ch}(av) + a\cos(bv)\operatorname{sh}(av)\right], \\ Y_2^{\,*} &= \frac{\operatorname{ch}(bu)\sin au}{a^2+b^2}\left[a\sin(bv)\operatorname{ch}(av) - b\cos(bv)\operatorname{sh}(av)\right] + \\ &\quad + \frac{\operatorname{sh}(bu)\cos au}{a^2+b^2}\left[b\sin(bv)\operatorname{ch}(av) + a\cos(bv)\operatorname{sh}(av)\right], \\ Z_2^{\,*} &= \frac{\cos(bv)\cdot\operatorname{ch} au}{b}. \end{aligned} \tag{19}$$

In Fig. 9 a minimal surface is shown, in Fig. 10 horizontal projection of this surface is shown, they are built on equations (18), in accordance with $a = 0{,}8,\ b = 0{,}1,\ \ u \in [0;\ldots\pi],\ \ v \in [-2;..2]$.

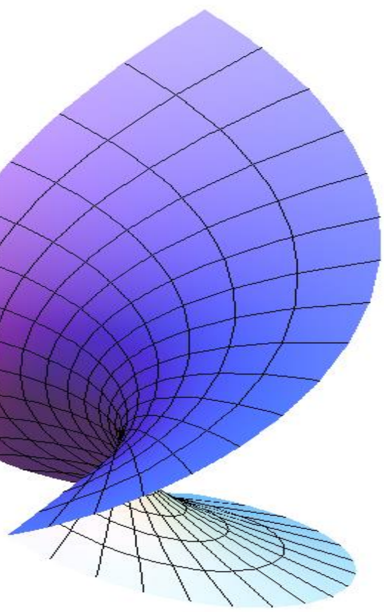

Fig. 9. Minimal surface built on equations (18)

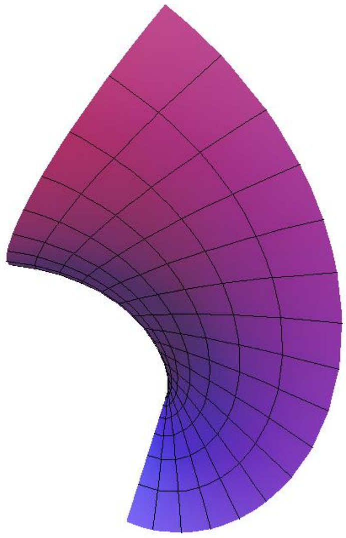

Fig. 10. Horizontal projection of the minimal surface built on equations (18)

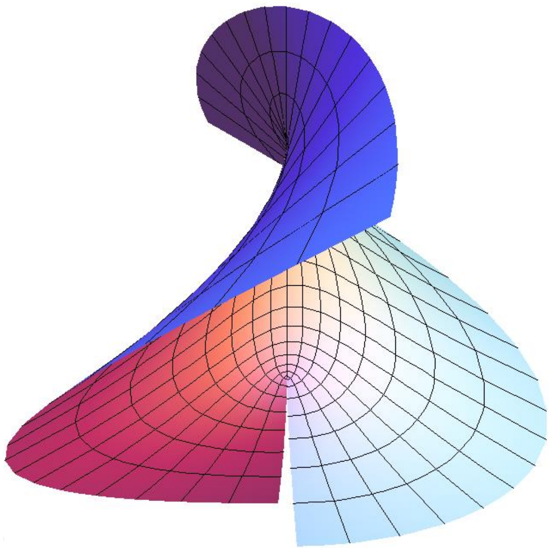

Fig. 11. Associated minimal surface built on equations (19)

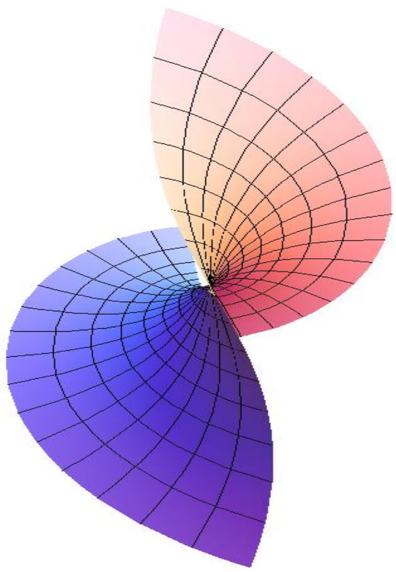

Fig. 12. Horizontal projection of the associated minimal surface built on equations (19)

In Fig. 11 the minimal surface is shown, in Fig. 12 horizontal projection of this surface is shown, they are built on equations (19), in accordance with $a = 0{,}8,\ b = 0{,}1,\ u \in [0;...\pi],\ v \in [-2;..2]$.

The coefficients of the first quadratic form of minimal surface (18) and the associated minimal surface (19), found according to formulas (9), equal to:

$$E = G = -\frac{1}{2}(\cos(2bv) - \mathrm{ch}(2bu)) \cdot [\mathrm{ch}(av)]^2,\ F = 0. \qquad (19)$$

The coefficients of the second quadratic form of minimal surface (18), found according to formulas (11), equal: $L = -N = a\,\mathrm{sh}(bu)\cdot\cos(bv),\ M = -a\,\mathrm{ch}(bu)\cdot\sin(bv)$.

The coefficients of the second quadratic form of associated minimal surface (19) equal to:

$$L^* = -N^* = a\,\mathrm{ch}(bu)\cdot\sin(bv),\ M^* = a\,\mathrm{sh}(bu)\cdot\cos(bv).$$

The coefficients of the first and second quadratic forms of minimal surfaces (18) and (19), transform the mean curvature expression to zero.

Minimal surfaces built on equations (18) and (19) have the same expression of coefficients of the first quadratic form, that's why they allow continuous bending one above the other.

Equations of one-parameter set of associated minimal surfaces formed with continuous bending are of the form [19]:

$$\begin{aligned} X_\varphi(u,v) &= X_2(u,v)\cdot\cos\varphi + X_2^*(u,v)\cdot\sin\varphi,\\ Y_\varphi(u,v) &= Y_2(u,v)\cdot\cos\varphi + Y_2^*(u,v)\cdot\sin\varphi,\\ Z_\varphi(u,v) &= Z_2(u,v)\cdot\cos\varphi + Z_2^*(u,v)\cdot\sin\varphi, \end{aligned} \qquad (20)$$

where: $X_2(u,v), Y_2(u,v), Z_2(u,v)$ – minimal surface equation (18),

$X_2^*(u,v), Y_2^*(u,v), Z_2^*(u,v)$ – associated minimal surface equation (19),

$\varphi -$ bending parameter of surfaces, $\varphi \in \left[0;\ \frac{\pi}{2}\right]$.

It is obviously that $\varphi = 0$ equations (20) define the minimal surface (18), at $\varphi = \frac{\pi}{2}$ equations (20) define the associated minimal surface (19), for other values $\varphi \in \left(0;\ \frac{\pi}{2}\right)$ equations (20) define associated minimal surfaces [19].

In Fig. 13, 14, 15, 16 images associated minimal surfaces built on equations (20) in accordance for $a = 0{,}8;$ $b = 0{,}1;$ $u \in [0;..\pi];$ $v \in [-2;..2],$ at $\varphi = \frac{\pi}{12};\ \varphi = \frac{\pi}{6};\ \varphi = \frac{\pi}{4};\ \varphi = \frac{3\pi}{8}$ respectively are built.

All associated minimal surfaces have the same expression (19) of coefficients of the first quadratic form.

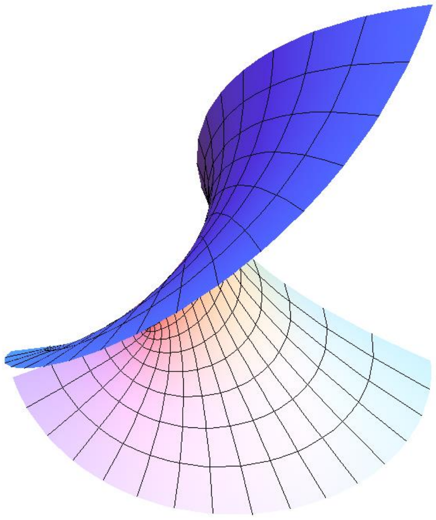

Fig. 13. Associated minimal surface built at $\varphi = \frac{\pi}{12}$

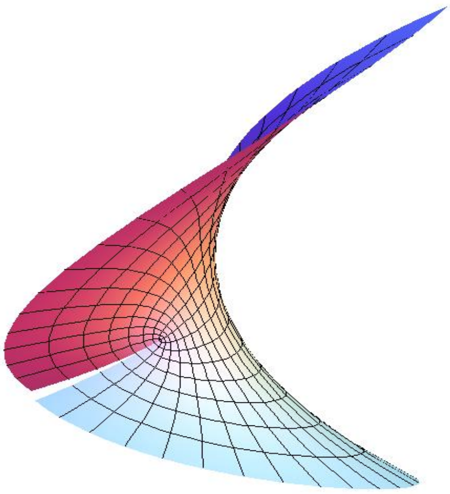

Fig. 14. Associated minimal surface built at $\varphi = \frac{\pi}{6}$

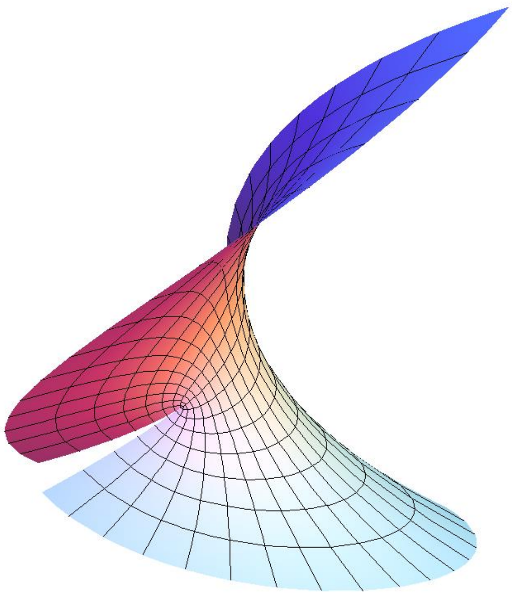

Fig. 15. Associated minimal surface built at $\varphi = \frac{\pi}{4}$

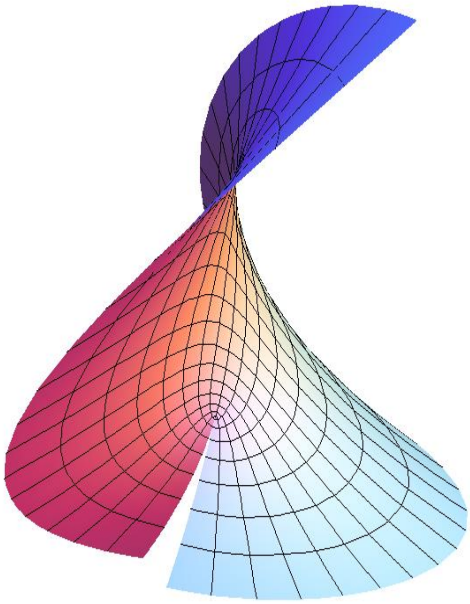

Fig. 16. Associated minimal surface built at $\varphi = \dfrac{3\pi}{8}$

These minimal surfaces are formed under continuous bending of a minimal surface (18) to associated minimal surface (19).

Use of flat curves given by parametric natural parameter equations with complex curvature, provides a relatively simple analytical description of minimal surfaces for further study of the geometrical properties.

CONCLUSIONS

1. The proposed method of finding isotropic curves parametric equations based on flat curves with constant complex curvature allows to determine analytical description of flat lines defined by natural parameter functions in complex space. The minimal surface (7), based on the specified isotropic line is "broken" Catenoid.

2. For isotropic line with constant complex curvature equations, it was found analytical description of isotropic lines with real and imaginary parts of the complex variable. For these isotropic lines analytical description of a minimal surfaces and associated minimal surfaces was made. It is investigated that minimal surface and associated minimal surface formed from isotropic line with the real part of complex variable is Catenoid and right helicoid. Coefficients expressions of the first and second generated minimal surfaces quadratic forms were found.

3. Minimal surface constructed using equations (18) can be used to design technical surfaces forms of soil loosening.

4. Minimal surfaces parametric equations were found in the form of elementary functions, which allows to explore their geometric properties and differential characteristics to optimize engineering methods to design technical forms and architectural constructions.

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КОНСТРУИРОВАНИЕ МИНИМАЛЬНЫХ ПОВЕРХНОСТЕЙ С ПОМОЩЬЮ ПЛОСКИХ КРИВЫХ С ПОСТОЯННОЙ КОМПЛЕКСНОЙ ВЕЛИЧИНОЙ КРИВИЗНЫ

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Аннотация. Получено аналитическое описание изотропных линий и минимальных поверхностей с помощью функций комплексного переменного. Для нахождения уравнений изотропных линий использовано параметрические уравнения плоской кривой, заданной функциями натурального параметра с постоянной комплексной величиной кривизны. Параметрические уравнения изотропных линий получены из условия равенства нулю дифференциала дуги пространственной линии. Аналитическое описание минимальных поверхностей и присоединённых минимальных поверхностей осуществляется в комплексном пространстве с изотропными линиями сети переноса.

Используя условия дифференцируемости Коши-Римана для уравнений изотропной линии с комплексной величиной кривизны, получено аналитическое описание изотропных линий с помощью действительной и мнимой части функций комплексного переменного. Для указанных изотропных линий осуществлено аналитическое описание минимальных и присоединённых минимальных поверхностей. Показано, что минимальной поверхностью и присоединённой минимальной поверхностью, образованными с помощью действительной части функций комплексного переменного указанной изотропной линии, являются катеноид и прямой геликоид. Получено аналитическое описание одно-параметрического множества ассоциированных минимальных поверхностей, образованных с помощью их непрерывного изгибания.

Предложенный способ образования параметрических уравнений изотропных линий с помощью плоских кривых, кривизна которых есть комплексной величиной, позволяет определять аналитическое описание плоских линий, заданных функциями натурального параметра, в комплексном пространстве.

Параметрические уравнения минимальных поверхностей получены в виде элементарных функций, что позволяет исследовать их геометрические свойства и дифференциальные характеристики для оптимизации инженерных методов проектирования технических форм и архитектурных конструкций.

Ключевые слова: изотропная линия, минимальная поверхность, функция комплексной переменной, постоянная комплексная величина кривизны, условия Коши-Римана, катеноид, прямой геликоид.

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Substantiation of Main Parameters of Size-Sized Series of Agricultural Energy Solutions

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Summary. The solution of the problems of the agro-industrial complex depends to a large extent on the provision of highly efficient mobile energy facilities, the availability of which is provided by a standard size series. The construction of the size range is based on the main parameters that should most fully characterize the technical, operational and technological capabilities of the product and have greater stability than the auxiliary parameters. It has been established that there are at least three approaches to the justification of the standard size series of power tools: according to the nominal tractive effort, On power of the installed engine, By annual load. In accordance with this, we can distinguish three main parameters for which there have been attempts to justify the size series, namely: nominal tractive effort, Installed engine power and annual load. The named parameters are disjointed because their rationale was taken in consideration of the various problems that need to be solved. The foregoing circumstances make it difficult to apply economically viable approaches to designing, manufacturing and ensuring the effective use of energy resources, which has led to the search for other, or additional, main parameters for constructing a standard size range of mobile power tools. The studies were carried out by analyzing the influence of the investigated parameters on the characteristics of energy facilities and their stability within the limits of the possible classes of the standard size series. As a result of the studies carried out to justify and improve the size of a number of mobile agricultural energy products, it has been established that, in order to provide the most informative information about mobile energy facilities, which is laid down in the main parameters of their size range, the latter can be represented as a multiparametric one, the main parameters of which are appropriate to take the nominal traction Power, engine power and level of versatility. These parameters will give an idea of the traction capabilities of the energy source, its energy potential and the availability of technical means for implementing traction capabilities and installed capacity.

Key words: mobile power facility, size range, main parameter, nominal tractive effort, installed engine power, level of versatility.

INTRODUCTION

The introduction of technological progress in agro-industrial production stimulated the tractor-building enterprises to significantly expand the standard-size series of products, the adequate elements of which very often differ in the values of similar estimated parameters. So, for example, according to the data of the catalog [1, 2, 3, 4], energy sources of the structural mass of 5000-5500 kg of firms Renault, Deutz-Fahr, Fendt are equipped with engines with a capacity of 63-88 kW, and energy facilities of Massey Ferguson, Case IH, John Deere, MTZ, New Holland in The same class of structural mass can be equipped with engines up to 119 kW. In the later catalogs, this increase in capacity is already observed in the energy resources of the previously named firms. The foregoing is evidence of the existence of certain difficulties with the method of justifying the standard series of mobile power means (MPM) based on the main parameters that should most fully characterize the technical, operational and technological capabilities of the product and have greater stability than auxiliary parameters [5, 6].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The rationale for the standard size row of tractors was previously carried out according to different main parameters. So in 1940, D. A. Chudakov suggested taking traction for a parameter to determine the class of the tractor. In the perspective type of tractors of 1946 in the Soviet Union, the main parameter was the engine power [7]. The increase in engine power required to provide higher operating speeds had little effect on the tractor's traction parameters, Therefore, at that time, the nominal traction force was accepted as the main parameter for justifying a standard row of tractors for a long time. The basis for the determination is the traction force, in which the coefficient of utilization of the clutch, and accordingly, the trailing of the tractor, does not exceed the preset values [7]:

$$P_{KP.\text{H}} = \varphi_{KP} \times G_1, \qquad (1)$$

where: $P_{KP.\text{H}}$ – is the nominal pulling force,

φ_{KP} – coefficient of use of the coupling weight,

G_1 – coupling weight of the tractor.

This indicator was more stable when modernizing machines, including increasing their capacity.

With the development of the construction of tractors and agricultural machinery, their recoil systems and energy intake, crop cultivation technologies, etc., the tractor is also seen as a mobile energy device capable of delivering energy through power take-off systems. First of all, this applies to harvesting machines. For harvesting self-propelled chassis (their feature is the ability to be released from the structure of an assembly), in which the bulk of the power is used through the power take-off shaft (PTO), the engine power rating can be retained [7].

Attempts to develop a standard size series of MPM for the installed engine power are described in [8, 9, 10, 11, 12]. The criteria for justifying the power levels in these works were the possibilities of providing economic performance indicators, mainly traction and traction drive units, under various conditions while ensuring the optimum level of engine loading. It should be noted that the above-mentioned papers show different power levels of power-driven engines. This fact indicates the absence of unified scientifically grounded approaches to the graduation of energy resources by installed engine power.

In [12], a classification of energy resources by annual load is proposed, which allows to predict the possible economic efficiency of the energy source. The drawbacks of this work are both the lack of a scientifically grounded methodology for classifying power resources to groups by the installed engine power and annual load, and the focus on cleaning machines specialized and created based on the released self-propelled chassis, which, in our opinion, complicates the forecast calculations of farm parks.

In [13, 14] the approximate power levels of MPM engines for agricultural purposes are presented both in the general case and within each of the existing traction classes, but nothing is said about using the established graduation as a standard range for energy resources.

Thus, as a result of the analysis, it has been established that there are at least three approaches to the justification of the MPM standard series: according to the nominal traction force, On power of the installed engine, By annual load. According to this, we can distinguish three main parameters for which there were attempts to justify the size series, namely: nominal tractive effort, Installed engine power and annual load. In addition, in later works (not shown here), the necessity of using several parameters or their derivatives for the characterization of the MPM size series (tractive effort and engine power, energy saturation, etc.) is substantiated. The foregoing circumstances make it difficult to apply economically viable approaches to designing, manufacturing and ensuring the effective use of energy resources, which encourages the search for other, or additional, main parameters for constructing a one- or multi-parametric MPM-type series.

OBJECTIVE

In connection with the foregoing, the purpose of this paper is to justify a list of the main parameters for characterizing a range of mobile agricultural energy products.

THE MAIN RESULTS OF THE RESEARCH

The studies were carried out by analyzing the influence of individual parameters on the characteristics of energy facilities and their stability within the limits of the possible classes of the standard size series. In this connection, it became necessary to conduct an analysis of the activities of the world's leading tractor-building enterprises on the characteristics of the energy facilities they create on the plane of the parameters, the mass of the structural energy, the mass of the total energy, the installed engine power and the price.

The existing technological processes of growing crops [15] envisage the implementation of predominantly traction operations, which indicates an indisputable relevance for the characterization of the standard size range of the parameter "nominal tractive effort", which is determined by the mass characteristics of the machine. The analysis of the design parameters and the total mass of energy means that the vast majority of machines due to ballasting can significantly change the traction performance up to the possibility of transition to other traction classes determined by the standard GOST 27021-86 [16]. Thus, for example, the Fendt Favorit-822 energy product, which has a structural mass of 8100 kg, belongs to the traction class 3 with a nominal pulling force of 30 kN, according to the graduation standard [16], and under the condition of its ballasting, according to the catalog data [1] to class 6 with a nominal pulling force of 60 kN.

And in this connection, it may be interesting that each hauling class of a standard range of energy facilities, built according to the nominal tractive effort, is characterized by the limits of the operational mass of the energy resources entering into it.

To establish this fact, the research was carried out by analyzing the procedure for the formation of the standard MPM series of standard size series and analyzing the characteristics of energy resources of the world's leading tractor-building enterprises on the parameters plane, the operating mass of the energy source and the nominal tractive effort.

In addition, despite the fact that mobile power means must provide for the implementation of traction, traction and drive and drive operations, the study of the boundaries of the change in the operational mass within each traction class was carried out with the following considerations.

According to the technique of the standard [16], the operating mass is determined using the dependence:

$$P_{\text{ГК.Н}} = A \times m_{eP_{\text{ГК.Н}}}, \qquad (2)$$

where: $P_{\text{ГК.Н}}$ – is the nominal pulling force of the energy facility, kN,

A – is a coefficient that is set depending on the type of energy source (the coefficient A is to be taken as: – 3.24 × 10-3 – for energy resources with an operating weight of up to 2,600 kg – 3,73 × 10-3 - for four and three-wheeled energy facilities with two driving wheels (4K2 and 3K2) with an operating weight of more than 2,600 kg – 3,92 × 10-3 – for energy facilities with a wheel formula 4K4 and an operating weight of more than 2,600 kg – 4.9 × 10-3 - for caterpillar power facilities),

$m_{eP_{\text{ГК.Н}}}$ – the operating mass of the energy medium, at which the nominal traction force of the level under study is reached, kg.

Table 1. Limits of variation of operational masses of wheeled power facilities of the current standard size range

Traction class of energy resources	Limits of variation of nominal tractive effort, kN		Operational mass of energy means *, kg		Change in operating weight	
	from	to	the lower limit	the upper limit	in ... times	by ...%
0,2	1,8	5,4	≥ 555,6	< 1666,7	3,00	200,0
0,6	5,4	8,1	≥ 1666,7	< 2500,0	1,50	50,0
0,9	8,1	12,6	≥ 2500,0	< 3214,3	1,29	28,6
1,4	12,6	18,0	≥ 3214,3	< 4591,8	1,43	42,8
2	18,0	27,0	≥ 4591,8	< 6887,7	1,50	50,0
3	27,0	36,0	≥ 6887,7	< 9183,7	1,33	33,3
4	36,0	45,0	≥ 9183,7	< 11479,6	1,25	25,0
5	45,0	54,0	≥ 11479,6	< 13775,5	1,20	20,0
6	54,0	72,0	≥ 13775,5	< 18367,3	1,33	33,3
8	72,0	108,0	≥ 18367,3	< 27551,0	1,50	50,0

*) The change in the value of the coefficient ***A*** provided in the explanations for the dependence (2) in accordance with the received level of the operational mass was carried out in the calculations at the first achievement of the above indicator value of 2600 kg and was subsequently assumed equal to 3.92×10^{-3}, The bulk of wheeled energy is produced in an all-wheel drive version, or one that can easily be transformed into a four-wheel drive.

The above dependence (2) is a consequence of the above dependence (1).

Proceeding from the above, in order to provide the traction efforts of wheeled energy facilities of various classes regulated by the standard size range [16], their operating masses can vary within the following limits – Table 1.

In Table 1 shows the limits of variation of the operating masses of energy resources for each traction class ensuring the implementation of the corresponding tractive effort. The data of Table. 1 indicate that even in the middle of the traction classes provided by the standard, the operating masses of energy resources can vary significantly. So, for class 0.2, the operating masses of energy resources can differ by three times, or by 200% compared to the lower limit of the operational mass, typical for the energy resources of this traction class. A similar picture is observed for energy resources of other traction classes, but with quantitative indicators, which are characterized by somewhat smaller values. Thus, the increase in the operational masses of energy classes 0.6, 0.9.1.4, 2, 3, 4, 5, 6 and 8 inside the traction classes is envisaged in 1.2...1.5 times, or 20...50%. The size range is organized in such a way that its points cover energy means of various designs, different manufacturers, and hence different masses. And only due to the boundaries of the variation of the operational mass of energy resources (see Table 1, columns 4 and 5) provided by the standard, it is possible to classify such energy assets and assign them to the appropriate traction class.

It should be noted that the actual operating mass of energy resources operating in farms is significantly higher than its lower limit is indicated in Table. 1. So the class 1.4 tractor "Belarus-1005" has an operational weight of 4025 kg with a minimum for this class of 3214.3 kg, a tractor of the same class "Belarus - 82" has an operating weight of 3900 kg, and UMZ- 6AKM - 3895 kg. The tractor of class 3 KhTZ -121 has an operational weight of 8,200 kg with the lower limit for this class equal to 6887.7 kg. A similar situation is typical for cars that represent the vast majority of traction classes. In this case, if we also take into account the possibility of ballasting of such energy resources, at least within the limits named in, then the maximum operational mass of tractors of classes 0.6, 0.9, 1.4, 3, 4, 5 Will exceed the level of the upper limits of the operational masses for the energy resources of the named classes and such machines will be transferred to higher traction classes. For example, a tractor of class 3 KhTZ-121, as already mentioned above, has an operating weight of 8,200 kg. The ballasting of this tractor at a rate of 23% will lead to an increase in its total operating weight to the level of 10086 kg, which is typical already for traction class 4 vehicles (see Table 1). Tractors class 0.2, with ballasting within 23%, do not go to higher traction classes because the standard provides for them a wide range of variation in the operational mass, and class 2 tractors, such as LTZ-155, "Belarus-1221" Have an initial operating weight, which, with ballasting by 23%, does not lead to a change in the traction class of the machines. Another situation with the class 5 energy equipment. So according to the catalog, the tractors K-744-1 and K-701M belong to the traction class 5, their operational masses have the value 15830 kg and 14570 kg respectively, which according to Table. 1 allows them to be attributed to the traction class 6 even without ballasting. The foregoing allows us to draw certain conclusions, namely: *a*) theoretically - about certain inaccuracies in the dependence (2), *b*) in practical terms - the lack of effective ways to implement the available operating mass of energy.

Based on the foregoing, it can be argued that, in practice, the range of variation of the operating mass of the energy source, conditioned by the standard, is, for the most part, of a reference nature. In such a case, it is important that the energy asset, in its characteristics, clearly correspond to the traction class to which it is assigned, and its operating mass achieved in any way, including ballasting, can vary both within the limits of the energy standard specified in the standard for this class, not excluding the transition to higher traction classes.

Thus, the limits of variation of the operating masses of power-supply devices of the type-size series, which are described by the values 555.6 - 27551.0 kg. When determining the position of the energy facility in a standard size, it should be ensured that its characteristics meet the requirements for machines of a specific traction class, and the operational weight, taking into account ballasting, could vary both within the limits of the energy facilities stipulated by regulatory documents for this class, Not excluding the transition to higher traction classes.

This fact suggests that the "nominal tractive effort" index can not be used as the main parameter for a one-parameter type series because the principle of parameter stability is violated.

Used by foreign experts, as the main parameter, the "installed engine power" parameter is an indicator of the efficiency of the energy medium and is also indispensable for the consumer. The data in the catalog [1] indicate that the power of the engines installed on the energy sources (the analysis was carried out for standard tractors with a capacity of over 24 kW, such as those that are basic for carrying out the main set of works in diversified agricultural enterprises) varies widely. So MTZ represents power facilities with engine power from 24 to 96 kW, Case IH - from 38 to 280 kW, Fendt - from 37 to 199 kW, John Deere - from 39 to 342 kW, etc. About the possibility of using the installed engine power The following should be noted as the main parameter of the MPM standard size series. The overwhelming majority of tractor-building firms in a standardized series declared for the production of energy resources has machines with the same power of the installed engine. Thus, Fendt produces three brands of energy products with an engine power of 63 kW with a structural mass of 3850, 4190 and 5070 kg, which, according to the procedure of [16], allows them to be assigned to traction classes of 1.4, 1.4 and 2 respectively, and taking into account the possible ballasting - to classes 2, 3 and 3 respectively. The analyzed characteristics belong, respectively, to the energy facilities of Fendt Farmer 308C, Fendt Farmer 308CA and Fendt Farmer 409 Vario [1]. In addition, we should also give an example of the KhTZ-120 tractors, which had an engine with a discretely adjustable power of 88 and 107 kW, where a higher power level is recommended for operation in the unit with machines that have a drive from the tractor PTO.

Based on the foregoing, it can be concluded that the two named parameters "nominal tractive effort" and "installed engine power" are inadequate characteristics of a standard range of mobile power facilities.

Taking into account that "... the optimization of parametric (standardized) series has an important ... value." Optimum selected parametric series satisfy the requirements ... in products of different species at the lowest total costs "[17], it is necessary to justify at least one Or several main parameters that would allow itself, or together with others (for example, the two above) to obtain the most complete information about the energy source.

The characteristics given in the catalog [1] show that the price of energy for leading manufacturers in the world varies widely, even if they have engines of the same power. To establish the reasons for this fact, we examined more detailed characteristics of energy facilities that have engines of the same power. The studies were carried out using the characteristics of John Deere and Fendt energy facilities with engines up to 60 kW (Table 2).

Table 2. Brief specifications of John Deere and Fendt energy tools with engine power up to 60 kW

Indicator	Units of measure	Brand of equipment				
		John Deere			Fendt	
		5510	6110A SE	6120A	Farmer 307C	F 370 GT
1 Engine power	kW	59	59	59	55	55
2 Engine displacement	cm^3	4530	4530	4530	3190	4086
3 Rated engine speed	min^{-1}	2400	2300	2300	2300	2400
4 Engine torque	H × m	301	327	328	296	263
3 Torque reserve	%	28	34	33.5	30	16
6 Number of gears:						
Forward motion	pcs.	24	16	24	21	21
Reverse gear	pcs.	24	16	24	6	6
7 Travel speed:						
The maximum	Km/hr	40	40	42	40	40
Minimal	Km/hr	0,5	0,8	1,0	0,7	0,4
8 Number of PTO	pcs.	2	2	2	2	2
9 Number of speeds PTO	pcs.	2	3	3	3	3
10 Payload of attached devices:						
Posterior	Kg	...*)	3990	4520	4980	3210
Front	Kg	2000	...	3500	2945	2250
11 Hydraulic system pump capacity	l/min	43,1+18.2	54	60/96	70	41+36
12 Hydraulic system pump type	-	Gear	Gear	Axial	Gear	Gear
13 Presence of a mounting platform	-	-	-	-	-	+
14 Weight of payload ballast	Kg	2075	3066	2650	2200	2410
15 Construction weight	Kg	2725	3934	4350	3800	3590
16 Price	DM	29700	37000	41800	36100	38900

**) There is no data on the indicator*

The data of Table 2 show that the John Deere energy used almost the same engine with a capacity of 4530 cm^3, which could not significantly change the manufacturer's pricing policy. The main differences in the technical characteristics were such indicators as the number of gears, the number of PTO speeds, the load capacity of mounted devices, the characteristics of the hydraulic system, the mass of the ballast and the structural mass. Each of these indicators is designed to ensure more efficient use of energy in various operations with a large number of machines and tools. So the number of gears determines the ability to ensure efficient use with machines and tools that are characterized by different levels of engine energy consumption, i.e. Allows you to more efficiently load the engine. The number of speeds of the power take-off shaft also provides more efficient loading of the engine, the lifting capacity of the attached devices limits the weight of the attached machines. The characteristics of the hydraulic system determine the possibility and efficiency of the energy output of the engine through the hydraulic system. In particular, the installation of an axial-type pump allows adapting the hydrosystem of the energy source to the hydraulic systems of machines with different characteristics of the flow of working fluid. Mass characteristics also determine the traction of energy.

So, for example, if we compare the energy of the John Deere 5510 and John Deere 6120, we can say that the latter significantly benefits in terms of the lifting capacity of the mounted devices, the characteristics of the hydraulic system and the tractive characteristics provided by the structural mass and ballast, which significantly influenced the increase in value within 12100 DM.

A similar picture is observed for Fendt's energy facilities. However, it should be noted that their cost is significantly higher than the energy facilities of John Deere, which is explained by the significantly better indicators of the lifting capacity of the mounted devices and the availability of a cargo platform for the Fendt F 370 GT. The foregoing is confirmed in the higher classes of capacity of energy resources.

The increase in the cost of Fendt's 74 and 154 kW power equipment is primarily due to the use of a hydrostatic transmission, which allows for any speed in the 0-50 km / h range and, therefore, to load the engine more efficiently, even when compared to the Fendt Favorit 822, Which is completely reversible and has 44 transmissions (Table 3).

If we analyze the indicators of Tables 2 and 3, especially from number 6 to 15, then taking into account the results of the studies described in [18, 19, 20], it can be asserted that these indicators determine the level of universality of the energy facility and, ultimately, influence its cost. In this case, it can be argued that the level of universality of energy resources can perform the function of the main parameter of a standard size series.

In addition, depending on the availability of machines for the creation of machine and tractor units based on this or that energy facility of the size range, which will be determined by the financial condition of the state as a whole and of the individual agricultural producer in particular, this parameter will allow to optimize the size range for economic indicators.

Table 3. Brief technical characteristics of Fendt energy facilities with engine power of 74 and 154 kW

Indicator	Unit of measure	Energy brand			
		Fendt Farmer 309	Fendt Farmer 410 Vario	Fendt Favorit 822	Fendt Favorit 920 Vario
1 Engine power	kW	74	74	154	154
2 Engine displacement	cm^3	3190	3800	6870	6870
3 Rated engine speed	min^{-1}	2300	2100	2200	2150
4 Engine torque	N × m	390	437	896	960
5 Engine torque reserve	%	30	35	34	40
6 Number of gears:					
Forward motion	pcs.	21	Hydrostat	44	Hydrostat
Reverse gear	pcs.	6	Hydrostat	44	Hydrostat
7 Travel speed:					
The maximum	Km/h	40	50	50	50
Minimal	Km/h	0,7	0,0*)	0,2	0,0
8 Number of PTO	pcs	2	2	2	2
9 Number of speeds PTO	pcs	3	3	2	2
10 Hoisting capacity of attachments:					
Posterior	Kg	4980	6440	9000	9000
Front	Kg	2945	2920	5000	5000
11 Hydraulic system pump performance	l/min.	70	75	102	112
12 Hydraulic system pump type	-	Gear	Axial	Axial	Axial
13 Presence of an installed site	-	-	-	-	-
14 Weight of payload ballast	Kg	3280	3790	5900	5250
15 Constructional weight	Kg	4220	5210	8100	8750
16 Price	DM	46500	63200	99200	110000

*) 0,0 - the phenomenon exists, but in values less than those that can be expressed by the digital digits used in the table

Table 4. The value of the coefficient of universality of the construction of tractors involved in the performance of various technological processes of growing and harvesting crops according to the technological maps of 2004

Culture	Brand tractor									
	KhTZ-170	T-150K	T-150	KhTZ-120	T-70S	UMZ-6AKL	UMZ-80	MTZ-80/82	T-25	T-16MG
1. Perennial Herbs	-	-	0,14	-	-	0,13	-	0,20	0,14	-
2. Potatoes	-	0,17	0,15	-	-	-	-	0,17	-	-
3. Corn for grain	0,15	0,15	0,15	-	-	0,10	-	0,15	-	-
4. Corn for silage	-	0,15	0,15	-	-	0,09	-	0,15	-	0,09
5. Winter Wheat	0,15	0,15	0,15	-	-	0,09	-	0,13	0,06	-
6. Winter Rye	-	0,15	0,15	-	-	0,10	-	-	0,06	0,09
7. Wheat Jara	0,15	0,14	0,15	-	-	0,09	-	0,11	-	-
8. Sunflower	-	0,17	0,15	0,14	-	0,10	0,20	-	0,06	0,09
9. Sugar Beet	-	0,15	0,15	-	0,17	0,10	-	0,14	-	-
10. Barley	-	0,15	0,15	-	-	0,12	-	-	0,06	0,09

This suggests that the parameter "level of universality of energy resources" will allow the process of optimization of the standard MPM series from the plane of solving static problems to the plane of solving dynamic problems, which is more reliable and promising.

In this case, it is worth paying more attention to the method of obtaining such an indicator as «the level of universality of $K_{УК}$ energy resources». In particular, studies on the dynamics of the variation in the design universality coefficient [21] carried out in the technological processes of growing and harvesting cereals, in particular winter wheat, winter rye, spring wheat, spring and winter barley, carried out according to the technological maps of 1984-2001 made it possible to establish that the estimated The values of the coefficient of universality of the design of certain brands of tractors involved in the performance of technological processes differ little both in the context of years (only 6-7%) and in p The number of cultivated crops (no more than 14-18%), which can be explained by the use of technologies from the times of the collective farm and state farm system and the machine complexes designed for their implementation. Several other values of the universality coefficient obtained during the research of technologies of recent years [15] - Table 4.

However, it should be borne in mind that a size range of products is created for its consumer. This means that the consumer should get the maximum information about the elements of the size series already from the very row, so the use of the parameter "level of universality of the energy facility" alone is not sufficient. In such conditions, it is advisable to use three parameters at the current stage when justifying a standard MES series: the nominal tractive effort, Engine power, level of versatility. These parameters will give an idea of the traction capabilities of the energy source, its energy potential and the availability of technical means for their implementation.

The results of the studies are presented in Table. 4 indicate that in recent years there have been some changes in the technology of growing crops and in the technical means for their implementation. So, in particular the technology of growing sunflower provides for the use of tractors of grade 1.4 of the UMZ brand, while the UMZ-6AKL tractors should provide a level of versatility of 0.10, and tractors of the UMZ-80 type should provide a level of versatility of 0.20, that is, two Times higher, which can be explained by certain progress in the design of tractors UMZ and the presence of more sophisticated machine complexes that allow this progress to be more fully realized. In confirmation of the above, it should be noted that in the previous crop rotation [21], sunflower is also present, and it was intended to use UMZ-6AKL tractors for its cultivation, but their planned level of universality should not exceed 0.13. Some analogies of such a plan could be made for tractors MTZ-80 and MTZ-82 in the technological process of growing perennial grasses, but for them the information presented in the tables is less complete than in tractors UMZ.

Taking into account the foregoing, the output parameters for constructing a geometric series of levels of universality of MPM should be taken in terms of indicators characteristic for tractors UMZ, since class 1.4 in which these tractors are included is the most widespread and most provided with machine complexes, and hence the most researched that for others Classes and brands of tractors for today is only desirable. Under such conditions, this allows us to take the value 0.10 as $K_{УК.min\ 1}$. And 0.20 for $K_{УК.max\ 1}$, while according to the condition of [18] $K_{УК}$ should not exceed unity.

After the calculations carried out by the method described in [13], it is established that the geometric series of levels of universality of the MPM is characterized by the denominator $g_{УК}$ = 1.778 and includes 5 levels, namely: 0.10, 0.18, 0.32, 0.56 and 1.00. The received level of versatility is a requirement for the overall design and layout of the machine.

So, for example, if it is necessary to provide a machine with a level of universality of 0.56 and lower, then it is possible to implement it with the help of all three construction and layout schemes, and if it is a level of universality of 1.00, then this can be realized only by the construction of a self-propelled chassis (cm See [18]).

It is logical to assume that the level of development of technological modules for aggregation with MPM and the most energy facilities will not be so rapid to realize all the declared level of universality. Therefore, it is advisable to assume that the increase in the level of universality of energy facilities will be carried out together with the development of technological modules to them at a slower pace due to a change in the equipment of a certain level of universality.

Table 5. Interaction of basic and intermediate levels of Universal Mobile power means (MPM)

The level of universality	The value of the level of universality									
Basic	0,10	0,18	0,32		0,56		1,00			
Intermediate	-	0,10	0,20	0,30	0,40	0,50	0,60	0,70	0,80	0,90

An additional analysis of [21] and Table 2 showed that this can be achieved if we introduce a number of intermediate levels of universality, while it is expedient to use an arithmetic progression with a difference d = 0.10 as an intermediate series. Then a number of intermediate levels of universality will be 9 orienting levels, namely: 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90.

Given that the base level is the maximum possible for a particular machine design, the interaction of the basic and intermediate levels of universality can be represented as follows (Table 5).

As shown by the data placed in Table. 5, the greatest number of intermediate levels is characteristic of the highest index among the basic levels of universality, which is understandable, since this level can be provided only by the constructive-layout scheme of the self-propelled chassis, which is intended for use as a multipurpose power facility. The practice of tractor construction shows that the classical and integral design and layout schemes of MPM may have slightly different universality [18], however, in our opinion, in order to avoid excessive costs, consumers of such equipment would be sufficient to make energy means of classical and integral assemblies With a basic level of universality not higher than 0.56, ensuring its full implementation of the corresponding machine complexes.

The results of additional studies have made it possible to establish that in the technological processes a maximum of 24...46% of the potential built into the design of domestic power facilities is realized. In this way, the UMZ-8240 type energy-generating equipment with the construction design value of the design universality coefficient at the level of 0.43 in the operating technological processes can maximally realize the level of 0.20, KhTZ -16131, with the available coefficient equal to 0.57, and T-16MG, respectively 0.38 and 0.09.

This situation can be explained by many reasons. First of all, these are stagnant phenomena in the development of technological processes, the lack of modern technical solutions in the creation of machine and tractor units, machines and tools designed to maximize the use of potential capabilities of energy resources, which negatively affects the production costs of agricultural enterprises and underscores the need to clarify the current technological processes in crop production and Complexes of machines for their implementation, including MPM.

The justification of the basic levels of universality in the development of MPM will allow solving the question of justifying the design of the machine at the design stage, providing for the maximum possible configuration and layout to achieve the required level of universality. And already the bundling in deliveries to the consumer (by installing or not installing the ordered units) to regulate the level of universality and, accordingly, the price of energy.

CONCLUSIONS

1. As a result of the conducted researches it is established that in order to provide the most informative information about mobile power means, which is placed in the main parameters of their standard series, the latter is expediently represented by a multiparameter, the main parameters of which are to take the nominal tractive effort, the installed engine power and the level of universality.
2. The main direction of further research on this issue is the substantiation of the multi-parametric, standard-size range of mobile agricultural energy products.

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ОБОСНОВАНИЕ ГЛАВНЫХ ПАРАМЕТРОВ ТИПОРАЗМЕРНОГО РЯДА ЭНЕРГОСРЕДСТВ СЕЛЬСКОХОЗЯЙСТВЕННОГО НАЗНАЧЕНИЯ

Григорий Шкаровский

Аннотация. Решение проблем агропромышленного комплекса в большой степени зависит от обеспеченности высокоэффективными мобильными энергетическими средствами, наличие которых предусматривается типоразмерным рядом. Построение типоразмерного ряда основывается на главных параметрах, которые должны наиболее полно характеризовать технические, эксплуатационные и технологические возможности изделия и обладать большей стабильностью, чем вспомогательные параметры. Установлено, что существует по меньшей мере три подхода к обоснованию типоразмерный рядов енергосредств: по номинальному тяговому усилию, по мощности установленного двигателя, по годовой загрузке. В соответствии с этим можно выделить три главных параметра, по которым существовали попытки обоснования типоразмерного рядов, а именно: номинальное тяговое усилие, мощность установленного двигателя и годовая загрузка. Названные параметры разрозненные поскольку их обоснования велось учитывая различные проблемы, которые необходимо решить. Изложенные обстоятельства затрудняют применение экономически целесообразных подходов к проектированию, изготовлению и обеспечению эффективного использования энергосредств, что привело к поиску других, или дополнительных главных параметров для построения типоразмерного ряда мобильных энергетических средств. Исследования проводились путем анализа влияния исследуемых параметров на характеристики энергосредств и их стабильности в пределах возможных классов типоразмерного ряда. В результате проведенных исследований по обоснованию и совершенствования типоразмерного ряда мобильных энергетических средств сельскохозяйственного назначения установлено, что с целью обеспечения наибольшей информативности о мобильных энергетических средствах, которая заложена в главных параметрах их типоразмерного ряда последний может быть представлен как многопараметрический, главными параметрами которого целесообразно принять номинальное тяговое усилия, мощность установленного двигателя и уровень универсальности. Названные параметры дадут представление о тяговые возможности энергосредства, его энергетическом потенциале и наличии технических средств для реализации тяговых возможностей и установленной мощности.

Ключевые слова: мобильное энергетическое средство, типоразмерный ряд, главный параметр, номицнальное тяговое усилие, мощность установленного двигателя, уровень универсальности.

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Determining Kinematic Characteristics of Planar Mechanisms' Driven Member Using Frenet Trihedron

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Summary. In lots of flat mechanisms the leading element is a crank, which is connected by a hinge to the driven member. The junction of these units, i.e. the crank, makes a circumference when rotated. The paper suggests to place the vertex of the Frenet trihedron in the junction, direct the principal unit normal vector to the circumference center, combine the unit tangent vector with the crank speed vector, that is, position it as a tangent to the circumference. When rotating the crank, the trihedron will also be rotated, and its principal unit normal vector will all the time coincide with the crank. Thus, the moving trihedron will accompany the circumference – its crank trajectory and the speed of its motion in a circumference will depend on the angular velocity of the crank rotation.

While rotating the crank, the Frenet trihedron will rotate as well, with the driven member in the form of a straight line segment passing across the vertex of the trihedron, and forming a certain angle with the unit tangent vector. The variation law of this angle will depend on the design and purpose of the mechanism. In order to get the kinematic characteristics of the driven member (its position depending on the angle of crank rotation, trajectory, velocity and acceleration of the random point), it is necessary to know the variation law of the angle of rotation of the driven member in the system of the moving trihedron in the function of the guide curve's arc length – the hinge motion trajectory.

The idea of this research lies in determining the kinematic characteristics of the complex motion of the point, when the latter performs relative motion in the moving coordinate system, and the system itself moves at a certain law towards the fixed system. If consider the convected trihedron of the curve as the moving coordinate system, than the law of the trihedron motion becomes known towards a fixed system. Thus, the rotation of the driven member around the vertex of the trihedron and simultaneous movement together with it determine the relative motion of the driven member towards the fixed coordinate system.

The position of the member is in projections on the unit vectors of the trihedron, and is immediately converted to the axis of the fixed system. The absolute trajectory of the member point movement is found in the same way, which in turn allows to define its velocity and acceleration. The resulting dependencies are common to the mechanisms' driven members, which are articulated by a hinge with a crank. For the specific mechanism, the law of rotation of the driven member in the moving trihedron system is the only thing to be known. The article uses examples of finding this law for certain mechanisms. It provides not only the charts of changes in velocity and acceleration of the individual points of the driven member, but also the direction along the member point's trajectory as a vector of the module, proportional to their size. This distribution of velocities and accelerations along the point movement trajectory may be performed with any density.

Key words: planar mechanism, crank, the driven member, Frenet trihedron, the relative motion of the point, trajectory, velocity, acceleration.

INTRODUCTION

The kinematic analysis of the planar mechanisms involves finding the positions of its members, individual points' trajectories, their velocities and accelerations. For a long time these calculations were carried out by graphic and graphoanalytical methods, including graphical differentiation of functions in the form of a curve, and graphical integration. The computer technologies' emergence allowed us to work at a new level, applying the analytical apparatus.

As one of the possible approaches, in this article it is proposed to apply two coordinate systems: a moving convected trihedron of a circumference (trajectory of the crank ending's movement), and a fixed coordinate system. The angle of the trihedron rotation with respect to the fixed coordinate system is known: it is equal to the angle of the crank rotation. The position of the vertex of a trihedron in a fixed system is also known. Thus, it becomes possible to investigate the motion of the driven member, one end of which coincides with the vertex of the trihedron, in the trihedron system itself. In the future, the resulting kinematic characteristics are recalculated in projection on the axes of the fixed coordinate system.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The study of trajectory curves of the mechanisms' member points' motion is of great importance in problems of synthesizing mechanisms. These are the tasks of the mechanisms' formation, which could reproduce the predefined curves. A group of such problems was resolved by academician P. L. Chebyshev, who applied the method of best function approximation, provided that the rod curve is a symmetric curve [1]. Some works on applied geometry are devoted to this topic [2-4]. A monograph [5] is devoted to finding a set of trajectory curves formed with the help of planetary mechanisms. The kinematics of the segment motion in the plane under the given conditions was considered in [6]. The use of the Frenet trihedron to determine the positions of the plane mechanism members is shown in [7]. The fundamental monographs [8, 9] are devoted to the study of the complex material point motion on the technological material particles' example.

The works about the particle moving along a rough surface are devoted to finding the moving point trajectory. The movement of soil particles along the plow's blade is considered in the monograph [10].

The simplest motion of a particle along an inclined plane is considered in [11, 12].

Finding the trajectory of a particle moving along a cylindrical surface under the influence of backup forces is depicted in [13].

A separate group is formed by the articles that target the particle moving along a rough surface under the influence of gravity, that is, on so-called gravitational surfaces [14-16].

A complex motion of a particle along an oscillating plane was investigated in [17, 18]. In [19], the relative motion of a particle along an internal rough surface of a rotational cone with a vertical axis of rotation is considered.

OBJECTIVE

The purpose of the research is to find the positions of the planar mechanism's driven member, to determine the trajectories, velocities and accelerations of its individual points.

THE MAIN RESULTS OF THE RESEARCH

When a trihedron moves along a plane curve, it rotates and makes an angle α at the current point with respect to the fixed coordinate system (Fig 1, a).

Its value depends on the curvature of the k curve.

Curvature is a variable and is given by the natural equation $k=k(s)$, where s is the arc length of the curve. The angular size is determined by integrating the expression $\alpha = \int k\, ds$.

For a circumference with a radius r the curvature is the reciprocal of the radius $k=1/r$ – const, and the angle will equal $\alpha=ks$.

For many mechanisms, the leading member is the crank OA, the *point* A of which circumscribes a circle (Fig. 1, b). In this case, the principal unit normal vector of the trihedron $\bar{n}$ will coincide with the crank OA as it rotates, the unit vector $\bar{\tau}$ will be tangent to the circle, and the crank swing angle ψ will equal $\psi=ks$.

When the crank rotates at a constant angular velocity ω, its point A, which is the vertex of the trihedron, will move with a *constant* velocity $V=\omega r=\omega/k$.

The same point is the beginning of the driven member ρ, which forms an angle φ with the unit vector $\bar{\tau}$, and an angle γ with the Ox axis (Fig.1, b).

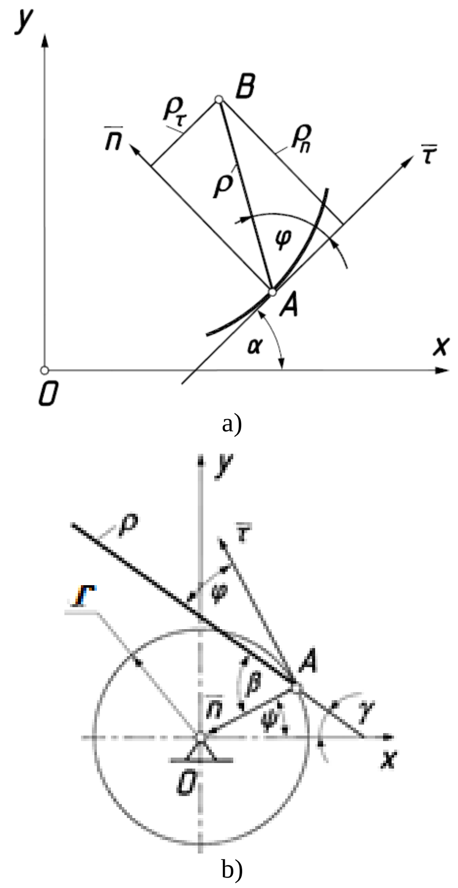

Fig. 1. Graphic illustrations to the two-link planar mechanism scheme:

a) the position of the AB member in the system of the convected trihedron of the curve,

b) member ρ in the trihedron circular system of the the trajectory of the crank OA's point A.

There is a relationship between ψ, φ, *and* γ angles, with which one can find the angle φ:

$$\varphi = 90^0 - (\gamma + ks). \qquad (1)$$

The angle change dependency $\gamma = \gamma(s)$ is determined for each specific mechanism.

In [20], the relative motion of a point in the system of the convected trihedron of the curve, given by the natural equation $k=k(s)$, is considered. The coordinates of the point B (Fig. 1, a) can be predefined by the projections $\rho\rho_\tau$ and ρ_n or by the angle φ and the distance ρ. Taking into account the fact that our guide curve is a circumference and $k=const$, the position of point B in the fixed system will be written as [20]:

$$x_B = \rho\cos(\varphi + ks) + \frac{1}{k}\sin(ks),$$
$$y_B = \rho\sin(\varphi + ks) - \frac{1}{k}\cos(ks). \tag{2}$$

In [20], there are certain expressions for determining velocity and acceleration of the point B in the projections onto the trihedron unit vectors, when both the quantities ρ and φ are variables and dependent on the guide curve's arc length s. In our case, the distance ρ will be a constant value, indicating at what distance from the hinge A the given member point is located. In this connection, the formulas will be simplified. Expressions for the velocity V in the projections onto the trihedron unit vectors are written as:

$$V_\tau = \frac{\omega}{k}\left[1 - \rho(k + \varphi')\sin\varphi\right],$$
$$V_n = \frac{\omega}{k}\rho(k + \varphi')\cos\varphi. \tag{3}$$

The acceleration projections W look as follows [21]:

$$W_\tau = -\frac{\omega^2}{k^2}\left[\rho\varphi''\sin\varphi + \rho(k + \varphi')^2\cos\varphi\right],$$
$$W_n = \frac{\omega^2}{k^2}\left[\rho\varphi''\cos\varphi - \rho(k + \varphi')^2\sin\varphi + k\right]. \tag{4}$$

The values of both the velocity (3) and the acceleration (4) are found as the square root of the sum of the components' squares, that is, as a vector sum. If it is necessary to know the direction of the velocity or acceleration vector, then it is necessary to switch from the projections (3) and (4) to the projections on the axis of the fixed system, taking into account the known angle between them $\alpha = ks$.

Let us consider some specific examples. Take the de-axial crank-slider mechanism (Fig. 2).

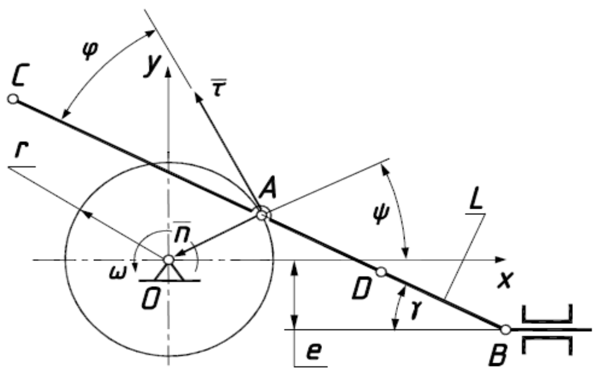

Fig. 2. The scheme of the crank-slider mechanism

Let us find the kinematic characteristics of the different points of the connecting rod L. To know the angle change dependency in the angle φ (1), it is necessary to find the angle change dependency $\gamma = \gamma(s)$. To do this, let us use the fact that the ordinate of the point A – $AB = L$ – is common for both the crank OA and the connecting rod. For the point A – the end of the crank OA, let us write:

$$y_A = r\sin\psi = \frac{1}{k}\sin(ks). \tag{5}$$

For the point A – the end of the connecting rod $AB = L$ let us write:

$$y_A = L\sin\gamma - e. \tag{6}$$

By equating the expressions (5) and (6) and solving for the angle γ, we get:

$$\gamma = -\arcsin\frac{ek + \cos(ks)}{Lk}. \tag{7}$$

According to (1), the expression for the angle φ takes the following form:

$$\varphi = 90^0 - ks + \arcsin\frac{ek + \cos(ks)}{Lk}. \tag{8}$$

To find the velocity and acceleration of a connecting rod's random point, it is necessary to have the first and the second derivatives of the expression (8). The first derivative looks as:

$$\varphi' = \frac{k\cos(ks)}{\sqrt{L^2k^2 - (ek + \sin(ks))^2}} - k. \tag{9}$$

The second derivative is obtained by differentiating the expression (9):

$$\varphi'' = \frac{2k^2\left(1 + e^2k^2 - L^2k^2\right)\sin(ks)}{2\left[L^2k^2 - (ek + \sin(ks))^2\right]^{3/2}} + \frac{ek^3\left(3 - \cos(2ks)\right)}{2\left[L^2k^2 - (ek + \sin(ks))^2\right]^{3/2}}. \tag{10}$$

The expressions (8), (9) and (10) allow to find all the kinematic characteristics of any point of the connecting rod L for a given distance ρ from the point A.

In Fig. 3, the $AB = L$ connecting rod's positions are constructed, with a defined cranking rotation density OA with an angle increment by the amount of $k\Delta s$ within the limits of its incomplete turn.

The trajectory of the connecting rod's starting point (point A) was determined by formulas (2) for $\rho = 0$. The trajectory of the opposite point B was at $\rho = AB = L$.

The connection of these points by a straight line segment, for a certain value of the parameter s, positions the connecting rod as a straight line segment.

Above the positions of the connecting rod *AB*, the trajectories of its individual points are constructed as well in Fig. 3, according to formulas (2).

When $\rho=0$, we get a circumference – the hinge movement trajectory.

When $\rho=AB=L$, we get a straight line – the slider movement trajectory (point *B*).

This proves the reliability of the obtained results.

Fig. 3 shows the trajectory of the point *A* constructed at $\rho=0$, as well as the trajectory of the points: *B* – for $\rho=AB=4m$, *C* for $\rho=-4m$, *D* for $\rho=L/2=2m$. Curvature $k=0{,}5\ m^{-1}$, $e=1m$.

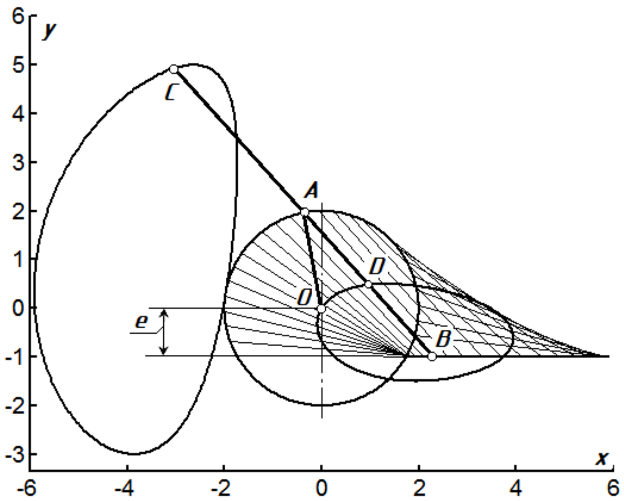

Fig. 3. One-parameter set of positions of the connecting rod and the trajectory of its individual points

Let us consider the construction of the connecting rod points' velocity. This will be done in a way that the direction and the value of the velocity along the point motion trajectory can clearly be seen. To do this, let us proceed from the velocity projections on the trihedron's unit vectors (3) to the projections on the fixed coordinate system's axes, rotating them by the angle $\alpha=ks$:

$$\begin{aligned} V_x &= V_\tau \cos(ks) - V_n \sin(ks), \\ V_y &= V_\tau \sin(ks) + V_n \cos(ks). \end{aligned} \qquad (11)$$

Depending on the connecting rod's position (variable *s*), the coordinates of a certain point (for example, the point *C* at $\rho=-4$) are found from formulas (2). It is necessary to add the obtained vector (11), previously multiplied by the scale factor *m*, to the coordinates of this point. The end of the velocity vector coordinates are found:

$$\begin{aligned} x_V &= x_C + mV_x, \\ y_V &= y_B + mV_y. \end{aligned} \qquad (12)$$

By connecting the point with the coordinates x_C and y_C on the trajectory with the coordinates of the end of the vector x_V and y_V by a segment, we obtain the velocity vector at a given point of the trajectory.

By increasing the variable *s* by some value Δs, we can construct vectors along the trajectory with the required density. In Fig. 4, the velocity vectors for the points *C* and *D* are plotted.

However, the visibility deteriorates in the sections of the trajectory close to the straight line, and totally disappears on the straight sections (for instance, for the trajectory of the point *B*).

The graph shows that the velocity of the point *A* is constant, and the velocity of the point *B* at a certain moment equals zero (in the extreme positions of the slider).

In the same sequence, we construct acceleration vectors using the expressions (4). Fig. 6 shows the visual distribution of the acceleration vectors along the *A*, *C* and *D* points' trajectory, and Fig. 7 – their value change graphs.

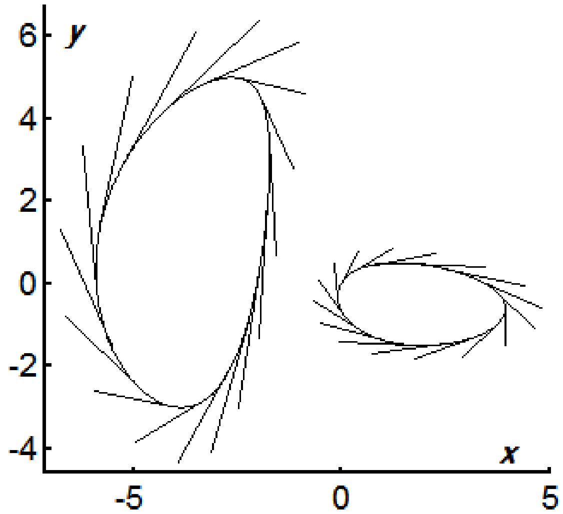

Fig. 4. Distribution of the velocity vectors along the trajectories of the points *C* and *D*

In such case, it is possible to construct a graph of the velocity value change. In Fig. 5 such graph is constructed, covering the four points of the connecting rod, which are indicated in Fig. 3.

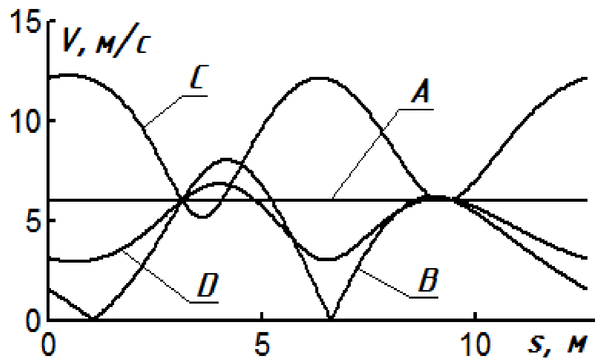

Fig. 5. A graph of the velocity value change for the connecting rod's points

To enable the mechanism work, the necessary relationships between the design parameters of the mechanism must be observed. This follows from the expression (7), in which the fraction in its absolute value should not exceed the unity. Fig. 8 shows some positions of the connecting rod and the individual points' trajectory for the following boundary values of the design parameters: $k=0{,}5\ m^{-1}$, $e=2\ m$, $L=4\ m$. In the extreme position of the slider, the connecting rod coincides with the crank along the vertical line.

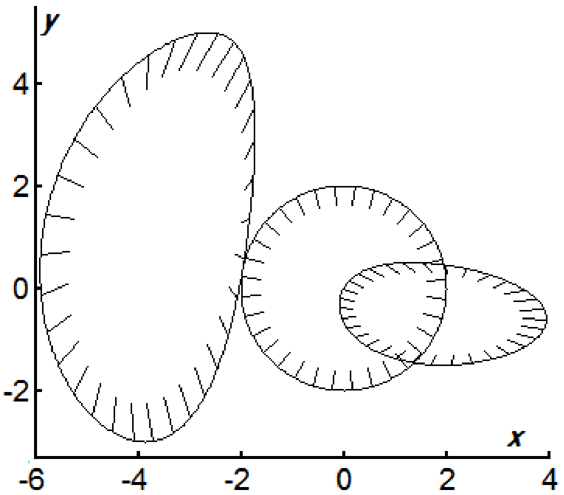

Fig. 6. Distribution of the acceleration vectors along the *A*, *C* and *D* points' trajectories.

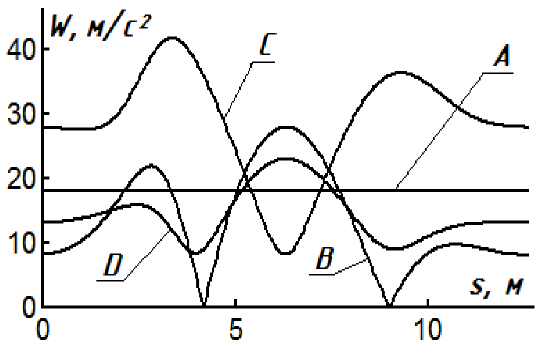

Fig. 7. A graph of the acceleration value change for the connecting rod's points

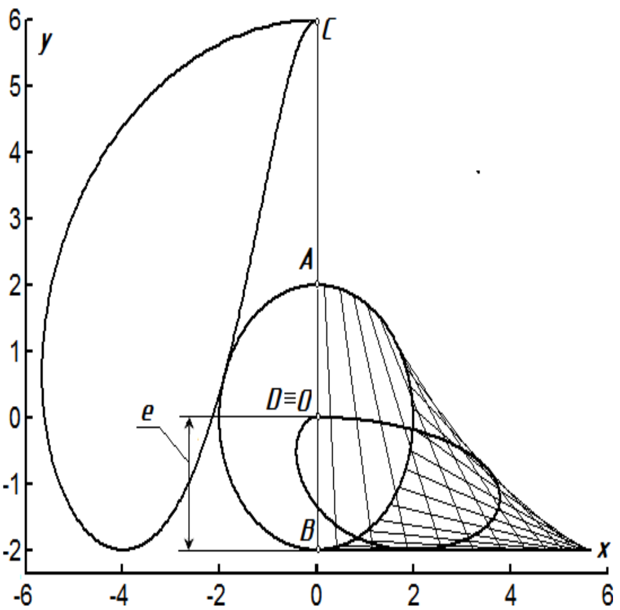

Fig. 8. One-parameter set of positions of the connecting rod and the trajectory of its individual points

In Fig. 9, the acceleration vectors are constructed along the *A*, *C* and *D* points' trajectories. With the analytical expressions for constructing velocity and acceleration vectors, it is very simple and quick to obtain their visual distribution along the trajectories, when the design parameters and the location of the point on the connecting rod change.

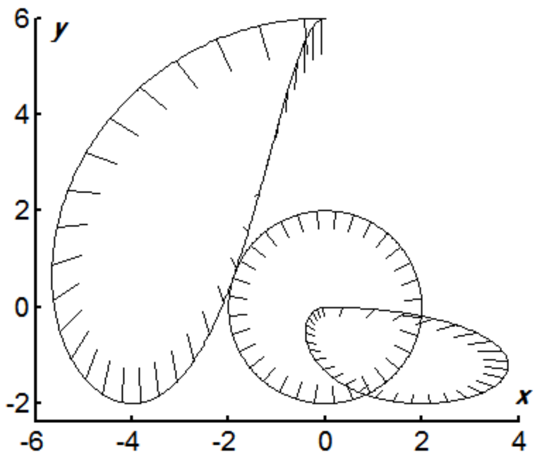

Fig. 9. Distribution of the acceleration vectors along the trajectories of the points *A*, *C* and *D*

Another mechanism with the boundary values of the design parameters: $k=0{,}5\ m^{-1}$, $e=1\ m$, $L=3\ m$ is shown in Fig. 10. It also demonstrates some of the connecting rod positions and points *A*, *B*, *C* and *D* trajectories. As in the previous case, in slider extreme position the connecting rod coincides with the crank along the vertical line.

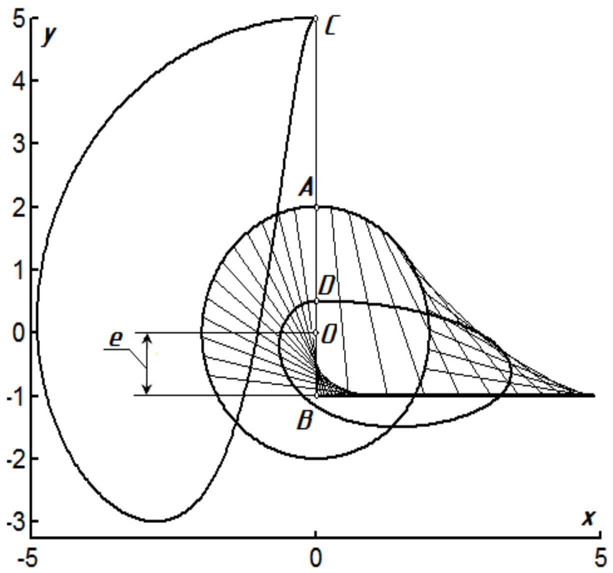

Fig. 10. One-parameter set of positions of the connecting rod and the trajectory of its individual points

In Fig. 11, the *A*, *C* and *D* points' trajectories are constructed with acceleration vectors for the mechanism (10).

One can judge about the point's velocity by the density of the vectors' arrangement along the trajectory.

For instance, for the point *C* at the top of the trajectory, the density of the vectors is lower, so the point's velocity will be greater.

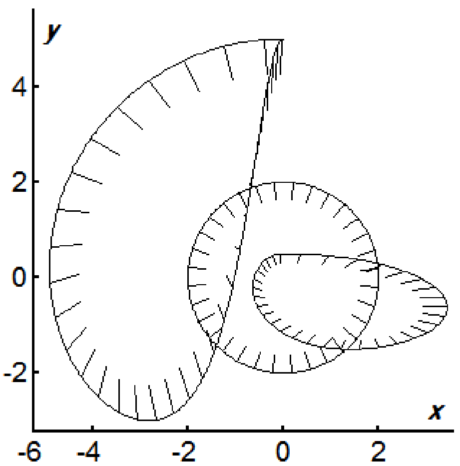

Fig. 11. Distribution of the acceleration vectors along the trajectories of the points *A*, *C* and *D*

Let us consider one more mechanism – a crank-rocker with points *A, C, D* on the rocker arm (Fig. 12). Its characteristic feature is that point *A* on the rocker arm moves along the circumference, and point *B* is fixed. This is ensured by sliding the rocker in a rocking or rotating stone, fixed at point *B.* To find the dependency of the angle φ (1) changing, it is necessary to know the expression for the angle γ. The guide vector of the rocker arm is found as a segment connecting point *A* with the coordinates $\{\cos(ks)/k, \sin(ks)/k\}$ with the fixed point with the coordinates *{0, d}*.

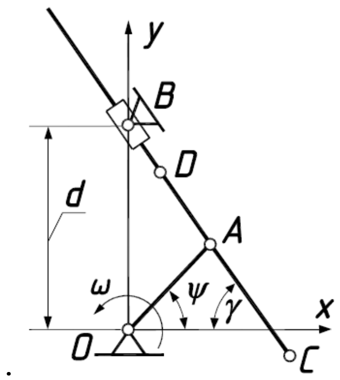

Fig. 12. The scheme of the crank-rocker mechanism

The vector coordinates will be:{cos*(ks)/k*, *d*-sin*(ks)/k*}.The γ angle between the rocker arm's vector and the *Ox* axis is defined from the following expression:

$$\gamma = \arccos\frac{\cos(ks)}{\sqrt{\cos^2 ks + (kd - \sin ks)^2}} = \arccos\frac{\cos(ks)}{\sqrt{1 + k^2 d^2 - 2kd\sin ks}}. \tag{13}$$

According to (1), the expression for angle φ is written as:

$$\varphi = 90^0 - ks - \arccos\frac{\cos(ks)}{\sqrt{1 + k^2 d^2 - 2kd\sin ks}}. \tag{14}$$

Let us find the first and the second derivatives of the expression (14):

$$\varphi' = -\frac{k\left(2 + d^2k^2 - 3dk\sin ks\right)}{1 + k^2d^2 - 2kd\sin ks}. \tag{15}$$

$$\varphi'' = \frac{dk^3\left(d^2k^2 - 1\right)\cos ks}{\left(1 + k^2d^2 - 2kd\sin ks\right)^2}. \tag{16}$$

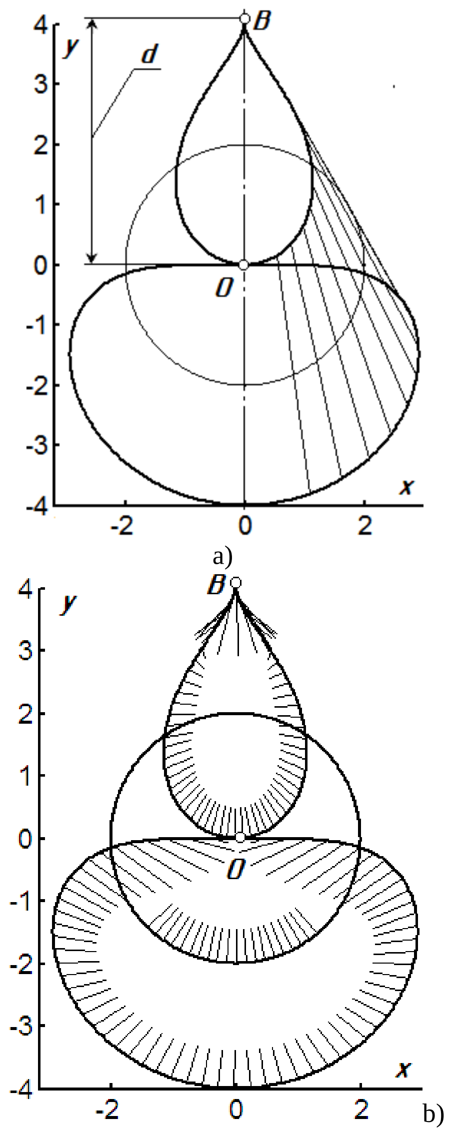

Fig. 13. Representation of the crank-rocker mechanism's kinematic elements:

a) points' trajectories and some rocker arm positions,

b) acceleration vectors' distribution along the trajectories.

Expressions (14), (15), (16) are sufficient to construct all the kinematic characteristics of the rocker arm points. Some rocker arm positions and the *A*, *C* and *D* points' trajectory are built in Fig. 13,a for $k=0{,}5\ m^{-1}$, $d=4\ m$, and the distance $\rho=\pm 4\ \ m$ from points C and D to point A. Fig. 13,b presents a graphic representation of the acceleration vectors of these points along the trajectories of their motion, and Fig. 14 is a graph of the change in their values. It follows from the graph that at a certain moment the acceleration of one of the rocker arm points is zero.

It can be visually determined from Fig. 13,b that this point belongs to the lower trajectory (the motion of the point C), when it coincides with the point O.

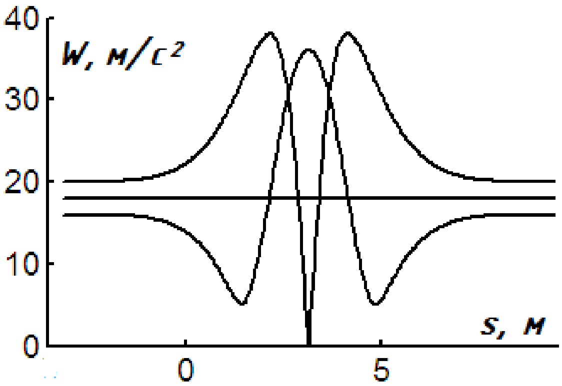

Fig. 14. A graph of the acceleration value change for the rocker arm's points

While analyzing expression (16) it can be seen that in the case $1/k=r=d$, the angular acceleration of the rocker arm in the trihedron system will equal zero, i.e. the angular velocity of its rotation will be constant. The family of rocker arm positions of such mechanism is shown in Fig. 15.

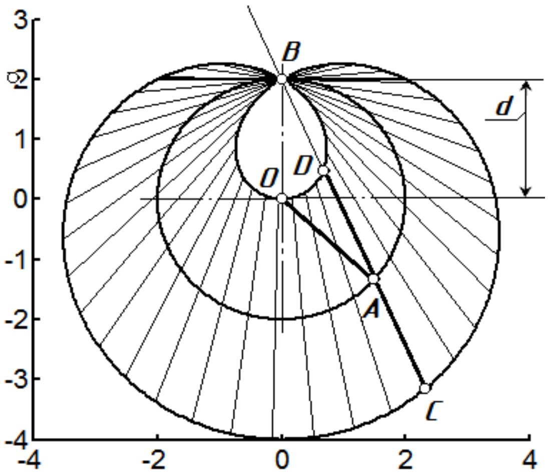

Fig. 15. Trajectories of the points and the position of the driven member in a special case of the crank-rocker mechanism

Its characteristic feature is that in the absence of an AC segment the pattern would not change.

When lifting up, point D, moving along the internal curve, after passing point B starts to move along the outer curve, and eventually takes the place of point C.

The segment of the rocker arm AD alternately occupies the inner and the outer spaces, delineated by the circumference – the trajectory of point A.

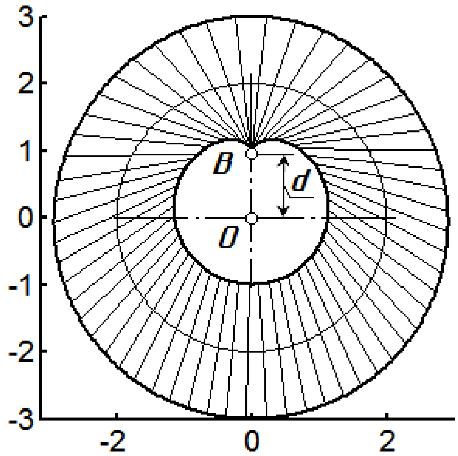

Fig. 16. Trajectories of the points and the position of the rocker arm mechanism when $k=0{,}5$ and $d=1$

If the stone rocks while the mechanism shown in Fig. 12 works, provided that $d>r$, then at $d=r$ (Fig. 15) it already rotates. Another illustration of the mechanism with a rotating stone for $d<r$ is shown in Fig. 16.

CONCLUSIONS

1. In certain planar mechanisms the leading member is a crank, which rotates with the permanent angular velocity. The trajectory of the crank's ending movement is a circumference, which is to be taken as a guide curve for the convected Frenet trihedron. The trihedron moves along the circumference in such a way that its main unit normal vector coincides with the crank.

2. The motion of the driven member is described analytically in the trihedron system. This allows to receive general relationships for determining all the necessary kinematic characteristics of the driven member: the family of its positions, the trajectories of the individual points' motion, their velocities and accelerations. For this, it is necessary to find the law of rotation of the driven member in the trihedron system for each mechanism.

3. The developed approach makes it possible to construct a visual representation of the velocity and acceleration vectors' distribution of the driven member's points along their curvilinear trajectory with the required density.

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ОПРЕДЕЛЕНИЕ КИНЕМАТИЧЕСКИХ ХАРАКТЕРИСТИК ВЕДОМОГО ЗВЕНА ПЛОСКИХ МЕХАНИЗМОВ С ПОМОЩЬЮ ТРЕХГРАННИКА ФРЕНЕ

Сергей Пилипака, Андрей Чепижный, Татьяна Кресан

Аннотация. У многих плоских механизмов ведущим звеном является кривошип, который посредством шарнира соединен с ведомым звеном. Точка соединения этих звеньев, то есть кривошип, при вращении описывает окружность. В статье предлагается в точку соединения звеньев поместить вершину трехгранника Френе, орт главной нормали направить к центру окружности, орт касательной совместить с вектором скорости кривошипа, то есть расположить по касательной к окружности. При вращении кривошипа трехгранник тоже будет вращаться, причем его главная нормаль все время будет совпадать с кривошипом. Таким образом, подвижный трехгранник будет сопровождающим для окружности – траектории движения кривошипа и скорость его движения по окружности будет зависеть от угловой скорости вращения кривошипа.

При вращении кривошипа вместе с ним будет вращаться трехгранник Френе, при этом ведомое звено в виде прямолинейного отрезка будет проходить через вершину трехгранника и образовывать с ортом касательной определенный угол. Закон изменения этого угла будет зависеть от конструкции и назначения механизма. Чтобы получить кинематические характеристики ведомого звена (его положение в зависимости угла поворота кривошипа, траекторию, скорость и ускорение произвольной точки), необходимо знать закон изменения угла поворота ведомого звена в системе подвижного трехгранника в функции длины дуги направляющей кривой – траектории движения шарнира.

Идея работы состоит в нахождении кинематических характеристик сложного движения точки, когда она совершает относительное движение в подвижной системе координат, а сама подвижная система по определенному закону движется по отношению к неподвижной системе. Если за подвижную систему координат взять сопровождающий трехгранник кривой, то закон движения трехгранника становится известным по отношению к неподвижной системе. Таким образом поворот ведомого звена вокруг вершины трехгранника и одновременное движение вместе с ним определяет относительное движение ведомого звена по отношению к неподвижной системе координат.

Положение звена находится в проекциях на орты трехгранника и сразу же пересчитывается на оси неподвижной системы. Таким же образом находится абсолютная траектория движения точки звена, что в свою очередь позволяет найти ее скорость и ускорение. Найденные зависимости являются общими для ведомых звеньев механизмов, которые сочленены посредством шарнира с кривошипом. Для конкретного механизма нужно знать только закон поворота ведомого звена в системе подвижного трехгранника. В статье наведены примеры нахождения этого закона для некоторых механизмов. Построены не только графики изменения величины скорости и ускорения отдельных точек ведомого звена, но и их направление вдоль траектории точки звена в виде вектора с модулем, пропорциональным их величине. Такое распределение векторов скоростей и ускорений вдоль траектории движения точки может быть выполнено с любой плотностью.

Ключевые слова: плоский механизм, кривошип, ведомое звено, подвижный трехгранник Френе, относительное движение точки, траектория, скорость, ускорение.

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Mathematical Modeling of Drying Process of Plant Material in Drum Dryer at Variable Speed of Movement of Material

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Summary. In the system of technological operations of post-harvest handling of the crop is drying. Universal dryer drum type are widely used in farms, because, allow for dewatering of various bulk wet materials, but for a number performance indicators (specific energy consumption, automation level, implementation of environmental requirements, and others), these dryers do not quite meet the modern requirements of agricultural production and processing sectors.

The decision of problems of optimization of performance and energy consumption of drum units is possible only when adequate mathematical models of processes of heat and mass transfer taking into account the governing parameters of the process. In article on the basis of the analysis of the literature substantiates the scientific tasks of the analytical mathematical description and calculation of parameters of process of drying particulate plant material in a pneumatic drum units.

Using the methods of thermal and material balance, based on simplified representations of the processes of heat and mass transfer mathematical model describing change of parameters of the drying agent and material in the pneumatic drum unit in the process of moving along the rotational drum.

For example, analytic analysis of changes in the temperature of the drying agent and the material and its moisture content is given the solution of the equations for a linear law of transfer of material along the drum.

So as a result, the research obtained a mathematical model of stationary process of drying the plant material in a pneumatic drum unit.

The analytical dependencies describing the distribution of parameters of process of drying of the material in the drum with a given speed of movement.

Key words: modeling, process, drying, material, drum, speed.

INTRODUCTION

In the system of technological operations of post-harvest processing of crops, is important thermal drying [1, 2, 3]. Given the wide range drying products, the most versatile dryer units are pneumatic drum assemblies [4, 5, 6]. But despite the widespread use of drum dryers the theory of processes taking place in them to date is not sufficiently developed. Compatible phenomena of heat and mass transfer associated with moving the drying agent, who also is a means of transporting material. Reducing the weight of the material in the drying process leads to changes in the speed of its movement along the drum, which in current models is not considered. However, the exclusion of the arbitrariness of the speed of movement of the material and development of methods to control the speed of movement (except changing the revolutions of the drum) can significantly intensify the process of drying and to improve the quality of the product dried. In addition, the relevant issue is not only the creation and implementation of new technologies and equipment to implement thermal drying , and a reduction in financial costs for the process of development of such machines [7].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Recent work on the problem of drying of agricultural plant materials and products note the works [8, 9, 10].

In [8] substantiated methods for determining displacement of the material in the drum that rotates with different type of attachments, in the monograph [9] investigated heat and mass transfer in processes of drying in drum-type units with the transverse and longitudinal flow of material.

In [10] is justified based on process parameters from the design parameters of the drum. In early works [11, 12] the mathematical model of the dynamic modes of a drum dryer.

Known works [13, 14, 15] reduced to the design and analysis determine residence time of material in the drum and the exposure of drying.

Change the speed of the moving material in the drum and its influence on the performance of the process is not considered.

OBJECTIVE

The determination of regularities of the drying process on the basis of simplified model representations, and taking into account the changes of the velocity of the material coordinate movement.

THE MAIN RESULTS OF THE RESEARCH

The processes of heat and mass transfer during drying of plant materials and products in installations of pneumatic drum type describes ordinary differential equations, which are formed in the closed system of the fourth order [11, 12]:

$$\frac{r_0}{C_м}\left(\frac{\partial U}{\partial \tau}+\upsilon_м\frac{\partial U}{\partial y}\right)+\left(\frac{\partial \theta}{\partial \tau}+\upsilon_м\frac{\partial \theta}{\partial y}\right)=\frac{\alpha f}{C_м m_м}(t-\theta) \quad (1)$$

$$\frac{\partial t}{\partial \tau}+\upsilon\frac{\partial t}{\partial y}=\frac{\alpha f}{C_p m_p}(\theta-t) \quad (2)$$

$$G_0\left(\frac{\partial U}{\partial \tau}+\upsilon_м\frac{\partial U}{\partial y}\right)=\beta f\left(P_н(\theta)-P(d)\right) \quad (3)$$

$$\frac{\partial d}{\partial \tau}+\upsilon\frac{\partial d}{\partial y}=\frac{G_0}{G_p}\left(\frac{\partial U}{\partial \tau}+\upsilon_м\frac{\partial U}{\partial y}\right) \quad (4)$$

where: $m_м = V_б \cdot \psi \cdot \rho_м$ – the mass of material in the dryer, $m_p = V_б \rho$ – weight of drying agent in the drum, $V_б$ – the volume of the drum, ψ – the fill factor, $\rho_м$, ρ – the density of the material and a drying agent, $\upsilon_м$, υ – the speed of the material and a drying agent, α, β – the coefficients of heat and mass transfer, f – the surface of the material that participates in the exchange processes, C_p, $C_м$ – the heat capacity of the drying agent and material, r_0 – heat of vaporization, $P_н$, P – elasticity of saturated steam in the drying agent.

Mathematical reasoning physics equations of heat and mass transfer are the following conditions: moisture of the material is removed according to Dalton's law, the moisture in the material evaporates and is removed at the same time, the moisture content and temperature in the bulk material is distributed evenly, heat and mass transfer occurs only between the surface of the material and the drying agent, the effects of radiation and contact heat transfer coefficients are taken into account heat transfer, stationary fields of temperatures and moisture content are accepted one-dimensional, that change with the coordinate y measured in the direction of movement of the material.

The system (1)-(4) is a complete mathematical model of the drying process in pravoberezhnomu the aggregate taking into account the adopted assumptions under appropriate boundary conditions:

$$\theta(0,\tau)=\theta_1(\tau), \quad t(0,\tau)=t_1(\tau), \quad U(0,\tau)=U_1,$$

$$d(0,\tau)=d_1, \quad \theta(y,0)=\theta_0, \quad t(y,0)=t_0,$$

$$U(y,0)=U_0, \quad d(y,0)=d_0.$$

For the solution of specific objectives – determine the impact velocity of the material (static and dynamic) modes of drying system of equations have greatly simplified and divided into two stages: determination of the steady-state mode of operation of the dryer and transition. The system of equations can be greatly simplied if we make an additional assumption: the intensity of drying is proportional to the current moisture content and the rate of heating of the material and can be described by the equations:

- Lykov [18]:

$$-\frac{dU}{d\tau}=k(t)(U-U_r), \quad (5)$$

$$dU=\frac{C_м}{r_0 Rb}d\theta, \quad (6)$$

where: $k(t)$ – coefficient of drying, U_r – equilibrium moisture content, $Rb=\frac{C_м(U)d\theta}{r_0(\theta)dU}$ – criterion Rebinder.

Since the heat transfer coefficient in the drying process is reduced [19] and decreases the mass of material in the drum (due to drying), the value $\frac{\alpha f}{m_м}$ – you can take a constant (average per process), the rate of drying depends on the temperature of the drying agent. We assume that the drying coefficient is linearly dependent on temperature:

$$k(t)=a+bt \quad (7)$$

The change in the moisture content of the drying agent affects the process of moisture removal from the material [20], but with increasing moisture content of the drying agent increases the heat transfer coefficient, so the assumption $\alpha(y)=const$ – formally justified. As in rotary dryers of agricultural materials used in high-temperature drying agent $t \geq 120\ ^0C$ the material can be dried to absolutely dry matter, suggesting that the magnitude of the equilibrium moisture content constant, according to the parameters of drying agent at the outlet of the drum – $U_r = U(t_2, d_2)$.

Assumptions allow to exclude from equation (1) variable *U(y)*, and from equation (3) component, which depends on the temperature of the material $P(\theta)$ and reduce the order of the system.

Consider a stationary mode of operation of the dryer (after warm-up time) when each point of the volume of the drum all process parameters are time variables and for each coordinate by the length and the output have constant values. Equating the time derivatives to zero and considering the equations (5) and (6) we get the system of equations in ordinary derivatives:

$$\upsilon\frac{dt(t)}{dy}=\frac{\alpha f}{C_p m_p}(\theta(y)-t(y)), \quad (8)$$

$$\upsilon_м\frac{d\theta(y)}{dy}-\frac{r_0}{C_м}\upsilon_м\frac{dU(y)}{dy}=\frac{\alpha f}{C_м m_м}(t(y)-\theta(y)), \quad (9)$$

$$-\upsilon_{м}\frac{dU}{dy}=\left(a+bt(y)\right)\left(U(y)-U_{r}\right). \quad (10)$$

We introduce the notation:

$$k_1=\frac{\alpha f}{C_{м}{}' m_{м}},\ k_2=\frac{\alpha f}{C_p m_p \upsilon},\ C_{м}{}'=C_{м}\left(1-\frac{1}{Rb}\right).$$

Given the assumptions made and considering the change of the velocity of the material along a drying path, according to the reduction of mass of material passing the drum from equations (8) and (9) we get:

$$\frac{dt(y)}{dy}=k_2\left[\theta(y)-t(y)\right], \quad (11)$$

$$\frac{d\theta(y)}{dy}=\frac{k_1}{\upsilon(y)}\left[t(y)-\theta(y)\right]. \quad (12)$$

Subtract the second equation from the first:

$$\frac{d}{dy}\left[t(y)-\theta(y)\right]=-\left[\frac{k_1}{\upsilon(y)}+k_2\right]\left(t(y)-\theta(y)\right) \quad (13)$$

Where one of the first integrals of the system takes the form:

$$ln\left|t(y)-\theta(y)\right|=ln(C_1)-\int_0^y\left[\frac{k_1}{\upsilon(s)}+k_2\right]ds. \quad (14)$$

Where one of the first integrals of the system takes the form:

$$t(y)-\theta(y)=C_1\cdot exp\left(-\int_0^y\left[\frac{k_1}{\upsilon(s)}+k_2\right]ds\right). \quad (15)$$

A decision on *t(y)*:

$$t(y)=\theta(y)+C_1\cdot exp\left(-\int_0^y\left[\frac{k_1}{\upsilon(s)}+k_2\right]ds\right). \quad (16)$$

A decision on θ*(y)*:

$$\theta(y)=t(y)-C_1\cdot exp\left(-\int_0^y\left[\frac{k_1}{\upsilon(s)}+k_2\right]ds\right). \quad (16a)$$

Let us substitute the expression (16A) in equation (11) and get:

$$\frac{dt(y)}{dy}=-k_2C_1\cdot exp\left(-\int_0^y\left[\frac{k_1}{\upsilon(s)}+k_2\right]ds\right). \quad (17)$$

Its solution has the form:

$$t(y)=-k_2C_1\int_0^y exp\left(-\int_0^{\xi}\left(k2+\frac{k1}{\upsilon(s)}\right)ds\right)d\xi+C_2. \quad (18)$$

Substitute the obtained expression (18) into equation (16a) and get the solution of the equation:

$$\begin{aligned}\theta(y)=&-k_2C_1\int_0^y\exp\left(-\int_0^{\xi}\left(k2+\frac{k1}{\upsilon(s)}\right)ds\right)d\xi+\\&+C_2-\\&-C_1\cdot\exp\left(-\int_0^y\left[\frac{k_1}{\upsilon(s)}+k_2\right]ds\right).\end{aligned} \quad (19)$$

Steel of integration C_1 and C_2 define the boundary conditions:

$$t(0)=t_1,$$

$$\theta(0)=\theta_1,$$

$C_2=t_1$,

$\theta_1=C_2-C_1$,

$C_1=t_1-\theta_1$.

The solution of the Cauchy problem would be:

$$\begin{aligned}\theta(y)=&-k_2(t_1-\theta_1)\int_0^y\exp\left(-\int_0^{\xi}\left(k2++\frac{k1}{\upsilon(s)}\right)ds\right)d\xi+\\&+t_1-\\&-(t_1-\theta_1)\cdot\exp\left(-\int_0^y\left[\frac{k_1}{\upsilon(s)}+k_2\right]ds\right).\end{aligned} \quad (20)$$

$$\begin{aligned}t(y)=&-k_2(t_1-\theta_1)\int_0^y\exp\left(-\int_0^{\xi}\left(k2++\frac{k1}{\upsilon(s)}\right)ds\right)d\xi+\\&+t_1.\end{aligned} \quad (21)$$

Take as a first approximation, a linear dependence of the rate of movement of the length of the drying path:

$$\upsilon(s)=a_1+b_1s.$$

Then:

$$-\int_0^y \left[\frac{k_1}{\upsilon(s)} + k_2\right] ds = -\left[k_2 y + \frac{k_1}{b_1} \cdot ln \frac{a_1 + b_1 y}{a_1}\right]. \quad (22)$$

Substitute (22) into (17) and taking into account the initial conditions we get:

$$t(y) = t_1 + \frac{1}{b_1}\left[\begin{array}{l} k_2(t_1 - \theta_1)\cdot \\ \exp\left(\frac{a_1 k_2}{b_1}\right) \\ \left(\begin{array}{l} a_1^{\frac{k_1}{b_1}}(a_1 + b_1 y)^{1-\frac{k_1}{b_1}} \\ E_n(Z_1) - a_1 E_n(Z_2) \end{array}\right) \end{array}\right] \quad (23)$$

where: $E_n(Z_1) = \int_1^\infty \frac{e^{-Z_1 t}}{t^n} dt$

and

$E_n(Z_2) = \int_1^\infty \frac{e^{-Z_2 t}}{t^n} dt$ – exponential integrals,

$$Z_1 = k_2\left(\frac{a_1}{b_1} + y\right),$$

$$Z_2 = \frac{a_1 k_2}{b_1},$$

$$n = \frac{k_1}{b_1}.$$

Substituting equation (22) and derive an equation for the temperature of the drying agent in (16A), we get:

$$\theta(y) = t_1 + \frac{1}{b_1}\left[\begin{array}{l} k_2(t_1 - \theta_1)\cdot \exp\left(\frac{a_1 k_2}{b_1}\right) \\ \left(\begin{array}{l} a_1^{\frac{k_1}{b_1}}(a_1 + b_1 y)^{1-\frac{k_1}{b_1}} E_n(Z_1) - \\ -a_1 E_n(Z_2) \end{array}\right) \end{array}\right] - $$
$$-(t_1 - \theta_1)\times \quad (24)$$
$$\times \exp\left(-k_2 y - \frac{k_1}{b_1}\cdot \ln\frac{a_1 + b_1 y}{a_1}\right).$$

Substituting values of temperature *t(y)* in equation (10) after separation of variables get:

$$U(y) = U_r - (U_1 - U_r)\cdot$$
$$\exp\left[\int_0^y \left[\begin{array}{l} \frac{1}{a_1 + b_1 y} \\ \left(a + b\cdot\left(\begin{array}{l} t_1 + \\ +\frac{1}{b_1}\left[\begin{array}{l} k_2(t_1 - \theta_1)\cdot \\ \exp\left(\frac{a_1 k_2}{b_1}\right)\times \\ \times\left(\begin{array}{l} a_1^{\frac{k_1}{b_1}}(a_1 + b_1 y)^{1-\frac{k_1}{b_1}} \\ E_n(Z_1) - \\ -a_1 E_n(Z_2) \end{array}\right) \end{array}\right] \end{array}\right)\right) \end{array}\right] dy\right] \quad (25)$$

Thus the resulting equation (23), (24), (25) determine the temperature distribution and the moisture content of the material during the drying process in a rotating drum when the speed of movement.

CONCLUSIONS

1. A mathematical model of stationary process of drying the plant material in pneumatic drum unit.
2. The analytical dependencies describing the distribution of parameters of process of drying of the material in the drum with a given speed of movement.-size range of mobile agricultural energy products.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССА СУШКИ РАСТИТЕЛЬНОГО МАТЕРИАЛА В БАРАБАННОЙ СУШИЛКЕ ПРИ ПЕРЕМЕННОЙ СКОРОСТИ ПЕРЕМЕЩЕНИЯ МАТЕРИАЛА

Роман Калиниченко, Валерий Войтюк

Аннотация. В системе технологических операций послеуборочной обработки урожая сельскохозяйственных культур важное место занимает сушки. Универсальные сушилки барабанного типа широко используются в хозяйствах, поскольку позволяют проводить обезвоживание различных сыпучих влажных материалов, но по целому ряду показателей работы (удельные затраты энергии, уровень автоматизации, выполнения экологических требований, и другие) эти сушилки не совсем соответствуют современным требованиям производства сельскохозяйственной и перерабатывающей отраслей.

Решение задач оптимизации по производительности и энергозатратам барабанных агрегатов возможно только при наличии адекватной математической модели процессов тепло- и массообмена с учетом определяющих параметров процесса. В статье на основе анализа литературных источников обоснованно научную задачу аналитического математического описания и расчета определяющих параметров процесса сушки растительных дисперсных материалов в пневмобарабанних агрегатах.

С помощью методов теплового и материального баланса на основе упрощенных представлений о процессах тепло- и массообмена построена математическая модель, описывающая изменение параметров сушильного агента и материала в пневмобарабанном агрегате в процессе перемещения вдоль вращательного барабана.

На примере аналитического анализа изменения температуры сушильного агента и материала и его влагосодержания приведены решение полученных уравнений для линейного закона перемещения материала вдоль барабана.

Таким образом в результате выполненного исследования получена математическая модель стационарного процесса сушки растительного материала в пневмобарабанном агрегате.

Определены аналитические зависимости, описывающие распределение параметров процесса сушки материала в барабане с учетом скорости перемещения.

Ключевые слова: модерирование, процесс, сушка, материал, барабан, скорость.

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Organizational and Technological Backgrounds of Project Configuration Management for Firefighting

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Summary. The structure of firefighting projects was solved. There was justified that the central place in them belongs to appropriate technological processes. Temporary technological systems create for doing these processes. The place and the role of processes of technology management processes and projects management of firefighting were determined. There was solved their differences and the systemic influence on value indicators of these projects was justified.

It's proven that the purpose of firefighting projects has been achieved through the coherence of the nomenclature and resources amount which are included in these projects configuration and configuration objects of the combustion (heat sources). The coherence of these configurations allows to realize firefighting projects timely with minimal and technological rates of human, technic, material and energetic resources.

The interrelation of processes for project management works, which are predetermined by firefighting technologies, and the configuration of these projects were solved. The question of their initiation and planning on the base of the forecasting for value indicators of temporary firefighting projects was considered. These projects use the analysis of existing statistic information, physic modeling and chronometric of project works.

Projects management configuration of the improvement for regional existing systems of firefighting is based on results of the determination for value indicators of temporary firefighting projects for objects of the combustion. The process of projects management configuration of the improvement for these systems provides the satisfaction by them four main organizational and technological requirements of temporary firefighting projects.

Key words: firefighting, projects, management, configuration, organizational and technological backgrounds.

INTRODUCTION

Project Configuration Management is one of the important areas of project management knowledge, from which greatly depends on their success [1]. Especially it concerns production and technological projects, which include firefighting projects. There is an appropriate system in Ukraine today. Its structure and functions do not fully meet the modern requirements of territorial and administrative reform in the state. One of the actual problems of firefighting protection. The search for effective ways of reforming the system of fire, which would to some extent meet the aforementioned requirements, is one of the urgent problems of fire protection. Each of effectively direct for the reform system of firefighting. This search must satisfy, to some extent, mentioned requirements. Its solution requires the development of new approaches as to creating a functioning firefighting systems, and so to mentioned projects management, in particular, to their configuration management.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Project configuration management of the creation and functioning for firefighting systems were not subject areas of special investigations. Well-known scientific works in the field of the configuration management for these systems provide an answer in regard to their technical and technological parameters [1-15]. Although these results are important for the problem solving to reforming the firefighting system, they do not relate to the configuration management process of appropriate projects, and therefore does not allow to create some tools (methods and models) for this management.

The analysis of recent publications [6-15] and standards [16-21] in projects configuration management and products configuration management allow us to conclude that they are important for managers because their activities are oriented on the synchronization (alignment) of configuration projects and their products. For this purpose, the corresponding process was developed [7, 8], and also basic methods and models for its implementation in practice were disclosed too. In particular, it pointed out that the product configuration model is the basis for the determination of the content and project works (actions), which require a specific type of technical means. These means related to the components of project and technological structures. The developed method of justification for their configuration provides for implementation of the alternative project works and the application of alternative technical means [19]. These results are important for our research, because the combustion of different materials can be in different conditions, and so appropriate firefighting operations require the using of different methods and extinguishing agents. However, the using these results for solving problems of projects configuration management for firefighting can be only conceptually. The configuration of project and technological structures should be justified, taking into account the existence of their alternatives.

According to other organizational and technological features of this management, they should also develop (to justify).

Thus, if we analyze scientific papers [8, 17, 19], standards and practical guidelines for projects configuration management and products configuration management [2], we can come a conclusion, that their results are important for our research, but they have no information about the impact of organizational and technological conditions on features of projects configuration management. They don't discover scientific and methodological basis for determining cause-effect relationships among the organizational and technological characteristics of fires and rational parameters of projects configuration for firefighting.

OBJECTIVE

Task assignment is to find out organizational and technological backgrounds of project configuration management for firefighting.

THE MAIN RESULTS OF THE RESEARCH

Firefighting projects consist of many components. Their main base (main component) is technological processes (TP) of firefighting. Appropriate technological systems (TS) temporary form for doing these TP. Technological systems provide the quality transformation of labour objects – extinguishing of the heat source (fires). These systems are temporary. They are made for a period of the extinguishing this or that fire (heat source). Quality transformations of labour objects form on appropriate technology – knowledge about nomenclature, content, sequence and continuance of the execution for technological operations. Furthermore, technologies often provide the availability of information about technical means with the help of which separate technological operations are performed. They also provide the availability of operational labour-intensive, the power consumption and material and technical means. To ensure the effectiveness and the quality of doing TP for firefighting, the managing is carried them out, which lies in the observance of developed organizational and technical regulations in advance.

The management of TP for firefighting, on our mind, can't be considered apart from the managing of appropriate projects for the functioning of temporal TS for firefighting. We can't also make progress in the managing of these projects without the quality of the TP management for firefighting. It is very important to consider these two managing processes autonomously. It is very important for making a maximal success with each of them, which eventually provides the recipiency of maximal value indicators for appropriate projects in results of the conformance for their rates. It is important to note that projects management of the functioning for TS firefighting is systemic.

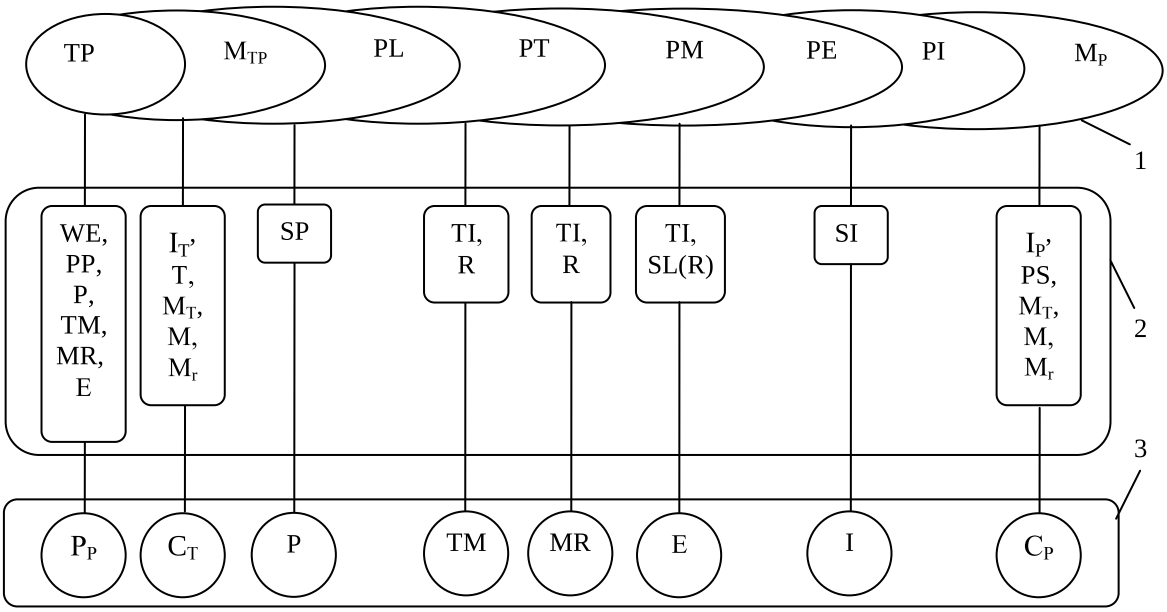

Fig. Approximate structure of the project functioning for TS of firefighting (1), main functional components (2), provision of appropriate processes and their results (3): TP, M_{TP}, PL – technological processes, management of technological processes, processes of provision for performers (life-savers), PT, PM, PE, PI, M_P – processes of provision for technic, materials, energetic resources, finance and informative resources, and processes of appropriate project (projects) management, WE, P_P , P, TM – working environment, products of a project, performers (firemen/ life-savers) and technical means, MR, E, I – material resources, energetic resources and informative resources, C_T, C_P – commands of execution for technological processes and project (projects) processes, I_T, I_P – information about the progress of technological processes and project (projects), T, PS, M_T, M, M_r – technologies, project standards, management tasks, methods of their solution and managers, SP, SI, TI – ensuring systems of performers, information, and transport infrastructure, R, SL – roads and service lines

Every TS firefighting can simultaneously realize many projects which based on appropriate TP. Every project can include one or many TP, which formulate its foundation (core).

So every project of the functioning for TS can show diagrammatically as an appropriate hierarchical structure (Fig).

The important basement of the dedication for appropriate project (resources interaction) is the coherence of nomenclature (type) and capacity resources with the configuration of the heat source (fire object), which is effect with the help of the doing for the appropriate management process. This process is realized as part of general process for project configuration management of TS functioning in the theory of project management.

So we must always solve scientific and industrial task during the functioning of any TS for firefighting. We must realized the appropriate project over definite time and we must quench the heat source (firefighting object) very fast with minimal technological, technical, material and energetic resources which are needed for human rates. So with the help of these manufacturing and technic conditions, projects will be characterized by the biggest (best) value.

If we analyze technological and resources bases of the dedication for projects of the functioning (firefighting) temporary TS, we can say that technological dedications determine the content and the execution time of main project works, and resources determine the configuration of these projects. Taking into account this specificity, tasks of management works (content and time) and projects configuration of the TS functioning for firefighting must be considered first in the hierarchical system of knowledge in appropriate projects management. In general terms, we can see main management processes which determine projects configuration (structure). These projects are realized by these TS.

If we consider the problem of operative forming for TS of the combustion for the target heat source, we can see that the base of these project works is the management process of their initiation which is determined by forecasting concern of value indicators as a project configuration of systems creation such as their functioning. In this time, the forecasting of these markers can be only with the help of the information existing about the configuration of fire objects, mass condition of its heat source, and about forecasting of value indicators for appropriate firefighting project with different variants of its configuration.

Obviously, the recipiency of some forecasting information can be only with the help of the appropriate information system, and with the help of the modeling for TS firefighting which have the information about the nomenclature (structure) of fire (heat sources), laboriousness and energy expenditures, labour and material resources in firefighting projects (functioning) and the creation of these systems. So if we want to forecast value indicators of project creation and the functioning of temporary TS rightly (objectively), we must have the information about works which are done in them, and about resources which are important for that. If we don't go into particulars of the process for works forecasting and resources in these projects, we can note that they are evaluated not only in initiation processes but in the planning. Results of appropriate assessment (forecasting) for value indicators in initiation processes are used for works management in planning processes and the project creation and the functioning of temporary TS for firefighting.

We must take note of the information recipiency (facts) about works in projects of temporary TS for firefighting too, because the configuration of these projects formulates on the base of existing fire stations. The information about project works of future (temporary) TS is mostly based on the analysis of the statistical information about last firefighting, their modeling, and the chronometric works in appropriate projects. Specified scientific and methodological basis of forecasting indicators for project value of firefighting for made temporary TS are the base of management works (content and execution time) and the configuration in these projects. In this time, we must consider that the needed configuration and needed works in temporary firefighting projects are formed and created on the base of available resources of regional systems for firefighting (RSF), and the argument of their configuration is the one of the basic task for the firefighting security. The base of its solution is the process of the coherence for the configuration of strategic projects for RSF and technic projects of the functioning for temporary firefighting TS.

We must not only consider the process of management works and the configuration in projects of the functioning for temporary TS, but also we must determine cause-effect connections between these works and projects configuration of the perfection for existing RSF for the deep determination of the process for the configuration coherence of mentioned projects. In this case, we must point out that works in temporary firefighting projects are determined the nomenclature and characteristics of objects configuration for TS of firefighting, and the configuration and the difficulty of fire objects. So value indicators $\{Y_p\}$ of projects for the functioning of temporary TS are the result of their configuration $\{G_{np}\}$, the condition $\{S_o\}$ of the heat source in the moment of the beginning for its firefighting, and the configuration $\{G_{oг}\}$ of fire objects:

$$\{Y_p\}=f(\{G_{np}\}, \{S_o\}, \{G_{oг}\}). \qquad (1)$$

In this formula the condition $\{S_o\}$ and the configuration $\{G_{oг}\}$ are organizational and technological characteristics of fire objects (fires). The configuration management $\{G_{np}\}$ of firefighting projects is reduced to its coherence with $\{S_o\}$ and $\{G_{oг}\}$. In this context, value indicators $\{Y_p\}$ achieve to extreme meanings:

$$Ó_ç \ : \{ G_{nð} \} \leftrightarrow \left(\{ S_o \},\{ G_{îã} \} \right),\{ Ó_ð \} \ \to exstr\,\{Y_p\}. \qquad (2)$$

So we must take into account that the condition of the coherence for projects configuration of firefighting with organizational and technological characteristics of fire objects (fires) can be with the help of the right management for the content and the execution time of these projects.

The provision of the condition (2) in the process of projects management configuration for firefighting can be with appropriate resources in the state system of firefighting which consists of many RSF. If we don't deeply analyze the appropriate configuration of separate RSF, we can conceptually prove main organizational and technological requirements to their functioning which must be satisfied the improvement base of their configurations (structures). Firstly, RSF must have such configuration which can ensure the mentioned timeliness of the projects configuration realization $\{G_{np}\}$ of firefighting (temporary TS). Secondly, reserved material resources (firefighting means) with the nomenclature and amounts in every RSF must respond to fire risks. Thirdly, these resources must be territorially stored as close as possible to these risks. And fourthly, territorial zones of each RSF action must be proven in such way that the differentiation of rate indicators for their firefighting security would be minimal.

CONCLUSIONS

1. The implemented technological analyze of firefighting projects has been allowed to solve their structure and find process functions of technological processes management and appropriate projects management which are in the systemic connection.
2. The purpose of firefighting projects can be achieved through the coherence of the nomenclature and resources amounts with the configuration of fire objects which are the base of these projects configuration management.
3. The process of projects management configuration for the improvement of active regional systems for firefighting is based on the cause-effect relationship between the configuration of these systems and the configuration of firefighting projects.
4. Four main requirements of temporary firefighting projects to the projects configuration of appropriate regional systems are the organizational and technological base for their configuration management.

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ОРГАНИЗАЦИОННЫЕ И ТЕХНОЛОГИЧЕСКИЕ ПРЕДПОСЫЛКИ УПРАВЛЕНИЯ КОНФИГУРАЦИЕЙ ПРОЕКТА ДЛЯ ПОЖАРОТУШЕНИЯ

Александр Щербаченко

Аннотация. Была решена структура проекты пожаротушения. Было обосновано, что центральное место в них принадлежит соответствующих технологических процессов. Временные технологические системы для выполнения этих процессов. Место и роль процессов, процессов управления технологии и управления проекты пожаротушения были определены. Было решено их различия и системное влияние на показатели стоимости этих проектов был оправдан.

Доказано, что целью пожаротушения проектов был достигнут благодаря слаженности номенклатура и объем ресурсов, которые включены в эти проекты и конфигурации объекты конфигурации сгорания (источников тепла). Согласованность этих конфигураций позволяет осуществить своевременную проекты пожаротушения с минимальными и технологические показатели человека, технике, материальных и энергетических ресурсов.

Взаимосвязь процессов управления проектных работ, которые определяются противопожарных технологий, и конфигурация этих проектов были решены. Вопрос об их инициации и планирования на основе прогнозирования стоимостных показателей временные проекты пожаротушения считался. Эти проекты используют анализ существующей статистической информации, физико-моделирования и хронометрические проектных работ.

Проекты конфигурации управление совершенствование регионального существующих систем пожаротушения основывается на результатах определения индикаторов стоимости на временные проекты пожаротушения для объектов горения. Процесс управления конфигурацией проектов совершенствования этих систем обеспечивает удовлетворение их четырех основных организационно-технологических требований, временных проектов пожаротушения.

Ключевые слова: пожаротушение, проекты, управление, конфигурация, организационных и технологических особенностей.

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Normatives of Technical Operation of Agricultural Machines

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Summary. For each type of agricultural machines and their operating conditions determined the scope and frequency of maintenance. Violation of standards of maintenance leads to deterioration of a technical condition of knots and units of agricultural machines, affecting its manufacturability. toxic and economic indicators.

In the appointment of technical conditions for the limit state of the output parameters of the mechanisms are selected only those that are possible in the process of operation. If operating experience suggests that the output parameter does not change or these changes are not regulated by the resource requirements of the agricultural machines, the technical standards do not establish and its limits. It should be noted that the complexity of the processes of functioning and loss mechanism health often lead to unwarranted assignments of standards on limit state or lack thereof for a number of characteristics. In addition, the numerical tolerance values for the output parameters are often installed for new mechanisms and does not specify allowable limits of their change. Therefore it is highly important for the justification and establishment of stockpile reliability output parameters of the mechanisms. However, for modern agricultural machines is often appropriate to set standards not only limit state for output parameters, but also on the degree of damage to individual elements of the machine, determining the change of its characteristics. So are limited to the ultimate limit state for wear, according to the degree of deformation, the magnitude of the arising of cracks and other damage. There are regulations on the limit of units and units of agricultural machines, which outlines criteria and a maximum value of damage, when you reach that node and the machine in need of repair.

The quality of the documentation for operation of agricultural machines is characterized not only errors in drawings, technical documentation or deviations from standards and regulations, but also such indicators as the level of standardization and harmonization, reasonableness and progressiveness of technical solutions, manufacturability, maintainability of the structure and its metal consumption, simple structural forms, validity of technical conditions for machine elements and output parameters and other indicators of excellence of the design of agricultural machines.

Requirements for the organization operating the agricultural machines include the norms for maintenance and repairs, instructions to personnel on the measures for the prevention of accidents and elimination of their consequences on the allocation of resources during peak load conditions.

Key words: normative, probability, operation, resource, agricultural machine.

INTRODUCTION

The standard is a quantitative or qualitative indicator is required to streamline the process of making and implementing decisions [1, 2].

The appointment standards are divided into governing [3–8]:

– properties of the product (reliability, performance, capacity etc.),

– the status of this product (normal, allowable and limit values of parameters of the technical condition),

– technical requirements governing the conduct of certain operations and works of maintenance and repair,

– provision of resources (consumption of spare parts, materials, labor costs, etc.).

The level standards are divided into state (state standards, etc.), inter-industry (maintenance and repair), industry (standard guidelines, industry standards), intra-industry (quality standards of maintenance and repair, standards of enterprises) [9, 10].

The standards are used in determining the level of efficiency of agricultural machinery, planning of quantities, determining the number of performers, the need for production base [11, 12].

The most important standards of technical maintenance includes frequency of maintenance, the life of the product before repair, the complexity of maintenance and repair, consumption of spare parts and materials [13–16].

Frequency of maintenance as it is needed (in hours) between two subsequent ongoing work of maintenance.

When carrying out maintenance there are two basic methods of bringing the product to the required technical condition [17–24]:

– at the time, that is, is assigned a frequency at which the system condition is restored to nominal or specified technical documentation of the level,

– the parameter of the technical condition, that is, at a given frequency is condition monitoring and the decision to conduct precautionary technical effects to bring the technical condition of the device to the nominal or established technical documentation level.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

In general operation maintenance consists of two parts – control and the executive that must be considered when determining the complexity of t_n and cost of maintenance.

$$t_n = t_k + kt_u, \tag{1}$$

where: t_k and t_u – complexity of the control and actuating parts of a maintenance,

k – the coefficient of repeatability ($0 \le k \le 1$).

The coefficient of repeatability for the case of maintenance in the mean time k=1, i.e. the controlling and Executive part of practically merge.

The feasibility of using a particular method of maintenance (controlled or not) is determined by the ratio of costs for the elimination and prevention of failures, monitoring and implementing of the operation, variations of random variables and other factors.

The cost of the maintenance:

$$C_n = C_k + kC_u, \tag{2}$$

where: C_k and C_u is the cost of monitoring and implementing parts of the maintenance operations.

In practice, there are the following methods for determining the frequency of maintenance:

– at acceptable level of reliability based on the choice of the value achievements, where the probability of failure of the elements does not exceed a predetermined value,

– at the acceptable value and regularities of change of a parameter of the technical condition based on the choice of the value achievements, where the parameters of the technical condition of agricultural machines with a given level of probability do not reach their allowable values,

– the feasibility method is based on choosing the magnitude of the developments, which will be a minimum total of unit costs for maintenance and repair,

– statistical tests based on the simulation of real and random processes, as a result, the rational method determines the frequency of maintenance,

– economic-the likely method generalizes the previous one and takes into account economic and risk factors, and allows to compare different strategies of maintaining and restoring the health of agricultural machines.

The method of determining the frequency of maintenance on acceptable level of reliability. this method is designed for the selection of the rational frequency, in which the probability of failure F(x) element is not more than a predetermined value and is called the risk.

The probability of failure is determined by:

$$P_Д(x_i \ge l_0) \ge R_Д = \gamma, \quad l_0 = x_\gamma, \tag{3}$$

where: $P_Д$ – allowable probability of failure,

x_i – time to failure,

F=1-γ – risk,

l_0 – periodicity of maintenance,

x_γ – gamma-percent resource.

OBJECTIVE

To summarize the analytical approaches to the justification of norms of technical operation of agricultural machines taking into account the actual production of growing cycles of production of agricultural crops.

THE MAIN RESULTS OF THE RESEARCH

For units and mechanisms, ensuring the safety:

$$R_Д = 0{,}9 \div 0{,}98\ (90 \div 98\%),$$

for other components and assemblies:

$$R_Д = 0{,}85 \div 0{,}9.$$

In this case, the frequency is much less than the average MTBF (Fig. 1) and is connected in the following way:

$$l_0 = \beta \bar{l} = \beta \overline{x_1}, \tag{2}$$

where: β – the rational frequency ratio, taking into account the amount and nature of variation of the MTBF and adopted by the permissible probability of failure (Tabl. 1).

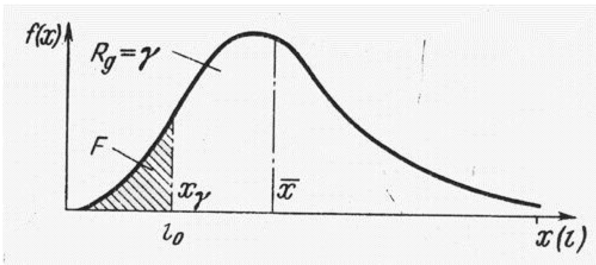


Fig. 1. Determining the frequency of maintenance at the acceptable level of reliability.

Table 1. The coefficients of the rational frequency for different values of $R_Д$ and ϑ.

№	$R_Д$	Coefficients of variation ϑ			
		0,22	0,4	0,6	0,8
1	0,85	0,80	0,55	0,40	0,25
2	0,95	0,67	0,37	0,20	0,10

Table 1 shows the variation of the random variable, the greater the duration between maintenance operations under other equal conditions may be imposed. The tougher security requirements, the less rational the frequency of maintenance.

For example, the frequency of the control and recovery of pre-torquing fasteners $\beta \cong 0{,}4 \div 0{,}6$.

The method of determining the frequency of maintenance at the acceptable value and regularities of change of a parameter of the technical condition. To modify a particular parameter of the technical condition for each of the groups of agricultural machines are different. However, the average for the group of agricultural machinery trend of each parameter is characterized by a curve on which, and the allowable value of the parameter "**У**Д" determine the average operating time $x_ч = \bar{l}$, then, average the whole set of products reaches the valid values for the parameter of the technical condition (Fig. 2).

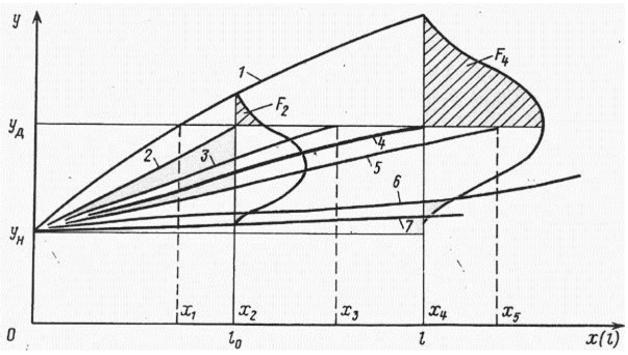


Fig. 2. Determining the frequency of maintenance at the acceptable value and regularities of change of a parameter of the technical condition

The average operating time corresponds to the average intensity change of the parameter $\bar{a}$: the products in which the intensity change of the parameter is above average, i.e. $a_i > \bar{a}$ reach the limit state much earlier (in less time). Consequently, when the assigned frequency $\bar{l}$ с вероятностью $F_ч \approx 0{,}5$ will be recorded a failure. Therefore choose a frequency $l_0 < \bar{l}$, in which the failure probability does not exceed a predetermined risk value F, for example ($F=F_2$). In this case, the degree of intensity change of the parameter of the technical condition of the product is higher than the average. The maximum intensity changes of the parameter of the technical condition:

$$a_0 = \mu \cdot \bar{a},$$

where: μ – the ratio of the maximum intensity changes of the parameter of the technical condition, this should respect the condition:

$$P_Д(a_i \le a_Д) = 1 - F = R_Д. \qquad (3)$$

The coefficient μ is affected by the degree of risk variation V and the form of the distribution of a random variable.

For the normal distribution:

$$\mu = 1 + z\vartheta, \qquad (4)$$

where: $z = \dfrac{(x-\bar{x})}{\sigma}$ – the normalized deflection corresponding to a confidence level of probability.

For the law of Weibull-Gnedenko ratio of maximum intensity change of the parameter:

$$\mu = \frac{\sqrt[-m]{-\ln(1-P_Д)}}{\Gamma(1+1/m)}, \qquad (5)$$

where: Γ – gamma function,

m – parameter of the distribution.

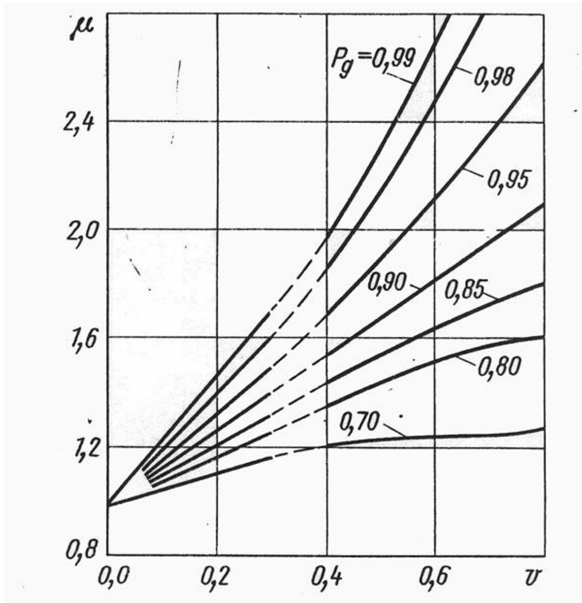


Fig. 3. The influence of the coefficient of variation ϑ for the ratio of the maximum intensity μ

From the graph Fig. 3 shows that the more ϑ or $P_Д$, the more μ (less than optimal maintenance intervals). This method can be used for nodes with fixed parameter change of the technical condition. These include most of the wear components, mechanisms and connections, the technical condition is maintained by adjusting (valve and brake mechanisms, etc.). For adjusting work is characterized $\vartheta = 0{,}5 \div 0{,}8$, in which $\mu = 1{,}6 \div 2{,}1$, i.e., good maintenance intervals will be $1{,}6 \div 2{,}1$ times below the average.

Techno-economic method. He is associated with Oprah-dividing the total specific costs for technical services and repair and their subsequent minimization. The minimum cost corresponds to the optimal frequency of maintenance – l_0.

Unit costs for maintenance:

$$C_1 = \frac{d}{l}, \qquad (6)$$

where: l – the frequency of maintenance,

d – the cost of operation maintenance.

With increasing frequency the cost of operation maintenance remain constant or slightly increase, and unit costs are significantly reduced.

Increase the frequency of maintenance leads to a reduction in resource parts, units, assemblies, mechanisms and machines in general, and the growth of repair costs:

$$C_{II} = \frac{C}{L},$$

where: C – repair costs, L – the resource to repair.

The expression $C_I = C_I + C_{II}$ is the objective function, extreme value, which corresponds to the optimum value, i.e. in this case a low unit cost.

The optimal value of periodicity of maintenance or minimum of the objective function is defined graphically (Fig. 4) or analytically for dependencies $C_I = f(l)$ *and* $C_{II} = \psi(l)\cdot$

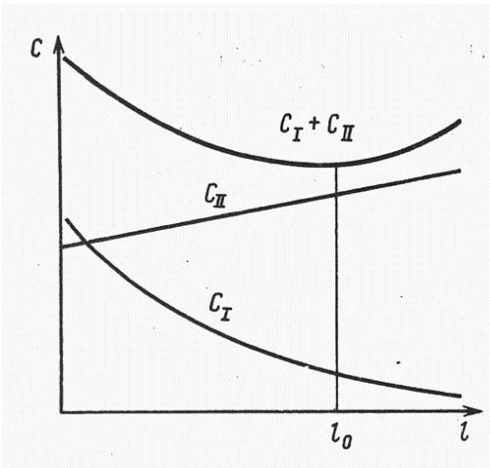


Fig. 4. The scheme for determining the frequency of maintenance of the techno-economic method

Techno-economic method is applied to determine the optimal frequency of work affecting the safety, if you assign the level of risk to take into account the losses associated with accidents.

Economic-probabilistic method – probabilistic and takes into account economic factors, and allows to compare different strategies of maintaining and restoring the health of agricultural machines.

The first strategy is the elimination of failures and malfunctions as they arise, i.e. according to needs (Fig. 5,a).

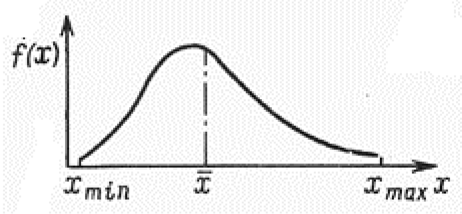
Unit costs:

$$C_{II} = \frac{C}{\overline{x}} = \frac{C}{\int\limits_{x\,\min}^{x\,\max} x \cdot f(x)dx}, \tag{7}$$

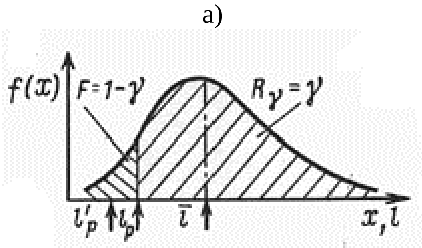
where: $\overline{x}, x_{\min}, x_{\max}$ – average, minimum and maximum time to failure,

C – cost of repair.

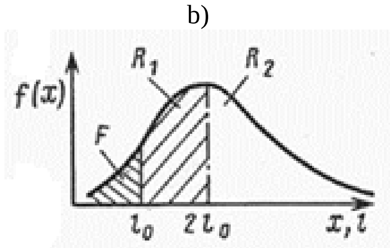
The advantage of this strategy is simplicity. The main disadvantages – uncertainty of the status of agricultural machinery in which the failure can occur at any time, hampered the planning and organization of maintenance and repair.



a)



b)



c)

Fig. 5. Methods of performing maintenance and repairs: a) repair needs, b) maintenance by operating time, c) maintenance of technical conditions

The second strategy involves the prevention of failures, restore the original or close to it condition of agricultural machinery and his components, assemblies and systems. However, theoretically, the failure and malfunction can occur with a frequency as many small (Fig. 5,b). The second strategy cannot be executed in pure form, i.e. the elimination of failures and malfunctions is carried out in the period of periodic control and recovery operations.

Thus, we can speak about mixed strategy, which is diagnostic and maintenance according to the preventive maintenance system and repair and elimination of failures and malfunctions as they arise. In this case, you specify the acceptable probability of failure or the required probability of failure.

Mean time, which will be eliminated waivers:

$$l'_p = \frac{\int\limits_{x\,\min}^{x\,\max} l \cdot f(l)dl}{\int\limits_{x\,\min}^{l_p} f(l)dl}, \tag{8}$$

where: b_p – the frequency of preventative maintenance.

Failures that occurred before held $l_p\ (x_i < l_p)$, eliminate at least the appearance. The cost to remediate these failures in any strategy is equal to C, i.e., have a value of fault that occur with certainty x_i, equal C.

The rest of the work is carried out with a frequency of b_p, cost d and the probability of this event $R = P_Д$.

The advantages of the second strategy:

– guaranteed a certain level of reliability of agricultural machines,

– expenses for maintenance of the healthy state is lower than in case of refusal (d < C), because Troubleshooting is accompanied by additional losses associated with aid on the line,

– the possibility of preventive maintenance determines rational ways of improving the maintenance system.

The main drawback – the underutilization of the resource of the separate units, aggregates and systems of agricultural machinery, because the average periodicity of maintenance and repair less MTBF $(l_p < \bar{x})$.

Unit costs are determined by the ratio of the weighted average cost of one operation To the weighted average resource:

$$C_{1-1} = \frac{c \cdot F + d \cdot R}{l_p \cdot R + l'_p \cdot F}. \qquad (9)$$

Then, differentiating the expression for l and equating the derivative to zero, and determine the frequency corresponding to b_0 $C_{1\text{-}1}$. When comparing unit costs according to the formulas (7) and (9) in the case $C_{1\text{-}1\ \min} < C_{II}$ first is the preferred method of preventive strategies, i.e. maintenance.

In Economics and probabilistic method in the same way as when determining the optimal frequency for reliability uses the concept of ratio is the optimal frequency:

$$\beta \le \frac{l_0}{\bar{x}} = \left[\frac{2k_{\Pi} \cdot \vartheta_x}{(1+\vartheta_x^2)(1-\vartheta_x^2)} \right]^{\vartheta_x}. \qquad (10)$$

where: $k_{\Pi} = \dfrac{d}{c}$ – the coefficient indicating the ratio of the cost of maintenance to the cost to eliminate failure,

ϑ_x – the coefficient of variation of the MTBF the first strategy (ϑ_x < 1).

If there are limitations in the reliability of the rational frequency ratio is determined:

$$\beta'_0 \le \left[\frac{k_{\omega}}{0{,}5 \cdot (\vartheta_1^2 + 1)} \right]^{\frac{\vartheta_x}{1-\vartheta_x}}, \text{ in } \vartheta_x < 1, \qquad (11)$$

where: $k_{\omega} = \dfrac{\omega_I}{\omega_{II}}$ – the reduction ratio parameter of stream of refusals,

ω_I – the parameter of stream of refusals in the use of preventive strategies,

ω_{II} – parameter flow of failures at the fault on demand.

It should be noted that the adoption of the additional requirements on reliability, reduces rational intervals compared to using only the economic-probabilistic criteria.

To a first approximation, without resorting to calculations on the theoretical dependency ratio rational maintenance intervals can also be found graphically (Fig. 6).

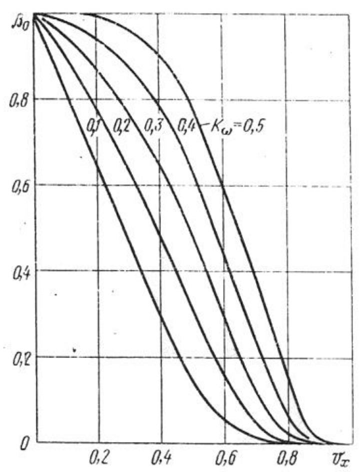


Fig. 6. Optimal maintenance intervals for a given level of reliability

Economic-probabilistic method allows us to find rational ways for improvement of the maintenance organization. Indeed, if the frequency l_0, preventative effects require the products (first group), potential failure which can occur with some probability R_1 (Fig. 5,c) in the mean time $l_0 < x_i < 2l_0$. Products of the second group with potential MTBF $x_i > 2l_0$ enjoy in this, and subsequent services. The probability of this event is R_2=R–R_1, so with this method of implementation of preventive strategies requires the division of products, which is carried out using a diagnosis that requires additional costs.

In this case, the optimal periodicity l_0 controlled all not failed up to this point products. The cost of this control is d_k, and the work to bring the technical condition to normal, with a cost of d_u, carried out only for the first group of products.

The development of preventive strategies using diagnosis would be appropriate if the additional cost of control will be offset by the reduction of the cost of preventive maintenance and damage from failures.

For the case of allowing only two consecutive maintenance unit costs in the prevention with advanced control will:

$$C_{1-2} = \frac{C \cdot F \cdot d_u \cdot R_1 + d_k \cdot R}{F' \cdot l'_p + l_p \cdot R} = \frac{C\dfrac{F}{R} + d_{\Pi}}{l'_p \dfrac{F}{R} + l_p}. \qquad (12)$$

where: $d_{\Pi} = d_k + kd_u$ – the cost of maintenance with advanced monitoring,

C – repair costs,

F – the probability of failure over a certain range developments,

d_u – the cost of repair,

R_1 – the likelihood of recovery,

d_k – cost control-diagnostic works (CDW),

l_p – the periodicity of maintenance operations,

l'_p – mean time, which will be eliminated waivers,

R – the probability that the CDW,

$k = \frac{R_1}{R_1 + R_2}$ – the coefficient of repeatability, which determines the proportion of products that will require, together with the monitoring and rectify deviations of the parameters of the technical condition of the normal values.

It is obvious that pre-control is appropriate when $(C'_{1-2})_{\min} < (C_{1-1})_{\min}$.

One of the methods of conducting examinations is diagnosis, which is used to determine the technical condition of agricultural machines, units and assemblies without dismantling and is a maintenance item and repair.

The method of statistical tests based on the simulation (imitation) of real random processes maintenance, which allows to exclude influence of adverse factors, to drastically reduce the cost of experiments and accelerated testing.

Modeling can be done manually or on a computer. The initial data for the simulation are applied as actual data observations and the laws of distribution of random variables. When determining optimal maintenance intervals proceed as follows:

– pre-assign one or more values of periodicity of maintenance service $(\bar{l}_1, \bar{l}_2, \bar{l}_3, \ldots)$ and coefficients of variation ϑ_l,

create two arrays of data: time between periodicity of maintenance service [X] maintenance intervals – [l],

– choose from the first array the value of Nara-processing to failure x_i,

– choose from the second array service interval value l_i is determined by taking into account the average frequency $\bar{l}$ and its variations ϑ.

A pair of numbers x_i and l_j is called the implementation. If it is identified $x_i < l_j$, as the failure, while the fixed is performing maintenance operations. If the probability of failure in the simulation more than the specified, then reduce the source data periodicity and repeat the simulation.

From Fig. 7 shows that increasing the frequency of maintenance is reduced the probability of carrying out operations of diagnostics, and increases the likelihood of failures between maintenance. The value of the probability of carrying out maintenance operations on the control results and the coefficient of the frequency of occurrence initially increases up to a certain limit and then decreases.

Thus, if optimum performance of the contents of the maintenance operations will be the most complete, and the ratio between the controlling and performing operations of rational.

The introduction of additional quantities (the cost or complexity of performing preventive or repair operations) will allow in each individual case to determine the total unit cost of maintenance and repair and to compare different maintenance intervals, according to the economic criterion.

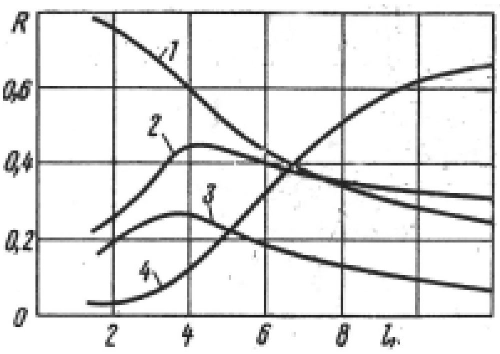


Fig. 7. Influence of maintenance intervals on the condition of the brake system: 1 – probability of executing only the control part of the operation, 2 – coefficient of repeatability, 3 – probability of completing the performing of the operation according to inspection results, 4 – probability of failure between maintenance.

The mapping of all possible strategies, means of implementation and the costs involved can be carried out using the card preventive operation (Fig. 8), which shows:

– the boundary unit cost (1) corresponding to elimination of failure on demand (C_{II}),

– unit costs (2) while holding the parameter of the technical condition, i.e., advanced control (C_{1-2}),

– unit costs (3) during the operating time (C_{1-1}),

– changing the tolerance parameter of the technical condition (4) when performing maintenance on (C_{1-2}).

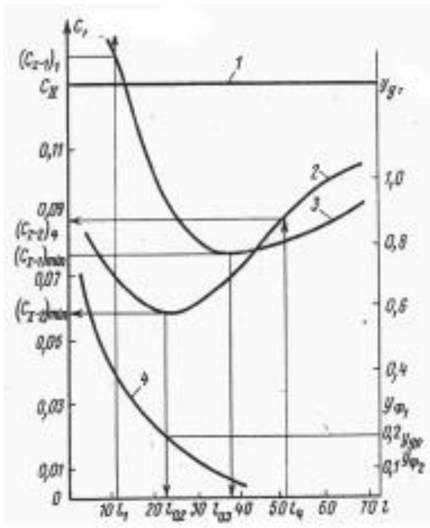


Fig. 8. Card of preventive maintenance operations

Map for the particular unit or host allow:

– to compare the different techniques and strategies,

– to determine for various methods of optimal frequency and the corresponding specific over-spending,

– assign the valid values for the parameters of the technical condition of the maintenance in conducting the parameters of the technical condition.

If, for example, the results of control when the periodicity $l_{0,2}$ (C_{1-2}) the actual value of a parameter of the technical condition $У_{ф,2} > У_Д$, in addition to diagnostics it is necessary to conduct Executive work, i.e. finishing of the parameter of the technical condition to the rated value. When $У_{ф.2} < У_Д$ the executive part of the operation when the maintenance is not carried out. It follows from the foregoing that, first, the use of diagnosis contributes to the development of preventive maintenance strategies, and secondly, whether and how the precautionary strategy (diagnosis or not) are determined by technical and economic calculations, thirdly, depending on the taken for the operation frequency is acceptable may be any of the described strategies (compare the frequency $l_1, l_{0.2}, l_{0.3}, l_4$).

Consider in General a few examples of determining the frequency of maintenance (l_0):

A) At the acceptable level of reliability. You must select a rational frequency, in which the probability of failure F(x) does not exceed a given degree of risk.

For all mechanisms and units, ensuring the safety taken $R_Д$ =0,9 and get a frequency significantly less than the average MTBF $\bar{x}(\bar{l})$:

$$l_0 = \beta \cdot \bar{l} = \beta \cdot \bar{x}.$$

The rational frequency ratio β takes into account the coefficient of variation ϑ of the MTBF and adopted by the permissible probability of failure $R_Д$ =0,9.

For the normal distribution take, for example, ϑ =0.2 and in Tabl. 1 find β =0,75.

In the end, we find about the periodicity of technical service of agricultural machines

$$l_0 = \beta \cdot \bar{l} = 0{,}75 \cdot \bar{l} = 0{,}75 \cdot \bar{x}.$$

B) At the acceptable value and regularities of changes in parameters of the technical condition.

We had already discussed the patterns of change in the technical state of the nodes of agricultural machinery for the development described power functions (1) or linear relationships (3).

Positioning the values of the parameters of the technical condition of several units or mechanisms, to the moment developments *l*, they are valid *УД* and the initial *УН* values, it is easy to calculate the time until each reaches $l_Д$.

Have

$$y_i = a_0 + a_{1i} l^b, \quad УН = a_0,$$

where: y_i – the value of the parameter of the technical condition of each agricultural machines.

The valid time of each of the agricultural machines to achieve the parameter *УД* is

$$l_Д = \left(\frac{У_Д - a_0}{a_{1i}} \right)^{1/b}.$$

Determine the average value of achievements

$$\bar{l}_Д = \sum_{i=1}^{n} \frac{\bar{l}_{Дi}}{n}.$$

The standard deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (l_{Дi} - \bar{l}_Д)^2}{n-1}}.$$

The coefficient of variation

$$\vartheta = \sigma / \bar{l}_Д.$$

It is necessary to consider the ratio of the maximum intensity changes of the parameter of the technical condition μ, provided the condition

$$P_Д(l_i \le l_{Дi}) = 1 - F = R_Д.$$

The ratio μ is affected by the coefficient of variation ϑ and the form of the distribution.

For the normal distribution

$$\mu = 1 + z\vartheta,$$

where: $z = \dfrac{\left(l_{Дi} - \bar{l}_Д\right)}{\sigma}$.

If $\vartheta = 0{,}4 \div 0{,}6$, the ratio of the maximum intensity μ for the law of distribution of Weibull–Gnedenko find out of based on

$$\mu = \frac{\sqrt[-m]{-\ln(1-P_Д)}}{\Gamma(1+1/m)},$$

where: Γ – gamma function, m – parameter of the distribution.

Having the value of the function of the standard normal distribution

$$\Phi(z) = 1 - F,$$

it is easy to determine the value of its argument Z and calculate the value for the service interval (*l*₀):

$$l_0 = \bar{l}_Д / \mu.$$

If you take accepted above the allowed probability of failure $R_Д$ = 0,9 and ϑ = 0,2, then find $z \approx 1{,}25$.

Hence the frequency when $\mu = 1 + 1{,}25 \cdot 0{,}2 = 1{,}25$ will

$$l_0 = \bar{l}_Д / \mu = \frac{\bar{l}_Д}{1+1,25\cdot 0,2} = 0,8\cdot \bar{l}_Д\,.$$

Values $P_Д$ and ϑ from the graph in Fig. 4 find $\mu \approx 1,25$ and get

$$l_0 = \bar{l}_Д / \mu = \frac{\bar{l}_Д}{1,25} = 0,8\cdot \bar{l}_Д\,.$$

C) Economic-probabilistic method, as well as in the frequency of reliability uses the concept of rational frequency ratio β:

$$\beta_0 \le \frac{l_0}{l_Д} = \left[\frac{2\cdot k_П \cdot \vartheta}{(1+\vartheta^2)\cdot(1-\vartheta^2)}\right]^{\vartheta}$$

where: $k_П = d/c$ – the ratio of cost of maintenance to repair,

ϑ – the coefficient of variation.

If the unit or the unit has indicators $k_П = 0,8$, ϑ =0,2, get

$$\beta_0 \le \frac{l_0}{l_Д} = \left[\frac{2\cdot 0,8\cdot 0,2}{(1+0,04)\cdot(1-0,04)}\right]^{0,2} = 0,81\cdot$$

If you want to reduce the parameter of stream of refusals in the use of preventive strategies in four times, i.e.

$$k_\omega = \frac{\omega_I}{\omega_П} = 0,25,$$

where: ω_I – parameter flow of failures of preventive strategies,

$\omega_П$ – the same, while eliminating failure demand, the coefficient of rational frequency will be determined by the formula

$$\beta_0 \le \frac{l_0}{l_Д} = \left[\frac{k_\omega}{0,5\cdot(\vartheta^2+1)}\right]^{\frac{\vartheta}{1-\vartheta}} = \left(\frac{0,25}{0,5\cdot 1,04}\right)^{0,25} \approx 0,83\,.$$

For these values k_ω= 0,25 and ϑ= 0,2 from the graph in Fig. 6 we find that $\beta'_0 \approx 0,88$.

The calculation of the coefficients of the rational frequency shows that with decreasing values of K-factor of the variation between failure ϑ and increases maintenance intervals, i.e., here based on the first strategy of cost C_I diagnostic work is reduced, and the cost C_{II} to repair under the second strategy rise or in the General case $l_0 \to \bar{l}_Д$.

Additionally it is necessary to analyze the feasibility of the method and statistical tests.

CONCLUSIONS

1. Additional requirements for reliability, reduce rational intervals compared to using only the economic-probabilistic criteria.
2. At optimum performance contents maintenance operations will be the most complete, and the ratio between the controlling and performing operations of rational. The introduction of additional quantities (the cost or complexity of performing preventive or repair operations) will allow in each individual case to determine the total unit cost of maintenance and repair and to compare different maintenance intervals, according to the economic criterion.
3. The calculation of the coefficients of the rational frequency shows that with decreasing values of the coefficient of variation of the MTBF is increased maintenance intervals, i.e., here based on the first strategy, the cost of diagnostic work is reduced and repair costs for the second increase.
4. Additionally it is necessary to analyze the feasibility of the method and statistical tests.

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НОРМАТИВЫ ТЕХНИЧЕСКОЙ ЭКСПЛУАТАЦИИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН

Иван Роговский, Эугениуш Красовски, Валентина Мельник

Аннотация. Для каждого типа сельскохозяйственных машин и условий их эксплуатации определены объем и периодичность технического обслуживания. Нарушение нормативов обслуживания приводит к ухудшению технического состояния узлов и агрегатов машин, влияющих на его технологичность. токсические и экономические показатели.
При назначении технических условий на предельные состояния выходных параметров механизмов выбираются лишь те, изменение которых возможно в процессе эксплуатации. Если опыт эксплуатации свидетельствуют, что данный выходной параметр не претерпевает изменений или эти изменения не регламентированы требованиями к работоспособности механизмов, то технические нормативы не устанавливают и его предельных значений. Следует отметить, что сложность процессов функционирования и потери

механизмом работоспособности часто приводят к необоснованным назначениям нормативов на предельные состояния или к их отсутствию для ряда характеристик. Кроме того, численные значения допусков на выходные параметры часто устанавливаются для новых механизмов и не оговариваются допустимые пределы их изменения. Поэтому весьма актуальной является задача по обоснованию и установлению запасов надежности по выходным параметрам механизмов. При этом для современных сельскохозяйственных машин часто целесообразно устанавливать нормативы не только на предельные состояния по выходным параметрам, но и по степени повреждения отдельных элементов машины, определяющих изменение ее характеристик. Так лимитируются предельные состояния по износу, по степени деформации, по величине возникающих трещин и другим повреждениям. Существуют нормативы на предельные состояния агрегатов и узлов сельскохозяйственной техники, где указываются критерии и величины наибольших повреждений, при достижении которых узел и машина требуют ремонта.

Качество документации на эксплуатацию машин характеризуют не только ошибки в чертежах, технической документации или отклонения от стандартов и нормативов, но и такие показатели, как уровень стандартизации и унификации, продуманность и прогрессивность технических решений, технологичность, ремонтопригодность конструкции и ее металлоемкость, простота конструктивных форм, обоснованность технических условий на элементы машин и на выходные параметры и другие показатели совершенства самой конструкции сельскохозяйственной машины.

Требования к организации эксплуатации сельскохозяйственной машины включают нормативы на проведение технического обслуживания и ремонтов, инструкции персоналу о мерах по предотвращению аварий и ликвидации их последствий, по распределению ресурсов в пиковых нагруженных состояниях.

Ключевые слова: норматив, вероятность, эксплуатация, ресурс, сельскохозяйственная машина.

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Optimization of Norm of Bringing of Technological Material Taking into Account the Agrobiological State of Agricultural Lands

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Summary. The technique method of calculation of optimum norm of bringing of technological material taking into account the agrobiological state of agricultural lands.

One promising direction using indirect information about the state of the soil with a reliable calculation algorithm such information is objectively necessary data are indicators of soil electrical conductivity and magnetic properties. The modern alternative to traditional agrochemical examination - contact and non-contact methods based on electromagnetic phenomena. Often this measurement, registration, processing, analysis and interpretation of conductive and electromagnetic properties of the soil, which makes it possible to determine the particle size (mechanical) composition of the soil, soil organic matter, salts, humidity, soil contours highlight and assess the heterogeneity of soil properties as a whole.

This is possible by obtaining reliable data on the state of the soil environment by reducing errors in determining the value of conductive properties of the soil and reduce the intensity of the destruction of soil structure and stability of electrical contact with the ground electrode, the use of integrating analog-to-digital converters local technical system monitoring conductive properties of the soil environment.

Key words: optimum norm of bringing, technological process, technical systems of the operative monitoring, agricultural production, agrobiological state monitoring of the state of agricultural lands.

INTRODUCTION

For today the question of providing of the proper efficiency of production of agricultural cultures is actual. Strategy of quality management of implementation of technological operation includes technology of variable norms of bringing of technological material, but this only one of numeral elements.

The optimum decision of productions questions lies it is inplane contingently by the technical resources of agrobiological by potential of the agricultural fields. The presence of technical resources enables potential to provide the proper internalss of implementation of technological operations in the plant-grower. Information about the agrobiological state of agricultural lands enable to define strategy of common management by their agrobiological state.

At that rate there will be optimum combination of the use of technical resource for the optimum management and use of the agrobiological state of the ground environment. In addition possibly also to make decision recognition information about the forecast cost of agricultural cultures, expedience of growing of that or other agricultural culture on the fields select to the area.

Subject to the condition these in the conditions of the limited resources it is necessary to carry out the automated technological processes control in agriculture taking into account the agrobiological and technical state of agricultural lands.

Under these conditions, in the conditions of limited resources needed to implement automated process control in agriculture with regard agrobiological and maintenance of agricultural land.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The aspects of optimum management by the use of resources, varied aspects of management by certainly-measurable linear objects, varied tasks of theory of traffic control, are in-process [1-17] explored, automatic control by the linear (nonlinear) systems. However much the management by the norm of bringing of technological material from the account of the agrobiological state of agricultural lands requires the subsequent comprehensive study.

- stationary electromagnetic fields in dispersive and conducting environments (such as AS) can be formed under the influence of short-wave impulses on these environments. Nowadays the effects of shock excitation and the propagation of such waves attract researchers of the AS electrical conductivity by means of non-stationary electrodynamics. This attention is due to a number of reasons:

1. Recent successes in generating video impulses using broadband radars have stimulated interest in the prospects of using video impulses for the transmission of energy and information through solid media [1]. The structure of such impulses is significantly different from the traditionally studied models with rectangular or Gaussian curvature:

a) the envelope of the video impulse consists of only one or several oscillations, the forms of which are usually far from sinusoidal,

b) the front and rear fronts are asymmetrical,

c) the distances between the points of the zero intersection are uneven.

2. Dispersion and diffraction of finite-duration video impulses on finite-size targets lead to a number of new

effects. In contrast to the usual representations of the stationary dispersion indicatrices and diffraction patterns characteristic of long stretched strings of sinusoidal waves, the field of the dispersive video impulse changes rapidly over time. Classical formulas for dispersion monochromatic waves on a cylinder or diffraction on a slit and circular aperture are only partial instances of expressions describing the non-stationary interaction of short video impulses with such objects [2].

3. Traditional solutions of the Maxwell equations in continuous media are connected with the representation of solutions in the form of product of functions dependent, either on coordinates or on time (i.e., separate solutions), at the same time, the time dependence is usually investigated using the Fourier transformation. For many years, such an approach shaped the language of describing quasi-monochromatic waves in optics, acoustics and radio physics, however, attempts to apply this same approach in the dynamics of the interaction of short video impulses with dispersive media and, in particular, conductors of (AS) encountered unexpected difficulties, both conceptual and computational:

a) due to Fourier transformation of the enveloping signal of finite duration averaged over an infinite interval of time (from $-\infty$ to $+\infty$). The areas of rapid change of envelope are hidden at this time, however, these areas are important for signal registration in the information machines for (AS). On the other hand, to restore the time bending localized signal with the help of a careful Fourier transformation, the fields of harmonics outside the localization area should be excluded, however, to clarify the region of localization should take into account the increasing density of harmonic components,

b) the deformation of the impulse in the dispersive medium is described, as it is known, in the frequency region by the method of decomposition of the phase in a series of degrees of the ratio of the spectral width of the impulse $\Delta\omega$ to the carrier frequency ω [2] However, for short impulses of a broad band consisting of one or more field fluctuations, the ratio $\Delta\omega/\omega$ is not a small parameter, with the amount of spectral components needed to synthesize the field of the impulse in the depth of the environment, it becomes quite large. This situation gives rise to a number of computational difficulties [3],

c) in the expansion of the phase of the wave due to degrees of ratio $\Delta\omega/\omega$, all components have a refractive index in the denominator $n(\omega)$. If in the impulse spectrum there is a cutoff frequency of a dispersive transparent medium ω_0, then $n(\omega_0)=0$, and the row which represents the phase layout, becomes discrepancy.

It should be emphasized that these difficulties are not related to the Maxwell equations, but with the traditional method of their solution by separating the Fourier transforms and transformations. However, the representation of fields using this method is not a consequence of the Maxwell equations, but only one of the ways of their solution, this method is convenient for describing quasi-monochromatic waves with slowly varying amplitude and phase, but is ineffective for the analysis of non-stationary and non-harmonic fields.

You can obtain information about such fields using new Maxwell equations, built directly in the time domain, without using the standard separation of variables and beyond the limits of Fourier-plans. Such inseparable, precise analytical solutions that are not bound by traditional assumptions about the small value and slowness of the time-varying fields form a mathematical basis for the description of fast-changing non-periodic fields and short impulses in dispersing media. This medium is considered to be stationary in the state of rest and not the stationary space-time structure of the propagating field due to significant changes in its bending characteristic time, which is determined by the microscopic processes of determining the field in the environment, in particular, in AS (for example, the time / duration of the bulk charge relaxation in the conductor). Such unsteady electrodynamics of stationary media is the subject of this study.

Clearly, that the design of optimization of norm of bringing of technological material taking into account the agrobiological state of agricultural lands is the actual task of requires the subsequent deep study.

It should be noted that jobs quoted higher performances will be used in this research.

Modern economic conditions of Ukraine dictate the necessity of structural adjustment of production (both industrial and agricultural) and realization of investment programs of enterprises of various industrial orientation (affiliation). The requirements for quality management are increasing, which necessitates the development, generalization and use of modern methods of strategic management and financial and economic analysis of the effectiveness of planned investment measures in the development, reconstruction and modernization of technical and economic systems of agricultural production (TESAP) in practical activity.

The definition and implementation of the TESAP development strategies are among the extremely complex, labor-intensive and difficultly formalized works, which at the present time are not being implemented at the proper level at the domestic agricultural enterprises. Today, these enterprises should be considered as "open" technical and economic systems of agricultural production, the success of which is primarily determined by how well they are attached to their external economic, scientific, technical, socio-political and other environment, taking into account the current state and available internal capabilities. Methodology, procedures and practice of planning and management at various levels of the Ukrainian economy, which largely retained the features of the administrative-command system, does not fully comply with the principles and practical conditions of the newest economic mechanisms and, as a consequence, do not meet modern requirements.

OBJECTIVE

The purpose of this work consists in development of method of calculation of optimum norm of bringing of technological material from the account of the agrobiological state of agricultural lands, developments of approach to the decision of basic problems of theory of management of the systems, dependency upon the parameters of other systems and also task of complete dirigibility of the similar systems during optimization of management.

THE MAIN RESULTS OF THE RESEARCH

Exposition of basic maintenance of research. Introduction of new technologies entails by additional economic expenses. That is why a primary concern at introduction of these technologies is the necessity of research of economic efficiency of such step.

Only giving an answer to these questions, it will be possible to define – whether technologies of variable norms will be covered a cost at their application. As an example, the analysis of the field area can in general rotin about its useless for agriculture. On such conditions technology of the use of variable norms will be the empty spending of facilities. Exactly for the receipt of such right answer economic advantageous and, a producer must use certain instruments and methods.

For providing of realization of strategy of variable norms of bringing of technological material it is needed that to the state of the ground environment made not less than 20% from the optimum value. Such enables to see effects from realization of such technologies and to collect an effect from introduction of these technologies on the agricultural fields.

To that end it is necessary to develop the complex automated checking system of internalss of implementation of technological process taking into account technical resource and the agrobiological state of agricultural lands. It enables quickly to estimate different combinations of the use of technical resources and agrobiological state of agricultural lands and to optimize the parameters of management by such system.

Such planning will enable to check up expedience of implementation of certain technological operation and to expect the amount of executable technological operations (for example amount of technological operations for a signup).

All these information will be used for the calculation of economic efficiency of implementation of technological operations and in eventual case of construction of areas of management of agricultural lands.

The agrobiological inspection of agricultural lands is the important constituent of this system. As agrobiological to the state of the ground environment is an effective government base by the agrobiological state of the ground environment and decision-making for his management.

The domain by these technologies enables to make effective decisions for the management by the agrobiological state of the ground environment.

Modern agricultural production requires optimizations of norm of the use of technological material in modern technologies of plant-grower from the account of the agrobiological state of agricultural lands.

Such given the agrobiological state of agricultural lands there is information about maintenance of nutritives of got a laboratory method or sensory method by determination of conductivity or with the use of the systems of technical sight (in the or infra-red spectrum of fellow creature).

It is known that the computer-integrated automatic control systems by implementation of technological processes in agricultural production are most perspective. Exactly they must provide creation high-quality new technologies (innovative technologies) which have the newest economic, social and ecological indicators.

Clearly, that for generalization of results of previous researches which touch determination of level of influencing of the varied factors on efficiency of plant-grower, it follows to define the basic technological (norm of bringing, depth of till and other), technical (rate of movement, loading of engine and others like that) and organizational (terms of implementation, load) criteria of high-quality work of agricultural machines, ponderability of influencing of these factors on the size of the collected harvest (end-point), and also probability (possible) level of efficiency of application of the proper hardwares of mechanization with the guided influence on the internalss of implementation of technological operations.

That is why it is necessary more in detail to consider the method of calculation of optimization of norm of bringing of technological material taking into account the agrobiological state of agricultural lands.

For the issue of certain type of agricultural product of kind A on the certain agricultural field n it is necessary to take into account the agrobiological state of agricultural lands, in particular maintenance of nutritives in soil. Taking into account maintenance of certain type of nutritives at soils of nourishing $c_1\ c_2\ c_3\ c_4\ .,c_j$ in soil, we get the amount of products a cost b_0 which annually can produce in the limited amount, taking into account maintenance of nutritives in soil from this area.

Base productivity of agricultural cultures b_0 which can be got from the agricultural field recognition maintenance of certain type of nutritives at soils of nourishing $c_1\ c_2\ c_3\ c_4\ .,c_j$.

For the receipt of the planned productivity $b_1\ b_2\ b_3\ b_4\ .,\ b_i$ it is necessary to to bring in the certain norms of nutritives accordingly $a_{11}\ a_{12}\ a_{13}\ a_{14}.,\ a_{1j},\ a_{21}\ a_{22}\ a_{23}\ a_{24}.,a_{2j},\ a_{31}\ a_{32}\ a_{33}\ a_{34}.,a_{3j},\ a_{41}\ a_{42}\ a_{43}\ a_{44}.,a_{4j}\ .,\ a_{i1}\ a_{i2}\ a_{i3}\ a_{i4}.,\ a_{ij}$ for the certain type of the got productivity $A_c\ A_1\ A_2\ A_3\ A_4\ .,\ A_i$ accordingly, an income makes from realization of which $Y_1\ Y_2\ Y_3\ Y_4\ .,Y_i$.

It is the classic task of the linear programming:

$$\text{Profit} = \text{Revenues} - \text{Costs}$$

$$\text{Costs} \downarrow \rightarrow \text{Profit} \uparrow$$

$$\begin{cases} Z = b_0 - (c_1 \cdot X_1 + c_2 \cdot X_2 + c_3 \cdot X_3 + c_4 \cdot X_4 + ... + c_n \cdot X_j) \to \max; \\ b_1 - (a_{11} \cdot X_1 + a_{12} \cdot X_2 + a_{13} \cdot X_3 + a_{14} \cdot X_4 + ... + a_{1j} \cdot X_j) = Y_1; \\ b_2 - (a_{21} \cdot X_1 + a_{22} \cdot X_2 + a_{23} \cdot X_3 + a_{24} \cdot X_4 + ... + a_{2j} \cdot X_j) = Y_2; \\ b_3 - (a_{31} \cdot X_1 + a_{32} \cdot X_2 + a_{33} \cdot X_3 + a_{34} \cdot X_4 + ... + a_{3j} \cdot X_j) = Y_3; \\ b_4 - (a_{41} \cdot X_1 + a_{42} \cdot X_2 + a_{43} \cdot X_3 + a_{44} \cdot X_4 + ... + a_{4j} \cdot X_j) = Y_4; \\ \text{......................................} \\ b_i - (a_{i1} \cdot X_1 + a_{i2} \cdot X_2 + a_{i3} \cdot X_3 + a_{i4} \cdot X_{i4} + ... + a_{ij} \cdot X_j) = Y_i. \end{cases} \quad (1)$$

$$X_1 \ge 0,\ X_2 \ge 0,\ X_3 \ge 0,\ X_4 \ge 0 ..\ X_j \ge 0 \quad (2)$$

Income from realization of products:

$$Z = b_0 + c_1 \cdot X_1 + c_2 \cdot X_2 + c_3 \cdot X_3 + c_4 \cdot X_4 + ... + c_n \cdot X_j \to \max \quad (3)$$

For the receipt of the planned productivity b_1 b_2 b_3 b_4 ., b_i taking into account obtained operative state information agrobiological agricultural lands by a cost k_0 k_1 k_2 k_3 k_4 ., k_i it is necessary to bring in the certain norms of nutritives accordingly a_{11} a_{12} a_{13} a_{14} ., a_{1j}, a_{21} a_{22} a_{23} a_{24} ., a_{2j}, a_{31} a_{32} a_{33} a_{34} ., a_{3j}, a_{41} a_{42} a_{43} a_{44} ., a_{4j} ,., a_{i1} a_{i2} a_{i3} a_{i4} ., a_{ij} for certain productivity A_c A_1 A_2 A_3 A_4 ., A_i accordingly on the basis of information about the agrobiological state of the ground environment, an income makes from realization of which Y_1^k Y_2^k Y_3^k Y_4^k ., Y_i^k .

Let the cost of information (annual) about possible interfere nutritives in soil makes k_1 k_2 k_3 k_4 ., k_i that gives to get possibility additional productivity which influences on eventual productivity b_1 b_2 b_3 b_4 ., b_i but accordingly on an income Y_1^k Y_2^k Y_3^k Y_4^k ., Y_i^k .

Then a table will be similar:

$$\begin{cases} Z^k = b_0 - k_0 - (c_1 \cdot X_1 + c_2 \cdot X_2 + c_3 \cdot X_3 + c_4 \cdot X_4 + ... + c_n \cdot X_i) \to \max \\ b_1 - k_1 - (a_{11} \cdot X_1 + a_{12} \cdot X_2 + a_{13} \cdot X_3 + a_{14} \cdot X_4 + ... + a_{1j} \cdot X_i) = Y_1^k; \\ b_2 - k_2 - (a_{21} \cdot X_1 + a_{22} \cdot X_2 + a_{23} \cdot X_3 + a_{24} \cdot X_4 + ... + a_{2j} \cdot X_i) = Y_2^k; \\ b_3 - k_3 - (a_{31} \cdot X_1 + a_{32} \cdot X_2 + a_{33} \cdot X_3 + a_{34} \cdot X_4 + ... + a_{3j} \cdot X_i) = Y_3^k; \\ b_4 - k_4 - (a_{41} \cdot X_1 + a_{42} \cdot X_2 + a_{43} \cdot X_3 + a_{44} \cdot X_4 + ... + a_{4j} \cdot X_i) = Y_4^k; \\ \text{......................................} \\ b_j - k_j - (a_{i1} \cdot X_1 + a_{i2} \cdot X_2 + a_{i3} \cdot X_3 + a_{i4} \cdot X_{i4} + ... + a_{ij} \cdot X_i) = Y_j^k. \end{cases} \quad (4)$$

$$X_1 \ge 0,\ X_2 \ge 0,\ X_3 \ge 0,\ X_4 \ge 0 ..\ X_j \ge 0 \quad (5)$$

Table 1. Table of optimization of norm of bringing of technological material taking into account the agrobiological state of agricultural lands

Feedstock	Profit from sales, dollar/hectare	The cost of the resulting product, dollar/hectare	Costs nutrients, кg/hectare					
			X_1	X_2	X_3	X_4	.	X_j
A_c	Z	b_0	c_1	c_2	c_3	c_4	.	c_j
A_1	Y_1	b_1	a_{11}	a_{12}	a_{13}	a_{14}	.	a_{1j}
A_2	Y_2	b_2	a_{21}	a_{22}	a_{23}	a_{24}	.	a_{2j}
A_3	Y_3	b_3	a_{31}	a_{32}	a_{33}	a_{34}	.	a_{3j}
A_4	Y_4	b_4	a_{41}	a_{42}	a_{43}	a_{44}	.	a_{4j}
...	.	..	.	.	.	.	.	.
A_i	Y_i	b_i	a_{i1}	a_{i2}	a_{i3}	a_{i4}	.	a_{ij}

Table 2.

Feedstock	Profit from sales, dollar/hectare	The cost of the resulting product, dollar/hectare	The cost information on nutrient dollar/hectare	The cost of wasted nutrients, dollar/hectare					
				X_1	X_2	X_3	X_4	.	X_j
A_c	Z^k	b_0	k_0	c_1	c_2	c_3	c_4	.	c_j
A_1	Y_1^k	b_1	k_1	a_{11}	a_{12}	a_{13}	a_{14}	.	a_{1j}
A_2	Y_2^k	b_2	k_2	a_{21}	a_{22}	a_{23}	a_{24}	.	a_{2j}
A_3	Y_3^k	b_3	k_3	a_{31}	a_{32}	a_{33}	a_{34}	.	a_{3j}
A_4	Y_4^k	b_4	k_4	a_{41}	a_{42}	a_{43}	a_{44}	.	a_{4j}
...	.	..	..	.	.	.	.	.	.
A_i	Y_i^k	b_i	k_i	a_{i1}	a_{i2}	a_{i3}	a_{i4}	.	a_{ij}

Cost of the got products:

$$b_n = S_n \cdot U_n ,$$

where: S_n – cost of one of agricultural product of kind, dollar/hectare,

U_n – productivity of agricultural product dollar/hectare.

Income from realization of products (dollar/hectare):

$$Z^k = b_0 + k_0 + c_1 \cdot X_1 + c_2 \cdot X_2 + c_3 \cdot X_3 + \\ + c_4 \cdot X_4 + ... + c_n \cdot X_i \rightarrow \max \quad (6)$$

To specify on how many anymore we will get an income in compared to the task, when no information is.

$$\Delta Z = Z^k - Z . \quad (7)$$

It is necessary for comparison of expedient norm of till of agricultural lands:

$$\Delta Z \geq Y_i . \quad (8)$$

Information which satisfy this requirement it is expedient to use from the point of view the conduct of agricultural production.

The main quantitative characteristics of the target segment are the volume of market demand and the capacity of the market itself. The volume of market demand $R(t)$ (expressed in real or value terms) determines the potential volume of purchase of (agricultural) products, localized in time and space terms. Capacity of the market $Q(t)$ characterizes the maximum possible demand. Thus, at any given time, the volume of market demand constitutes a part (share) of market capacity. The difference between them $\Delta_{QR}(t)$ characterizes the potential perspective of the investigated market (see Fig. 2).

The volume of demand and the capacity of the market (goods/services) are dynamic functions, depending on many factors: market structures, competition from other enterprises, price elasticity of demand, rates of consumption change, distribution channels, etc.

In world practice there is a wide range of methods for forecasting the market, most of which use a rather complicated mathematical apparatus and require the availability of a large amount of diverse information, the collection and processing of which is not always possible [3, 4]. In practice, simplified methods are usually used:

1) simple extrapolation method (determination of stands and their parameters),

2) method of consumption level (the level of direct consumption of a particular product of agricultural production is determined),

3) the method of end (consumption) use (all possible variants of the use of products are determined, the coefficient of its use in the consuming industries is calculated, the level of production in these industries is forecasted, the consumption forecast is made), etc.

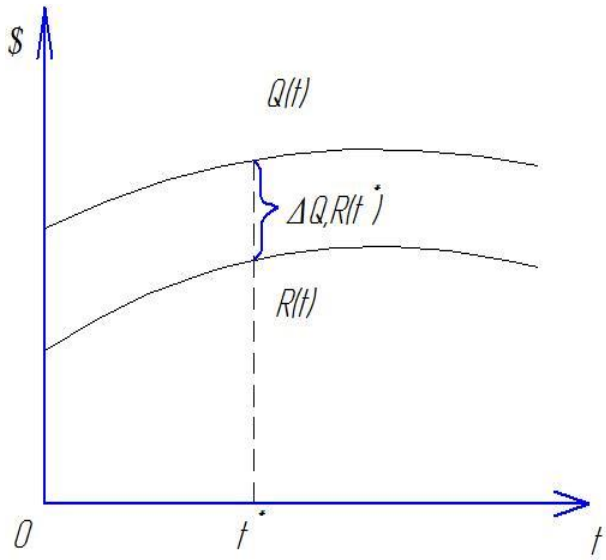

Fig. 1. Potential perspective of the investigated market of sales (agricultural products)

The most widespread methods are based on the principles of regression-correlation analysis. Correlation analysis is used to find the level of interdependence between different sizes and characteristics of the market.

The method of regression analysis is used to find the average of some variable that characterizes the market under study, depending on the value of the second variable by comparing and solving the level of regression.

If the value of the desired variable is dependent on the values of several parameters, then the multi-factor regression equation is formed.

An important stage in market research (Fig. 1) is an analysis of the conditions of competition in the selected market segment and their impact on the magnitude of the potential market niche, which is considered by TESAP in its development.

At this stage, expert methods of qualitative analysis of the situation play an important role, but some formalized means of decision support are also used.

Thus, for example, the possible share (fraction) of specific products (services) of agricultural production of TESAP in the market (specific weight in percentage of total demand or market capacity) at the moment is determined taking into account the competitiveness of products, comparison of the enterprise with the competing, the ratio of supply and demand, and other factors.

Approximately this share can be determined by the formula:

$$\delta^t = \frac{100\%}{\left(\frac{\sum_{j=1}^{J} a_j^t}{\alpha^t} + 1\right) \cdot \frac{m^t}{k^t}},$$

$$m^t = \frac{n^t}{c^t}, \qquad (8)$$

where: δ^t – the share of specific products of agricultural production in the market,

J – number of competitors, $\alpha_j \in [0,1]$ - competitiveness index of the enterprise j,

$\alpha \in [0,1]$ – indicator of competitiveness of the investigated enterprise,

n^t, c^t – supply and demand for agricultural products (services) sold, respectively,

$k^t \in [0,1]$ – relative competitiveness of products (services), which is produced, all at the time t.

In determining the potential sales volume of the products being produced by the TESAP under investigation, the methods of game theory (game models of Cournot, Stackkelberg, Forchheimer et al. [2]) are widely used in the selected market segments under the conditions of competition.

Let's consider the basic idea of these methods on the example of the simplest model of Cournot in the conditions of a duopoly (on the investigated segment of the market two firms compete).

Each firm determines its level of sales (production) q_1 and q_2, respectively

Market price – the linear function of the sectoral volume of production:

$$P(Q) = a - b \cdot Q, \qquad (9)$$

where: $Q = q_1 + q_2$.

The profit Π_1 of the firm 1 is the difference between total income $P(Q) \cdot q_1$ and total expenses equal to the product of constant average costs "C" on the volume of production q_1:

$$\Pi_1 = (a - b \cdot Q) \cdot q_1 - c \cdot q_1. \qquad (10)$$

Since the price also depends on the volume of output by firm 2, as well as on its own production, firm 1 can not determine the level of sales (production) that maximizes profits without the assumption of how the firm 2 will react. The Cournot model is based on the assumption , that each firm proceeds from a constant volume of release by another firm. In this case, the firm 1 maximizes its profit, differentiating Π_1 to q_1 and equating the obtained expression to zero (the condition for the existence of the maximum function of profit of the first order):

$$\frac{d\Pi_1}{dq_1} = P(Q) + \left(\frac{dP}{dQ}\right) \cdot q_1 - c = a - 2 \cdot b \cdot q_1 - b \cdot q_2 - c = 0. \qquad (11)$$

Converting this equation, you can get a function that indicates the maximizing profit level of sales (production) of firm 1 with the object of sales (production) of firm 2:

$$q_1 = \frac{(a - c)}{2 \cdot b} - \frac{1}{2} \cdot q_2. \qquad (12)$$

This equation is a function of the reaction or the reaction curve, because it registers maximizing the profit of the firm 1 and response to the decisions of the firm 2 (see Fig. 1).

Firm 2 solves the exact same problem and has its own reaction function:

$$q_2 = \frac{(a - c)}{2 \cdot b} - \frac{1}{2} \cdot q_1. \qquad (13)$$

The solution that corresponds to the equilibrium (Fig. 1), that is, the solution to the problem of maximizing the profit of each firm, which does not leave any of them an incentive to change the volume of sales (production) of agricultural production, lies at the intersection of two reaction curves. It was found by the substitution of the expression for the function of the reaction of firm 1 and is solved in the following way:

$$q_1 = \frac{(a - c)}{3 \cdot b}. \qquad (14)$$

Similar considerations apply when determining the volume of sales (production) of agricultural production and in more generalized models that reflect a more complex market structure (oligopoly, dominant firm, etc.).

CONCLUSIONS

1. Due to the use of such technologies it is possible to decrease the common amount of fertilizers 25% not reducing general efficiency of their use here is their optimization. Thus possible increase of productivity to 20%.

2. Clearly, that on the fields with high maintenance of nutritives their influence on eventual productivity and accordingly and general efficiency it will be minimum.

3. Subject to the condition these the increase of exactness of leadthrough of the fields works is carried out with the use of software which constantly is perfected.

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ОПТИМИЗАЦИЯ НОРМ ВНЕСЕНИЯ ТЕХНОЛОГИЧЕСКИХ МАТЕРИАЛОВ С УЧЕТОМ АГРОБИОЛОГИЧЕСКОГО СОСТОЯНИЯ ЗЕМЕЛЬ СЕЛЬСКОХОЗЯЙСТВЕННОГО НАЗНАЧЕНИЯ

Александр Броварец

Аннотация. Определена методика расчета оптимальной нормы внесения технологических материалов с учетом состояния агробиологические сельскохозяйственных земель.

Одним из перспективных направлений, используя косвенную информацию о состоянии почвы с надежным алгоритм расчета такой информации это объективно необходимые данные показатели почвы, электропроводность и магнитные свойства. Современная альтернатива традиционной агрохимическое обследование – контактные и бесконтактные методы, основанные на использовании электромагнитных явлений. Часто это измерение, Регистрация, обработка, анализ и интерпретация кондуктивных и электромагнитных свойств грунта, что позволяет определить гранулометрический (механический) состав почвы, органическое вещество почвы, соли, влажности, почвенных контуров, выявления и оценки неоднородности свойств почв в целом.

Это возможно путем получения достоверных данных о состоянии почвенной среды путем уменьшения ошибки при определении стоимости проводящих свойств почвы и снижению интенсивности разрушения почвенной структуры и стабильности электрического контакта с электродом заземления, использование интегрирующих аналого-цифровых преобразователей локальной технической системы мониторинга электропроводящие свойства почвенной среды.

Ключевые слова: оптимальные нормы внесения, технологический процесс, техническая система, оперативный мониторинг, сельскохозяйственное производство, агробиологическое состояние земель сельскохозяйственного назначения.

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System of Control of Parameters Technical Condition of Machines for Forestry Work

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Summary. It is known that forest machines include various harvesters, forwarders and combinations of them, which is also called combined machines. In this description, these combined machines are also included when harvesters are mentioned, if we consider a function similar to the function in a harvester. It is known that control systems are used to control the forestry machines. One control system of prior art is Jack Matic, which is a system for controlling functions of the forest machine and particularly a harvester head (harvester head) and for measuring and sawing timber. In the forest machine control system controls, among other things, a diesel engine, a transmission unit of the hydrostatic drive of the harvester head and crane system, which is connected with the capture of the harvester, as well as all auxiliary functions associated with them. The control system operates, for example, in the operating environment PC/Windows 2000. In team sawing control system to be treated wood may include, for example, the value distribution and table color paint, group types of wood and types of trunks. Through the included in the in matic 300 application it is possible to analyze and compute the production results, such as number, length and diameter of the logs, levels of distribution, group types of wood and types of trunks.

The control system manages, for example, the capture of the harvester so that the supply control log will automatically adjust the feed rate and pressure of feed rollers and knives and succoring that the protection function of the slippage will prevent slippage of the feed rollers and will give the possibility to stop the tree trunk exactly to cut.

The display device and the CPU of the control system are placed in the cockpit within reach for the driver. Typically, the system also includes a printer.

Control bus in the control and measuring automatics of the control system is based on the known from the prior art technical solution CAN bus (asynchronous serial communication bus) in which data is routed in digital form. In the bus control and measurement signals are transmitted by way of also as such known. Based on the data it is possible to monitor measurements relating to the duration and functional performance of various stages during processing. On the basis of signals and measurements, get information about the functional times and duration for the components responsible for different functions. Components can be, for example, is designed for functions of the crane system or the harvester head connected with her, such as feeding, diameter measurement, length measurement, sawing and cutting branches. Separate treatment of the trunk of a tree includes a large number of measurement values that can be stored in a database that further comprises a classification, for example, on the basis of size classes trunks and logs. Size class of the trunk is known on the basis of the measurement values.

Key words: technical control, parameter, technical condition, resource, system, machine for forestry work.

INTRODUCTION

The system of measurement of parameters of technical condition of machines for forestry work refers to the measurement of the condition or characteristic values for the performance of one or more subsystems in the machine for forestry work and submission of the result of the operator [1, 2]. Each measurement includes filtering the interfering data to each individual event and data processing (obtaining) reliable characteristic value that can be used in the maintenance and optimization of the parameters of the technical condition of the machine [3, 4].

A group of systems of measurement of parameters of technical condition of machines for forestry work is a means of monitoring the performance of the subsystem of forest machines [5, 6]. The principle of group of inventions is that accumulate data related to a function of said subsystem or to perform the mentioned functions, determine one or more characteristic values to describe the parameters of the technical state of machines are constantly in accordance with the data, and monitor changes over time mentioned one characteristic value or several characteristic values, the time variation of the mentioned one characteristic value or several characteristic values displays the user in form of graphical representation [7¸ 8].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The system of measurement of parameters of technical condition of machines for forestry work relates to a computer program, which relates to a method and to a computer program product [9, 10].

Implementation of systems of measurement of parameters of technical condition of machines for forestry activities in accordance with the options for monitoring are separated:

- current status for the close function of the harvester [11, 12],
- the current state of the supply function of the harvester [13, 14],
- capture device of the harvester [15, 16],
- performance of machines for forestry work [17, 18],
- the fuel consumption of machines for forestry work [19, 20],

- condition (block) transmission hydrostatic drive of machines for forestry work [21]
- function crane systems of machines for forestry work [22].

OBJECTIVE

The purpose of the paper was put to analytically describe the methodological approaches to control system parameters of the technical condition of machines for forestry work.

THE MAIN RESULTS OF THE RESEARCH

In the prior art it is known that machines for forestry work included in the various harvester, forwarders and combinations of them, which is also called combined machines.

In this review, these combined machines also are included when mentioned harvester if we consider a function similar to the function in harvester. It is known that control systems are used to control machines for forestry work.

One control system of the previous prior art is Timberjack Timbermatic 300 (Fig. 1), which, in turn, is a system for controlling machine functions, for timber works and specifically the head of the harvester and for measuring and sawing timber.

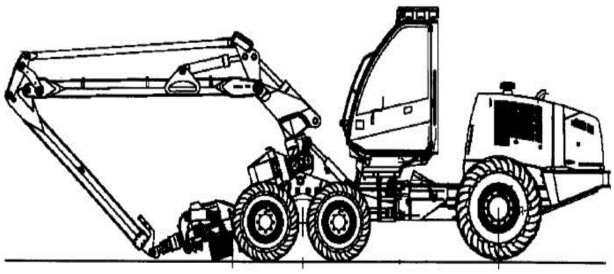

Fig. 1. General view of machines for forestry work

The forestry works management system controls, among others, a diesel engine, a transmission unit of the hydrostatic drive of the harvester head and crane system, which is connected with the capture of the harvester, as well as all auxiliary functions associated with them.

Considered control system works in the operating environment PC/Windows 2010.

The team sawmilling management system to be processed wood, you can include the value, distribution, and color table, group types of wood and types of trunks.

With the help of included in the Timbermatic 300 system application, you can analyze and compute the production results, such as number, length and diameter of the logs, the distribution level, group types of wood and types of trunks (Fig. 2).

The control system controls the capture of the harvester so that the supply control log will automatically adjust the feed rate and the pressure feed rollers and accordnig knives, and a function of preventing slippage will prevent slippage of the feed rollers and to give the possibility to stop the tree trunk exactly to cut (Fig. 3).

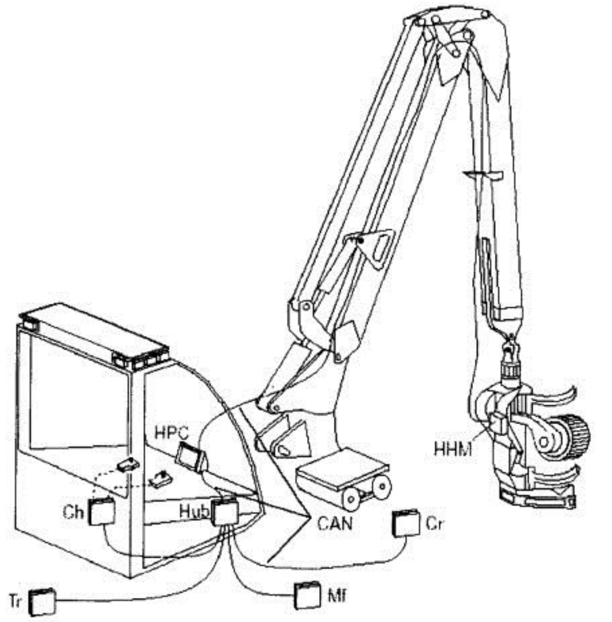

Fig. 2. General view of the control parameters of the technical condition of machines for forestry work

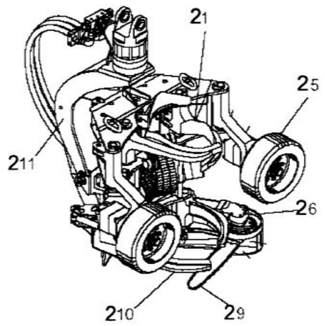

Fig. 3. General view of the control parameters of the technical condition of heads machine for forestry work

The display device and the CPU of the control system are placed in the cockpit within reach for the driver. Typically, the system also includes a printer. Control bus the control and measuring automatics of the control system is based on the known from the prior art technical solution CAN bus (asynchronous serial communication bus) in which data is routed in digital form. In the bus control and measure signals transmitted by a known method. Based on the data is the ability to monitor measurements relating to the duration and functional performance of various stages during processing (Fig. 4). On the basis of signals and measurements, get information about the functional times and duration for the components responsible for different functions. For example, components can be designed for the functions of the crane system or the harvester head connected with it, such as a view, diameter measurement, length measurement, sawing and cutting of knots. Separate treatment of the trunk of a tree includes a large number of measurement values that can be stored in a database that further comprises a classification, for example, on the basis of size classes trunks and logs. Size class of the trunk we know on the basis of the measurement values. Reduced technical characteristics of the forwarder, harvester or harvester capture how the system and its subsystems and components of function will reduce the optimality and efficiency of logging operations (Fig. 5).

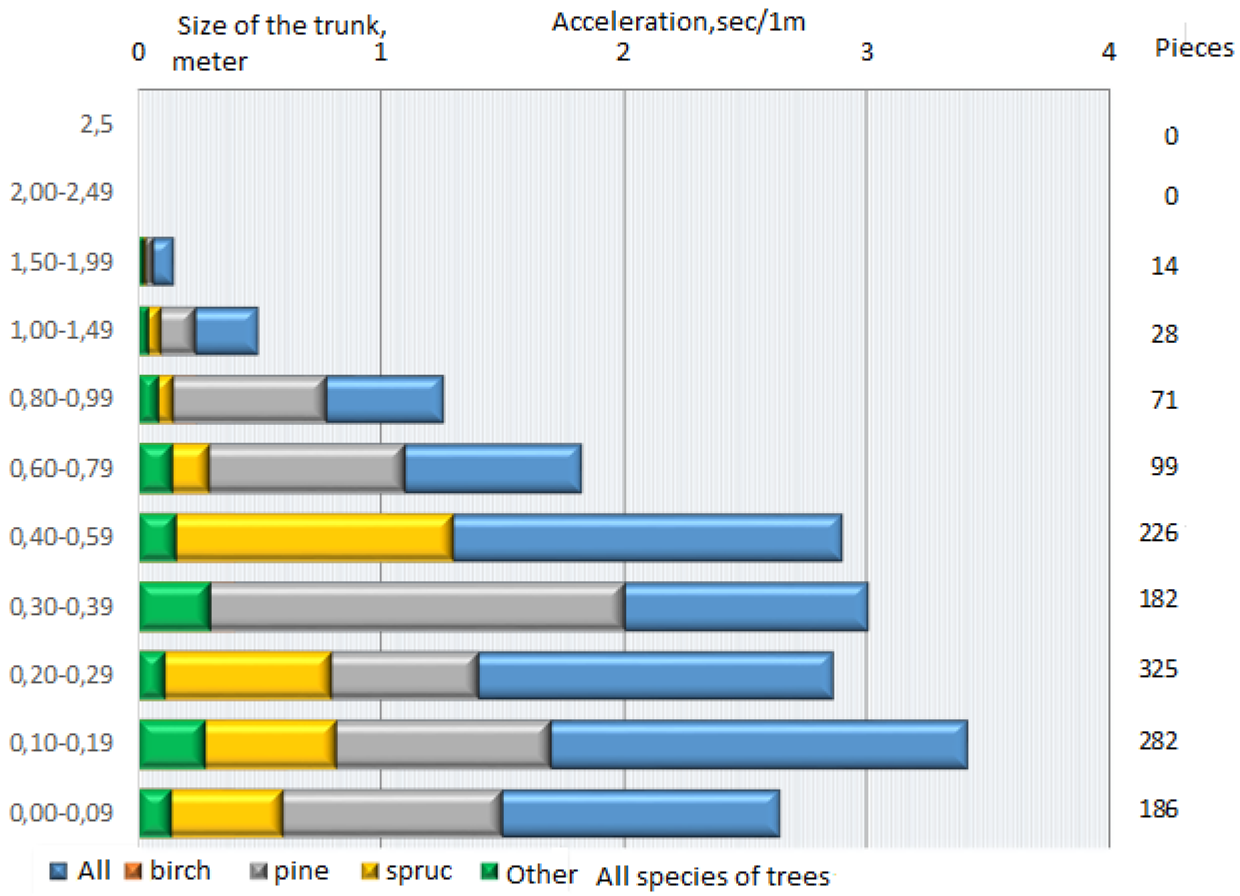

Fig. 4. The dependence of values trunk acceleration and head harvester for the trees

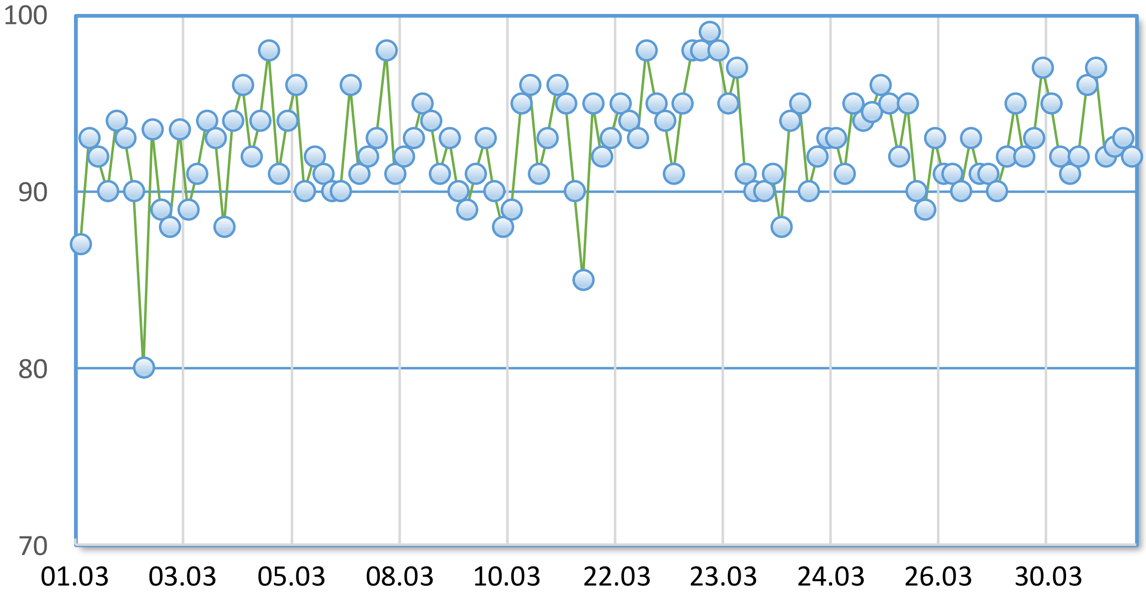

Fig. 5. The index of the harvester head

It was difficult to have a long-term decrease of parameters of technical condition of machines for forestry work as they were based on subjective assessments and experience of the operator or maintenance staff and fitters, which can be time-limited and apply only to certain individual machines for forestry work. In addition, it was impossible in a reliable way to assess the effectiveness of the repair and replacement of parts, or changes in the ways disability (Fig. 6). For example, earlier it was not possible in a reliable way to monitor the condition of the cutting function or the supply function of the harvester. In the technical solutions of the prior art time periods of spraying are compared with set alarm limits and when the limit is exceeded, the driver displays warning (Fig. 7).

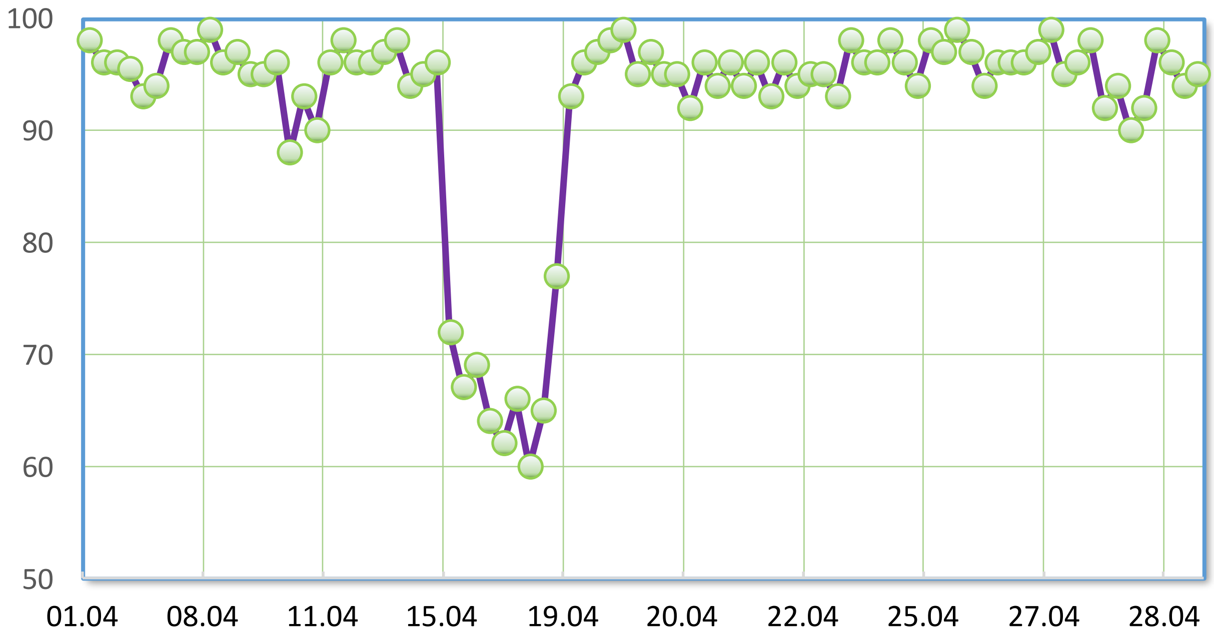

Fig. 6. The index submission of the harvester head

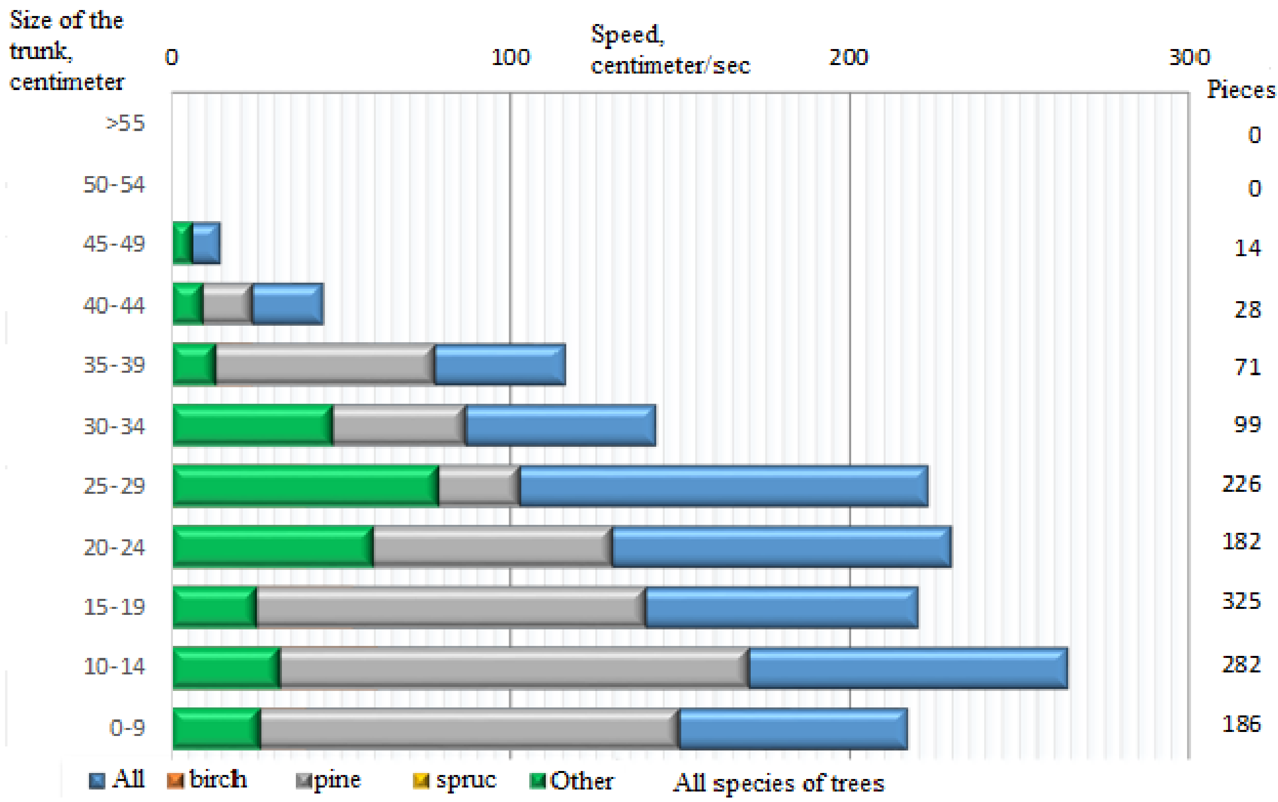

Fig. 7. The dependence of values trunk speed and head harvester for the trees

However, the working characteristics of the spray system or, on the other hand, the supply function is one of the most important factors in the performance of the harvester (Fig. 8).

The reduced performance will reduce the effectiveness of logging and if a long time a failure can lead to further damage, what is worse still, or to stop production.

In addition, previously it was not possible to monitor the state of the contents of the barrel grip harvester.

The contents of the barrel grip harvester is an important factor in the performance and measurement accuracy of the harvester (Fig. 9).

The deterioration in retention of the barrel will reduce the effectiveness of the logging operations.

For example, if the clip soccorsi knives is insufficient, the driving force of the paper feed roller is not effectively transmitted to the barrel and, on the other hand, will be degraded the accuracy of the diameter measurement (Fig. 10).

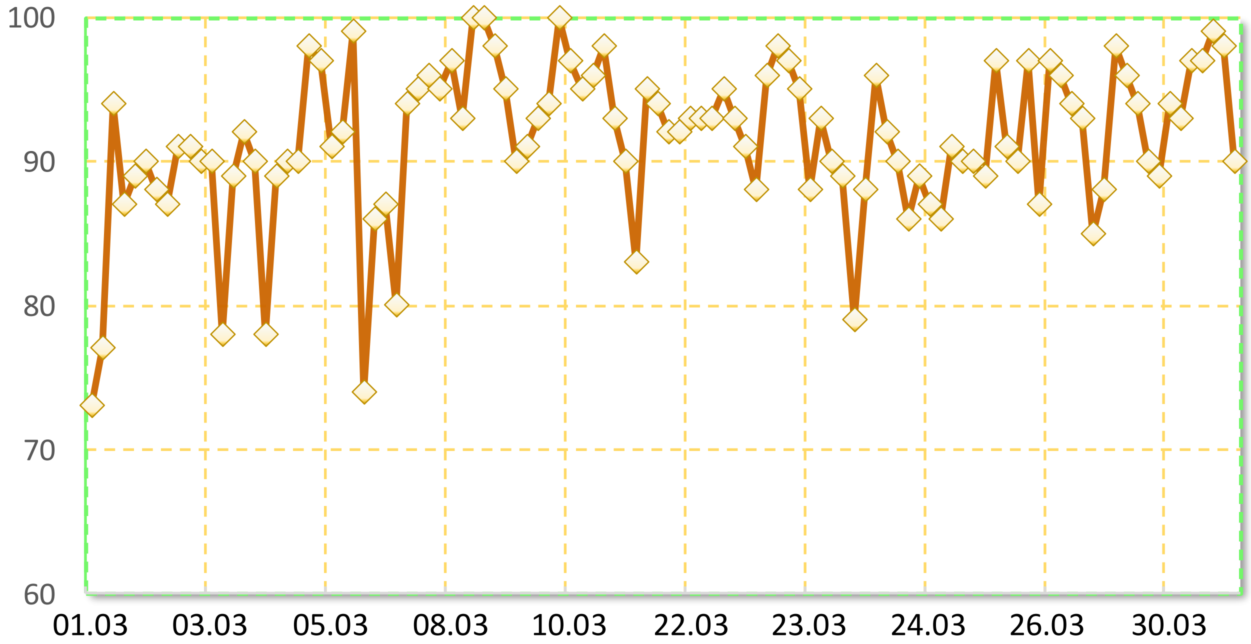

Fig. 8. The index sawing function of the harvester head

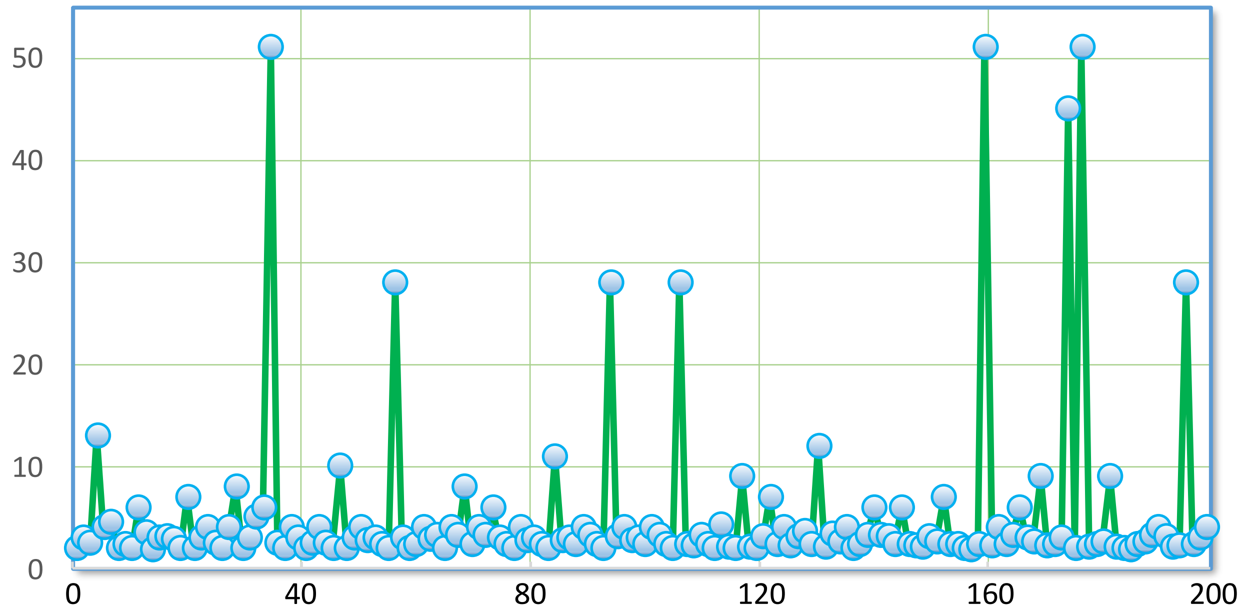

Fig. 9. The index of the harvester head with round wood

The accuracy of the measurement of length will also be degraded because it will increase violation of the contact between the measuring roller and the barrel.

If the clip soccorsi knives is too strong then the force of friction between the blade and the barrel is too big.

Thus, the feed rate and the capture performance will decrease and fuel consumption will increase.

Also it was not possible to measure the performance of machines for forestry work so that the measurement was useful in monitoring the performance and specifically the technical condition of machines for forestry work.

Sufficient productivity of the harvester, that is a large amount of timber processed in cubic meters per hour (m^3/h), is the basic requirement for economic efficiency of mechanized logging.

However, the performance of the harvester may be reduced for a number of reasons such as technical failures or installed machine options that are not suitable for conditions. In addition, previously it was not possible to measure the fuel consumption of machines for forestry work so that the measurement was useful for monitoring the condition of the machine.

Previously measured direct consumption per hour which is not sufficient for evaluation of technical condition of machines for forestry work and for long-term monitoring characteristics. The calculation of characteristic values is usually performed in four steps: measurement, removal of the abnormal dimension values, classification and compensation of measurement data, and calculating characteristic values.

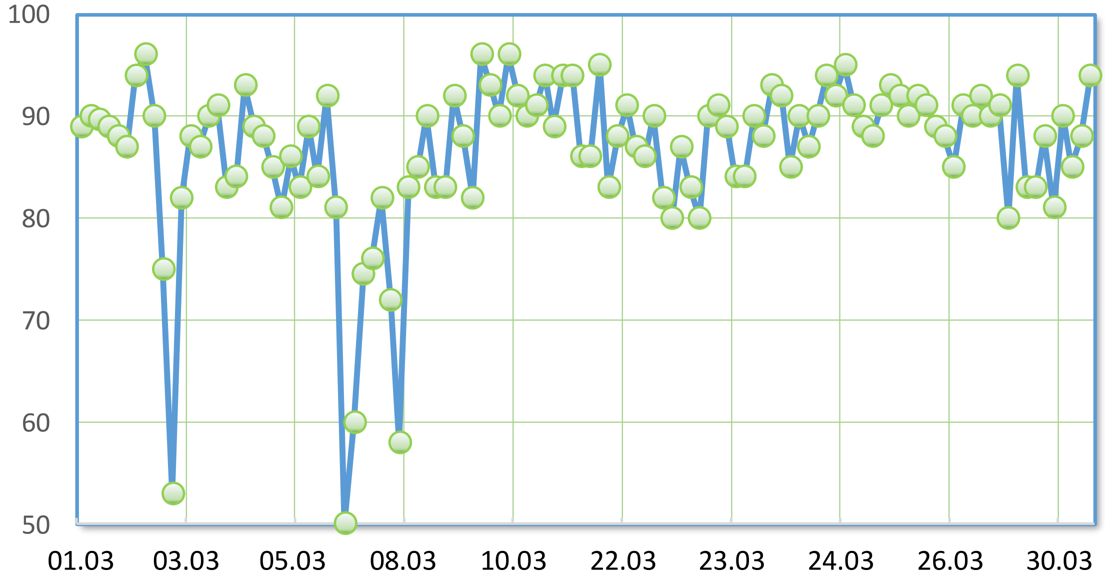

Fig. 10. The index productivity of the harvester head

After the characteristic value was calculated in real time, the result is stored, and the user can observe the dynamic changes of the characteristic values for the desired period of time. Subsystems of machines for forestry work included in the transmission system hydrostatic drive Kranevo system, the sawing function of the harvester, the feeding function of the harvester and the function of holding the barrel of the harvester. The characteristic values of the parameters of the technical condition of machines for forestry work is the performance and fuel economy of the harvester.

Using a system of measurement of parameters of technical condition of machines for forestry work to control the technical characteristics of machines for forestry work, such as forwarders, harvester also allows you to control the grip harvesters and monitoring long-term trend, i.e. the change in time, which may be accomplished by use of measurement values of the indices for various components of the machine functions to forestry operations. Monitoring is carried out by maintaining sufficient historical information or using the display changes graphically or in the form of numerical data, or by obtaining log data for analysis. Using a system of measurement of parameters of technical condition of machines for forestry operations, it is possible to compare data relating to the performance of functions and the data parameters of the technical condition of the machine, measured in different working conditions of machines for forestry work since the parameters to be determined, the index values can be established independent of variable factors, if needed.

The index values can be used to highlight the most important information in a very compact form, in other words, a complete picture of the parameters of the technical condition of the machine can be removed from multidimensional measurement data and a large number of single measurements. The index, which is used as the characteristic value is specified multiple times, and it is determined at timed intervals when some conditions are satisfied or, for example, when a sufficiently large processing quantity or number of logs. The data used in the system to monitor the status of machines for forestry work, and the illustrative, comprehensive and detailed data provides an excellent basis for expert evaluations as to what the characteristics of these machines for forestry work, which can take place possible problems, and what needs to be done to improve the technical condition.

Specifically, when a measured parameter of the technical condition of machines for forestry work, another particular problem is the dependence of measured values, operating conditions and driving style of the driver. Even these problems can be solved in accordance with the system of measurement of parameters of technical condition of machines for forestry work.

The developed system of measurement and calculation generates a characteristic value indicating the overall technical condition of machines for forestry work, for example, sputtering system or the supply function (sawing index, feeding index). The cutting system consists of a system formed by, diesel engine, drive pump, drive motor saw and chain saw. Changes in the value of the characteristic value that is continuously updated indicate changes in the technical condition of the spray system or supply function.

In addition, the system of measurement of parameters of technical condition of machines for forestry work provides an index used to transfer the state of the actuator as the harvester and forwarder that indicates the relation between the required rotation speed of the hydraulic motor and used speed. The drive transmission system typically contains the hydraulic motor and hydraulic pump operating in a closed system. By monitoring the load distribution are found to be the relative change in the transmission drive and maintenance requirements. Historical information is an important source of information in an unexpected failure events.

In addition, the system of measurement of parameters of technical condition of machines for forestry work provides an index that indicates the parameter of the technical condition of the crane system, describing the function of the crane system or forwarder or harvester.

Thanks to the system of measurement of parameters of technical condition of machines for forestry work can be:

- Proactively identify reduced parameter of the technical condition of the machine. Work parameters can be restored to an acceptable level faster than before, and the average productivity will increase. Repair work can be performed in advance in connection with the usual service, and the resulting increase in utilization will also increase average productivity.

- Proactively detect errors in the contents of the trunk and the causes can be established immediately. The performance can be raised to an acceptable level faster than before, and the average productivity, the average measurement accuracy of the machine will be improved.

- Monitor fuel economy or performance, which can be restored to an acceptable level faster than before, and maintenance costs for the machine will be reduced. Repair work can be performed in advance, and utilization will increase.

In various embodiments of the system of measurement of parameters of technical condition of machines for forestry work includes the steps of calculating in real time, for example, characteristic values of the technical parameters of cutting with a saw or view the characteristic values for the performance of the fuel consumption, the characteristic values for the working characteristics of crane system, the characteristic values for the condition of the drive transmission or the characteristic performance values save characteristic value and display to the operator the prehistory of the parameters of the technical condition of the machine. The measurement, calculation and display of results are performed on a personal computer (PC) related to the control system for forestry machinery.

In various embodiments of the system of measurement of parameters of technical condition of machines for forestry work also include the steps of calculating in real time the characteristic values for retention of the trunk, save characteristic value and display to the operator the prehistory of the working characteristics. The measurement, calculation and display of results are performed in modules that are related to the control system machine.

CONCLUSIONS

1. A particular advantage lies in the fact that the implementation of the various embodiments of the invention does not require the inclusion in the machine of new sensors or computing modules, if it is not necessary. By incorporating the new sensors is also possible to control objects that are not usually included in the monitoring using the control system of the machine for forestry work, but which may be significant for condition monitoring.

2. In one embodiment of the system restore parameters of the technical condition of machines for forestry work calculation according to the invention uses the key dimensions of diameter and length to handle the characteristic value retention of the barrel, which can be used as the basis for maintenance activities and settings the setup acquisition parameters. This is not allowed in any monitoring solution, the relevant prior art.

3. The most important feature of graphical representation of the background characteristic values in accordance with various embodiments of the invention is that it is illustrative for the operator. The background of the index can be graphically represented in various ways.

4. The indexes derived in the different examples of the implementation of the system of measurement of parameters of technical condition of machines for forestry work, can be used to calculate the common index to describe the full operation of the machine for forestry work, for example, using a weighted average. The index values for the various components functions are used to configure optimally the various control parameters of the control system of the forestry machine.

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СИСТЕМА КОНТРОЛЯ ПАРАМЕТРОВ ТЕХНИЧЕСКОГО СОСТОЯНИЯ МАШИН ДЛЯ ЛЕСОТЕХНИЧЕСКИХ РАБОТ

Людмила Титова, Иван Роговский

Аннотация. Известно, что лесохозяйственные машины включают в состав различные харвестеры, форвардеры и комбинации из них, которые также называют комбинированными машинами. В данном описании такие комбинированные машины также являются включенными, когда упоминаются харвестеры, если рассматриваемая функция подобна функции в харвестере. Известно, что системы управления используются, чтобы управлять лесохозяйственными машинами. Одной системой управления предшествующего уровня техники является jack matic, которая является системой для управления функциями лесохозяйственной машины и конкретно головкой харвестера (валочной головкой) и для измерения и распиловки лесоматериалов. В лесохозяйственной машине система управления управляет, среди прочего, дизельным двигателем, блоком передачи гидростатического привода, головкой харвестера и крановой системой, с которой соединен захват харвестера, а также всеми вспомогательными функциями, связанными с ними. Рассматриваемая система управления работает, например, в операционной среде PC/Windows 2000. В команды распиловки системы управления для подлежащей обработке древесины возможно включать, например, значение, распределение и таблицы цветовой окраски, группы типов древесины и типы стволов. Посредством включенного в состав в системы matic 300 приложения возможно анализировать и вычислять результаты выработки, такие как количество, длина и диаметр бревен, уровни распределения, группы типов древесины и типы стволов.

Система управления управляет, например, захватом харвестера таким образом, что управление подачей бревна будет автоматически подстраивать скорость подачи и давление подающих роликов и сучкорезных ножей и что функция предохранения от проскальзывания будет предотвращать проскальзывание подающих роликов и будет давать возможность останавливать ствол дерева точно для распила.

Устройство отображения и центральный процессор системы управления помещаются в кабине в пределах досягаемости для водителя. Обычно система также содержит принтер.

Шина управления в контрольно-измерительной автоматике системы управления основывается на известном из уровня техники техническом решении шины CAN (асинхронная последовательная коммуникационная шина), в которой данные пропускаются в цифровой форме. В шине управления измерения и сигналы передаются способом, также как таковым известным. На основе данных является возможным контролировать измерения, относящиеся к продолжительности и функциональному быстродействию различных этапов в ходе обработки. На основании сигналов и измерений получают информацию о функциональных временах и хронометраже для компонентов, отвечающих за различные функции. Компоненты могут быть, например, предназначены для функций крановой системы или головки харвестера, связанной с ней, таких как подача, измерение диаметра, измерение длины, пиление и резка сучьев. Обработка отдельного ствола дерева включает в состав большое количество значений измерений, которые могут храниться в базе данных, которая дополнительно содержит классификацию, например, на основе размерных классов стволов и бревен. Размерный класс ствола является известным на основе значений измерений.

Ключевые слова: технический контроль, параметр, техническое состояния, ресурс, система, машина для лесотехнических работ.

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System of Registration and Control the Flight of Transportation of Grain Harvest by Vehicles

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Summary. The study relates to technical means of registration and control of flight vehicles. The technical result is the implementation of the monitoring schedule specified route of movement of vehicles. The system of registration and control of flights moving objects contains controlled moving objects, RFID tags, contains piezocrystal, microstrip transceiver antenna, electrodes, two buses and a set of reflectors, and control. On a movable object installed: pressure transducers, body position, fuel consumption, trip distance, elements, block encoding, the transmitter, the high-frequency generator, phase manipulator, power amplifier, transceiver antenna, a circulator, a high frequency amplifier, phase detector, an adder, a timer and driver code. At the point of control is established: the receiving antenna, amplifier high frequency, the search block, two local oscillators, two amplifiers, two mixers, two amplifiers of intermediate frequency, amplitude detector, two multiplier, a narrow-band filter, low pass filter, panoramic receiver, decoder, registration block, an element of the ban, the shaper pulse duration, two keys, a correlator, a threshold unit, frequency meter, fuel meter, trip meter and an additional unit.

The proposed system relates to the field of technical means of registration and control of flights moving objects and can be used to account for the efficiency of the use of vehicles in an automated warehouse shipment of goods in trade or account the receipt of raw materials, shipment of products in agriculture, during transportation of the grain harvest of crops and bulk cargo.

Of the known systems and devices closest to the proposed is a device for metering flights trucks, which is selected as a prototype.

The known device provides increased noise immunity and selectivity panoramic receiver by suppressing spurious signals (noise) taken on additional channels.

The technical challenge is to expand the functionality of the system by controlling the execution schedule of a specified route in the registration and control of flights transportation of the grain harvest vehicles.

Key words: system, registration, control, flight, transport, vintage, vehicle.

INTRODUCTION

The study relates to technical means of registration and control of flight vehicles [1]. The technical result - the implementation of the monitoring schedule specified route of movement of vehicles [2, 3]. The system of registration and control of flights moving objects contains controlled moving objects, RFID tags, contains piezocrystal, microstrip transceiver antenna, electrodes, two buses and a set of reflectors, and control [4, 5]. On a movable object installed: pressure transducers [6], body position [7], fuel consumption [8], trip distance [9], elements [10], block encoding [11], transmitter [12], high-frequency generator [13], phase manipulator [14], power amplifier [15], transceiver antenna, a circulator, a high frequency amplifier [16], phase detector, an adder, a timer and driver code [17]. At the point of control is established: the receiving antenna, amplifier high frequency, the search block, two local oscillators, two amplifiers, two mixers, two amplifiers of intermediate frequency, amplitude detector, two multiplier, a narrow-band filter, low pass filter, panoramic receiver, decoder, registration block, an element of the ban, the shaper pulse duration, two keys, a correlator, a threshold unit, frequency meter, fuel meter, trip meter and an additional unit [18].

The proposed system relates to the field of technical means of registration and control of flights moving objects and can be used to account for the efficiency of the use of vehicles in an automated warehouse shipment of goods in trade or account the receipt of raw materials, shipment of products in agriculture, during transportation of the grain harvest of crops and bulk cargo [19].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Of the known systems and devices closest to the proposed is a device for metering flights trucks, which is selected as a prototype [20]. The known device provides increased noise immunity and selectivity panoramic receiver by suppressing spurious signals (noise) taken on additional channels [22].

OBJECTIVE

The technical challenge is to expand the functionality of the system by controlling the execution schedule of a specified route in the registration and control of flights transportation of the grain harvest vehicles.

THE MAIN RESULTS OF THE RESEARCH

The problem is solved in that the system of registration and control of flights moving objects, containing, in accordance with the closest analogue, each controlled movable object sequentially enabled sensor pressure element And a second input coupled with the output of the position sensor body, block coding, second and third inputs connected to the outputs of flow sensor and fuel sensor of the traversed path, respectively, the phase manipulator, a second input coupled to the first output of the high-frequency generator and power amplifier, and the control point consistently included receiving antenna, amplifier high frequency, the first mixer, the second input is via the first local oscillator connected to the output of the search block, the first intermediate frequency amplifier, the second key, the first multiplier, a second input coupled with the output of the low pass filter, narrow band filter, second multiplier, a second input connected to the output of the second key, the lowpass filter and a decoder, the outputs of which are connected by the number of controlled moving objects, the Executive blocks, each of which consists of sequentially connected to the decoder element of the ban, the registration unit and shaper pulse duration, the output of which is connected to prohibit the entrance element of the ban, connected in series to the output of the amplifier high frequency, a second mixer, the second input is via a second local oscillator connected to the output of the search block, the second intermediate frequency amplifier, the correlator, a second input coupled to the output of the first amplifier intermediate height, and a threshold unit, the output of which is connected to the second input of the second key, sequentially connected to the second input of the first oscillator, the first key, the second input of which through the amplitude detector connected to the output of the second key, frequency and additional registration unit, second, the third and fourth inputs of which are connected directly and through the meter fuel consumption and trip meter with the corresponding outputs of the decoder, the frequencies of the local oscillators spaced at twice the value of the intermediate frequency:

$$f_{g2}–f_{g1}=2f_{pr},$$

selected symmetric about the carrier frequency of the main channel:

$$f_1–f_{g1}=f_{g2}–f_1=f_{pr},$$

and rebuilt synchronously, differs from the closest analogue because it is equipped with an RF tag installed at checkpoints along the route of the mobile object which is equipped with a transceiving antenna, a circulator, a high frequency amplifier, phase detector, integrator, and driver code and the timer and to the output of the power amplifier sequentially connected to the circulator, input-output of which is connected with the transmitting-receiving antenna, amplifier high frequency, a phase detector, a second input coupled with the second output of the high-frequency generator and the adder, the second input of which through the shaper code is connected to the output of the timer and the output connected to the fourth input unit of coding, each RF tag is made in the form of piezocrystal coated on the surface of the aluminum thin-film interdigital transducer and reflectors, the interdigital transducer of the surface acoustic wave and contains two comb system of electrodes connected by a tire associated with microstrip transceiver antenna, also made on the surface of piezocrystal.

Block diagram of equipment installed on a movable object represented in Fig. 1. Block diagram of equipment installed on the control point, Fig. 3. Functional diagram of the radio frequency tag depicted in Fig. 2.

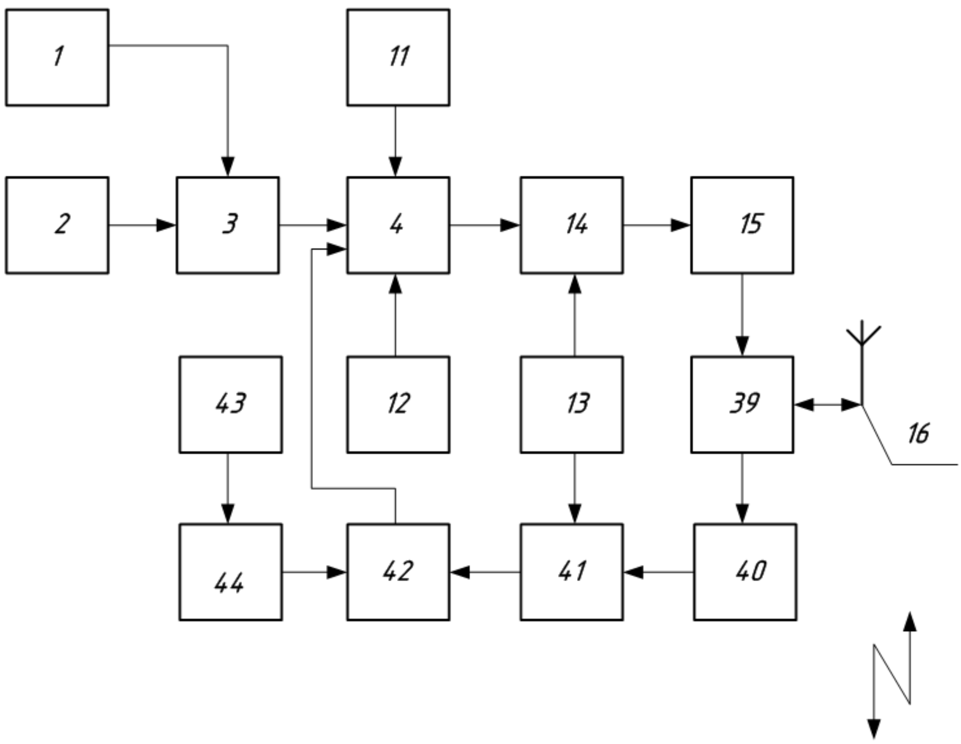

Fig. 1. Registration system for flight vehicles

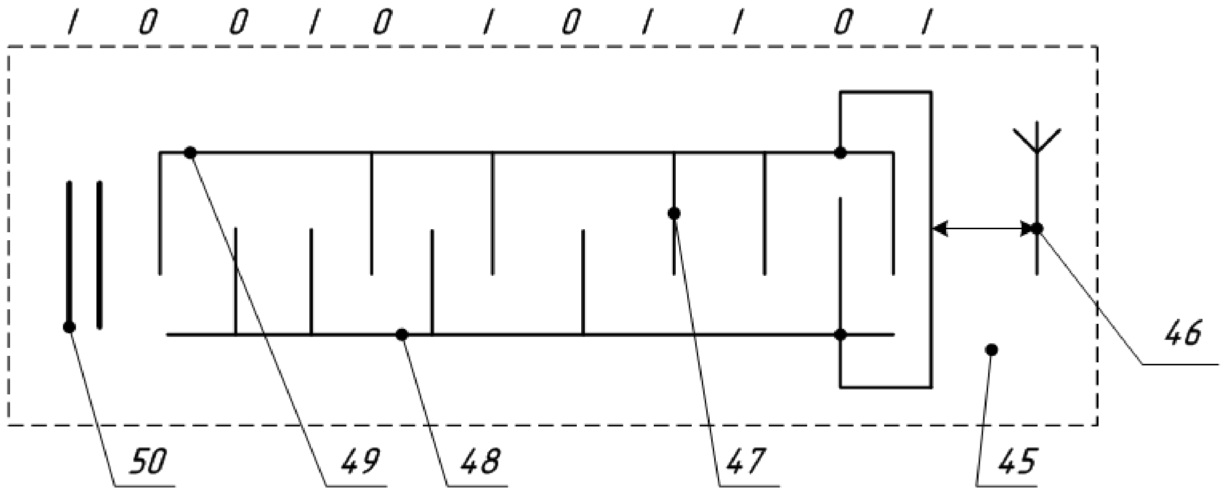

Fig. 2. Control system for flight vehicles

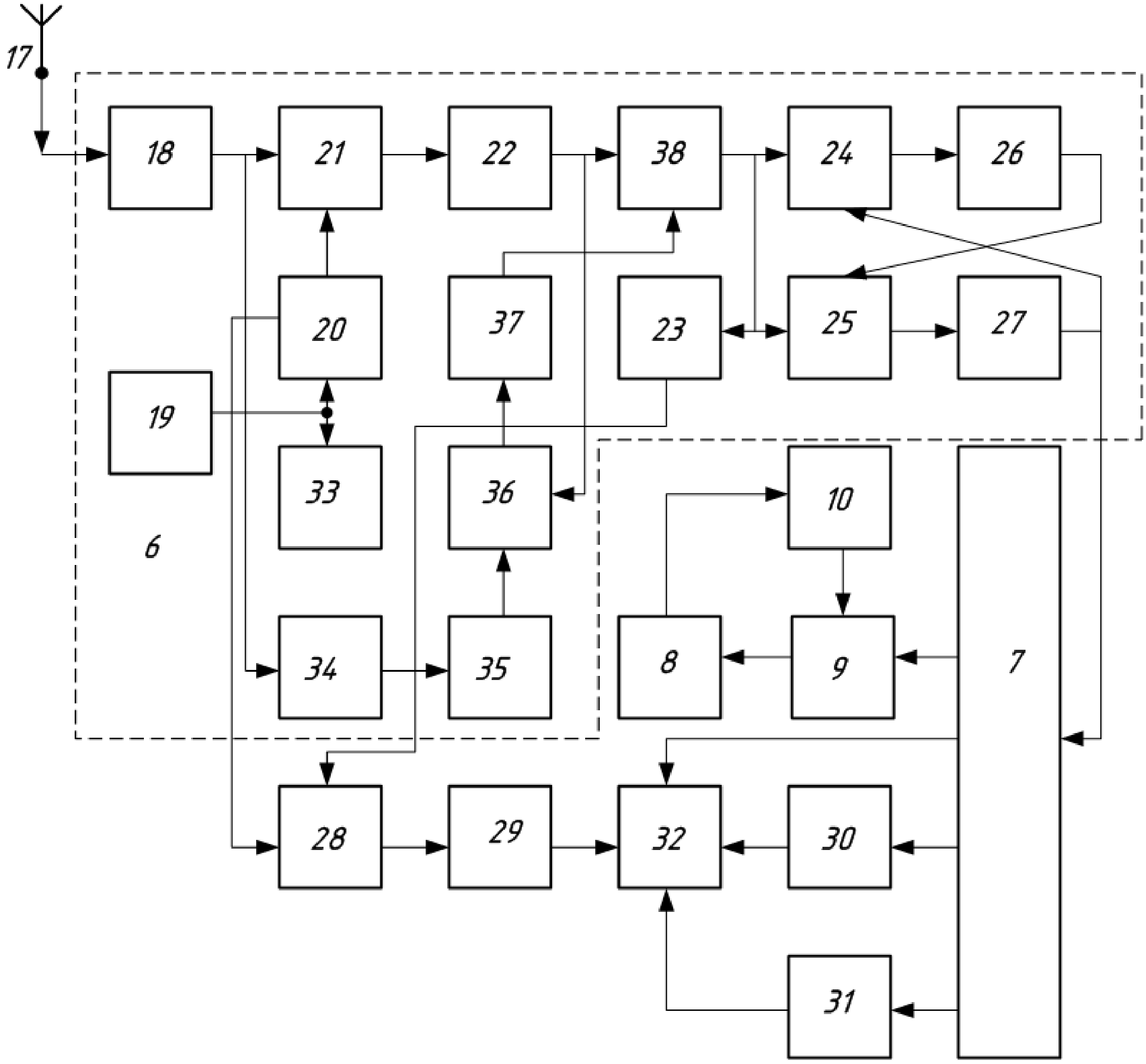

Fig. 3. System of registration and control of flight vehicles

The equipment that is installed on a movable object includes sequentially enabled sensor 1 pressure element And 3, the second input of which is connected to the output of the position sensor 2 body, 4 block coding, second and third inputs connected to the outputs of the sensor 11 of the fuel and the sensor 12 of the traversed path, respectively, of the phase manipulator 14, a second input coupled to the first output of the generator 13 high frequency amplifier 15 power, a circulator 39, the input-output of which is connected with the transmitting-receiving antenna 16, amplifier 40 is a high frequency, the phase detector 41, the second input of which is coupled to the second output of the generator 13 high frequency, and the adder 42, the second input is through the shaper 44 code connected to the output of the timer 43, and the output connected to the fourth input of the unit 4 encoding.

RF tag is made in the form of piezocrystal coated on 45 the surface of the aluminum thin-film interdigital transducer and a set of 50 reflectors. Interdigital transducer (IDT) surface acoustic wave (saw) contains two comb system of electrodes 47, which are connected to each other tires 48 and 49 associated with microstrip transceiver antenna 46, also performed on the surface of the piezoelectric crystal 45.

The equipment installed at the point of control contains consistently included receiving antenna 17, the amplifier 18 high frequency, the first mixer 21, the second input is via the first local oscillator 20 is connected to the output of the block 19 of the search, the first amplifier 22 intermediate frequency, the second key 38, the first multiplier 24, a second input coupled to the output of the filter 27 of the lower frequencies, narrow-band filter 26, a second multiplier 25, a second input connected to the output of the second key 38, the filter 27 of the lower frequencies and the decoder 7, the outputs of which are connected by the number of controlled moving objects, the executive blocks each of which consists of sequentially connected to the decoder 7 item ban 9, block 8 registration and driver 10 pulse duration, the output of which is connected to prohibit the entrance of item 9 of the ban.

The output of the amplifier 18 high frequency sequentially connected to the second mixer 34, the second input of which through the second local oscillator 33 connected to the output unit 19 of the search, and the second amplifier 35 intermediate frequency, the correlator 36, a second input coupled to the output of the first amplifier 22 intermediate frequency, and the threshold unit 37, the output of which is connected to the second input of the second key 38.

To the second input of the first local oscillator 20 connected in series the first key 28, the second input of which through the amplitude detector 23 is connected to the output of the second key 38, a frequency counter 29 and an additional unit 32 of the registration, the second, third and fourth inputs of which are connected directly and through the meter 30 fuel consumption, and the counter 31 of the traversed path with the corresponding outputs of the decoder 7. The system of registration and control of flights moving objects operates as follows.

When lifting the body with the load pressure in the oil line of the lifting body increases, the sensor 1 pressure produces a signal which is supplied to first input of gate 3.

The latter produces a signal only when the second input receives the signal from the sensor 2 position of the body, which produces a signal only when raised to the upper position of the body.

If there are two signals from sensor 1 pressure sensor 2 position of the body element 3 and produces an output signal which is supplied to the first input unit 4 encoding.

The above-described operation of the system corresponds to the case when the mobile object uses the dump truck.

During movement of the dump signal from the sensor 11 of the fuel and the sensor 12 of the traversed path in the form of a series of pulses is received by the second and third inputs of the block 4 encoding.

The encoding unit 4 generates the modulating code $M_1(t)$, where "coded" information about the license plate of the dump truck, the number of the lifting body with load, fuel consumption and distance traveled.

Modulating code M1(t) contains N1 elementary parcels duration TE. The first n elementary parcels are in digital form information on the license plate of a dump truck, m elementary parcels are discharged to the number of lifts of the body with the load, l elementary parcels reported fuel consumption, and z basic assumptions reflect the path of the dump truck (N_1=n+m+l+z).

Modulating code M1(t) output from the encoding unit 4 is supplied to a first input of the phase manipulator 14, to the second input of which is applied harmonic oscillation from the first output of the generator 13 high frequency:

$$U_1(t)=V_1\times \mathrm{Cos}(2\pi f_1 t+\varphi_1),\ 0\le t\le T_1,$$

where: V_1, f_1, φ_1, T_1 – amplitude, carrier frequency, initial phase and duration of harmonic oscillations.

The output of the phase manipulator 14 is formed a phase-shift keyed (F_{MN}) signal:

$$U_2(t)=V_1\times \mathrm{Cos}(2\pi f_1 t+\varphi_{k1}(t)+\varphi_1),\ 0\le t\le T_1,$$

where: $\varphi_{k1}(t)=\{0,\pi\}$ – manipulated component phases, reflecting the law of phase manipulation in accordance with the modulating code $M_1(t)$, and $\varphi_{k1}(t)$=const when kTE<t<(k 1)TE and may change abruptly at t=kTE, i.e. at the boundaries between elementary parcels (k=1, 2, ... N_1-1), TE, N_1 – duration and the number of elementary parcels that form the signal duration T_1 ($T_1=N_1$*TE),
which after amplification in the amplifier 15 power through the circulator 39 is received in the transmitting-receiving antenna 16 and is radiated into the ether.

It should be noted that each truck has its own modulating code $M_i(t)$ and carrier frequency:

$$f_i\ (i=1, 2, ..., S),$$

where: S – number of controlled trucks.

With the passage of dump trucks by the control point, which has RF tag, F_{MN}-signal $U_2(t)$ is captured by mitropolski antenna 46, is converted IDT in an acoustic wave which propagates on the surface of the piezoelectric crystal 45 is reflected from a set of 50 reflectors and again converted into a signal with phase manipulation:

$$U_3=V_3\times \cos(2\pi f_1 t+\varphi_{k2}(t)+\varphi_1),\ 0\le t\le T_1,$$

where: $\varphi_{k2}(t)=\{0,\pi\}$ – manipulated component phases, reflecting the law of phase manipulation in accordance with the topology of IDT $M_2(t)$, which in turn defines the number and location of control points.

Which is radiated microstrip transceiver antenna 46 on the air, is caught transmitting antenna 16 of the dump and through the circulator 39 and the amplifier 40 of high frequency is supplied to the first (information) input of phase detector 41, the second (reference) input of which the reference voltage is served harmonic oscillation $U_1(t)$ from the second output of the generator 13 high frequency.

The result of the synchronous detection output of the phase detector 41 is formed of a low-frequency voltage:

$$U_{H1}(t)=V_{H1}\times\cos\varphi_{k2}(t),\ 0\leq t\leq T_1,$$

where:

$$U_{H1}(t)=½V_3\times V_1,$$

proportional to the modulating code $M_2(t)$, which defines the number and location of control points.

This voltage is supplied to a first input of adder 42.

The current time output from the timer 43 is supplied to the input of the shaper 44 code which generates the modulating code $M_3(t)$. This code is supplied to the second input of the adder 42, the output of which is formed total code:

$$M_\Sigma(t)=M_2(t)+M_3(t),$$

which is output from the adder 42 is supplied to the fourth input of the unit 4 encoding. The encoding unit 4 generates the simulation code $M_4(t)$, which contains information about the modulating codes $M_1(t)$ and $M_\Sigma(t)$. Modulating code $M_4(t)$ contains N_2 elementary parcels duration TE. [$N_2=N_1+p$, where: p – number of elementary parcels, containing the modulating code $M_\Sigma(t)$].

Modulating code $M_4(t)$ from the output of the encoding unit 4 is supplied to a first input of the phase manipulator 14, to the second input of which is applied harmonic oscillation $U_1(t)$ from the first output of the generator 13 high frequency.

The output of the phase manipulator 14 in this case is formed F_{MN} signal:

$$U_4(t)=V_1\times\mathrm{Cos}[2\pi f_1 t+\varphi_{k3}(t)+\varphi_1],\ 0\leq t\leq T_1,$$

where: $\varphi_{k3}(t)=\{0,\pi\}$ – manipulated component phases, reflecting the law of phase manipulation in accordance with the simulation code $M_4(t)$.

Which after amplification in the amplifier 15 power through the circulator 39 is received in the transmitting-receiving antenna 16 and is radiated into the ether.

On the control point search F_{MN}-signals belonging to different moving entities (trucks), by using panoramic receiver 6.

This block 19 search periodically with period TP by sawtooth law synchronously change frequency f_{g1} and f_{g2} local oscillators 20 and 33.

Taken F_{MN}-signal $U_4(t)$ output from the receiving antenna 17 through the amplifier 18 high frequency is supplied to the first inputs of mixers 21 and 34, the second inputs of which are served voltage of the local oscillators 20 and 33:

$$U_{g1}(t)=V_{g1}\times\cos(2\pi f_{\Gamma1}t+\pi\gamma t^2+\varphi_{g1}),$$

$$U_{g2}(t)=V_{g2}\times\cos(2\pi f_{\Gamma2}t+\pi\gamma t^2+\varphi_{g2}),\ 0\leq t\leq T_1,$$

where: V_{g1}, V_{g2}, f_{g1}, f_{g2}, φ_{g1}, φ_{g2}, $T_п$ – amplitude, initial frequency, initial phase and the period of repetition (restructuring) voltage of the local oscillators, $\gamma=D_f/TP$ – the rate of change of the frequencies of the local oscillators (speed of viewing a given frequency range D_f).

The frequencies f_{g1} and f_{g2} of the local oscillators 20 and 33 spaced at twice the value of the intermediate frequency:

$$f_{g2}-f_{g1}=2f_{pr},$$

selected symmetric about the carrier frequency f_1 of the primary receiving channel:

$$f_1-f_{g1}=t_{g2}-f_1=f_{pr},$$

and rebuilt synchronously.

This circumstance leads to a doubling of the number of additional receiving channels, but creates favorable conditions for their suppression due to correlation processing channel stress.

At the output of mixers 21 and 34 are formed voltage Raman frequencies. Amplifiers 22 and 35 intermediate frequency are the following voltage:

$$U_{pr1}(t)=V_{pr1}\cos(2\pi f_{pr}t+\varphi_{k3}(t)-\pi\gamma t^2+\varphi_{pr1}),$$

$$U_{pr2}(t)=V_{pr2}\cos(2\pi f_{pr}t+\varphi_{k3}(t)+\pi\gamma t^2+\varphi_{pr2}),\ 0\leq t\leq T_1,$$

where:

$$V_{pr1}=½V_1*V_{g1},$$

$$V_{pr2}=½V_1*V_{g2},$$

$$f_{pr}=f_1-f_{g1}=f_{g2}-f_1 \text{ – intermediate frequency},$$

$$\varphi_{pr1}=\varphi_1-\varphi_{g1},$$

$$\varphi_{pr2}=\varphi_{g2}-\varphi_1,$$

which represent the complex signals with the combined phase manipulation and linear frequency modulation (F_{MN}-chirp).

These voltages are delivered to two inputs of the correlator 36, the output of which is formed correlation function $R(\tau)$, which is compared to a threshold voltage V_{por} in the threshold block 37.

V_{por} threshold level is exceeded only when the maximum value of the correlation function $R(\tau)$.

Since channel voltage $U_{pr1}(t)$ and $U_{pr2}(t)$ are formed by the same complex F_{MN}-signal $U_4(t)$ taken by the two channels on the same frequency f_1, between the specified channel voltages there is a strong correlation. Correlation function $R(\tau)$ FMN-signals has a distinct main lobe, which exceeds the threshold level V_{por} in the threshold block 37. If the threshold level V_{por} in the threshold block 37 is formed by a constant voltage, which is supplied to the control input of the key 38, opening it. In the initial state, the keys 28 and 38 are always closed.

The voltage $U_{pr}1(t)$ from the output of the amplifier 22 intermediate frequency via a public key 38 is supplied to the first inputs of multiplier products 24 and 25. To the second input of the multiplier 25 is energized from the output of notch filter 26:

$$U_5(t)=V_5\cos(2\pi f_{pr}t-\pi\gamma t^2+\varphi_{pr1}),\ 0\le t\le T_1,$$

the output of the multiplier 25 is formed of a low-frequency voltage:

$$U_{H2}(t)=V_{H2}\cos\varphi_{k3}(t),\ 0\le t\le T_1,$$

where:

$$V_{H2}(t)=½V_1\times V_5,$$

proportional modeling code $M_4(t)$.

This voltage is supplied to the second input of multiplier 24, whose output forms a voltage $U_5(t)$ emitted narrow-band filter 26.

Voltage $U_{H2}(t)$ simultaneously with the output of the filter 27 of the lower frequencies fed to the input of decoder 7, which depending on the code mobile object (dump) generates a signal through item 9 of the ban on the entry of block 8 of the Desk. Unit 8 registration, receiving and memorizing the signal that the flight is made, gives the signal shaper 10, which closes by using item 9 of the ban the input unit 8 registration from the decoder 7 to the minimum time of flight, excluding the false classification of flight in block 8 of the Desk when re-raising the body in the case of material sticking to the wall of the body. In addition, when lifting an empty body sensor 1 pressure produces a signal.

Voltage $U_{pr}1(t)$ simultaneously fed to the input of the amplitude detector 23, the detected video signal which is supplied to the control input of the key 28, opening it. The voltage of the local oscillator 20 via the public key 28 is fed to the input of the frequency meter 29, where the measured carrier frequency f_1 taken F_{MN}-signal.

$$f_1 = fg_1' + f_{pr},$$

where: fg_1' – the frequency of the first local oscillator 20 at a given time.

The measured value of the carrier frequency is fixed by the additional block 32 of the Desk, where both fixed tail number of the movable object (the dump), traveled way, the fuel consumption numbers and the location of control points through which proceeded the dump.

Discussed above the operation of the system corresponds to the case of receiving useful F_{MN}-signals in the main channel at frequency f_1.

If a complex signal (interference) is received by the first image channel at frequency fz_1, the mixers 21 and 34, it is converted to voltage following frequencies:

$$fz_{11}=f_{g1}+\gamma_1 t - fz_1=f_{pr}+\gamma_1 t,$$

$$fz_{12}=f_{g2}+\gamma_1 t - fz_1=3f_{pr}+\gamma_1 t,$$

$$fz_{11}^{(2)}=2f_{g1}+2\gamma_1 t - fz_1,$$

$$fz_{12}^{(2)}=2f_{g2}+2\gamma_1 t - fz_1,$$

where the index of degree refers to second harmonic frequencies of the local oscillators.

However, only the voltage with frequency fz_{11} falls into the bandwidth Δf_1 of the amplifier 22 intermediate frequency. The output voltage of the correlator 36 is zero, the key 38 is not opened and a false signal (interference) taken by the first image channel at frequency fz_1, is suppressed.

For a similar reason suppressed and false signals (interference) taken by the second image channel at frequency fz_2, by the first Raman channel at frequency $f\kappa_1$ and other additional channels.

If complex signals (noise) taken simultaneously by the first and second mirror channels at frequencies f_{31} and f_{32}, the voltage fall within the bandwidth of Δf_1 and Δf_2 of the amplifiers 22 and 35 intermediate frequency. But the key 38 in this case doesn't open. This is due to the fact that different spurious signals (noise) taken at different frequencies f_{31} and f_{32}, so between the two channel voltages there is a weak correlation. In addition, it should be noted that correlation function of noise has a pronounced main lobe, as is the case in complex FMN-signals. The output voltage of the correlator 36 in this case, does not exceed the threshold level V_{por} in the threshold unit 37, the key 38 is not opened and a false signal (noise) taken simultaneously by the first and second mirror channels at frequencies f_{31} and f_{32}, are suppressed.

For a similar reason suppressed and false signals (noise) taken simultaneously by two additional channels.

For transmission of operational parameters of mobile objects (trucks) to the control point using complex F_{MN}-signals with high noise immunity, energy and structural secrecy.

The system provides increased noise immunity and selectivity panoramic receiver. This is achieved by suppressing spurious signals (noise) taken on additional channels, by correlation processing.

Thus, the proposed system is compared with the prototype provides remote control over the implementation timetable for a given route of movement of mobile objects (trucks). This is achieved using control points that have radio-frequency tags on surface acoustic waves.

Fixing the time of passage of mobile objects (trucks) certain checkpoints allows the remote to control the schedule of their movement on a given route and to make timely decisions on the restoration of the rhythm of movement.

The main characteristics of the used RFID tags on surface acoustic waves include the following:

- the average power of the transmitter scanning device – no more than 100 mWt,
- frequency range – 400–420 MHz (900–920 MHz),
- type artificial signal is a complex signal with phase manipulation,
- the number of code combinations is 2^{32}–2^{128},
- dimensions 8×15×5 mm,
- service life - not less than 20 years,

- power consumption is 0 Wt,
- transmission range (distance) is at least 100 m.

The main distinguishing feature of RFID tags on surface waves are small size and lack of power sources. Thereby the functionality of the system expanded.

The system of registration and control of flights moving objects, containing for each controlled movable object sequentially enabled sensor pressure element and a second input coupled with the output of the position sensor body, block coding, second and third inputs connected to the outputs of flow sensor and fuel sensor of the traversed path, respectively, of the phase manipulator. The second input of which is connected to the first output of the high-frequency generator and power amplifier, and the control point consistently included receiving antenna, amplifier high frequency, the first mixer, the second input is via the first local oscillator connected to the output of the search block, the first intermediate frequency amplifier, the second key, the first multiplier, a second input coupled with the output of the low pass filter, narrow band filter, second multiplier, a second input connected to the output of the second key, the lowpass filter and a decoder, the outputs of which are connected by the number of controlled objects, the Executive blocks each of which consists of sequentially connected to the decoder element of the ban, the registration unit of the shaper pulse duration, the output of which is connected to prohibit the entrance element of the ban, connected in series to the output of the amplifier high frequency, a second mixer, the second input is via a second local oscillator connected to the output of the search block, the second amplifier intermediate frequency, the correlator.

The second input of which is connected to the output of the first amplifier intermediate frequency, a threshold unit, the output of which is connected to the second input of the second key, sequentially connected to the second input of the first oscillator, the first key, the second input of which through the amplitude detector connected to the output of the second key, frequency and additional registration unit.

The second, third and fourth inputs of which are connected directly and through the meter fuel consumption and trip meter with the corresponding outputs of the decoder, the frequencies of the local oscillators spaced at twice the value of the intermediate frequency $f_{g2}–f_{g1}=2f_{pr}$ where f_{g2} and f_{g1} frequencies of the first and second local oscillators, respectively, f_{pr} – intermediate frequency, the selected symmetric about the carrier frequency of the main channel of $f_1–f_{g1}=f_{g2}–f_1=f_{pr}$, where f_1 is the carrier frequency and reconstructed synchronously, characterized in that it is provided with a radiofrequency tag, installed at checkpoints along the route of the mobile object which is equipped with a transceiving antenna, a circulator.

CONCLUSIONS

1. At the point of control is established: the receiving antenna, amplifier high frequency, the search block, two local oscillators, two amplifiers, two mixers, two amplifiers of intermediate frequency, amplitude detector, two multiplier, a narrow-band filter, low pass filter, panoramic receiver, decoder, registration block, an element of the ban, the shaper pulse duration, two keys, a correlator, a threshold unit, frequency meter, fuel meter, trip meter and an additional unit.

2. The proposed system relates to the field of technical means of registration and control of flights moving objects and can be used to account for the efficiency of the use of vehicles in an automated warehouse shipment of goods in trade or account the receipt of raw materials, shipment of products in agriculture, during transportation of the grain harvest of crops and bulk cargo.

3. Amplifier high frequency, a phase detector, an adder, the driver code and the timer and to the output of the power amplifier sequentially connected to the circulator, input-output of which is connected with the transmitting-receiving antenna, amplifier high frequency, a phase detector, a second input coupled with the second output of the high-frequency generator and the adder, the second input of which through the shaper code is connected to the timer output, and the output connected to the fourth input unit of coding, each RF tag is made in the form of piezocrystal coated on its surface prokopinsky aluminum interdigital transducer and the reflectors, interdigital transducer of the surface acoustic wave and contains two comb system of electrodes connected by a tire associated with microstrip transceiver antenna, also made on the surface of piezocrystal.

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СИСТЕМА РЕГИСТРАЦИИ И КОНТРОЛЯ РЕЙСОВ ПЕРЕВОЗКИ УРОЖАЯ ЗЕРНОВЫХ ТРАНСПОРТНЫМИ СРЕДСТВАМИ

Алексей Воронков, Иван Роговский

Аннотация. Исследование относится к области технических средств регистрации и контроля рейсов транспортных средств. Технический результат это осуществление контроля за выполнением графика заданного маршрута движения транспортных средств. Система регистрации и контроля рейсов подвижных объектов содержит контролируемые подвижные объекты, радиочастотные метки, содержащие пьезокристалл, микрополосковую приемопередающую антенну, электроды, две шины, и набор отражателей, и пункт контроля. На подвижном

объекте установлены: датчики давления, положения кузова, расхода топлива, пройденного пути, элементы, блок кодирования, передатчик, генератор высокой частоты, фазовый манипулятор, усилитель мощности, приемопередающую антенну, циркулятор, усилитель высокой частоты, фазовый детектор, сумматор, таймер и формирователь кода. На пункте контроля установлены: приемная антенна, усилитель высокой частоты, блок поиска, две гетеродины, два усилителя, два смесителя, два усилителя промежуточной частоты, амплитудный детектор, два перемножителя, узкополосный фильтр, фильтр низких частот, панорамный приемник, дешифратор, блок регистрации, элемент запрета, формирователь длительности импульсов, два ключа, коррелятор, пороговый блок, частотомер, счетчик расхода топлива, счетчик пройденного пути и дополнительный блок регистрации.

Предлагаемая система относится к области технических средств регистрации и контроля рейсов подвижных объектов и может быть использована для учета эффективности применения транспортных средств при автоматическом учете отгрузки продукции в торговле или учете приемки сырья, отгрузки продукции в сельском хозяйстве, при перевозке урожая зерновых сельскохозяйственных культур и сыпучих грузов.

Из известных систем и устройств наиболее близким к предлагаемым является устройство для учета рейсов автосамосвалов, которое и выбрано в качестве прототипа.

Известное устройство обеспечивает повышение помехозащищенности и избирательности панорамного приемника путем подавления ложных сигналов (помех), принимаемых по дополнительным каналам.

Технической задачей является расширение функциональных возможностей системы путем контроля за выполнением графика заданного маршрута движения при регистрации и контроле рейсов перевозки урожая зерновых транспортными средствами.

Ключевые слова: система, регистрация, контроль, рейс, перевозка, урожай, транспортное средство.

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Modeling Technology in Centralized Technical Maintenance of Combine Harvesters

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Summary. In Ukraine and abroad in several sectors of industries, a system of informational support of products lifecycle. Which is based on the standardized representation of product data and assumes brand warranty and post-warranty service. Such technologies typically include control system reliability: the system collects information about failures, scheduled and emergency repairs, as well as about the technical condition detected with special test and diagnostic tools. Similar systems are being introduced in the high technology industries of our country, and in the sphere of technical maintenance of combine harvesters are being introduced separate elements of the system.

Analysis of the possible production situations with an organized enterprise centralized technical maintenance of combine harvesters on the technical condition of the units allows to make a conclusion on what to reduce in-plant losses is possible by reducing errors and detection of aggregates and their distribution.

Selection of artificial neural networks as a mathematical apparatus for the solution to reduce error detection of aggregates and their distribution for technological routes at the centralized maintenance of combine harvesters was justified by the ability of this mathematical tool to the study, analysis and retention results, as well as high adaptation to the solution of the problem.

When building a neural network classifier of the system of technical maintenance of combine harvesters, it is first necessary to determine the complexity of the division of objects into classes. To simplify the problem of classification of the system of technical maintenance of combine harvesters, it is necessary to achieve a linear separation of the objects of study.

Since the task involves more than two classes of system of technical maintenance of combine harvesters for the distribution of units between them, the most efficient method of forming output signals will be a set of vector components. In other words, every possible defect combine harvester will have its output signal, and the presence of a defect or lack of it will say 0 or 1 on the corresponding output. It is very important to achieve close as possible to 0 or 1 values, this requires preprocessing the input data.

Key words: modeling, technology, operation, maintenance, combine harvester.

INTRODUCTION

The use of monitoring was especially effective with acquisition of parts and assigning routes to restore worn parts, as the decision about the technical condition of a part, assembly or assembly of combine harvesters was carried out by computer, which allowed to reduce the influence of subjective factors in the allocation of maintenance fund for trails.

The functions of the majority of computerized control systems for maintenance of combine harvesters in the agricultural repair shops has been expanded by adding the possibility of inventory management and maintenance personnel.

Later, any system, EAM system (from the English. Enterprise Asset Management), which are mainly used to maintain production equipment and machinery in good technical condition. These systems can consistently manage the following processes:

- maintenance,
- manage inventory,
- logistics,
- management of finance, quality and human resources under a unified strategy.

When implementing data systems in the enterprise focus on reducing the cost of maintenance of combine harvesters without compromising the level of reliability, or to improve certain production parameters without increasing costs.

Of EAM-systems for the sphere of technical maintenance of combine harvesters appeared in the integrated management – MRO-system (from the English. Maintenance, Repair and Overhaul), whose main purpose is automation of the planning activities of personnel involved in the maintenance of combine harvesters, and provide them with the necessary resources. In addition, these systems involve functionality for informing and solving a number of problems:

- manage timing of service and cancellation of combine harvesters,
- optimization of structure and size of the Park of combine harvesters,
- storing information about each unit of the convoy of combines, failures in the process of operation, and also maintenance of combine harvesters,
- support the territorial subdivisions of the enterprise, engaged in technical maintenance of combine harvesters, in the framework of a unified strategy.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

In Ukraine and abroad in several sectors of industries, a system of informational support of products lifecycle [1, 2]. Which is based on the standardized representation of product data and assumes brand warranty and post-warranty service [3, 4]. Such technologies typically include control system reliability: the system collects information about failures [5], scheduled and emergency repairs [6], as well as about the technical condition detected with special test and diagnostic tools [7]. Similar systems are being introduced in the high technology industries of our country [8], and in the sphere of technical maintenance of combine harvesters are being introduced separate elements of the system [9].

Currently in control theory the processes of technical maintenance of combine harvesters is popular techniques service-oriented reliability of machinery and equipment – known in the world as RCM (Reliability–centered Maintenance) [10, 11]. According to this method, the maintenance of all units of combine harvesters in immaculate condition not an end in itself, the main thing is the efficiency of the production system as a whole and not the performance of each unit [12, 13].

The goal of RCM is to ensure reliable operation of critical facilities [14], in accordance with their criticality [15], the failure of which will entail significant consequences [16]. In the assessment of impacts takes into account the various risks – disruption of the production plan, compliance with product quality, environmental disaster [17].

The main stages of the RCM analysis [18–20]:

• A – definition of the limits of the system and/or subsystem

• B – define all functions of the system and/or subsystem

• C – identification of functionally significant items (FSI),

• D – define the reasons of failures of functional elements, forecasting of failures and probability of their occurrence,

• E – use problem solving to classify the results of the failure of functionally important elements

• F – select operations for the initial maintenance program combines

• G – in case some operations for maintenance of combine harvesters can not be established, the set of operations is reviewed

• H – create a dynamic programme of technical maintenance of combine harvesters as a result of planned and systematic maintenance by monitoring (systematic monitoring), the collection and analysis of operational data.

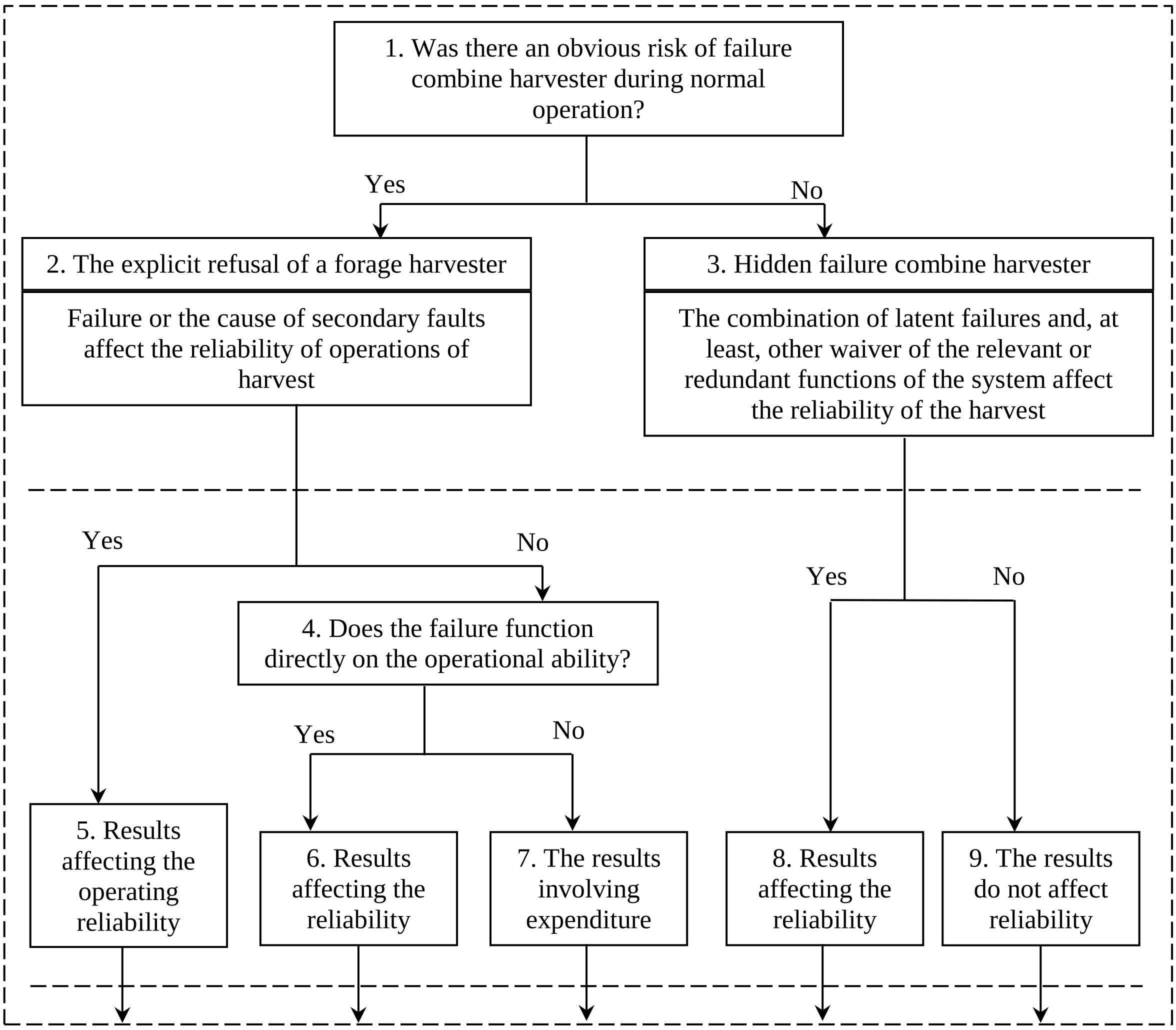

Fig. 1. The decision tree for maintenance of combine harvesters in the system of the RCM

OBJECTIVE

The article presents the analytical statements of methodological approaches to modeling technology in centralized technical maintenance of combine harvesters.

THE MAIN RESULTS OF THE RESEARCH

The first step when using the RCM methodology is to define the limits or boundaries of the subsystem. This means that the system is divided into subsystems of more than simple complexity.

The second step is the identification of functionally significant elements.

The next step involves identifying the causes of failures of functionally important elements and the prediction of the probability of their occurrence. Qualitative methods (based on the collective professional opinion and practical application) and quantitative methods (e.g., method of analysis of the nature and consequences of failures (FMEA–Failure Modeand Effect Analysis) or the method of risk analysis) can be used to identify the causes and results of failure elements. The average time to failure is based on competent analysis diagram cause – failure – effect.

Logical tree of decision-making shown in Fig. 1, is used to classify the results of failures.

Analysis of the nature and consequences of failures (FMEA) and logic tree decision making (FTA–Fault Tree Analysis) faults, can be a successful approaches in solving the tasks related to the prioritization of Troubleshooting in the first place.

If the probability of failure was predictable even during normal system operation, this denial is explicit, otherwise it is classified as hidden.

Centralized maintenance of combine harvesters according to the technical state based on the principles of the routing technology and information technology, a key factor in the question of its effectiveness.

In Fig. 2 presents a breakdown of technological and information support of the centralized maintenance of combine harvesters, which greatly determine its effectiveness.

However, in addition to the technological and information support and the efficiency of centralized maintenance of combine harvesters is also significantly affected by the human factor, which is the origin of the false defect of 1st kind and 2nd kind the pass of the defect at the stage of pre-repair diagnosis.

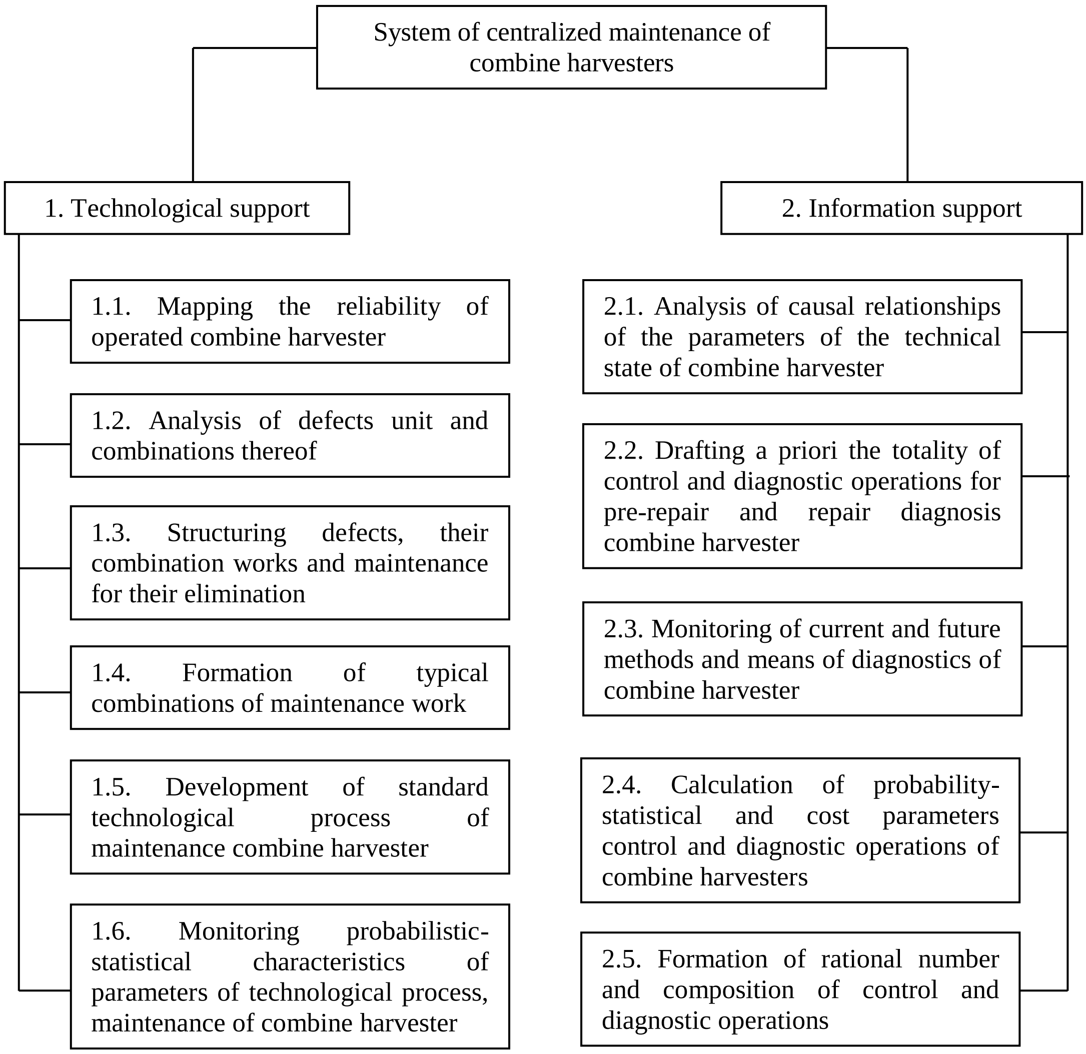

Fig. 2. Components of technological and information support of the centralized maintenance of combine harvesters

In Fig. 3 and Fig. 4 presents the dependence of the recognition errors of the 1st kind from the time of day (depending on shift) taking into account the category and age of the operator-diagnostician, where α is a recognition error of the 1st kind of false defect determination of the operator-diagnostician of repair works, P – working category of the operator-diagnostician, W – the age of the operator-diagnostician, years, L – shift working time pre-repair diagnosis, hour.

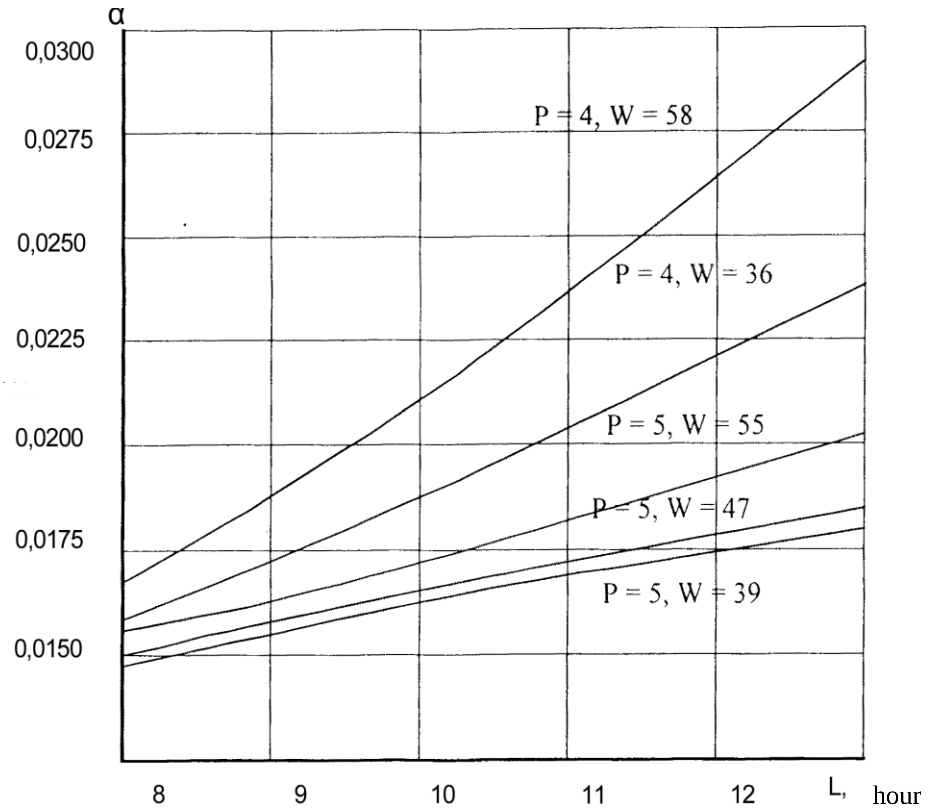

Fig. 3. The dependence of the probabilities of errors of the 1st kind, the first shift from time to time taking into account the category and age of the operator-diagnostician

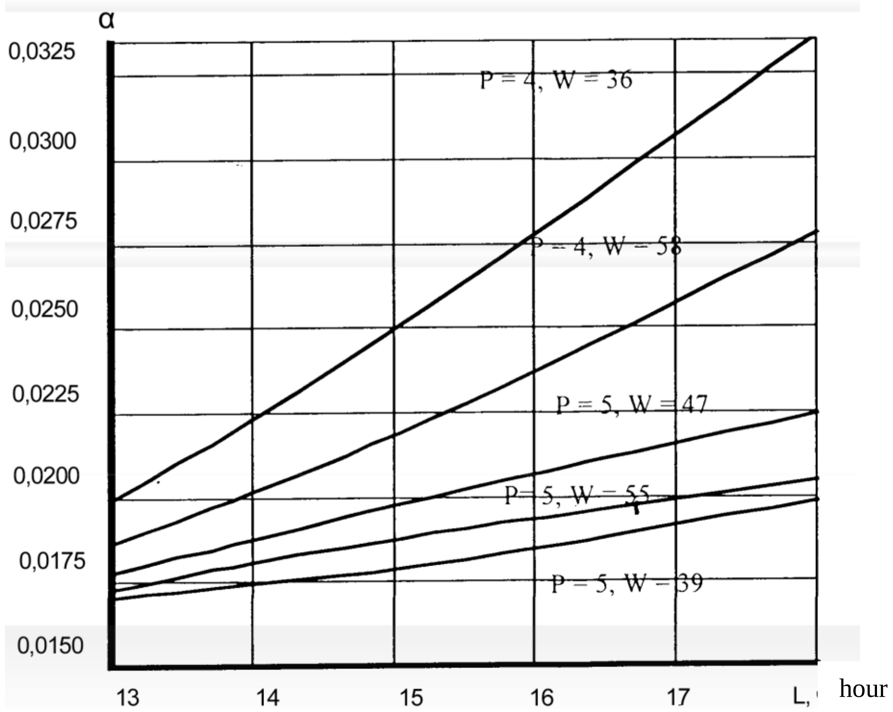

Fig. 4. The dependence of the probabilities of errors of the 1st kind the second shift from time to time, taking into account the category and age of the operator-diagnostician

In Fig. 5 and Fig. 6 are presented the dependence of the recognition errors of the 2nd kind from various factors, where β is the recognition error of the 2nd kind the pass of the defect in the definition of the operator - diagnostician of repair works, P – working category of the operator-diagnostician, W – the age of the operator-diagnostician, years, L – shift working time pre-diagnosis, hour, N – the time unit (mileage), hours.

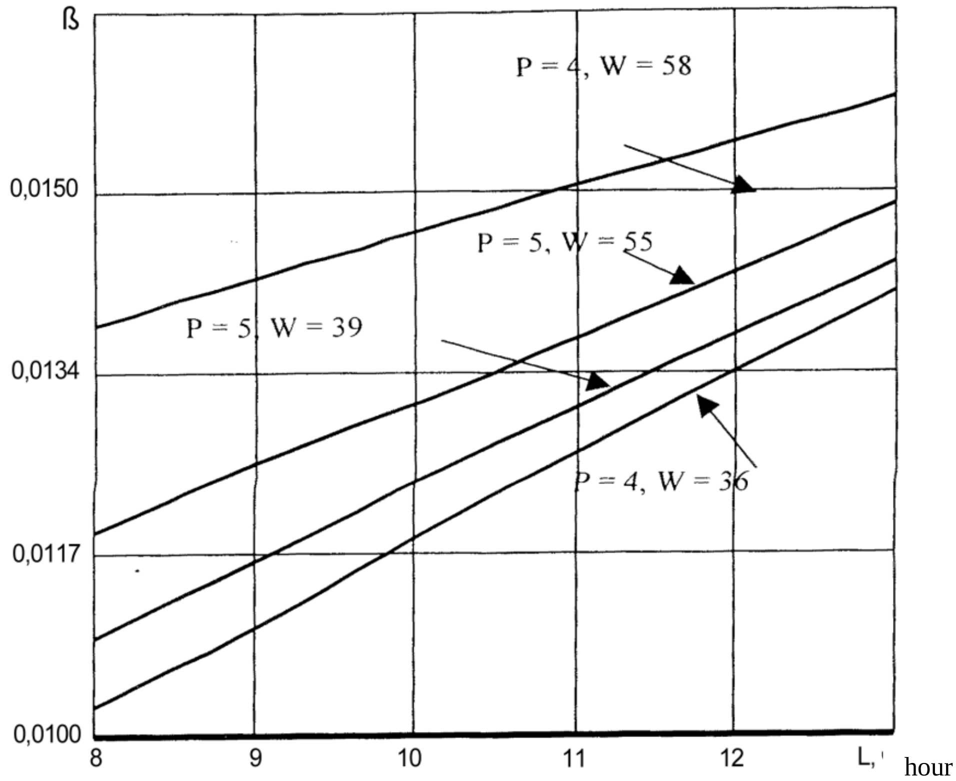

Fig. 5. Dependence of the probability of error of the 2nd kind from the time of the day taking into account the category and age of the operator-diagnostician

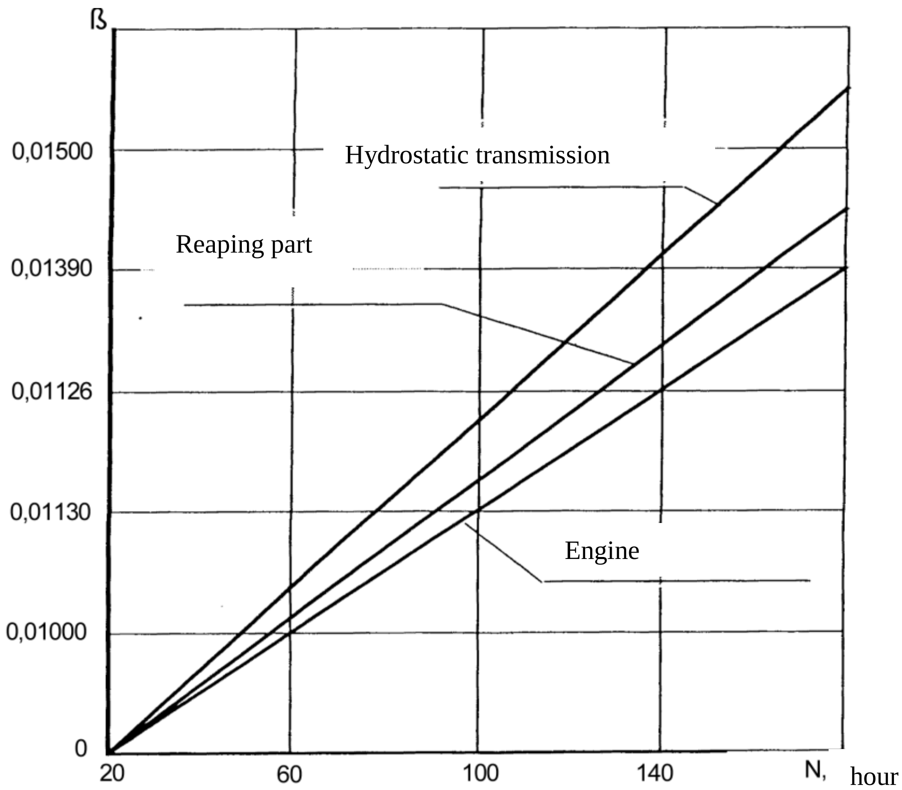

Fig. 6. Dependence of the probability of error of the 2nd kind from the achievements of the unıt

The design process centralized maintenance of combine harvesters is due to the formation of the most efficient production-technical base, providing a significant reduction in internal losses of the agrarian enterprises. In this case external to the plant-specific factors, in accordance with the purpose and objectives of the present study can be considered a force majeure and to exclude them from further analysis.

Taking as a basis the classical form of organization of centralized technical maintenance of combine harvesters, where the process of disassembly $K = \{k: k = \overline{1, K}\}$ of units of combine harvesters is the set of installed in advance of typical combinations of repairs (more complex restoration work), the objective function of the study can be represented as an additive expression, which characterize current production losses:

$$C_{\sum VN} = \sum C_{\sum sh} = (C_{\sum obs} + C_{\sum prop} + C_{\sum dis})\, N_g \rightarrow \min,$$

where: $C_{\sum VN}$ – generalized loss of industrial repair business, UAH,

$C_{\sum sh}$ – loss of production generated by the error distribution of the repaired units to complex recovery operations, UAH,

$C_{\sum obs}$ – the costs of unnecessary work in eliminating erroneously detected defects, UAH,

$C_{\sum prop}$ – costs of executing the conditionally re-work when skipping erroneously detected defects, UAH,

$C_{\sum dis}$ – losses generated by errors in the allocation of the units on the technological routes of repair, hryvnia,

N_g – production program of the enterprise, units/year.

In addition, each set of reconstruction efforts represents some subset of $\{i\}_k$ repair (disassembly and assembly) operations, many $R = \{r: r = \overline{1, R}\}$ which is necessary and sufficient, to eliminate defects of any units among the repaired at this facility.

Component $C_{\sum sh}$ – the objective function (2.1) can be expressed functional:

$$C_{\sum sh} = f\,(C_{ij}, P_{ij}),$$

where C_{ij} – generalized cost of running works on revealing and elimination of the i-th defect the j-th repair of the unit, UAH,

P_{ij} – probability of the event consisting in the occurrence of recognition errors of the i-th defect the j-th repair of the unit.

The probability P_{ij}, taking into account the provisions of probability theory, you can define the following expression:

$$P_{ij} = \alpha_{ij} + \beta_{ij},$$

where a_{ij} – the recognition error of the 1st kind (false failure) of the i-th defect the j-th repair of the unit at the stage of pre-repair diagnosis,

β_{ij} – recognition error of the 2nd kind (omission faults) of the i-th defect the j-th repair of the unit at the stage of pre-repair diagnosis.

Introducing integer variables taking values:

$$\delta_{ij} = \begin{cases} 1 \\ 0 \end{cases},$$

where: 1 – where a_{ij} are the recognition error of the 1st kind (false failure) of the i-th defect the j-th repair of the unit if the i-th missing defect of the j-th repair of the unit is determined to be present,
0 – otherwise (false failure).

$$\mu_{ij} = \begin{cases} 1 \\ 0 \end{cases},$$

where: 1 – if the i-th present the defect of the j-th repair of the unit is defined as missing,
0 – otherwise (skipping faulty).

The probability P_{ij} can be written in expanded form:

$$P_{ij} = \{1-[\delta_{ij}\,(1-\alpha_{ij}) + \eta_{ij}(1-\beta_{ij})]\}.$$

In the general case due to an erroneous determination of the i-th defect the j-th engine, when in reality is no such defect (about fault – α_{ij}) any losses $C_{\sum obs}$. Costs $C_{\sum prop}$ – to conditionally re-run work generated errors β_{ij} resulting from crossing the i-th defect PD of the j-th repair of the unit (omission faults).

Analysis of the possible production situations allows us to represent the functional $C_{\sum VN}$ in the following form:

$$C_{\sum VN} = \sum C_{\sum sh} = (C_{\sum obs} + C_{\sum prop} + C_{\sum dis})\, N_g.$$

Thus, the achievement of the goal – reduction of internal losses in operation of the system of centralized maintenance of combine harvesters is possible only when solving the task of decrease of absolute values of errors at all stages of the production process restore functionality.

A set of methods for data mining object of research called Data Mining. Knowledge produced by these methods usually represent in the form of models.

One such class of models are the artificial neural network is a mathematical model that represents an ordered set of artificial neurons that are linked together in a certain way.

Selection of artificial neural network as a mathematical apparatus for the decision of tasks of recognition of defects the repair of units of the Fund and their distribution for complexes of repairs in a centralized technical maintenance of combine harvesters due to several reasons.

1. With the ability to learn and remember, and by changing the adaptive parameters of the artificial neurons of the network, it is possible to achieve a high degree of accuracy when solving this problem.

2. The use of artificial neural networks allows to avoid the process of accumulation of statistical information for calculation of probabilities of occurrence of defects (as does the method of organization and optimization of technological processes centralized maintenance of combine harvesters on standard combinations of repairs) for the optimal allocation of units for complexes of repairs.

3. Check the adequacy of the constructed on the basis of artificial neural network models is carried out using

test samples that are formed during the experiment the object of research, which ensures a high degree of reliability models.

In the application of artificial neural networks first of all the question of the choice of the network architecture (number of "hidden layers" and the number "artificial neurons" in each of them) for a specific task.

An artificial neuron is a node, artificial neural networks, modeled after the simplified principle of functioning of biological neuron. The first work that laid the theoretical foundations for creation of intelligent devices, is the article by W. Mac-Colloca and V. Pitts.

From a mathematical point of view, an artificial neuron is a function of a single argument – a linear combination of all signals at the input (this function called the activation function), which produces an output signal of the neuron.

In general, the mathematical model of artificial neuron is the weighted adder and has the form:

$$S = \sum_{i=1}^{n} x_i \cdot w_i + x_0 \cdot w_0 = \sum_{i=0}^{n} x_i \cdot w_i,$$

where: S – weighted sum of the input signals of the neuron,

x_i – value at the i-th input neuron,

w_i – weight of the i-th synapse,

n – number of inputs,

x_0 and w_0 – accordingly, the values of the additional input (X_0=1) and its weight.

The output value of the neuron is a function of its state:

$$Y = f(S),$$

where: $f(S)$ – activation function.

All layers of a neural network can be divided into three groups:

• the first layer of neurons in a multilayer neural network is called the input. It usually do not perform any computational operations, since it consists of neurons, which are used for receiving data (signals) and further transmission to the inputs of hidden layer artificial neural networks,

• hidden (intermediate) layers are the key, because often make up a large part of the structure of artificial neural networks,

• the output layer – the result of the operation of the network.

Choice sigmoid as the activation function because it is differentiable on the entire axis x and has a very simple derivative. When using the back-propagation algorithm errors, it accelerates the learning process of the network.

The output value of the neuron with sigmoidal activation functions, takes the following form:

$$Y = f(S) = \frac{1}{1+e^{-\alpha S}}.$$

In Fig. 7 graphically shows the model of an artificial neuron, where the number of input signals is denoted by X. Here multiple signals x_1, x_2, x_3, ..., x_j at the corresponding inputs (in the aggregate denoted by the vector X) have their weights (which reflect the strength of synaptic connections and their set is denoted by the vector W). The product of the signals and the corresponding weights is supplied to the summing unit, which algebraically adds the inputs.

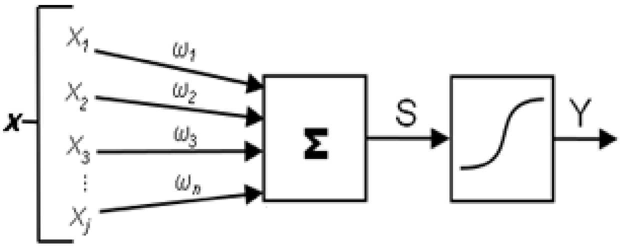

Fig. 7. Model of artificial neuron

The resulting sum, the value obtained is the argument of the activation function, which generates the output value Y.

Based on theoretical elaborations Hecht-Nielsen the question of the optimal number of hidden layers, as well as from the analysis of the practical applicability of artificial neural networks for different classification tasks, we can conclude that using more than two hidden layers in the network design are often inappropriate.

Formula, which is a consequence of the theorem of Arnold–Kolmogorov–Hecht-Nielsen, it is possible to calculate the required number of neurons for the hidden layer.

First there is the assessment of necessary number of synaptic weights when:

$$L = \frac{N_w}{N_x+N_y}.$$

However, as the practice of constructing artificial neural networks in this approach, one can argue that the number of neurons in the hidden layer was optimally matched to the task, in addition, usually the result is a large scale interval, which is the value of L.

Therefore, a consequence of the theorem of Arnold–Kolmogorov–Hecht-Nielsen will be used only to determine the upper limit values of the neurons (R) in the hidden layer. Dropping the lower bound of the interval, and equating the remaining N_w to the upper boundary and substituting in the formula, we get:

$$\frac{N_y \cdot Q}{1 + log_2 Q} \le N_w \le N_y \cdot \left(\frac{Q}{N_x} + 1\right) \cdot \\ \cdot \left(N_x + N_y + 1\right) + N_y.$$

where: N_y – number of neurons in the output layer,

Q – the number of values of the training sample,

N_w – the required number of synaptic weights,

N_x – number of neurons in the input layer.

After that, the number of neurons in the hidden layer will be determined by the formula:

$$R = \frac{N_y \cdot \left(\frac{Q}{N_x}+1\right) \cdot \left(N_x+N_y+1\right)+N_y}{N_x+N_y}.$$

Further, R is used as the upper limit to which the number of neurons will grow until it reaches the optimal values. As the experience of building models based on artificial neural networks, capacity of neurons in the hidden layer over the resulting limit R in most cases is impractical.

Technical condition of each of a plurality $O=\{O_i: i = 1, 2, 3, ..., M\}$ received at the repair Fund units of combine harvesters is characterized by a set of controllable parameters whose values are determined at the stage of pre-repair diagnosis with centralized technical maintenance of combine harvesters. Certain combinations of these parameters and their values imply the presence or absence of defects of the units.

We introduce the notion of the ability to generalization ability is acquired in the process of learning property of a neural network to give correct results for any new input combinations that did not participate in the learning process.

If an artificial neural network give a high percentage of correct results not only for training samples but also new, previously unknown examples, it is considered that it has acquired the ability to generalize.

In the case where a high percentage of correct results are ensured only for training samples and test samples is often wrong, it can be concluded that neural networks do not have the ability to generalize.

Let the number of complexes and rehabilitation works in the centralized technical maintenance of combine harvesters is known in advance the value of Z, and X is a combination of controlled parameters of the units, coming in repair fond. Deviations in parameter values from nominal indicate the presence of defects in the units Y. In this case, the task of neural network classification is reduced to the construction of the algorithm Θ, where the initial stage, the classification $\Theta : X \rightarrow Y$, based on acquired in the learning process, the ability of neural networks to generalize, and further there is a distribution of the aggregate units in the complex of restoration work on from the identified combinations of defects: $\Theta : X \rightarrow Y$, where $y \in Y$ and $y \in Z$.

When building a neural network classifier of the system of technical maintenance of combine harvesters, it is first necessary to determine the complexity of the division of objects into classes. To simplify the problem of classification of the system of technical maintenance of combine harvesters, it is necessary to achieve a linear separation of the objects of study.

Since the task involves more than two classes of system of technical maintenance of combine harvesters for the distribution of units between them, the most efficient method of forming output signals will be a set of vector components. In other words, every possible defect combine harvester will have its output signal, and the presence of a defect or lack of it will say 0 or 1 on the corresponding output. It is very important to achieve close as possible to 0 or 1 values, this requires preprocessing the input data.

CONCLUSIONS

1. Thus, the achievement of the goal – reduction of internal losses in operation of the system of centralized maintenance of combine harvesters is possible only when solving the task of decrease of absolute values of errors at all stages of the production process restore functionality.

2. Further, R is used as the upper limit to which the number of neurons will grow until it reaches the optimal values. As the experience of building models based on artificial neural networks, capacity of neurons in the hidden layer over the resulting limit R in most cases is impractical.

3. Since the task involves more than two classes of system of technical maintenance of combine harvesters for the distribution of units between them, the most efficient method of forming output signals will be a set of vector components. In other words, every possible defect combine harvester will have its output signal, and the presence of a defect or lack of it will say 0 or 1 on the corresponding output. It is very important to achieve close as possible to 0 or 1 values, this requires preprocessing the input data.

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МОДЕЛИРОВАНИЕ ТЕХНОЛОГИИ ВЫПОЛНЕНИЯ РАБОТ ПРИ ЦЕНТРАЛИЗОВАННОМ ТЕХНИЧЕСКОМ ОБСЛУЖИВАНИИ ЗЕРНОУБОРОЧНЫХ КОМБАЙНОВ

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Аннотация. В Украине и за рубежом в ряде отраслей промышленностей применяется система информационной поддержки жизненного цикла изделия. В основе которой лежит стандартизированное представление данных об изделии и предполагается фирменное сервисное гарантийное и постгарантийное обслуживание. Подобные технологии, как правило, включают в себя систему управления надежностью: осуществляется сбор сведений об отказах, плановых и аварийных ремонтах, а также о техническом состоянии выявляемых с помощью специальных контрольно-диагностических средств. Подобные системы активно внедряются в наукоемких отраслях промышленности нашей страны, а в сфере технического обслуживания зерноуборочных комбайнов внедряются отдельные элементы данной системы.

Анализ возможных производственных ситуаций при организованном на предприятии централизованном техническом обслуживании зерноуборочных комбайнов по техническому состоянию агрегатов позволяет сделать вывод о том, что добиться снижения внутрипроизводственных потерь можно при снижении возникающих ошибок распознавания дефектов агрегатов и их распределения.

Выбор искусственных нейронных сетей в качестве математического аппарата для решения задачи снижения ошибок распознавания дефектов агрегатов и их распределения по технологическим маршрутам при централизованном техническом обслуживании зерноуборочных комбайнов обоснован способностью данного математического аппарата к обучения, анализу и запоминанию результатов, а также высокой адаптации под решение поставленной задачи.

При построении нейросетевого классификатора системы технического обслуживании зерноуборочных комбайнов, прежде всего, необходимо определить сложность разделения объектов на классы. Для упрощения задачи

классификации системы технического обслуживании зерноуборочных комбайнов, следует добиться линейного разделения объектов исследования.
Так как поставленная задача подразумевает более двух классов системы технического обслуживании зерноуборочных комбайнов для распределения агрегатов между ними, то наиболее рациональным способом формирования выходных сигналов будет являться совокупность компонентов вектора. Иными словами, каждый возможный дефект зерноуборочных комбайнов будет иметь свой выходной сигнал, а о наличии дефекта или его отсутствии будет говорить 0 или 1 на соответствующем выходе. При этом очень важно добиться как можно более близких к 0 или 1 значений, для этого необходимо провести предварительную обработку входных данных.
Ключевые слова: моделирование, технология, работа, техническое обслуживание, зерноуборочный комбайн.

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Choice of Model Class and Method of Modeling the Resilience of Agricultural Machinery

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Summary. In the article the requirements to the mathematical model of the process of technical operation of agricultural machines selected by model class and the method of modeling. It is possible to develop the formalized description of the process of recovery of agricultural machinery, is investigated to justify the form of performance indicators and the optimality criterion is to implement the mathematical formulation of specific problems of the study.

On the basis of a formalized description of the mathematical model of process of technical exploitation of the object of agricultural machinery in the regenerative recovery process. The analytical dependence of the parameters on the parameters of the maintenance system for the case of single-stage periodic monitoring of performance. The obtained expressions to calculate asymptotic estimates of the selected performance indicators with exponential distributions of uptime object of agricultural machinery and time independent manifestations of failure in operation.

Stochastic models are usually classified as random processes and can represent processes with discrete States (set of States finite or counted) and continuous set of States (set of States is in one-one correspondence to the set of points of a numerical interval), discrete time (random sequence) and with continuous time. Currently being developed by a large number of stochastic models used to describe the operation of complex technical systems, the main classes which are: logical, linear, Gaussian, automatic, aggregation, Markov, semi-Markov, regenerative, multi-component models in the form of systems of mass service.

Examines the case of multi-stage maintenance subject to the full control of the technical condition of objects of agricultural machinery.

Key words: modeling, technology, model, method, restoration, agricultural machine.

INTRODUCTION

Stochastic models are usually classified as random processes and can represent processes with discrete States (set of States finite or counted) and continuous set of States (set of States is in one-one correspondence to the set of points of a numerical interval), discrete time (random sequence) and with continuous time [1]. Currently being developed by a large number of stochastic models used to describe the operation of complex technical systems, the main classes which are [2]: logical, linear, gaussy, automatic, aggregation, Markov, nephwrack, regenerative, multi-component models in the form of systems of mass service.

In the framework of probabilistic Boolean model assumes that the functioning of a technical system can be represented in the form of series-parallel circuits with input and output, as well as a specified number of intermediate nodes (contacts), isolation of which is interpreted as the event that is modeled. It is clear that such a simple interpretation of the functioning of technical systems does not allow the use of probabilistic logic for the adequate quantitative description of the process of technical operation of objects. This class of models generally used for the simplified probabilistic calculation of reliability of technical systems are investigated in [3]. Thus, a Boolean probabilistic model satisfies only the requirements of 3.4.

The difficulty with linear [4] and gaussy [5] probabilistic models to describe the process of technical operation of agricultural machines is the complexity of the justification of a linear relationship between the parameters describing the operating rules and indicators of its effectiveness, as well as in the severity of the agent linear transformation (the transfer function). It is obvious that the application of these classes of models allows to satisfy requirements 1 and 3 [6].

Thus, using the logical, linear and gaussy probabilistic models the process of functioning adequately described only for a limited range of technical systems, subject to stringent laws that are appropriate to the models assumptions regarding the probabilistic nature of random processes is considered [7].

Automatic statistical and probabilistic models are based on the concept of technical systems, which are modeled as finite state machines (units) [8]. Functioning of real technical systems in the framework of automatic (statistical) model is described by the transition operator and the operators, and outputs, as well as diagrams of the combinations, characterized by the combination of contact sets and operators combinations. Probabilistic automata (units), typically used to assess complex technical systems with unreliable elements, systems with variable time-random structure and systems, structure and status of which at some point time not known and cannot be described only in terms of probability theory [9]. Like any universal system, aggregative approach leads to an overload of the model, which is a significant drawback for the system, consisting of hundreds of elements, which is the system of exploitation of the park. In addition, a model is built as a modular system loses visibility [10], which can be a significant barrier to its active use. Thus, the use of these classes of models allows to satisfy the requirements 1 and 2 [11].

Research has shown [12] that for real stochastic systems that change their state abruptly, characterized by a finite number of possible transitions determined by a finite number of random factors changing the state of the system. Each of these factors is characterized by a certain random time effects, that depends, as a rule, from the state of the system. In this regard, many stochastic models of systems are highlighted Markov, nephwrack and regenerating system [13].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The process of docum functioning of technical systems S in a Markov model describes a Markov process $S(t)$, which can be represented as a random process with discrete or continuous states, discrete or continuous time [14]. In practice, to describe the process of functioning of real technical systems, typically use a Markov process (MP) FPS with discrete and continuous time [15]. In this case, it is assumed that the simulated system S can be in finite set of states $E=\{e_1,e_2,\ldots,e_N\}$, where is the number of all possible states. The process of evolution of the system S by changing its states $S(T)=S_n$ due to the transition from one state e_i to another e_j [16]. Markov process is determined Markovsky property that is created by the independence of the transition probabilities of the system from a given state from all the previous evolution of the system before falling into this state and independent of the distributions of length of stay in the state Θ_n from all preceding this condition of the system evolution [17]. However, the strong restrictive assumption in Markov models is the assumption about exponential distribution of length of stay of the simulated system Θ_n, in any of model states $E=\{e_1,e_2,\ldots,e_N\}$ [18].

Studies have shown [19], the formal description of most technical systems such that knowledge of any previous history of this system does not significantly affect its state in the future, in connection with the class of Markov systems have been widely used for the mathematical description of processes of functioning of different technical systems. This is also due to the high visibility of the Markov model, the adoption of a relatively small number of assumptions, simplicity of the mathematical apparatus of analysis.

However, the condition exponentialist the distributions of the residence time in model States which provides the effect of lack pclady Markov process, in practical tasks of technical operation, which involves performing various operations and repair, is rarely performed. Primarily, this is due to the presence in the process of operation States of the planned checks and controls, various types of maintenance etc. with specified time and nawaseri flow that takes the system from state to state [20]. Thus, the Markov model satisfies the requirements 1, 3, 4, but does not satisfy the requirement 2 that do not adequately describe the real process of technical operation of agricultural machinery within a Markov probabilistic model.

Probabilistic model is characterized by the fact that it is free of restrictions on the law of distribution of residence time in model states [21]. In this regard, the class napumsaka systems is more suitable to describe the operating rules of real complex technical systems, in which change of state occurs under the action of random factors, accessible to observation and mathematical description. NMZ insufcient effective mathematical apparatus for the analysis and represent an immediate generalization of Markov chains to the case of arbitrary distributions of time spent in states [22]. Along with the fact nephwrack models require quite a considerable statistical material to adequately specify the distributions of the residence time in model states, which is not always possible and leads to significant errors due to subjective assumptions of the researcher about FRC stay in the states [23].

In the vast number of problems of applied nature of the use of the Markov approximation yields solutions with an accuracy of within the accuracy of the input data. Modeling of PTE of complex technical systems using Markov processes (napumsaka) recovery have shown that in most cases, this error is limited to 3...5%. Therefore, a class napumsaka models meets the requirements 1, 2, 4 due to requirements 3, 6.

OBJECTIVE

The process of technical exploitation of fleet is a complex interconnected stochastic process of functioning of separate objects of agricultural machinery in the vessel. Such a system can be described by classes of regenerating, multi-component stochastic systems and queueing systems.

THE MAIN RESULTS OF THE RESEARCH

Class of multicomponent systems stands out from a wide range of stochastic systems because the evolution of such a system is set napumsaka model that adequately describes it, and yet sufficiently affordable and efficient in the analysis of the operation [79]. In this case l^k, it $k=\overline{1,L}$ is assumed that the system which is investigated, consists of a finite number of objects, each of which can be in a finite number of N_k, $k=\overline{1,N_k}$ possible states. The functioning of each object l^k is described by semi-Markov process $(l^k{}_n,\Theta^k{}_n;n\geq 0)$ in a finite phase space of states (FPS) $E^k=\overline{1,N}$. This assumes that each object operates independently of the other objects in the system. Multicomponent system is set to a finite collection of independent napumsaka (NM) $(l^k{}_n,\Theta^k{}_n;n\geq 0)$ updates with the ultimate FPS $E^k=\overline{1,N}$.

This class of systems has an effective unit of analysis that when using the NM model of the process of technical operation of a single object of agricultural machinery as part of the fleet of vessels makes it relatively easy to estimate the desired characteristics of the Park of the same objects of agricultural machinery. Class of multicomponent systems satisfies the requirements 1, 3, but not entirely consistent with requirement 2 and does not satisfy the requirement 4.

From the assumption of independence of the functioning of the individual objects are deprived of the models constructed in the form of systems of mass service (SMO). The functioning of a complex system describes the SMO is represented as a certain set of service channels with a particular service mechanism that receives a stream of service requests with a given discipline of the queue. A characteristic problem of the theory of mass service is the relationship between the nature of stream applications, the performance of individual channels and the efficiency of the service.

Currently, the analytical solution of the characteristics for SMO with a simple discipline turns and elemental structure, as a rule, is characterized by the Markov properties of the process under study. Thus, the class of stochastic models in the form of the CFR satisfies the requirements of 1.4 but not fully satisfies requirements 2, 3.

The other broad class of models are models that use regenerative stochastic processes. These models are based on the assumption that the examined technical object during operation with a probability in finite time (cycle duration) is some condition (time of regeneration), in which all previous history ceases to affect its further evolution. The functioning of a technical object describes a regenerative process with a finite set of regeneration cycles, each of which consists of a finite multiple of the number of phases (States) in the ultimate FPS , and not necessarily to the process in each first cycle went through all the phases. The cyclical nature of these random processes facilitates the study of their asymptotic properties, which is consistent with the purpose of this study. Furthermore, unlike Markov models do not put forward strict restrictions on the distribution of the residence time in model States. But the idea of PTE in the form of a regenerative process involves that the stream of recoveries is recurrentis.

This class of models has an effective unit of analysis, that the representation of the process of technical operation of complex technical systems in the form of regenerating makes it easy to determine stationary characteristics for a fleet of similar objects SK. The class of models regenerative processes satisfy the requirements 1 - 4 and does not meet the requirements 5, 7.

The results of the analysis of stochastic models of functioning of objects of operation, are used to create mathematical models of PTE of complex technical systems, allow you to choose the class of models that use regenerative repair processes. The use of models of this type allows to solve successfully the problem of choice of rational strategies and repair, and in some cases can be solved the problem of optimization.

Definition of probability characteristics of stochastic models can be handled in various methods of simulation of random processes. Distinguish between analytical, simulation and combined methods.

Analytical models are usually used in cases when the number of parameters characterizing the studied process, is not very big, any dependence between them is not very difficult. They allow using algebraic, differential, difference and other equations to establish the formulae of dependence between the main determinants of the studied process and the indicators of its efficiency. They are also convenient and the fact that their construction and study, you can apply different mathematical methods and techniques.

Methods of analytical and stochastic analysis provide the formulation and solution of systems of differential equations for the probabilities of possible States of PTE, which allows to satisfy the requirements of consistency and reliability, due to the possibility of obtaining the distributions of the desired characteristics of the model and the values of the desired performance indicators according to the results of the calculations can be obtained with a single value of confidence and zero – confidence interval. In addition, this method provides controllability results and low complexity computing.

In probability theory differential equations are made taking into account the state of each object operation and its characteristics that technical systems large scale (Park courts or its components) leads to a sharp increase in the number of equations. As a consequence, the model loses clarity and does not meet the requirements regarding ease of creation and control of simulation results.

A common disadvantage of the analog-to-stochastic and theoretical mornong modelling techniques is the inability to develop on their basis a universal adaptive model of PTE of objects SK, due to the fact that any changes in the composition of the state space the operating rules or the distribution functions of time (FRC) stay in the model state leads to the need to re-output all required analytical dependences for the evaluation of performance indicators. That is actually to create a new model.

Dynamics of average method allows for a large number of possible states docum complex technical system (the functioning of the individual elements is described by the processes of recovery in the final FFS) to evaluate average characteristics of the system. It can be used to circumvent the computational difficulties associated with the joint decision of a large number of differential or algebraic equations for finding the probabilities of the States of a complex system which is investigated. The essence of the dynamics of average method is that during the process of mathematical analysis of complex multicomponent systems are considered the state of the system as a whole and its separate elements. This is based on the assumption of independence of event streams, sending part of the system from state to state, from the number of items in this and other States. It is obvious that this assumption can be done if the individual elements of the system operate independently of one another, or options FRCH stay a separate element of the system in any of model States before moving to the adjacent set taking into account the interactions (dependencies) of processes of functioning of the remaining elements of a complex system. In addition, this assumption can be relaxed through the use of the principle quaeso, as well as by taking into account the replenishment of the total number of states. Thus, the main disadvantage of the dynamics of average method is the disparity between the requirements of consistency.

Along with analytical simulation methods are the most common tools of control theory and operations research for the management efficiency of complex systems [114]. Simulation is the representation of the dynamic behavior of docum system by moving it from one state to another in accordance with clearly defined operating rules. The changes of system state occur either continuously or at discrete points in time, that is the basic concept of the simulation system that is seen is a reflection of the change of its States over time. An important advantage of simulation is the ability to lock the intermediate values of different parameters during simulation just as it occurs during the operation of the real system. Simulation models typically are used for design, analysis and evaluation of the functioning of complex systems. The simulation is based on the concept of building an iterative model in which the model changes by adding new or eliminating some of its elements and (or) interrelationships between them. This assumes that the system can be described in terms that are understandable to a computing system.

Deterministic simulation (detailed) model, based on the development of deterministic counterpart of the process is investigated. But due to the fact that the process of technical operation of objects of SK is categorized as stochastic, they can not be used to create a mathematical model of PTE of objects SK.

In statistical models relatively simply count discrete, continuous, logical parameters and their nonlinear relationships, and a variety of random factors and to influence the process of technical operation, which allows to meet the requirements of adaptability, versatility and ease of creating a model that is being developed. Statistical modeling method provides for a multiple run of a simulation model for a set of statistics that allows to satisfy also the requirements of accuracy and consistency of simulation results. Until recently, the main disadvantage of statistical models considered the need for time-consuming to conduct the simulation experiments (large volume of calculations) to obtain reliable characteristics of the studied process. But the emergence in recent high-speed personal computers has made this drawback is immaterial.

A common drawback of simulation models is the lack of control results due to the fact that the simulation model is built on the principle of “black box”.

Combined modeling methods combine the advantages of statistical and analytical modeling.

So when “direct modeling” is a preliminary calculation results for many conditions statistical method, and then constructed tables or approximating functions for quick calculations and regression models models method of group accounting of arguments and things. These models meet the requirements of the low complexity of the calculations. At the time of creation of the model the reliability of the results corresponds to the reliability of the statistical model. However, the change of conditions, methods of operation, that is, the emergence of a new source of data leads to unreliable results of calculation and requires significant expenses for revision regression models by collecting new statistics and its approximation that does not satisfy the requirements of adaptability. In addition, aproximaci dependence usually does not have a clear physical meaning, so the model does not satisfy the requirements regarding the verifiability of the results and consistency.

Analytical and statistical models represent a set of methods of accelerated modeling, based on a combination of analytical and statistical methods.

Analytical and statistical methods based on the method of small parameter among the output characteristics of the operation process that is simulated, is determined by TA, which can be selected as a small parameter ε. Then using various analytical methods, the desired characteristics of the process (performance indicators) are presented in the form of a series in powers of ε, the coefficients of this series are interpreted as the mathematical expectation of functional from some auxiliary random processes and are defined using the method of statistical modeling. Basically, this method developed for evaluation of reliability of highly reliable systems. Obviously, when developing mathematical models of PTE of objects of SK these models do not satisfy the requirements of adaptability and versatility, it does not fully satisfy the requirements of verifiability of the results and ease of creation.

The results of the analysis of the methods used for the simulation of the operation of the CCC with the selected class of stochastic mathematical models allow to choose the methods of analytical modeling and midrange.

As shown above, the actual scientific problem is the rationale for the selection of one of the variants of the organization of the recovery system on the basis of appropriate assessment and prediction of changes of indicators of technical and economic efficiency of operation of the machine, including taking into account the possible implementation and operation of advanced means of monitoring and diagnosing.

It is obvious that the solution of specified research tasks should be based on appropriate mathematical models (MM) process and repair of objects of SK, because the practical application of various options for system recovery due to the risk of material losses. Thus the mathematical model is developed (applied) must take into account how the organization (construction) of the recovery system with a variety of options, and the application of various tools for monitoring and diagnosing.

In the study of the effectiveness of the recovery system as the object of SK taken constructively-removable units (assembly, unit, module) machines.

Use the approach outlined and present formally the task of estimation and forecasting of technical and economic efficiency of implementation of different options for system recovery machine IC to justify their introduction into a system that reflects the relationship of the main elements of the decision-making process and the sequence of formation of the partial tasks:

$$\langle U,\ \Lambda,\ H,\ G,\ Y,\ \Psi,\ W,\ K,\ \Im,\ \Theta \rangle,$$

where: U – set of variants of the organization of the recovery process, Λ – the set of values of certain Λ_F and uncertain Λ_E factors influencing the process of technical operation (PTE) of objects of SK, G – number of possible outcomes of PTE of objects SK, Y – vector of characteristics of the result, i.e. numeric expression of result objects PTE-IC, H – model, i.e. the mapping that compliance with the many options for organizing the recovery process of U and factors Λ many results Y(G) W – an indicator of technical and economic efficiency, Ψ – operator matching result, K – criterion of efficiency, $\mathfrak{I}$ – model the properties of the decision maker (DM) on the elements of the set $V=\{U,\Lambda,G,Y,W,K\}$, Θ – information about the operating rules of objects of SK that is available.

It is known, the system of vessels typical of various types of works, preparations and repairs to maintain given equal reliability and usability:

– regular maintenance,

– scheduled (average and capital) repairs of objects of SK,

– unscheduled repairs related to the elimination of identified failures and malfunctions,

– work on periodic control and diagnostics of objects of SK and the like.

Thus, operation of objects of SK represents a succession of stages such as use, maintenance, repair, and storage. expectations are falling in each of these stages. Therefore, we represent formally the process and repair the machine in the process of changing various process States technical operation in accordance with the adopted strategy strategy and the exploitation that it corresponds to.

Under the state process and R cars will understand the appropriate stages of technical operations, characterized by the impact machine of the personnel who performs maintenance or the external environment. The structure and nature of the process and repair, and thus the state space of the process of technical operation, determined by the accepted strategy and repair, which generally represents a set of principles and rules that provide a predetermined control of the process of technical operation.

For a formal description, let us characterize the operation of the object SK two interrelated processes: an objective process of change of its technical condition and the subjective process of its operation.

Due to the fact that FS machine consists of a finite number of elements and can be in a finite number of different states, differing technical conditions, as well as operations on the elements (control during maintenance, rehabilitation, etc.), describe the process of technical operation of objects of SK a finite set E states e_i, created by breaking down $D \subseteq E$, where $i \in I$, and items I the identified elements of the breakdown D. We assume that the state e_i some are assigned in accordance with the emerging state of the object SK ω_k and the process of technical exploitation of mashine $e(t)$ created by the sequential change of states of PTE e_i. That is, assume that $e(t)$ is some reflection of the process $\omega(t)$:

$$e_i(\Omega): \Omega \to \omega_k(E).$$

In turn, the object of the SC, introduced in the state PTE, act of external influence in this state so:

$$\omega_k(E): E \to e_i(\Omega).$$

That is, we assume that the technical condition of objects of SK cause the appropriate status of PTE. In turn, the technical condition of objects of SK arise due to the influence of external conditions defined by the corresponding condition of PTE.

If the object SK is characterized by a finite set of states $n+1$: $E=\{e_0, e_1, \ldots, e_i, \ldots, e_n\}$, where e_0 – the state of health of the object, e_n – a state of complete denial, you can select a subset of the States corresponding to various levels of efficiency of object SK. In this case $e_0 \in A_1, e_n \in A_3$, where A_1 – a subset of states, which corresponds to maximum efficiency, A_3 – a subset of States of a complete failure, which is equivalent to the minimum performance level. Many working conditions $e_i \in A_2$, $i=1,2,\ldots,n-2,n-1$.

Random events of type $e_j[\omega_k(e_i)]$, $i \le j$ define the transitions between process States technical operation is determined by the particular operating conditions. The sequence of transitions e_{ij} before the return of the object in a state e_0 determines the probability space of the process $\omega(t)$. Not necessarily that the process $\omega(t)$ in each cycle passes through all the States, that is neviluna that $P\{e_i = 0\} > 0$. If θ_i – nonnegative random variables, in the General case are dependent on each other that determine the residence time of the object in the state e_i, that $\omega(t)$ it's hit value:

$$\xi_n = \sum_{k=1}^{n} \theta_k, \; n \ge 1, \; T_0 = 0, \; e_{n+1} = e_0,$$

there is a waiting time to recovery (duration of cycle) process $\omega(t)$, determined by its possible trajectories.

Under the cycle duration ξ we understand an ordered pair $\{\xi, z(t)\}$, where ξ – valid non-negative integer, and $z(t)$ – function is defined $0 \le t < \xi$ when the value of n-dimensional euclidean space R_n. Suppose that the set of all possible cycles specified probability measure such that:

$$P\{\xi = 0\} < 1, \quad P\{\xi < \infty\} = 1, \tag{1}$$

and for all $t \ge 0$ a certain probability:

$$P_A(t) = P\{z(t) \in A; \xi > t\}, \; A \in R_n. \tag{2}$$

Suppose also that, in accordance with a given probabilistic measure is chosen an infinite set of mutually independent cycles $\{\xi_i, z_i(t)\}$ $(i=1,2,\ldots)$. In this case, using the values $\xi_1, \xi_2, \ldots$ can create the recovery process such that:

$$F_\xi(t) = P\{\xi \le t\} = 1 - P\{z(t) \in R_n; \xi < t\}. \qquad (3)$$

In the General case, the values $\xi_1, \xi_2, \ldots$ may be different from each other distributions. But the greatest practical importance is the case when the values ξ_i, $i = 1, 2, \ldots$ are equally distributed according to the law $F_\xi(t)$. Then the sequence $\{\xi_i\}, \forall\, i = 1, 2, 3, \ldots$ creates a recurrent stream (stream recovery), the time n of recovery is equal:

$$X_n = \xi_1 + \ldots + \xi_n. \qquad (4)$$

In this case, random process $\xi(t)\,(t > 0)$ specifies the number of events in the stream restoration incurred prior to the date t. Given (1)...(3) determine if $t \ge 0$ random process:

$$Z(t) = z_{\xi(t)+1} \cdot \left(t - X_{\xi(t)}\right).$$

Process $Z(t)$ is a regenerative stochastic process and the moments $\{X_i\}_{i=0}^{\infty}$ – the point of the regeneration process. It is proved that the mathematical expectation $M(\xi_i)$ time to recovery (MTTR) makes sense for any finite interval $T = [t_1, t_2]$ the number of restore points X_n, which fall into T, finite with probability one and is a definite value N. It is proved that the random variable N at large t asymptotically normally distributed with mathematical expectation and variance, respectively:

$$M[N(t)] = 1/M[\psi(t)],$$

$$\sigma[N(t)]^2 = t \cdot \sigma[\psi(t)]^2 / M[\psi(t)]^3.$$

Since the transition to exploitation $e_i \to e_0$, $i = l, l+1, \ldots, n$, are the moments of regeneration process $Z(t) \equiv \omega(t)$, and the random duration between the moments of recovery form the recovery process, to assess the effectiveness of the recovery system, it is sufficient to have only one cycle of recovery of a random process $\omega(t)$, we characterize the mathematical expectation of the regeneration $M(\xi_i)$ and the number of updates N during the study period of time T.

Для формального представлення процесу maintenance and repair a single object of IC, we define the following events:

Event of failure of the facility during a campaign (task) at a random point in the cycle of operation ξ, where ξ is counted from the moment $t = 0$ and a random amount of time, in which there was a failure of the object. Based on the fact that the monitored object, the IC operates continuously when passing between the ports and time in port are neglected, the random variable of an operating time of object before refusal θ will be equal to the random time of operation ξ.

The event of detection of failure in this or subsequent transitions random transitions between fields $\xi + \eta$, where η – random variable from the moment of occurrence of the failure until its detection (self-manifestation) while performing the task.

The recovery event coincides with the event identified during execution of the task or in the port due to the assumption of instantaneous restoration of an object of SK.

Event failure detection during the transition between the ports, in which it originated, will be interpreted in the following way: failure can be detected within a transition using on-Board controls (UPC) (readout of the crew) or a crew with direct (indirect) signs of failure (lack of communication, the disappearance of data with indicators of the object SK or their apparent inconsistency, etc.). These characteristics allow for control of the operation of the facility, the IC transitions to establish the fact of failure.

If control of the technical state of the object is not carried out, the random process of technical operation $\omega(t)$ at the time of operation of the machine t can you imagine how a sequence of random time intervals of operation of the machine with the object in a healthy state ξ_i and in a state of latent failure η_i.

Given the conditions (4), we consider the values ξ_i, $i = 1, 2, \ldots$ identically distributed according to the law $F_\xi(t)$, values $\eta_i, i = 1, 2, \ldots$ identically distributed according to the law $F_\eta(t)$.

If you select condition, which can be exploited during the process of technical maintenance during the operation of the machine as S_1, if at time t the property is situated in a healthy state and S_2, if at time t the object is in a state of latent failure, random process $\omega(t)$ state changes S_1 i S_2 alternative is a random process (Fig. 1).

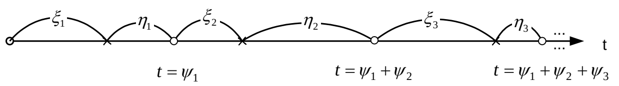

Fig. 1. Alternative random process

During the transition process from the state S_2 in the state S_1 is full of restoration (regeneration). Then the duration of the period of regeneration (between the two moments of recovery) is:

$$\psi_i = \xi_i + \eta_i.$$

In the general case, the residence time of the object SK in the transition to a state of latent failure (after failure until its detection) depends not only on how distributed random variable η_i, but from the moment of technical inspection of the facility operation.

Provided that the technical condition of the object of operation is controlled every x units of time at the time of operation of the machine, x = const, the failure that occurred at a random point in time ξ_i, distributed according to the law $F_\xi(t)$, is, or during the transition using a random time distributed according to the law $F_\eta(t)$, during the periodic monitoring of the technical condition (TC) of the object of operation. The event of detection of failure is determined by the perfection of the means of control applied at different stages of operation, and the allocation of time "the expression" failure $F_\eta(t)$ is a property of a complex technical object. Therefore, in the simulation process and R we assume that if the next control of the vehicle at the time $t_k = (k+1)\cdot x, k = 0,1,2,\ldots,N$ it is established that test object is in state e_i, $e_i \in A_1 \cup A_2$, $i = 0,1,2,\ldots,l-1$ (or is a test object in a state of full health, or a means of control is not able to detect the failure of a faulty but workable), the decision about any control action not taken until the next monitoring of performance after time *x*, if in e_i, $e_i \in A_2$, $i = l, l+1,\ldots,n-2, n-1$, or in e_n – work is being done on the recovery, which transferred the exploitation to the state e_0.

In this case, the time of finding the object in a state of latent failure prior to the first restore is:

$$\psi^{(1)} = \begin{cases} (k+1)\cdot x - \xi_1, \;\; k\cdot x < \xi_1 \le (k+1)\cdot x; \\ \qquad\qquad \eta_1 \ge (k+1)\cdot x - \xi_1;\; k = 0,1,\ldots,; \\ \eta_1, \;\; 0 \le \eta_1 < (k+1)\cdot x - \xi_1. \end{cases}$$

We assume, as before, the quantities $\{\xi_i\}$ identically distributed according to the law $F_{\xi_i}(t) = F_\xi(t), \forall\, i = 1,2,3,\ldots$ and size $\{\eta_i\}$ identically distributed according to the law $F_{\eta_i}(t) = F_\eta(t), \forall\, i = 1,2,3,\ldots,$ the process lasts sufficiently long $t \to \infty$ $(i \to \infty)$, and the control period TC – X, does not change after 1, 2,..., *i* recovery.

The first assumption implies that in each state, operating rules, the object is the end time θ, then jump instantly into another state. In fact, the transition from one state to the other PTE takes some time. However, if this intermediate state is not used in the analysis, the transition time will include the time spent in the initial state of the PTE, and the transition is considered instantaneous.

The second assumption involves the random character of change of the States of the maintenance process and the randomness of time spent in these States. The assumption of stochasticity of the evolution of object SK in the process THAT does not exclude a certain set of deterministic transitions and deterministic durations of stay in States of PTE.

The third assumption assumes that in a nite time with probability one the process will end up in a state in which the entire background does not affect its further development.

In the above formalized description of the process and R are not taken into account the costs of calendar time to perform operations to control the vehicle and the object is restored, operation (instant on time of operation).

Meanwhile, a simple machine to work on the control of vehicle and Troubleshooting significantly affect the characteristics of the SK, in performance of assigned tasks. In this connection it is necessary to introduce a mathematical model that is developed, independent variable, calendar time of operation, and the set of possible States of the facility should include condition of the host facility for operations control, operations recovery failure.

In accordance with formalized description of PTE single object, SC as part of the Park the same type of vessels in the regenerating process with a discrete set of possible States of operation $E = \{e_0, e_1,\ldots,e_i,\ldots,e_n\}$, where *n* – the total number of States of PTE, imagine a process that explores geometric pattern – stochastic graph of States and transitions of PTE object of SK (Fig. 2).

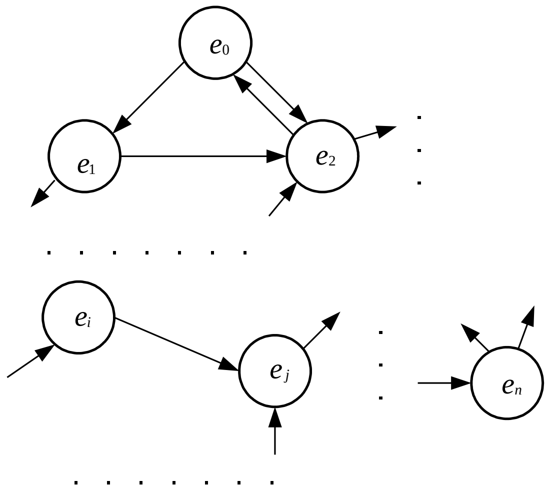

Fig. 2. Directed graph of states and transitions of PTE single object, SK

Thus the possible States of PTE will be in the form of circles and arrows the possible directions of transitions from one state to another. In this case, the graph of States and transitions displays a geometrically possible in the framework of the model taking into account the accepted assumptions the state of the PTE of the facility IC that is investigated (model state) and the possible transitions from state to state.

It is obvious that the study process of technical operation of objects of SK is convenient to consider as a random process with discrete States, that is, as a process, the possible States which can be counted. On the other hand, the real process of technical operation of STS of various types is characterized by the fact that the transition from one state to another PTE in the General case can happen at any random time. In this regard, the process is modeled, we will consider as a random process with continuous time. Thus, we describe the PTE single object of SK as a random process with discrete States and continuous time.

As shown the modern machines are complex technical systems consisting of a large number of systems, modules, assemblies, components (blocks) and individual elements that are sources of failures with different patterns of change in their intensity, their detection and removal during operation. In this regard, for an adequate description of the process of technical operation of the machine as a complex technical system will present it as a product consisting of many components, by which we understand objects that cannot be further detailed in the study. For example, a set of modules separate block in the functional system (FS) machines, the set of blocks of the FS machine, a set of functional systems of the machine, and the like.

Another feature that should be considered in the study of the effectiveness of the recovery system and its impact on the efficiency of the process and repair cars, is that in actual operation recovery efficiency of the constituent elements of the machine (the COA) is carried out upon detection of failure (peredove state) of object, despite its performance at the moment. For example, a failure is detected a backup element operable object SK (damage SK) leads to its replacement by a fully intact, with restoration to a healthy state. Therefore, in this study we assume that the failure of any core element (unit, unit, unit) puts the car to the disabled state.

Thus, when considering the machine as a set of functional systems will be presenting it in the form of the STS with elements, connected to the reliability (dependability) in series (Fig. 3).

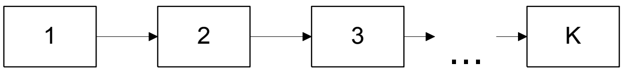

Fig. 3. The approved scheme of connection of functional systems of machine reliability (K is the number of functional systems of this type).

In this case, the probability of failure-free operation of the machine (assuming no or limited exchange of Fund units) is defined as:

$$P_C(t) = \prod_{k=1}^{K} P_k(t),$$

$$Q_C(t) = 1 - P_C(t),$$

$$N_{o\phi_k}(t) << n_k(t),$$

where: $P_C(t)$ – the probability of failure of the machine, $P_k(t)$ – the probability of failure of components of the product, $Q_C(t)$ – the probability of machine failure, $N_{o\phi_k}(t)$ – the number of objects k type in the exchange fund operator, $n_k(t)$ – the number of failures of an object k type during the study period.

Process $\omega(t)$ is determined by the vector of parameters of the recovery process, as managed $\Lambda_u = \{\Lambda_{u1}, \Lambda_{u2}, \ldots, \Lambda_{ul}\}$ so unmanageable $\Lambda_V = \{\Lambda_{V1}, \Lambda_{V2}, \ldots, \Lambda_{Vk}\}$, as well as the parameters characterizing the conditions of application of the machine $\Lambda_R = \{\Lambda_{R1}, \Lambda_{R2}, \ldots, \Lambda_{Rn}\}$. Typically, the separation parameters for managed and unmanaged conditional and depends on the type of problem that is being solved. In some problems part of the managed settings can be defined as (uncontrollable). In addition, the controlled parameters can cause the unmanageable. As a rule, at formation of system recovery on-Board equipment of the machine to the managed settings will include: types of control, means of control applied at different stages and R, the completeness and depth control, tool reliability raskladami means of control, frequency of control, completeness of recovery, the number and qualification of personnel, and the like.

Unmanaged parameters Λ_V Typically, the separation parameters for managed and unmanaged conditional and depends on the type of problem that is being solved. In the attitude – structural characteristics and reliability of the objects of the IC, the testing efforts and the search space of the failure using this monitoring tool.

Settings Λ_R related the intensity of flights, their duration, nature of tasks etc.

Change at least one component of the vector control u on the maintenance stages are considered, leads to the creation of a new version of the construction of the recovery process.

In reality, the number of possible variants is limited. On this basis, the task of choosing a rational variant of the process of recovery of SK machines are able to reduce to the problem in variational formulation, in which of the many alternative options to select the most favorable. Alternatives u_j are formed by changing the values of the components of the vector u,

$$u = (\lambda, \mu, x, P, q, Q, \eta, T),$$

where: λ – the failure rate of the object SK, μ – the intensity of the self-manifestation of the failure of the object SK, x – the frequency of the control, P – the probability of detection of failure of control, q – the likelihood of providing control information on the “about” denial, Q – completeness of recovery of the object SK in the operating organization, η – full control of failures (damages), T – the duration of operation of the IC.

Due to the fact that the attraction of objects of SK in different States of the real process of PTE is statistically repeated, and as the formal description of the selected scheme of the recycling process, to assess the effectiveness of this process will use performance indicators expected result:

$$\vec{W}(u) = M\left[Y^{\langle R \rangle}(u)\right],$$

$$W_r(u) = M[y_r(u)],$$

$$r = \overline{1, R},\ u \in U, \tag{5}$$

where: $W_r(u)$ – private utilization u the variant of the organization of the process of recovery of SK machine, reliability (dependability) economic and other types of effectiveness of PTE machines, $y_r(u)$ – partial characteristics of the result of the operating rules of the machine.

Figure (5) is a special case of the rate at which the feature is equal to the real result:

$$\rho\left\{Y^{\langle R\rangle}(u), Y_{в}^{\langle R\rangle}\right\} = Y^{\langle R\rangle}(u).$$

The average result (5) is widely used in studies of the effectiveness of complex technical systems. This is due to the property of additivity, which greatly simplifies their assessment lies in the fact that in case of the possibility to submit result $Y^{\langle R\rangle}(u)$ the operation of docum system as the sum of results of individual stages $Y^{\langle R\rangle}{}_i(u)$:

$$Y^{\langle R\rangle}(u) = \sum_i Y^{\langle R\rangle}{}_i(u),$$

the average result of the process is considered to present a medium amount of private results, despite their possible stochastic dependence:

$$M\left[\sum_i Y^{\langle R\rangle}{}_i(u)\right] = \sum_i M\left[Y^{\langle R\rangle}{}_i(u)\right].$$

Вибір та обґрунтування показників ефективності СК allows the machine to evaluate the different options (strategies or modes of recovery and to elect for the formulated criterion K the "best" option u^* under given operating conditions Λ. As is known, criterion of efficiency K there is a rule that allows you to compare the options $u \in U$, characterized by different degrees of goal achievement, and to implement a directed choice of options u from the set of the admissible U. When using the concept of optimization criteria major results in the form of: highest average score, the highest probabilistic guarantee of results, the largest guaranteed result.

Imagine in the mathematical form of the partial tasks which are given above and answer the two main decision-making processes in the study of efficiency of various variants of the organization of the process of recovery of SK machines and need to be addressed:

1) the process of obtaining results:

$$\Psi : \left\{ Y \;\middle|\; H : U \times \Lambda \xrightarrow{\Theta} Y(G) \right\} \xrightarrow{\Theta} W, \quad (6)$$

2) the process of analysis of the results:

$$\Im \xrightarrow{\Theta} K : U \xrightarrow{W} u^*.$$

The expression (6) means that the dependence of the vector efficiency index $\vec{W}(u)$ the organization of the recovery process $u \in U$ and other relevant factors Λ, defining the conditions of PTE of objects of SK that is set in the display view:

$$\Psi : \left\{ H : U \times \Lambda \rightarrow Y^{\langle R\rangle} \right\} \rightarrow W,$$

where: $H(\varphi): U \times \Lambda \rightarrow Y^{\langle R\rangle}$ – a mathematical model of PTE STS that allows us to estimate the value of different characteristics of partial implementation $y_r(u)$ result $Y^{\langle R\rangle}(u)$ for each option $u \in U$, φ – the transition operator.

Formally, we represent the model of PTE of the facility, the IC developed, $\Psi : U \times \Lambda \rightarrow W$ in the form of a compound statement assessment of effectiveness, which is a superposition of operators:

$$\Psi = H \circ Q \circ M,$$

where: Q – the compliance statement,

M – the operator of averaging,

$\circ$ – character superposition.

That is, we assume that the operators Q і M display multiple values $Y^{\langle R\rangle}(u)$ results of PTE object SK in the set of values of the performance indicator $\vec{W}(u)$. In this case, the set of values $Y^{\langle R\rangle}(u)$ with the statement of compliance $Q : Y \times Y_{в} \rightarrow \rho$ appears in the set of values of the function of compliance ρ, and the operator of averaging $M : \rho \rightarrow W$ translates the value set of compliance features ρ in the set of values of the performance indicator $\vec{W}(u)$:

$$Q \circ M : Y \rightarrow W.$$

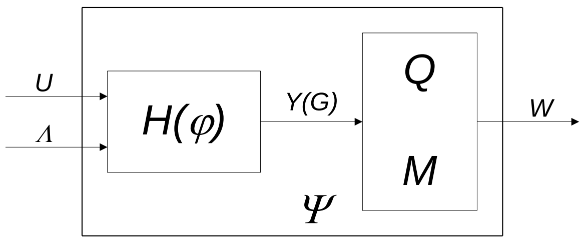

Fig. 4. The structural diagram model of the process of technical operation of complex technical systems

In accordance with the above formalized representation of the process object SC as a process changes its States in the plural, imagine normal operators , that is operators of transition and exit, respectively, in the form of correspondences:

$$\varphi : E \times U \times \Lambda \rightarrow E,$$

$$H : E \times U \times T \times \Lambda \rightarrow Y(G),$$

where: T – the duration of the operating period that is studied.

The necessity of use of mathematical model of investigated process in which interrelated parameters, indicators and criteria, based on the principle of system approach when evaluating the performance of complex systems.

The choice of the mathematical device of the analysis of the studied phenomenon, based on previous experience and data obtained as a result of studying the real objects. Considering, in General terms, any phenomenon is investigated, can be chosen as one of the two mathematical models – deterministic or stochastic . A deterministic model is chosen in those cases in which it is possible to accurately specify the reasons which influenced changes of the investigated process, and in the case of known input impacts with any degree of accuracy calculate the output.

Due to the fact that the process of maintenance and repair of objects of SK is categorized as stochastic, just take into account all the random factors that influence it is almost impossible, for an adequate description of the process and P must be a stochastic model.

CONCLUSIONS

1. As is known, a mathematical model to quantitatively describe the process of functioning of objects of exploitation, based on a priori information about the possible states of the process of technical operation and the transition from one state to another, as well as on statistical data obtained during the operation of the same technical systems. In this regard, based on the analysis of features of process of technical exploitation of vessels and the purpose of the study, formulate the requirements of a mathematical model is developed:

1.1. The requirement of the model building process: the transition of the SK object from one state of the process of technical operation to the other occurs over time, so the mathematical model of process of technical exploitation of SK machine must be a model of the process with known statistical description.

1.2. The requirement for restrictions: to allow a comparative techno-economic evaluation of various options for the organization of the process of recovery of the UK and influence the process of technical operation of hardware and software systems for monitoring and diagnosing the technical condition of the IC on the results of simulation models should not be severe restrictions on the state space of the process of technical operation and functions of distribution of time of stay in the state of the process operation.

1.3. The requirement of simplicity: to be easy to describe the process of technical operation of SC in the model, which will allow you to solve the problem with sufficient accuracy, and to ensure the ease of creating the model itself. This requirement is based, on the one hand, the necessity of obtaining the desired result, and on the other practical limitations on the amount of information needed to determine the desired characteristics of the studied process.

1.4. The requirement of clarity: to provide visual expression of the process that is investigated, the restoration models developed for easy understanding.

1.5. The requirement of adaptability: allow for the rapid refinement of the model with the accumulation of current information on the progress of the real operation.

1.6. The requirement of verifiability of the results: provide a real opportunity to trace the causal relationships of the model parameters of process of technical exploitation in the course of the simulation.

1.7. The requirement of low complexity of the calculations: provide efficient algorithms for estimating the unknown indicators of technical and economic efficiency of the process of technical operation of objects of SK with the aim of obtaining foreseeable simulation results.

2. As can be seen from the developed requirements to the mathematical model of the process of technical operation, insurance car, requirements 1–3 are determined by the class of the selected stochastic model requirements 5–7 are determined by simulation, with the requirement of simplicity of the model 4 is. Based on the above requirements, the mathematical model will select the class of stochastic model and simulation method.

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ВЫБОР КЛАССА МОДЕЛИ И МЕТОДА МОДЕЛИРОВАНИЯ СИСТЕМЫ ВОССТАНОВЛЕНИЯ РАБОТОСПОСОБНОСТИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН

Иван Роговский

Аннотация. В статье разработаны требования к математической модели процесса технической эксплуатации объектов сельскохозяйственных машин, выбран класс модели и метод моделирования. Это позволило разработать формализованное описание процесса восстановления работоспособности сельскохозяйственных машин, что исследуется, обосновать форму показателей эффективности и критерия оптимальности, осуществить математическую постановку частных задач исследования.

На основании формализованного описания рассматривается математическая модель процесса технической эксплуатации объекта сельскохозяйственных машин в виде регенерирующего процесса восстановления. Приведены аналитические зависимости показателей от параметров системы технического обслуживания для случая одноэтапного периодического контроля работоспособности. Получены выражения для расчета асимптотических оценок выбранных показателей

эффективности при экспоненциальных распределениях времени безотказной работы объекта сельскохозяйственных машин и времени самостоятельного проявления отказа в эксплуатации.

Стохастические модели обычно классифицируются как случайные процессы и могут представлять собой процессы с дискретными состояниями (множество состояний конечная или подсчитывается) и с непрерывным множеством состояний (множество состояний ставится во взаимно-однозначное соответствие множеству точек числового интервала), с дискретным временем (случайные последовательности) и с непрерывным временем. В настоящее время разработано большое количество стохастических моделей, применяемых для описания функционирования сложных технических систем, основными классами которых являются: логические, линейные, гауссовские, автоматные, агрегатные, марковские, полумарковские, регенерирующие, многокомпонентные, модели в виде систем массового обслуживания.

Исследуется случай многоэтапного технического обслуживания с учетом полноты контроля технического состояния объектов сельскохозяйственных машин.

Ключевые слова: моделирование, технология, модель, метод, восстановление, сельскохозяйственная машина.

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