Механізація

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DETERMINATION OF READINESS FUNCTION OF NOZZLE FOR OPERATION

The article describes determination of readiness function of nozzle for operation that based on the charts of conditions and mathematical modeling of transitions of nozzles of automated control systems for temperature and humidity parameters of air in the area of cultivation of plants under protected ground into various possible conditions. To clarify the form of total three-expositional and graphical representation of results, developed a flowchart calculations that establish values, which ultimately provide the function of readiness. Block diagram of the calculation is shown in articale. Function preparedness is a dynamic characteristic of reliability, the considered technical system. Probabilty for non-failure operation for nozzles is represented by a coefficient of readiness that changes the dynamics of operating time seems function of the technical system readiness for operation. The function of readiness is descending exponential nature of the system is completely ready to start working to its asymptotic value, which reflects the steady availability factor.

Key words: *Nozzle, operation condition, probability of non-failure operation, intensity of failures, failure.*

A problem statement

This nozzles for spraying liquid under 70 Bar pressure, which the intergral part of an automatic system for controlling humidity and temperature parameters of air in the area of plants cultivation under the terms of protected soil. The system is designed to produce a necessary microclimate in the premises of industrial greenhouses.

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Review of recent researches and publications

Work [1] describes the problems of ensuring the reliability of process equipment during the growth of production in agriculture protected ground Ukraine. Work [2] describes the the model of the use of nozzle for liquid sprayer and generation of microclimate in the premises of greenhouses. Work [3] based on the researching indexes of reliability of systems of microclimate control onto productivity of products of protected soil. The [4] was describes charts of conditions and mathematical modelling of transition of nozzles into various possible conditions.

Purpose, objects and methods of research

The task of work is determination of readiness function of nozzle for operation that based on the charts of conditions and mathematical modeling of transitions of nozzles of automated control systems for temperature and humidity parameters of air in the area of cultivation of plants under protected ground into various possible conditions.

The paper based on the theory of mathematical modeling of nozzles transition in various possible states.

Research results

A probability of condition of nozzle in operation condition «0» [4] can be set in Laplace, according to Cramer rule, by the following correlation:

$$\varphi_0(S) = \frac{\Delta_0}{\Delta}, \tag{1}$$

where Δ_0 – is matrix to position «0» - of operation condition of system,

Δ – main matrix of equasion system describing possible conditions and transitions of nozzle (13) [1].

Matrix to working condition can be written from the main determinant (6) [4] by replacing the first column to free parts. Then we have:

$$\Delta_0 = \begin{vmatrix} 1 & -\mu_{10} & 0 & -\mu_{20} \\ 0 & S+\mu_{10} & 0 & 0 \\ 1 & S & S & S \\ 0 & 0 & -\lambda_{2'2} & S+\mu_{20} \end{vmatrix}$$

We lower ranking matrix. For this purpose it is reasonable to divide it on the second line of the elements:

$$\Delta_0 = (S+\mu_{10})(-1)^{2+2}\begin{vmatrix} 1 & 0 & -\mu_{20} \\ 1 & S & S \\ 0 & -\lambda_{2'2} & S+\mu_{20} \end{vmatrix}\begin{matrix} 1 & 0 \\ 1 & S \\ 0 & -\lambda_{2'2} \end{matrix}$$

Using the rule Sarryusa decision matrix is written as follows:

$$\Delta_0 = (S+\mu_{10})\cdot 1\left[1\cdot S\cdot(S+\mu_{20}) + ((-\mu_{20})\cdot 1\cdot(-\lambda_{2'2})) - (-\lambda_{2'2}\cdot S\cdot 1)\right]$$

$$\Delta_0 = (S+\mu_{10})\left[S\cdot(S+\mu_{20}) + \mu_{20}\lambda_{2'2} + \lambda_{2'2}\cdot S\right]$$

After algebraic manipulations, simplification and describing to degrees of unknown *S* we shall have:

$$\Delta_0 = (S+\mu_{10})\left[S\cdot(S+\mu_{20}) + \mu_{20}\lambda_{2'2} + \lambda_{2'2}\cdot S\right]$$

$$\Delta_0 = S^3 + S^2\mu_{20} + S\mu_{20}\lambda_{2'2} + \lambda_{2'2}S^2 + \mu_{10}S^2 + S\mu_{10}\mu_{20} + \mu_{10}\mu_{20}\lambda_{2'2} + \mu_{10}\lambda_{2'2}S \quad (2)$$

$$\Delta_0 = S^3 + S^2(\mu_{20} + \lambda_{2'2} + \mu_{10}) + S(\mu_{20}\lambda_{2'2} + \mu_{10}\mu_{20} + \mu_{10}\lambda_{2'2}) + \\ + \mu_{10}\mu_{20}\lambda_{2'2}.$$

Returning to determining the probability of failure of the nozzle and substituting the expression (1) of the matrix (2) and (13) [4] we shall write:

$$\varphi_0(S) = \frac{S^3 + S^2(\mu_{20} + \lambda_{2'2} + \mu_{10}) + S(\mu_{20}\lambda_{2'2} + \mu_{10}\mu_{20} + \mu_{10}\lambda_{2'2}) + \mu_{10}\mu_{20}\lambda_{2'2}}{\begin{aligned} & S^4 + (\lambda_{01} + \lambda_{02'} + \mu_{20} + \mu_{10} + \lambda_{2'2})S^3 + \\ & + (\lambda_{01}\mu_{20} + \lambda_{01}\lambda_{2'2} + \mu_{10}\mu_{20} + \lambda_{2'2}\mu_{10} + \mu_{20}\lambda_{2'2})S^2 + \\ & + (\lambda_{02'}\mu_{10}\mu_{20} + \lambda_{02'}\lambda_{2'2}\mu_{10} + \mu_{20}\lambda_{01}\lambda_{2'2} + \mu_{20}\lambda_{2'2}\mu_{10})S \end{aligned}}. \quad (3)$$

Presented equation is too big and makes it possible to perform inverse Laplace transform, i.e. the transition from the original image $\varphi_0(S) \to P(t)$. To this transformation possible, it is necessary to spread the denominator of (3) at multipliers. It is necessary to find the roots of the polynomial fourth degree.

Inserting indexes:

$$\begin{aligned} &S^4;\ a = 1; \\ &S^3;\ b = \lambda_{01} + \lambda_{02'} + \mu_{20} + \mu_{10} + \lambda_{2'2}; \\ &S^2;\ c = \lambda_{01}\mu_{20} + \lambda_{01}\lambda_{2'2} + \mu_{10}\mu_{20} + \lambda_{2'2}\mu_{10} + \mu_{20}\lambda_{2'2}; \\ &S;\quad d = \lambda_{02'}\mu_{10}\mu_{20} + \lambda_{02'}\lambda_{2'2}\mu_{10} + \mu_{20}\lambda_{01}\lambda_{2'2} + \mu_{20}\lambda_{2'2}\mu_{10}. \end{aligned} \tag{4}$$

We shall write an equasion (13) [1] in shorter form:

$$\Delta = aS^4 + bS^3 + cS^2 + dS. \tag{5}$$

To find the roots we shall have:

$$S\left(aS^3 + bS^2 + cS + d\right) = 0.$$

The obtained equasion shall be divided into two, one of which has a solution $S_1=0$, and the second represents an equasion of the third degree:

$$S^3 + bS^2 + cS + d = 0.$$

By changing:

$$y = S + \frac{b}{3}, \tag{6}$$

after algebraic simplification should form the reduced equation [2]:

$$y^3 + py + q = 0, \tag{7}$$

where

$$p = \frac{3c - b^2}{3}; \tag{8}$$

$$q = \frac{2b^3}{27} - \frac{b \cdot c}{3} + d. \tag{9}$$

The number of real solutions (roots) equation (7) depends on the sign of discriminant that is defined by the formula:

$$D = \left(\frac{p}{3}\right)^3 + \left(\frac{q}{2}\right)^2 \tag{10}$$

Preliminary assessment of the sign discriminant can be made by substituting components of formula (10), and the components included in the formula (8) and (9). The final component represented by equation (4) and includes $\lambda, \ \mu$ - characteristics of states and transitions nozzles in various possible states. Is legitimately assume that periods of normal operation of the nozzle to failure greatly exaggerated periods of recovery. Moreover, this corresponds to reality, as the recovery comes to cleaning the valve or replacing the filter. And both operations are fast enough compared to the normal term of the nozzle. Then you can take the following condition:

where $\bar{t}$ – average opeation time of the nozzle before failure;

$\bar{\tau}$ – average resoration time of the nozzle.

Taking into consideration that $\bar{t} = \frac{1}{\lambda}$, and $\bar{\tau} = \frac{1}{\mu}$ we shall have:

Putting the obtained condition of intensity ratios of failures and restorations, as well as neglecting λ in the second and higher levels as low values, the values of variables analyzed *p* and *q*. The more real it appears that the case is considered an option *p* takes a negative value, that is, $p<0$. On this basis the quantities and ratios *p* and *q* we can assume that also has negative discriminant value $D<0$. In this case, the solution of equation (7) is in the field of real roots.

Cubic equations can be solved by Cardano formula. To do this, type the following replacement:

$$\rho = \sqrt{-\frac{p^3}{27}};$$

$$\cos\varphi = -\frac{q}{2\rho}.$$

At the root of the equation (7) is in the form:

$$y_1 = 2\sqrt[3]{\rho}\cos\frac{\varphi}{3};$$
$$y_2 = 2\sqrt[3]{\rho}\cos\left(\frac{\varphi}{3}+\frac{2\pi}{3}\right); \qquad (11)$$
$$y_3 = 2\sqrt[3]{\rho}\cos\left(\frac{\varphi}{3}+\frac{4\pi}{3}\right).$$

By flip replacement from (6) we shall have:

$$S_1 = y_1 - \frac{1}{3}b;$$
$$S_2 = y_2 - \frac{1}{3}b; \qquad (12)$$
$$S_3 = y_3 - \frac{1}{3}b.$$

Thus all the components of the initial decision right equation (5) and found it can be presented in the schedule obtained by the roots. Then in general expression for the likelihood of working condition nozzles can be represented by an equivalent equation and write it as the following amounts:

$$\varphi_0(S) = \frac{A_0}{S-S_1} + \frac{B_0}{S-S_2} + \frac{C_0}{S-S_3} + \frac{D_0}{S-S_4}, \qquad (13)$$

where: $A_0, B_0, C_0, D_0 -$ some unknown fixed values that can be determined from the condition of equivalence of polynomials (3, 8).

For further algebraic manipulations we rewrite equation (8) given that the root $S_1 = 0$

$$\varphi_0(S) = \frac{A_0}{S} + \frac{B_0}{S-S_2} + \frac{C_0}{S-S_3} + \frac{D_0}{S-S_4}. \qquad (14)$$

then:

$$\varphi_0(S)=\frac{\begin{aligned}&A_0(S-S_2)(S-S_3)(S-S_4)+B_0S(S-S_3)(S-S_4)+\\&+C_0S(S-S_2)(S-S_4)+D_0S(S-S_2)(S-S_3)\end{aligned}}{S(S-S_2)(S-S_3)(S-S_4)} \qquad (15)$$

Expanding the brackets after algebraic manipulations and simplifications in the expansion in degrees of unknown (S), the numerator (10) is represented as:

$$\begin{aligned}&S^3(A_0+B_0+C_0+D_0)-\\&-S^2(A_0S_3+A_0S_2+A_0S_4+B_0S_4+B_0S_3+C_0S_4+C_0S_2+D_0S_3+D_0S_2)+\\&+S(A_0S_2S_3+A_0S_4S_3+A_0S_4S_2+B_0S_3S_4+C_0S_2S_4+D_0S_2S_3)+A_0S_4S_2S_3\end{aligned}$$

In case of equal denominators represented by formula (13) [4] and in expansion for the roots of the denominator of the formula (10), values Δ_0 (2) and the numerator (2) may be equal under the condition that the coefficients of equal powers of unknown *S* will also be equal. On this basis, and comparing these expressions can write the following additional system of equations for determining a constant A_0, B_0, C_0, D_0.

$$\begin{cases}A_0, B_0, C_0, D_0 = 1;\\-(A_0S_3+A_0S_2+A_0S_4+B_0S_4+B_0S_3+C_0S_4+C_0S_2+D_0S_3+D_0S_2)=\mu_{20}+\lambda_{2'2}+\mu_{10}\\A_0S_2S_3+A_0S_4S_3+A_0S_4S_2+B_0S_3S_4+C_0S_2S_4+D_0S_2S_3=\mu_{20}\lambda_{2'2}+\mu_{10}\mu_{20}+\mu_{10}\lambda_{2'2}\\A_0S_4S_2S_3=\mu_{10}\mu_{20}\lambda_{2'2}\end{cases} \qquad (16)$$

Unidentified fixed values (A_0, B_0, C_0, D_0) Therefore, we shall find a method of successive substitutions. To do this, the last equations define sustainable (A_0).

$$A_0=\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3}. \qquad (17)$$

We shall put the value (A_0) into the third equasion of system (16):

$$\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3}(S_2S_3+S_4S_3+S_4S_2)+B_0S_3S_4+C_0S_2S_4+D_0S_2S_3=$$
$$=\mu_{20}\lambda_{2'2}+\mu_{10}\mu_{20}+\mu_{10}\lambda_{2'2}$$

From which we obtain (B_0):

$$B_0 = -\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3S_3S_4}\left(S_2S_3 + S_4S_3 + S_4S_2\right) - C_0\frac{S_2S_4}{S_3S_4} - -D_0\frac{S_2S_3}{S_3S_4} + \frac{\mu_{10}\mu_{20} + \mu_{10}\lambda_{2'2}}{S_3S_4} \quad (18)$$

The obtained values (A_0) and (B_0) we substitute into the second equation of (16):

$$-\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3}\left(S_3 + S_2 + S_4\right) - \left[\begin{array}{l} -\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3S_3^2S_4^2}\left(S_2S_3 + S_4S_3 + S_4S_2\right) - \\ -C_0\frac{S_2}{S_3} - D_0\frac{S_2}{S_4} + \frac{\mu_{10}\mu_{20} + \mu_{10}\lambda_{2'2}}{S_3S_4} \end{array}\right] \times$$

$$\times\left(S_4 + S_3\right) - C_0\left(S_4 + S_2\right) - D_0\left(S_3 + S_2\right) = \mu_{20} + \lambda_{2'2} + \mu_{10}$$

Select the equation derived from sustainable (C_0):

$$C_0\left[\frac{S_2\left(S_4 + S_3\right)}{S_3} - \left(S_4 + S_2\right)\right] = -D_0\left[\frac{S_2\left(S_4 + S_3\right)}{S_4} - \left(S_3 + S_2\right)\right] + \mu_{20} + \lambda_{2'2} + \mu_{10} -$$

$$-\frac{\mu_{10}\mu_{20} + \mu_{10}\lambda_{2'2}\left(S_4 + S_3\right)}{S_3S_4} + \frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3}\left(S_3 + S_2 + S_4\right) -$$

$$-\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_2S_3^2S_4^2}\left(S_2S_3 + S_4S_3 + S_4S_2\right).$$

After shorting and reforming we shall have:

$$C_0 = -D_0\left[\frac{S_3}{S_4} - \frac{\left(S_3 + S_2\right)S_3}{S_2\left(S_4 + S_3\right)}\right] + \frac{\left(\mu_{20} + \lambda_{2'2} + \mu_{10}\right)S_3}{S_2\left(S_4 + S_3\right)} - \frac{\left(\mu_{10}\mu_{20} + \mu_{10}\lambda_{2'2}\right)}{S_4S_2} + + \frac{\mu_{10}\mu_{20}\lambda_{2'2}\left(S_3 + S_2 + S_4\right)}{S_4S_2^2\left(S_4 + S_3\right)} - \frac{\mu_{10}\mu_{20}\lambda_{2'2}\left(S_2S_3 + S_4S_3 + S_4S_2\right)}{S_2^2S_3S_4^2}. \quad (19)$$

We use the first equation of the system (16) for determining sustainable $\left(D_0\right)$. Substituting the values $\left(A_0, B_0 \; i \; C_0\right)$, presenting the first equation follows:

$$D_0 = 1 - A_0 - B_0 - C_0;$$

$$D_0\left(1-\frac{S_2}{S_4}\right) = 1-\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3}+\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4^2S_2S_3^2}\left(S_2S_3+S_4S_3+S_4S_2\right)-$$

$$-D_0\left[\frac{S_3}{S_4}-\frac{\left(S_3+S_2\right)S_3}{S_2\left(S_4+S_3\right)}\right]+\frac{S_2}{S_4}\frac{\left(\mu_{20}+\lambda_{2'2}+\mu_{10}\right)S_3}{S_2\left(S_4+S_3\right)}-\frac{\left(\mu_{10}\mu_{20}+\mu_{10}\lambda_{2'2}\right)S_2}{S_4^2S_2}+$$

$$+\frac{\mu_{10}\mu_{20}\lambda_{2'2}\left(S_3+S_2+S_4\right)S_2}{S_4S_2^2\left(S_4+S_3\right)S_4}+\frac{\mu_{10}\mu_{20}\lambda_{2'2}\left(S_2S_3+S_4S_3+S_4S_2\right)S_2}{S_2^2S_3S_4^2S_4}.$$

Solving equations relatively regarding to the searched unknown $\left(D_0\right)$ after algebraic manipulations eventually have a:

$$D_0=\frac{1}{1-\frac{S_2}{S_4}+\frac{S_3S_2}{S_4^2}-\frac{S_3+S_2}{\left(S_4+S_3\right)S_4}}\left[\begin{array}{l}1-\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4S_2S_3}+\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4^2S_2S_3^2}\left(S_2S_3+S_4S_3+S_4S_2\right)+\\+\frac{S_3\left(\mu_{20}+\lambda_{2'2}+\mu_{10}\right)}{S_4\left(S_4+S_3\right)}-\frac{\left(\mu_{10}\mu_{20}+\mu_{10}\lambda_{2'2}\right)}{S_4^2}+\\+\frac{\mu_{10}\mu_{20}\lambda_{2'2}\left(S_3+S_2+S_4\right)}{S_4^2S_2\left(S_4+S_3\right)}+\\+\frac{\mu_{10}\mu_{20}\lambda_{2'2}\left(S_2S_3+S_4S_3+S_4S_2\right)}{S_2S_3S_4^2}\end{array}\right] \quad (20)$$

The flip substitution in (19) we obtain sustainable values $\left(C_0\right)$ via $\lambda,\ \mu-$ Technical characteristics of the system (injectors). Further substituting values (D_0) i (C_0) into (18) we shall find sustainable value $\left(B_0\right)$. Constant $\left(A_0\right)$ is known from equasion (17).

Due to the large equasions of formulas those substitions are not availale, but their performance does not represent mathematical difficulties.

Note that all got fixed values $\left(A_0,\ B_0,\ C_0 \; i \; D_0\right)$ in end view expressed directly or through $\lambda,\ \mu-$ technical characteristics of the system, or through the roots

S_2, S_3 i S_4, having in its composition as well. Thus, despite hromistkist calculations, oshukuvani constants to represent equation (14) unfolded on a denominator polynomial roots, obtained . So, back to equation (4), which defines probability in the Laplace transform nozzle can apply the reverse transition from the original image. Then get dependent probability of failure of the system (non-stationary readiness coefficient) of operating time. It has the following view:

$$P_0(t) = K_Г(t) = A_0 + B_0 \exp(-S_2 t) + C_0 \exp(-S_3 t) + D_0 \exp(-S_4 t) \quad (21)$$

In this case, the probability of technical systems and functions the same readiness as well as behavior in operating model is seen as such, allowing recovery in the event of damage [3]. Marked chart of states and transitions, as the equation of dynamic equilibrium probabilities into account not only the parameters of normal work, but also options to restore it if damaged.

The function has four components: one fixed (A_0) and three, depending on the time and vary according to the exponential law. Depending analysis shows that at the beginning of operation at $t = 0$ function of readiness obtains:

$$K_Г(t = 0) = A_0 + B_0 + C_0 + D_0$$

However, according to the first equation of (16) the amount equal to one constant. That is, at $t = 0;\ K_Г(t) = 1$, corresponding to the physical nature of the technical state of the system (nozzles).

The second extreme case occurs when time equals infinity $t \to \infty$. Then by substituting into equasion (21), we obtain:

$$K_Г(t \to \infty) = A_0,$$

or

$$K_Г(t \to \infty) = \frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4 S_2 S_3}. \quad (22)$$

Thus the function of readiness $K_Г(t)$ when time goes to infinity asymptotically approaching a constant value and gaining its value known as fixed rate tender.

In general, the function of readiness, analysis shows that by changing exponentially complex and within:

$$\frac{\mu_{10}\mu_{20}\lambda_{2'2}}{S_4 S_2 S_3} \geq K_Г(t) \geq 0$$

To clarify the form of total three-expositional and graphical representation of results, developed a flowchart calculations that establish values, which ultimately provide the function of readiness. Block diagram of the calculation is shown in Fig.1.

The data of expositional function of readiness preparedness function and its importance in the extreme points at $t = 0 \; i \; t \to \infty$, and the ability to calculate the present interim results in accordance flowchart (Fig. 1), enabled with the initial values $\lambda, \; \mu -$ plot characteristics change preparedness functions depending on time of operation of the nozzle.

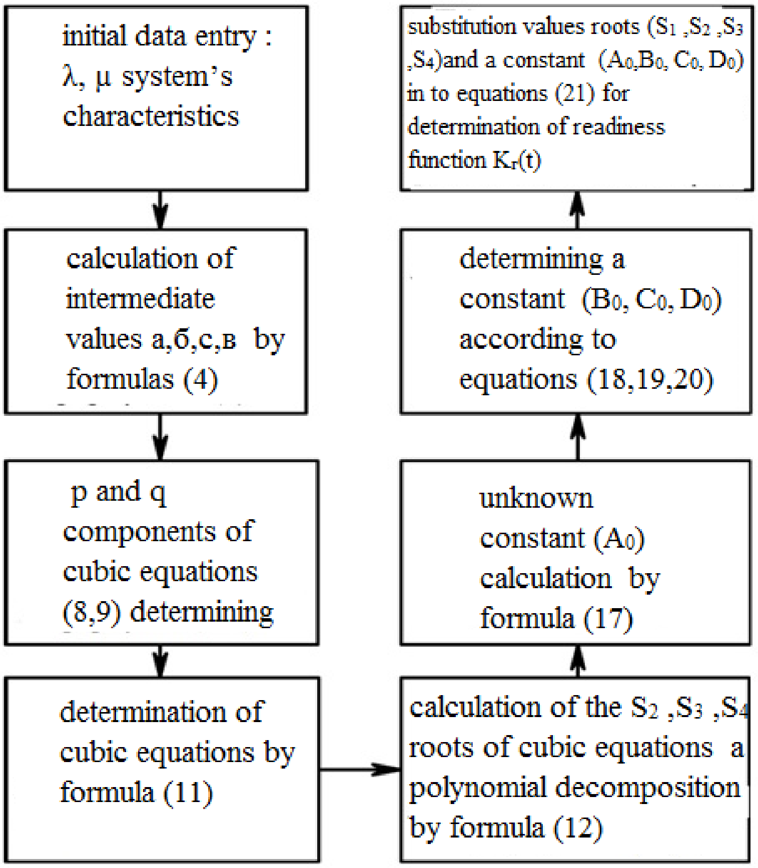

Fig. 1. **Block diagram of the calculations to determine the function of readiness $K_Г(t)$ of nozzles**

Function preparedness is a dynamic characteristic of reliability, the considered technical system (Fig. 2).

As shown in the graph of readiness has descending character of the maximum cooked $K_{\Gamma}(t)=1$ at the beginning of the operation to its asymptotic approximation to its stationary value (22).

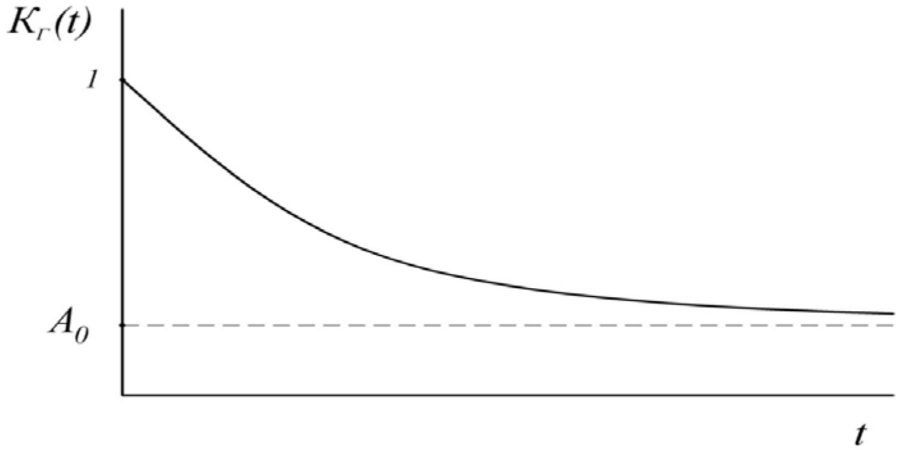

Fig. 2. **Changes of readiness of nozzles work depending on the time of its operation. ($\lambda_{01} \approx$ 0,001 1/h; $\mu_{10} \approx$ 1,7 1/h; $\lambda_{02'} \approx$ 0,0008 1/h; $\mu_{20} \approx$ 0,5 1/h)**

Findings and prospects of the further researches

Probabilty for non-failure operation for nozzles is represented by a coefficient of readiness that changes the dynamics of operating time seems function of the technical system readiness for operation. The function of readiness is descending exponential nature of the system is completely ready to start working to its asymptotic value (22), which reflects the steady availability factor.

References

1. Міненко С. В. Аналіз залежності інтенсивності продуктивного фотосинтезу від режимів мікроклімату в індустріальних теплицях / С. В. Міненко // Вісник ЖНАЕУ. – 2016. – № 1 (53), т. 1. – С. 270–276.

2. Міненко С.В. Стратегії контролю процесами мікроклімату в індустріальних теплицях / С. В. Міненко, О. А. Махов // Підвищення надійності машин і обладнання : зб. тез доп. VII Всеукр. наук.-практ. конф. студентів та аспірантів, 3–5 квітня 2013 р. – Кіровоград : КНТУ, 2013. – С. 48–49.

3. Міненко С. В. Класифікація способів зняття перегріву рослин в індустріальних теплицях / С. В. Міненко // Вісник ЖНАЕУ. – 2016. – № 1 (53), т. 1. – С. 276–282.

4. Бодров В. И. Комплексная система снятия перегрева в теплице в теплый период года / В. И. Бодров, И. В. Баулина, М. А. Абазалиева. – М., 1992. – 15 с.

5. Егиазаров А. Г. Термодинамические процессы обработки воздуха при работе систем водоаэрозольного охлаждения / А. Г. Егиазаров, В. И.Бодров, М. А. Абазалиева. – М., 1992. – 13 с. – Деп. в ВПИИПТПИ, № 11221.

6. Бойко А.І. Проблеми забезпечення надійності технологічного обладнання при вирощуванні продукції захищеного ґрунту в апк україни / А.І. Бойко, В. М. Савченко, В. В. Крот // Технічний сервіс агропромислового, лісового та транспортного комплексів. – 2016. – № 6. – С. 200-2003.

7. Бойко А.І. Основні несправності форсунок систем автоматизованого контролю вологісними та температурними параметрами повітря в приміщеннях теплиць / А.І. Бойко, В. М. Савченко, В. В. Крот // Крамаровські читання : зб. тез доп. IV міжнар. наук.-техн. конф., 16-17 лют. 2017. – К. : НУБіП, 2017. – С. 61–64.

8. Minenko S. Researching indexes of reliability of systems of microclimate control onto productivity of products of protected soil/ S. Minenko// Загальнодержавний міжвідомчий науково-технічний збірник. Конструювання, виробництво та експлуатація сільськогосподарських машин, вип. 46. – Кіровоград: КНТУ, 2016. – С. 105–108.

9. Boiko A.I. Charts of conditions and mathematical modelling of transition of nozzles into various possible conditions/A. Boiko, V. Savchenko, V. Krot// Вісн. ХНТУСГ ім. Василенка – 2017 – Вип. 181– С. 173–178.

10. Boiko A.I. Mathematical modelling of transition of nozzles for liquid sprayer and generation of microclimate in the premises of greenhouses into various possible conditions /A. Boiko, V. Savchenko, V. Krot// Вісн. ХНТУСГ ім. Василенка – 2017 – Вип. 180– С. 72–77.