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Engineering

Theoretical Aspects of Calculating the Reliability Indicators of Agricultural Machinery

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Abstract. This article presents a fundamentally new methodology and theoretical foundation for calculating the reliability indicators of agricultural machinery. Unlike existing classical theory, this methodology takes into account specific design, soil, climatic, and dynamic operating conditions, such as complex configurations of working parts, high humidity, soil physicomechanical composition, terrain slopes and low contours, alternating dynamic forces acting on working parts, abrasive particles in the working environment and machine interfaces causing intensive wear of parts, and other factors. Structural and logical connection diagrams of the relevant agricultural machinery components for reliability calculations, differential equations for transitions to various states taking into account Markov processes, and an original reliability calculation method for obtaining probabilistic-statistical models are developed. *© 2026 Bull. Natl. Acad. Sci. Georg.*

Keywords: reliability, probability of failure-free operation, agricultural machinery durability, probabilistic-statistical model

Introduction

Improving equipment reliability is a global issue. No machine can be competitive in the global market without high reliability. It should be noted that the reliability of agricultural machinery remains low and does not meet modern scientific and technological requirements. According to official data (Katsitadze, et al., 2024), 22% of total production capacity is devoted to the production of new agricultural machinery, 44% is devoted to maintenance and repair, and 34% – to spare parts. This is a consequence of the low reliability of this equipment, improving which is a source of inexhaustible reserves and is equivalent to increasing the fleet without any capital investment (Katsitadze, et al., 2016).

A general theory of reliability has been developed recently. However, such studies are insufficient for agricultural machinery. The general theory of reliability developed in aviation, radio electronics, automation, and machine building needs to take into account the structural features of agricultural machinery, the specific working conditions, and the modes in them; the stationary failure flow begins relatively lately or does not begin at all; thus, the parts are sent for repairs.

As mentioned above, the calculation of the reliability of agricultural machinery differs in principle from the general theory of reliability developed in aviation, radio electronics, automation, and machine building (Katsitadze, 2001; Katsitadze, 2012). The scheme of functioning of agricultural machinery is presented in Fig. 1.

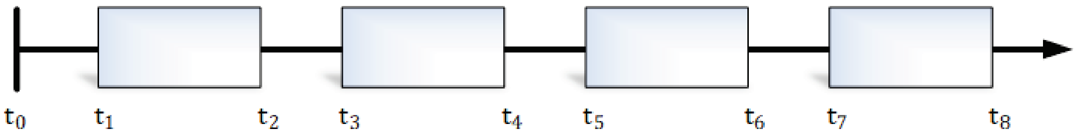

Fig. 1. The scheme of functioning of agricultural machinery.

The following stages of functioning of agricultural machinery according to the scheme are possible: $(t_0 \ldots t_1), (t_2 \ldots t_3), (t_4 \ldots t_5), (t_6 \ldots t_7)$ machinery is working. $(t_1 \ldots t_2), (t_3 \ldots t_4)$ – the adjustment of machinery is being made. $(t_5 \ldots t_6)$ – the service of machinery is being made. $(t_6 \ldots t_7)$ – the repair is being made.

This graph shows one repair cycle and can be used to assess the reliability of agricultural machinery.

When calculating the reliability of agricultural machinery, there is often a situation when the transition from one state to another proceeds step-wise, at a random moment, which is almost impossible to predict. The future development of Poisson's failure flows of recovery time for a recoverable system depends only on its current state and not on what was happening in the past. Such processes are called Markovian processes and are used to account for mass service theory-system graphs. Fig. 2 shows the graphs of the possible condition of agricultural machinery (Katsitadze, 2013).

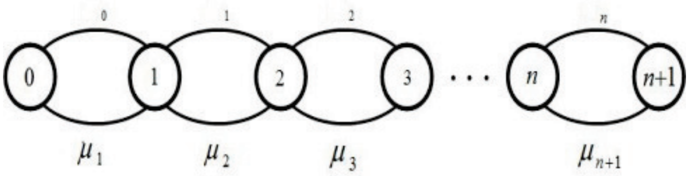

Fig. 2. Graphs of transition of agricultural machinery in various states.

$0,1,2,3, \ldots, n$ – various states of agricultural machinery – $\lambda_0, \lambda_1, \lambda_2, \lambda_3 \ldots \lambda_n$ and $\mu_1, \mu_2, \mu_3 \ldots \mu_n$ (intensities of failures and recovery).

The vertices of the graphs correspond to the states of the machines, and the arcs correspond to the possible transitions from one state to another.

To calculate the probability of transition to different states, Kolmogorov differential equations are determined according to the graphs. Such probabilities are called interval-transient, and the more difficult their calculation is, the more the system states there are. Therefore, the Laplace transform is used to solve such equations:

$$F(S) = \int_0^\infty e^{-st} f(t) dt, \tag{1}$$

where F(s) – is the function transform, f(t) – original.

Kolmogorov differential equations are as follows:

$$\frac{dP_0}{dt} = -(\lambda_{03} - \lambda_{01})P_0, \tag{2}$$

$$\frac{dP_3}{dt} = \lambda_{13}P_1 + \lambda_{03}P_0 \ldots, \tag{3}$$

$$\frac{dP_1}{dt} = \lambda_{01}P_0 - (\lambda_{12} + \lambda_{13})P_1, \quad (4)$$

$$\frac{dP_2}{dt} = \lambda_{12}P_1, \quad (5)$$

Solving a system of differential equations using the Laplace transform with condition $P_0(t = 0) = 1$ gives the following:

$$\lambda(t) = \frac{(\lambda_{03}+\lambda_{01})(\lambda_{03}-\lambda_{13}-\lambda_{12})e^{-(\lambda_{03}+\lambda_{01})t}+\lambda_{01}(\lambda_{13}+\lambda_{12})e^{-(\lambda_{03}+\lambda_{01})t}}{(\lambda_{03}-\lambda_{13}-\lambda_{12})e^{-(\lambda_{03}+\lambda_{01})}+\lambda_{01}e^{-(\lambda_{13}+\lambda_{01})t}}. \quad (6)$$

According to the obtained formula, the so-called approximation of the "bath curve" is made, which adequately reflects the intensity of failures of agricultural machinery during their running in, normal operation, and emergency condition.

In general, the reliability of agricultural machinery is a complex function and can be represented as follows (Katsitadze et al., 2008; Katsitadze, 2013).

$$\phi(t) = f(A, B, C, D, E, K), \quad (7)$$

A is the reliability indicators; B – the durability indicators; C – the maintainability indicators; D – the preservation indicators; E – the complex indicators; K – the factors that take into account the specific operating conditions of agricultural machinery.

Obtaining a mathematical model of reliability is a complex task and therefore it is assessed by separate indicators. These are the single indicators: P(t) – probability of failure-free operation (FOP) of agricultural machinery in the time interval – t, T – time between failures, hour. $\lambda(t)$ – failure rate, hour – 1, $\omega(t)$ – failure flow parameter, hour – 1, t – average recovery time, hour.

Complex indicators: K_1 – readiness factor, K_2 – technical utilization coefficient. In general, FOP can be defined as follows:

$$P(t) = P_1(t)P_2(t), \quad (8)$$

$P_1(t)$ is FOP in case of sudden failures, $P_2(t)$ – FOP for gradual failures. Our theoretical and experimental research (Katsitadze et al., 2001; Katsitadze, 2012). $P_1(t)$ showed that in most cases it is described exponential law, $P_2(t)$ but normal. Then the equation (3) takes the form:

$$P(t) = \frac{e^{-\lambda t}}{\sigma\sqrt{2\pi}} \int_t^{\infty} e^{-\frac{(t-\bar{T})^2}{2\sigma^2}} dt, \quad (9)$$

σ – standard deviation of the indicator reliability; $\bar{T}$ is the mathematical expectation of failure-free time machine operation.

Below is the sequence of reliability calculations according to the following structural and logical diagram (Katsitadze et al., 2008) (Fig. 3).

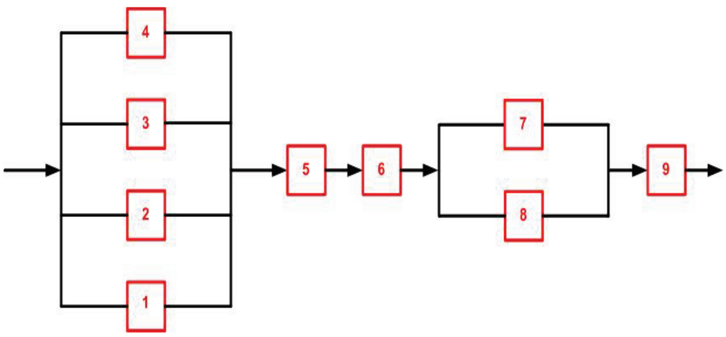

Fig. 3. Structural and logical diagram of connecting machine elements.

Using this scheme, you can calculate the probability of failure-free operation (FBO) of a machine, if this indicator for each structural element is equal to $P_i(t) = 0.85$.

$$P(t) = P_{1\ldots4}(t) \cdot P_5(t) \cdot P_6(t) \cdot P_{7\ldots8}(t) \cdot P_9(t) =$$
$$=(1 - (1 - 0.85)^4) \cdot 0.85 \cdot 0.85 \cdot (1 - (1 - 0.85)^2) \cdot 0.85 = 0.58. \qquad (10)$$

When using this technique, it is necessary to take into account the difference between agricultural machinery and radio electronics objects. The stationary flow of failures in the latter begins much earlier, and in agricultural machinery sometimes does not begin at all and the object is sent for repair. In addition, the reliability of these machines, unlike non-repairable machines, is variable and depends on repair and preventive measures.

Below is a structural and logical diagram of a plow with variable width grip for calculating reliability, which we developed at the patent level (Katsitadze & Kapanadze, 2010; Chalaganidze et al., 2017; Katsitadze et al., 2016) (Fig. 4).

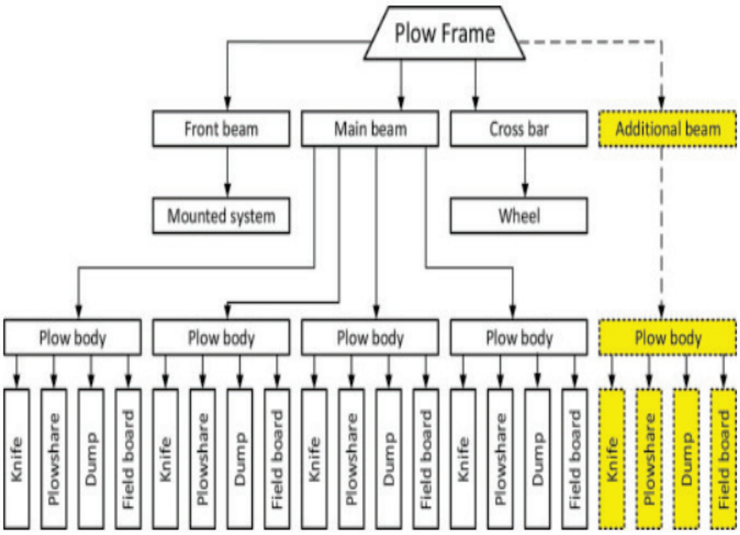

Fig. 4. The structural and logical scheme of a flow for calculation of reliability.

The methodology we propose can be used to calculate reliability indicators for specific agricultural Machine.

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Conclusion

- The design and operation features of agricultural machinery are considered for reliability calculations.
- A methodology has been proposed for calculating single and complex indicators of the reliability of agricultural machines using structural and logical diagrams, and such diagrams have been compiled for specific machines.

- Theoretical prerequisites for calculating the reliability of agricultural machines using Markov processes have been developed, graphs of the transition of machines to various states have been drawn up, and directions for solving Kolmogorov's differential equations have been indicated in order to obtain a mathematical model of reliability.

ინჟინერია

სასოფლო-სამეურნეო ტექნიკის საიმედოობის მაჩვენებლების გაანგარიშების თეორიული ასპექტები

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ნაშრომში წარმოდგენილია სასოფლო-სამეურნეო ტექნიკის საიმედოობის მაჩვენებლების გაანგარიშების პრინციპულად ახალი მეთოდიკა და თეორიული საფუძვლები, რომლებშიც არსებული კლასიკური თეორიისაგან განსხვავებით გათვალისწინებულია ისეთი თავისებური კონსტრუქციული ნიადაგობრივ-კლიმატური და დინამიკური პირობები, როგორიცაა: მუშა ორგანოების რთული კონფიგურაცია, მაღალი ნესტიანობა, ნიადაგის ფიზიკურ-მექანიკური შედგენილობა, რელიეფის დახრილობა და მცირე მოხაზულობა, მუშა ორგანოებზე მოქმედი ნიშანცვლადი დინამიკური ძალები, მუშა გარემოსა და მანქანების შეუღლებებში არსებული აბრაზიული ნაწილაკები, რომლებიც იწვევს დეტალების ინტენსიურ ცვეთას და სხვა ფაქტორები. შედგენილია შესაბამისი სასოფლო სამეურნეო ტექნიკის დეტალების შეერთების სტრუქტურულ-ლოგიკური სქემები საიმედოობის გაანგარიშებისათვის, სხვადასხვა მდგომარეობაში გადასვლის დიფერენციალური განტოლებები მარკოვის პროცესების გათვალისწინებით, ასევე ორიგინალური მეთოდიკა საექსპლუატაციო საიმედოობის ერთეული და კომპლექსური მაჩვენებლების გაანგრიშებისათვის ალბათურ-სტატისტიკური მოდელების მისაღებად.

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