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PROBABILITY MODEL OF STATES OF SYSTEMS OF GRAIN HARVESTERS TAKING INTO ACCOUNT FAILURES

https://doi.org/10.37700/ts.2024.24.198-205

UDC 631.928.93

Hnatyuk O.F. ***Probability model of states of systems of grain harvesters taking into account failures.***

Abstract. *The author proposed analytical statements regarding the probability model of states of grain harvester systems, taking into account failures. The obtained dependences of the state probabilities of grain harvester systems make it possible to establish rational values of machine parameters. The technology for working with dependencies is as follows. A number of parameters, such as* μ_1, λ_{21}, λ_{22}, λ_{23}, λ_{24} *or* λ_{25}, *are adopted on the basis of technical characteristics, and the parameters are set from the constructed dependencies. For example,* λ_1, μ_{21}, μ_{22}, μ_{23}, μ_{24} *or* μ_{25}.

Key words: *failure, model, probability, condition, harvester.*

Гнатюк О.Ф. ***Модель ймовірностей станів систем зернозбиральних комбайнів з врахуванням відмов.***

Анотація. *Автором запропоновані аналітичні викладки щодо моделі ймовірностей станів систем зернозбиральних комбайнів з врахуванням відмов. Отримані залежності ймовірностей станів систем зернозбиральних комбайнів дають змогу встановити раціональні значення параметрів машини. Технологія роботи із залежностями наступна. Приймається на основі технічних характеристик ряд параметрів, наприклад* μ_1, λ_{21}, λ_{22}, λ_{23}, λ_{24} *або* λ_{25}, *і з побудованих залежностей встановлюються параметри. Наприклад,* λ_1, μ_{21}, μ_{22}, μ_{23}, μ_{24} *або* μ_{25}.

Ключові слова: *відмова, модель, ймовірність, стан, комбайн.*

Introduction

Modern grain harvesters are complex systems, and establishing rational parameters of their operation will ensure the efficiency of the functioning of such machines in the future [1].

Existing combine harvesters are aging both mentally and physically [2]. Old harvesters not only no longer meet today's requirements, moreover, with each year of use, their productivity decreases and repair costs increase. In this way, costs for the production of agricultural products increase and its production becomes unprofitable, and it becomes uncompetitive on the market [3].

In order for the equipment to work reliably and efficiently, it is necessary to constantly maintain it in good condition, and therefore constantly invest money in it [4]. When the harvester is new, the costs are small, but when it is worn out, they grow like an avalanche from year to year and can exceed its initial cost several times [5]. And it is no accident that farmers in developed agricultural countries are constantly updating or modernizing equipment. Even the most perfect combine harvester has a tendency to wear out. It is relatively easy to restore the functionality of the threshing and separating device of the combine if spare parts are available [6]. But with the engine it is more difficult. Engines of foreign harvesters require not only high-quality maintenance, but also highly qualified repair, which not every workshop can perform. These engines have some design features, different from domestic ones, and increased requirements for the accuracy of parts selection. And you have to pay for original spare parts from the manufacturer and quality work [7]. High-performance equipment, primarily imported, must work with maximum efficiency, otherwise it will not pay for itself. Summarizing the experience of advanced farmers who work stably with profits, it should be noted that they invest money not just in high-quality repair of the harvester, but also in its modernization, thereby ensuring an increase in the technical level of the existing equipment.

Analysis of recent researches

To ensure the high-quality performance of the technological process, the engine of the harvester must have the appropriate characteristics [8]. The main ones are: power sufficient to perform a technological operation with minimal fuel consumption; required torque reserve; high reliability; ease of maintenance and repair [9].

As a compromise option to restore the technical characteristics of the combine built into the design, there is its modernization with the installation of a new engine [10]. However, during modernization, there is a desire not only to restore the factory indicators of the combine, but also to improve them. Therefore, it is advisable to install a powerful economical engine with a large reserve of torque. In addition, the determining factors are consumer qualities: that the engine is inexpensive to operate and easy to maintain and repair [11].

A grain harvester with a powerful engine will ensure the successful and quick conduct of the harvesting company.But when choosing a model, first of all, you should pay attention not just to the power of the engine, but to the balance of the received power and the power needs of all working units and nodes of the combine (type of threshing-separating device, width of the harvester, capacity of the hopper, etc.), because it is these that will largely determine level of fuel consumption during combining [12]. The greater the torque of the engine and, more importantly, the better it is distributed over the range of revolutions – the faster the working organs of the threshing-separating device of the combine are accelerated and the greater the resistance forces (for example, when a large amount of bread mass is suddenly fed) it is able to overcome without significant reduction of rotation frequency. This makes it possible to thresh with less energy and with minimal loss and damage to the grain [13].

The repair of the grain harvester is carried out in order to ensure the efficiency of this equipment during the harvest. This leads to timely completion, and also allows for a high harvest. So that this efficiency is constantly maintained, and the equipment does not fail at an inappropriate moment, the maintenance of the grain harvester should be carried out regularly according to the established frequency [14].

The periodicity with which the repair of the combine harvester is carried out depends on many factors, among which the following can be singled out separately:

- minimal possibility of failure;
- maximum productivity;
- minimum specific costs during operation;
- average working time during fault-free operation, from failure or to failure.

There is currently no complete single algorithm [15]. Also, there is no standard methodology for substantiating the timing of the recovery of the combine harvester. It is based on the given conditions, which take into account the available statistical data and the experience of using technical means. Failure data is collected, analyzed, grouped by frequency and complexity, averaged data, upper and lower limits of periods of operation without failures are calculated [16]. In this way, both the periodicity of works and the list of performed actions are obtained.

The aim and objectives of research

The purpose of the research is to form analytical statements regarding the probability model of the states of grain harvester systems, taking into account their technical failures.

Research methodology

The mathematical model for grain harvesters was developed taking into account technical failures (Fig. 1). It is characterized by the following states: S_0 – the car is in good working order, idling or moving from parking lot to parking lot, but not collecting; S1 – the machine is in good working order, performs assembly; S_{21} – undercarriage failure; S_{22} – engine failure; S_{23} – failure of technological equipment (harvester, pick-up); S_{24} – hydraulic system failure; S_{25} – control system failure.

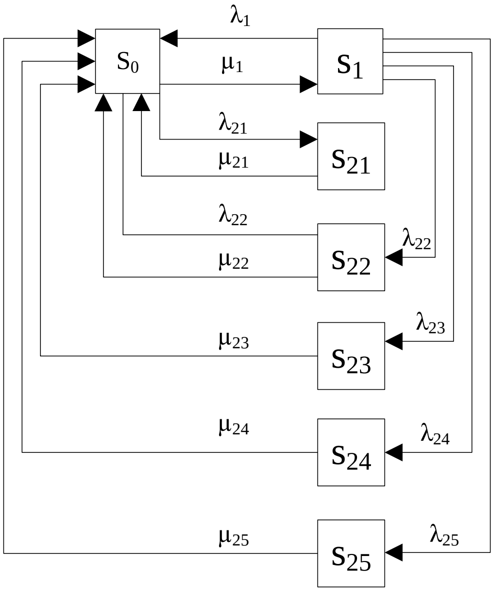

Fig. 1. Scheme of the state of the system of grain harvesters

In such a model, two types of flows occur: trees and hardware failures. Priority is given to the flow of failures, because when they occur, they are processed or repaired first.

From the free state S_0 to the working state S_1, the system goes with the intensity λ_1 of the supply of the working body to the tree. The backward transition is carried out using tree processing with intensity μ_1. When the running gear failure occurs, the system with intensity λ_{21} will go from S_0 to S_{21} state. After performing the repair at a rate of μ_{21}, the system will return to the S_0 state. A motor failure can lead to a transition to position S_{22}, both from state S_0 and S_1 with an intensity of λ_{22}. After repair, the system will go to state S_0 at a rate of μ_{22}. The failure of technological equipment will lead to a transition to state S_{23} from state S_1 with an intensity of λ_{23}. After repair, the system will go from state S_{23} to S_0 at a rate of μ_{23}. Failure of the hydraulic system will bring the system from state S_1 to S_{24} with an intensity of λ_{24}. After repair, the system will go from state S_{24} to S_0 at a rate of μ_{24}. Failure of the control system will bring the system from state S_1 S_{25} with intensity λ_{25}. After repair, the system will go from state S_{25} at a rate of μ_{25} to state S_0.

The unknown parameters λ_{ij} and μ_{ij} are set as follows:

- $\lambda_1 = 1/t_p$, where t_p is the duration of the supply time of the working body;
- $\mu_1 = 1 / t_c$, where t_c is the duration of the felling and wood processing cycle;
- $\lambda_{21} = 1 / t_{21ot}$, where t_{21ot} is the length of time between chassis failures;
- $\mu_{21} = 1 / t_{21v}$, where t_{21v} is the duration of the chassis recovery time;
- $\lambda_{22} = 1 / t_{22ot}$, where t_{22ot} is the time between engine failures;
- $\mu_{22} = 1 / t_{22v}$, where t_{22v} is the duration of the engine recovery time;
- $\lambda_{23} = 1 / t_{23ot}$, where t_{23ot} is the length of time between technological equipment failures;
- $\mu_{23} = 1 / t_{23v}$, where t_{23v} is the duration of time to restore the operational efficiency of the technological equipment;
- $\lambda_{24} = 1 / t_{24ot}$, where t_{24ot} is the length of time between failures of the hydraulic system;
- $\mu_{24} = 1 / t_{24v}$, where t_{24v} is the duration of the hydraulic system recovery time;
- $\lambda_{25} = 1 / t_{25ot}$, where t_{25ot} is the length of time between failures of the control system;
- $\mu_{25} = 1 / t_{25v}$, where t_{25v} is the duration of the control system recovery time.

Research results

The system functioning model will look like this:

$$\frac{dP_0}{dt} = -(\lambda_1 + \lambda_{21} + \lambda_{22}) \cdot P_0 + \mu_1 \cdot P_1 + \mu_{21} \cdot P_{21}$$

$$+\mu_{22} \cdot P_{22} + \mu_{23} \cdot P_{23} + \mu_{24} \cdot P_{24} + \mu_{25} \cdot P_{25};$$

$$\frac{dP_0}{dt} = -(\mu_1 + \lambda_{22} + \lambda_{23} + \lambda_{24} + \lambda_{25}) \cdot P_1 + \lambda_1 \cdot P_0;$$

$$\frac{dP_{21}}{dt} = -\mu_{22} \cdot P_{22} + \lambda_{21} \cdot P_0;$$

$$\frac{dP_{22}}{dt} = -\mu_{22} \cdot P_{22} + \lambda_{22} \cdot P_1 + \lambda_{22} \cdot P_0;$$

$$\frac{dP_{23}}{dt} = -\mu_{23} \cdot P_{23} + \lambda_{23} \cdot P_1;$$

$$\frac{dP_{24}}{dt} = -\mu_{24} \cdot P_{24} + \lambda_{24} \cdot P_1;$$

$$\frac{dP_{25}}{dt} = -\mu_{25} \cdot P_{25} + \lambda_{25} \cdot P_1;$$

$$P_0 + P_1 + P_{21} + P_{22} + P_{23} + P_{24} + P_{25} = 1. \tag{1}$$

Given that the simulations and studies of the operation of grain harvesters are carried out over a long period of time (month, year, etc.), the values of the pij probabilities will fluctuate about a certain average value.

Then we can assume that $P_0 \approx$ const, $P_1 \approx$ const, $P_{21} \approx$ const, $P_{22} \approx$ const, $P_{23} \approx$ const, $P_{24} \approx$ const, $P_{25} \approx$ const.

The error in accepting this assumption does not exceed 8%.

Having solved the system of equations regarding the probabilities of states P_0, P_1, P_{21}, P_{22}, P_{23}, P_{24}, P_{25}, we will obtain expressions for calculating the modes of operation of grain harvesters:

$$P_1 = \frac{\lambda_1}{\mu_1 + \lambda_{22} + \lambda_{23} + \lambda_{24} + \lambda_{25}} P_0; \tag{2}$$

$$P_{21} = \frac{\lambda_{21}}{\mu_{21}} P_0; \tag{3}$$

$$P_{22}=\frac{\lambda_{22}}{\mu_{22}}\cdot\frac{\lambda_1}{\mu_1+\lambda_{22}+\lambda_{23}+\lambda_{24}+\lambda_{25}}P_0; \tag{4}$$

$$P_{23}=\frac{\lambda_{23}}{\mu_{23}}\cdot\frac{\lambda_1}{\mu_1+\lambda_{22}+\lambda_{23}+\lambda_{24}+\lambda_{25}}P_0; \tag{5}$$

$$P_{24}=\frac{\lambda_{24}}{\mu_{24}}\cdot\frac{\lambda_1}{\mu_1+\lambda_{22}+\lambda_{23}+\lambda_{24}+\lambda_{25}}P_0; \tag{6}$$

$$P_{25}=\frac{\lambda_{25}}{\mu_{25}}\cdot\frac{\lambda_1}{\mu_1+\lambda_{22}+\lambda_{23}+\lambda_{24}+\lambda_{25}}P_0. \tag{7}$$

Let's accept that

$$\frac{\lambda_{21}}{\mu_{21}}=\rho_{21};\frac{\lambda_{22}}{\mu_{22}}=\rho_{22};\frac{\lambda_{23}}{\mu_{23}}=\rho_{23};\frac{\lambda_{24}}{\mu_{24}}=\rho_{24};$$

$$\frac{\lambda_{25}}{\mu_{25}}=\rho_{25};\frac{\lambda_1}{\mu_1+\lambda_{22}+\lambda_{23}+\lambda_{24}+\lambda_{25}}=\varphi.$$

After substituting expressions (2)-(7) into equation (1), we obtain the equation for calculating the probability of the P0 state:

$$P_0=\frac{1}{1+\rho_{21}+\rho_{22}+\varphi\cdot(1+\rho_{22}+\rho_{23}+\rho_{24}+\rho_{25})}. \tag{8}$$

By substituting the value of the probability P_0 into the expression (2)-(7), we will find the values of the probabilities P_{21}, P_{22}, P_{23}, P_{24}, P_{25}.

The obtained dependences of the state probabilities of grain harvester systems make it possible to establish rational values of machine parameters. The technology for working with dependencies is as follows. A number of parameters, such as μ_1, λ_{21}, λ22, λ23, λ24 or λ25, are adopted on the basis of technical characteristics, and the parameters are set from the constructed dependencies. For example, λ1, μ21, μ22, μ23, μ24 or μ25.

Below is an example of setting these parameters.

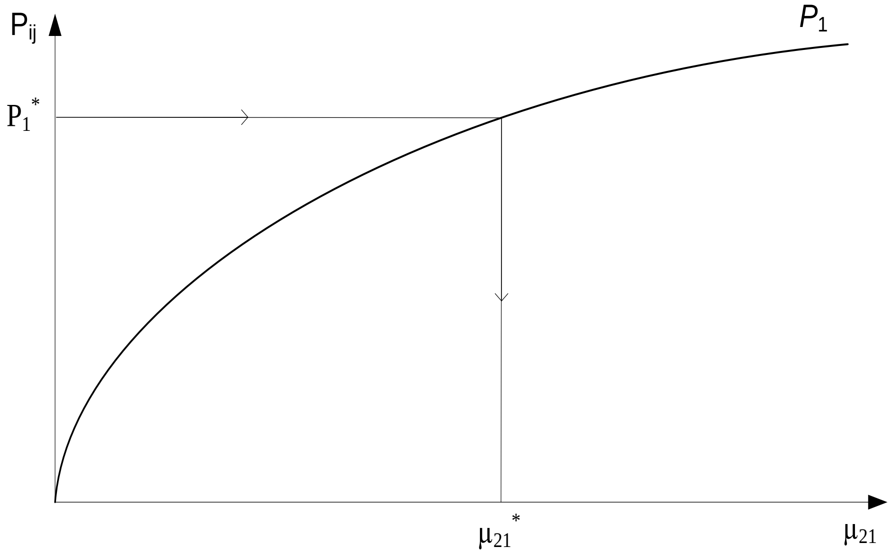

Fig. 2. Dependence of the state probabilities of the combine harvester systems

Set value μ_{21}^{*} allows you to determine the rational, in this case, duration of recovery of the undercarriage of grain harvesters:

$$t_{21}^{*} = \frac{1}{\mu_{21}^{*}}.$$

At the same time, the proper productivity of grain harvesters is ensured, because its maximum value P1* (probability of operation) is reached.

Conclusions

1. The developed model makes it possible to obtain rational modes of supply of raw materials for processing and repair of technological equipment in case of technical failures, given the specified characteristics of the studied harvesters. This will lead to an increase in equipment productivity without significant financial costs.

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