ANALYSIS OF THE RELIABILITY OF MACHINES FOR THE HARVESTING AND TRANSPORT COMPLEX AND JUSTIFICATION OF THE REQUIREMENTS FOR THEIR RESERVATION

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Abstract

Reliable operation of the machines of the harvesting and transport complex is one of the main requirements for the implementation of the technological process of harvesting grain crops. An analysis of the machines of the harvesting and transport complex is presented, as a complex system consisting of many elements, which is performed using modeling methods. Ensuring trouble-free operation of the machines of the harvesting and transport complex is solved by optimization methods, taking into account various ways to ensure their reliability from the perspective of a systematic approach and taking into account a large number of factors: operating conditions of the machines, organization of preparation of equipment for harvesting work and elimination of failures, level of operation. The requirements for the redundancy of individual elements, links and systems of the harvesting and transport complex are substantiated, in combination with monitoring their condition and restoring failed elements, which is a means for creating highly reliable systems from elements with relatively low reliability.

Key words: harvesting and transport complex, machine, reliability, operable condition, failures, redundancy.

Introduction

Ensuring trouble-free operation of machines (energy technical means – combine harvesters – CH and vehicles – V) of harvesting and transport complexes (HTC) of agricultural enterprises is one of the main directions for increasing the efficiency of agricultural production (Ustuanov et al., 2022). Harvesting grain crops is the final stage of its cultivation, and the quantity of harvested grain, its quality and cost largely depend on the correctness of the chosen harvesting technology (Domushchi and Novakovsky, 2013).

The optimal duration of harvesting work can be determined by economic indicators, taking into account the technical condition of harvesting equipment (Domushchi and Molchanyuk, 2022). Reliable operation of HTC machines is one of the main requirements for the implementation of the harvesting process (Gaiduk et al., 2022). Therefore, the tasks associated with ensuring trouble-free operation of HTC machines represent technical optimization solutions taking into account various ways to ensure their reliability using technical services of various levels of service.

Materials and methods

In agriculture, the components of production cycles are probable (stochastic) in nature. This is especially true for harvesting (Domushchi and Suprunyuk, 2022). Therefore, the method for solving the problem is determined by the need to take into account a large number of factors: machine operating conditions, organization of preparation of equipment for harvesting work and elimination of failures, level of operation, etc. All this requires consideration of issues from the perspective of a systematic approach. When analyzing complex systems, we use the modeling method. The accuracy of the resulting solutions depends on the adequacy of the models and the accuracy of the initial information.

We will consider reliability as a complex property that includes reliability, maintainability, durability and storage, i.e. in a certain combination of these properties (Topilin et al., 1999). In most cases, units, components and parts (hereinafter referred to as elements) of harvesting machines (combine harvesters) after a failure are restored or replaced with reserve ones, which makes it possible to restore the functionality of harvesting machines without a long loss of time (Domushchi et al., 2009).

Restoration and preventive maintenance of harvesting machines does not eliminate the possibility of failures, but significantly reduces their likelihood, i.e. increase reliability (Domushchi et al., 2004). A mathematical description of the processes of failure occurrence taking into account restoration and technical service (prevention) is called reliability modeling (Molchanyuk et al., 2022).

Results and discussion

When determining the reliability of HTC machines with restoration, we consider it as a complex system consisting of many elements. In the general case, the operation of harvesting machines in the management center can be represented as two alternating intervals:

t_{ij} – operating time;

τ_{ij} – downtime.

We will represent the harvesting of grain crops HTC as a set of states of combine harvesters – N and vehicles – N_t, changing and alternating in time. In this case, the following options are possible: when all machines (CH and V) are working in the V, the productivity is the maximum possible; the technological complex operates with reduced efficiency – some of the machines are faulty; The technological complex does not work at all – all the machines are faulty (Domushchi et al., 2023).

We determine the operating efficiency of the V by assessing the impact of failures of various machines on the degree to which their productivity is realized. Total number of unit failures – $n(t)$, units. in the time interval $[0; t]$ is determined from the equality:

$$n(t) = \sum_{i=1}^{n} n_i(t), \qquad (1)$$

where $n_i(t)$ – number of failures of the i-th element during time – t, units.

The total operating time of the energy means – machine (CH and V) – t, hours is determined from the expression:

$$t = T_p(t) + T_в(t), \qquad (2)$$

where $Tp(t)$, $Tв(t)$ – the total time of operation and restoration of the machine's operability respectively, hours.

Let us imagine the number of CH – N, units. in the V, as the sum of technically operable and recoverable objects:

$$N = N_p(t) + N_в(t) \qquad (3)$$

Let the technological complex operate in a stationary mode, and the distributions of failure-free operation and recovery are described by an exponential function. Then we can assume that the values of the probability of failure-free operation and availability coefficient - K_g are equal (Domushi et al., 2022):

$$K_г = \left(1 + \frac{T_В(t)}{T_р(t)}\right)^{-1}; \quad K_г = \left(1 + \frac{N_{Bi}}{N_{Pi}}\right) \tag{4}$$

Total downtime of CH – V, hours due to the "*i-i*" machine in the time interval [*0; t*] is determined from the expression:

$$T_В = \lim_{t \to \infty} \frac{T_{Bi}}{t} = K_г \sum_{i=1}^{N} \frac{\tau_{Bi}}{t_i}. \tag{5}$$

The average failure time per unit time per machine is λ_i, *h*. For elements of each type is determined from the expression (Wentzel, 1972):

$$\lambda_i = \lim_{t \to \infty} \frac{n(t)}{t} = \frac{K_г}{t_{pi}}. \tag{6}$$

The average time of failure-free operation of the combine – t_p, is determined from the expression:

$$\bar{t}_p = \left(\sum_{i=1}^{N} \frac{1}{t_{pi}}\right)^{-1}. \tag{7}$$

The average downtime of a combine is determined from the expression:

$$\bar{\tau}_В = \bar{t}_p \sum_{i=1}^{N} \frac{\tau_{Bi}}{t_{pi}}. \tag{8}$$

To determine the probability of failure-free operation of an CH, it is necessary to take into account all mutually exclusive ways of failure occurrence. It should be noted that restoration without redundancy increases reliability only in the sense of availability, while the probability of failure-free operation does not change.

Redundancy of individual elements of units and V systems as a whole, combined with monitoring their condition and restoration of failed elements, is a means for creating highly reliable systems from elements with relatively low reliability (Domushchi et al., 2018). Reservation of HTC with complete machines (CM) involves keeping fluctuations in the availability factor – k_g within the planned value. This will ensure that harvesting work is completed within the established agrotechnical timeframes.

Element-by-element redundancy of the V provides for separate backup vehicles in the technical waiting area; elements (parts, assemblies) for harvesting machines at different reserve warehouses; backup machines during operation for the harvesting unit or technological complex. With fractional redundancy, as with general redundancy, there can be a constantly on and cold reserve.

Let us present the optimal reservation problem as follows. Let there be a system consisting of *N* subsystems or elements independent from each other. Each subsystem itself can represent a parallel, serial or some other connection of similar elements. So, if we talk about providing the system with spare elements, then a subsystem can be considered a link consisting of machines of the same type, which in case of failure are replaced by machines of the same type. In relation to a machine, assembly units, assemblies or individual parts, etc. can be considered as elements.

Assuming an exponential law of distribution of reliability indicators, the FBR of the CH link with "*X*" reserve combines when redundant with a fractional multiplicity for any value of "*m*" can be written as (Wentzel, 1972):

$$P_m(t) = e^{-\lambda t}\sum_{i=1}^{x}\frac{(\lambda_0 t)^i}{i\,!}, \qquad (9)$$

then $\lambda_0 = N\lambda_i$ – failure rate.

Let us evaluate the influence of the number of reserve combines on the readiness of technological units (TU) of the HTC. In the general case, we will assume that the technical task functions effectively if the number of faulty machines does not exceed the number of standby machines. According to Poisson's law, the probability of occurrence of "*n*" failures in the interval *[0; t*] will be equal to (Wentzel and Ovcharov, 1991):

$$P_n = \frac{(\lambda t)^n e^{-\lambda t}}{n} \qquad (10)$$

In this case, the technical task will work flawlessly if not a single machine fails, if one or two fail, etc. up to "*x*" inclusive.

The probability that the technical assignment will not fail (will work with the same efficiency) is equal to the sum of the specified probabilities, i.e.:

$$P_m(n < x) = e^{-\lambda t}\sum_{i=1}^{x}\frac{(\lambda_0 t)^i}{i\,!} \qquad (11)$$

The harvesting and transport complex, consisting of "*m*" main and "*x*" reserve combines – *N*, will fail when using all the main and reserve – (*m*+*x*) combines. Time to failure will be equal to the sum: $t_c = t_1 + t_2 + \ldots + t_n$, i.e. there is a need for spare backup elements.

Assuming that the distributions of all time values "*t*" obey the same law, we can determine the number of reserve elements using the formula (Enakiev et al., 2016):

$$n_p = \left[\frac{\dfrac{2t_n N}{t_э}}{\sqrt{\dfrac{(A\nu)^2 + 4tN}{t_э}} - A\nu}\right]^2 - N \qquad (12)$$

From expression (12) it is clear that ensuring the operation of the system with a given confidence probability (*A*) is influenced by the designed and actual service life of the elements (t_n, t_e), the number of machines in the V (*N*) that this element uses and the coefficient of variation (ν).

The presented methodology for assessing the reliability of combine harvesters and HTC vehicles indicates the need for repair and technical actions and justification of the requirements for redundancy of HTC elements and machines.

Conclusion

An analysis of the work of the harvesting and transport complex is presented, as a complex system consisting of many machines – energy technical means – grain harvesters and vehicles, which is performed using modeling methods.

Ensuring trouble-free operation of harvesting and transport complex machines is solved by optimization methods, taking into account various ways to ensure their reliability from the perspective of a systematic approach and taking into account a large number of different factors – production, technological, technical and organizational.

The requirements for the redundancy of individual elements and machines of the harvesting and transport complex, in combination with monitoring their condition and restoring their functionality, are substantiated.

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