SUBSTANTIATION OF REQUIREMENTS FOR THE RESERVATION OF ELEMENTS OF COMPLEX TECHNICAL SYSTEMS FOR HARVESTING GRAIN CROPS

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ABSTRACT

An analysis of the reliability of complex technical systems for harvesting grain crops, taking into account their trouble-free operation, is presented. The model of functioning of harvesting machines and vehicles as a complex technical system, as a part of harvesting and transport complexes has been substantiated. A technique has been developed for the effective replacement of parts, components and assemblies of combines of technological complexes for harvesting grain crops.
Key words: system, harvester, reliability, service, parts, units, assemblies, probability, modeling.

INTRODUCTION

Reliable functioning of machines of complex technical systems - harvesting and transport complexes for harvesting grain crops - is one of the main requirements when performing the harvesting process. Practical problems associated with the smooth operation of complex technical systems during their formation and operation is solved by optimizing various ways to ensure their reliability.

THE STATEMENT OF THE PROBLEM

The method for solving the problem is determined from the conditions taking into account a large number of factors: operating conditions of machines, organization of preparation of equipment for cleaning and troubleshooting, level of operation, etc. All this requires consideration of issues from the standpoint of a systematic approach. When analyzing complex systems, we use the modeling method. The accuracy of the solutions obtained depends on the adequacy of the models and the accuracy of the initial information.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Reliability will be considered as a complex property, including reliability, maintainability, durability and safety, that is, in a certain combination of these properties (Anilovich et al., 1996).

In most cases, parts, assemblies and assemblies (hereinafter elements) of harvesting machines are restored or replaced with backup ones after failure, which allows you to restore operability without a long loss of time (Kravchuk and Miller, 2009).

Recovery and preventive maintenance of machines do not exclude the possibility of failures, but significantly reduce their likelihood, i.e. increase reliability (Dumenko and Boyko, 2011).The mathematical description of failure processes taking into account recovery and prevention is called reliability modeling (Dumenko, 2010).

Determining the reliability of the machines of the harvesting and transport complex with restoration, we will consider it as a complex system, consisting of many elements. In the general case, the operation of the harvesting machines of the complex can be represented in the form of two alternating intervals: operating time – «t_{ij}» and idle time – «τ_{ij}» (Sidorchuk et al., 2011).

The functioning of a harvesting and transport complex containing "N" grain harvesters and "N_T" vehicles will be represented as a set of states that change and alternate in time. In this case, several options are possible. The first option, all machines work in the harvesting and transport complex - the maximum productivity of the complex. The second option, the harvesting and transport complex, works with reduced efficiency - some of the machines are out of order. The third option, the harvesting and transport complex does not work - all the machines are out of order (Enakiev et al., 2016).

PURPOSE OF RESEARCHES

Ensuring the reliability of complex technical systems for harvesting grain crops through the redundancy of elements and assemblies.

MATERIALS AND METHODS

The effectiveness of complex technical systems can be determined by assessing the impact of failures of various machines on the degree of realization of their productivity. The total number of unit failures during the time interval [0; t] is equal to:

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

where $n_i(t)$ – is the number of failures of the i-th element during time «t».

The total running time of the unit:

$$t = T_p(t) + T_в(t), \tag{2}$$

where $T_p(t)$, $T_в(t)$ – is the total recovery time of the unit.

The number of combine harvesters in the complex N, units can be calculated as the sum of technically sound machines Np, units and faulty machines Nв, units for time (t), hours:

$$N = N_p(t) + N_в(t) \tag{3}$$

Let the complex functions in the stationary mode, the distributions of failure-free operation and recovery be described by an exponential function. Then we can assume that the values of the indicators of the *probability of no-failure operation (PNO)* and the availability factor $K_Г$ are equal (Domuschi et al., 2017).

$$K_Г = \left(1 + \frac{T_B(t)}{T_p(t)}\right)^{-1}; \quad K_Г = \left(1 + \frac{N_{Bi}}{N_{Pi}}\right) \tag{4}$$

The total downtime of the combine harvester $T_{Bi}(t)$ due to the i-th unit in the time interval [0; t] is defined from the expression:

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

The average failure time per unit of time – λ_i per machine for elements of each type is determined from the expression:

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

The average uptime of the combine 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 the combine is determined from the expression:

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

To determine the PNO of combine harvesters, it is necessary to take into account all mutually exclusive ways of occurrence of failures. It should be noted that the reliability of the system increases when the operability is restored without redundancy of elements, only in the sense of the technical readiness of the system, while the PNO does not change.

Reservation of harvesting and transport complexes with complete units - combine harvesters assumes keeping Kg fluctuations within the planned value. This will ensure the completion of harvesting operations within the established agro technical terms. The element-by-element reservation provides for: individual machines in the area of use; elements (parts, assemblies) for machines; large units for the complex. With fractional redundancy, as with general redundancy, there can be always-on and cold reserves.

RESULTS

We represent the problem of optimal redundancy as follows. Let a system consisting of «N» independe subsystems or elements. Each subsystem itself can represent parallel, sequential, or some kind of connectic of the same type of elements.

The system is provided with spare elements, when a link consisting of units of the same type considered as a subsystem, the replacement of which, in case of failure, is carried out by units of the san type. With regard to the combine, assembly units, subassemblies or individual parts can be considered elements (spare parts).

The probability of failure-free operation $P_m(t)$ of a link of combine harvesters with X reserve harveste for any value of "m", with fractional redundancy and the assumption of an exponential law of distribution reliability indicators, can be obtained from the expression:

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

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

Let us estimate the influence of the number of reserve combines on the readiness of the technologic links of the harvesting and transport complex. In the general case, we will assume that the technological lir functions effectively if the number of faulty machines does not exceed the number of reserve ones.

According to Poisson's law, the probability of occurrence of "n" failures P_n on the interval [0; t] will be equal to (Domuschi and Osadchuk, 2020).

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

In this case, the technological link will work flawlessly if not a single machine fails. Also, th technological link will require spare elements if one, two or more machines up to «X» fail.
The probability that a technological link will not fail (will work with the same efficiency) is equal to the su of the indicated probabilities, i.e.:

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

Harvesting and transport complex, consisting of "m" main and "X" standby combines - N, will fail whe using all main and standby (m + x) combines. MTBF will be equal to the sum:
$t_c = t_1 + t_2 + \ldots + t_n$, i.e. there is a need for spare parts.

Assuming that the distributions of all values of "t" obey the same law, it is possible to determine th number of reserve elements np, od. to ensure the operation of the system with a given confidence level - (Domuschi and Ustuyanov 2020):

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

where t_n – projected service life of the elements (spare parts), hours;
$t_з$ – actual life of the elements (spare parts), hours;
N – the number of machines in the harvesting and transport complex, units;
ν – the coefficient of variation.

Using the results of experimental studies (Domushchi et al., 2018; Domushchi et al., 2019) the time for tl delivery of spare parts (SP) from different storage levels was determined (Table 1).

Table 1 Distribution of delivery times for spare parts from different storage levels

Spare parts storage levels (group of complexity of refusal)	Number of refusals by difficulty groups, units	Spare parts delivery time, hours.	Time of car movement in one direction, hour.	Average distance of delivery of spare parts, km	Average vehicle speed when delivering spare parts, km / h	Spare parts delivery time, hours.	
						for one non-working state	for all non-working states
1.Warehouse complex (1 group of complexity)	18,7	0,1	0,08	1,19	15	0,13	2,43
2.Warehouse brigade or farm (2 group of difficulty)	2,86	0,1	0,26	5,77/ 3,91*; 7,62**	22	0,36	1,03
3. District or regional warehouse (3rd group of difficulty)	0,44	0,7	2,02/ 1,01	30,31/ 22,69**	30	2,72	1,19
TOTAL	–	–	–	–	–	–	4,65

*– to the warehouse of the brigade; ** – to the farm warehouse.

When calculating, the following conditions are accepted:

1) When a spare part is requested, there is always a vehicle in the warehouse.

2) In the warehouses, spare parts of such groups of complexity are stored: warehouse of the technological complex - the 1st group of complexity; warehouse of the brigade or farm - the 2nd group of complexity; district level warehouse - 3rd group of complexity.

3) The distance from the warehouse of the district or regional level was determined as the sum of the distances to the warehouse of the farm and from the warehouse of the farm.

4) Spare parts are delivered by the farm's vehicle, that is, they will move to the warehouse in one direction and back to the other.

Redundancy of individual elements of links and systems in conjunction with monitoring their condition and restoration of failed elements is a means for creating highly reliable systems from elements with relatively low reliability.

CONCLUSIONS

1. The described methodology and the results of assessing the reliability of machines of complex technical systems indicate the need for repair and technical measures and substantiation of the requirements for the reservation of elements and units of harvesting and transport complexes at various storage levels.
2. The effective operation of complex technical systems is influenced by the projected and actual service life of the elements (spare parts), the number of machines in the harvesting and transport complex, the coefficient of variation and the delivery time of spare parts from different storage levels.

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