To the problem of efficiency of reliability assessment of agricultural units

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Abstract. The theoretical analysis of the processes occurring in operation, which determine the reliability of the elements of agricultural units and machines, made it possible to develop a universal approach to the construction of mathematical models of reliability. Practical use of the proposed reliability models is advisable both for accelerated assessment and for predicting reliability at the resource design stage. This article proposes a method for assessing and predicting the reliability of a complex system, if there is information about the reliability level of a sample of its elements.

1. Introduction
The improvement of domestic agricultural units is directly related to ensuring the required level of reliability. Repair and maintenance of various units in the machines is laborious, and failures in operation can lead to emergency situations. Therefore, the identification of the causes and patterns of failure of parts, the development of methods for assessing the reliability of its elements, the search for ways to increase the durability and reduce the consumption of spare parts are urgent problems of the domestic agricultural engineering.

A mathematical model of reliability can not only speed up the search for optimal solutions, but also clarify predictive estimates of reliability indicators. Anilovich V.Ya., Karpov V.G., Pogorely L.V., Khazov B.F. performed the fundamental experimental and theoretical work on increasing and optimizing durability, modeling the reliability of agricultural machines and tractors. and etc. The generally accepted criteria used to assess and predict product reliability are the wear rate and specific pressures on the working surface of parts. But the need to model the durability of the product arises in other parameters as well. As experimental studies and theoretical calculation methods improve, the method of manufacturing parts, chemical and structural composition, the nature of surface treatment, which determine the wear resistance and strength of elements, can be attributed to the number of standardized reliability indicators. In order to take the necessary measures in a timely manner to meet the specified requirements for products, it is necessary to have a complete picture and reliable information about the level of reliability of the machine before the start of its serial production [1-5].

Based on previous experience and statistical information on failures in operation, it is necessary to develop methods and recommendations aimed at predicting the optimal reliability of elements of agricultural units, taking into account their initial characteristics.
2. Materials and Methods

The probability of failure-free operation $R_c(t)$ of a system consisting of $n$ sequentially operating elements with a sequential structure is generally accepted to be determined by the formula:

$$R_c(t) = \prod_{i=1}^{n} R_i(t),$$

where $R_i(t)$ - probability of failure-free operation of the $i$-th element.

The main disadvantage of this approach should be considered that for its implementation it is necessary to know the probability of failure-free operation of all elements, which is practically impossible with a large number of elements included in the machine. In practice, the problem often arises of assessing the reliability of a system (machine) by the known indicators of the reliability of its individual elements. In order to obtain such information, the technical condition of agricultural units was investigated (a mounted loader with replaceable working bodies PFP-2, a machine for spreading organic fertilizers from heaps of RUN-15B, an aggregate for surface application of liquid complex fertilizers and pesticides APV-5 and an aggregate for subsoil application of liquid complex fertilizers AVB-5), received in the first overhaul [6-11].

The probabilities of failure-free operation $R_i$ of each node for the given values of the operating time $T$ (1 - 6000 hours, 2 - 4000 hours, 3 - 2000 hours) are determined by the formula:

$$R_i = \exp \left[ - \left( \frac{T}{a_i} \right)^b \right],$$

where $b = 2.7$ and $a_i = \frac{T_i}{\Gamma(1+\frac{1}{b})}$ parameters of the shape and scale of the Weibull distribution.

The obtained values of probabilities are entered into table 1.

**Table 1.** Probabilities of failure-free operation of the main units of agricultural machines for a given operating time.

| № | Name of nodes | $R_{(6000)}$ | $R_{(4000)}$ | $R_{(2000)}$ | Average node resource $T$, moto/hour |
|---|----------------|------------|------------|------------|----------------------------------------|
| 1 | Engine         | 0.01       | 0.1        | 0.44       | 1920                                   |
| 2 | Clutch         | 0.01       | 0.1        | 0.47       | 1980                                   |
| 3 | Gearbox        | 0.01       | 0.15       | 0.48       | 2000                                   |
| 4 | Front axle     | 0.05       | 0.25       | 0.72       | 2700                                   |
| 5 | Hydraulic system | 0.26     | 0.635      | 0.93       | 4770                                   |
| 6 | Mechanism of the Turn Control | 0.71 | 0.839 | 0.983 | 7960                                   |
| 7 | Cardan transmission | 0.64 | 0.863 | 0.977 | 7230                                   |
| 8 | PTO (power take-off) | 0.65 | 0.864 | 0.978 | 7260                                   |
| 9 | Pneumatic system | 0.58     | 0.832      | 0.972      | 6670                                   |
| 10 | Rear axle      | 0.02       | 0.125      | 0.72       | 2700                                   |

The increase in the resource of the part can be achieved in various ways, and each of them provides different ways of increasing the durability to the required level. Increasing the resource when changing only one of these parameters: hardness (H), mass of the part (G) or its kinematic accuracy ($\Delta$) is not always possible. The general view of the dependence of the parameter of increasing the resource $\beta_T$ of parts on the listed factors is (for parts with low hardness) [12-15]:

$$\beta_T = \beta_G^{0.8} \beta_H^{2.5} \beta_\Delta^{(0.8-4)}$$ (3)
3. Results

Taking into account the experimental and theoretical data, the optimal (really possible) increase in the resource is in the range $\beta_t = 1.6 \ldots 1.8$. A program has been developed that allows, for a given value of $\beta_t$, by varying the above parameters (with given intervals of change of values $\beta_N = 1 \ldots 1.5$, $\beta_C = 1 \ldots 1.8$, $\beta_G = 1 \ldots 1.5$), to find a combination of parameters providing a minimum increase in costs per unit $\beta_C$.

The use of materials with low mechanical properties leads to an increase in the size of these parts, and hence the mass of the entire machine, which is an ineffective solution to the issue of increasing reliability. Therefore, modern methods of increasing the durability of elements are associated with an increase in wear resistance, the use of progressive materials with improved strength characteristics.

To assess the indicators of the durability of the nodes, parts for which the spread of factors within certain limits relative to the nominal values were selected. Taking into account the small size of the data sample ($n = 10$), when determining the parameters of the empirical distribution function, a statistical estimate of the probability was used, which is plausible on average. Having given the probability of no-failure operation for the parts of the unit $(R)$, we can obtain the probability distribution function of the no-failure operation of the system $F^*(\frac{R}{t})$ for different periods of operation. To normalize this function, we use the coefficient

$$F_1 = 1 - \exp \left[ - \left( a_c(t) \right)^{-\frac{b_c(t)}{t}} \right]$$

Then the normalized probability distribution function (at $0 \leq R \leq 1$) will have the form:

$$F^*(\frac{R}{t}) = 1 - \exp \left[ - \left( \frac{R}{a_c(t)} \right)^{b_c(t)} \right] \left/ \left( 1 - \exp \left[ - \left( a_c(t) \right)^{-\frac{b_c(t)}{t}} \right] \right) \right.$$  \hspace{1cm} \hspace{1cm} (5)

where $a_c(t)$ и $b_c(t)$ – functional relation of changing the parameters of the probability distribution law of failure-free operation.

Calculating the probability of no-failure operation of nodes $R$ and the given values of the operating time $t$ values of the normalized distribution function $F^*(\frac{R}{t})$, we obtain a series of graphs (Fig. 1).

It can be seen from the graphs that with an increase in the durability of the limiting parts of the nodes under consideration by 40 ... 60%, the number of failures to run 2000 motor-hours with a probability $R = 0.5$ will be reduced by 2 times (graph 4, Fig. 1) in comparison with the original version (graph 3, fig. 1). This indicates that the durability should not be increased for the entire machine, but only for those parts which characteristics do not correspond to the required level of reliability.

**Figure 1.** The normalized function of the probability distribution of the failure-free operation of the nodes: 1 - 6000 motor-hours, 2 - 4000 motor-hours, 3 - 2000 motor-hours, 4 - 2000 motor-hours when using parts with increased durability.
4. Conclusions
The proposed method for assessing the reliability of a system (machine, unit) makes it possible to predict the number of failures with a given probability to the specified operating time. For example, graph 1 (Fig. 1) shows that with the probability of no-failure operation of the unit $R=0.5$, 72% of the parts will fail for a machine with an operating time of 6000 motor hours. This approach more fully characterizes the reliability of the machine than existing methods.

Since the function $F^*(R/i)$ characterizes reliability integrally (on average), it makes it possible to selectively assess the reliability of the unit. This makes it possible to compare the level of reliability of various systems with each other in the presence of a significantly smaller amount of information than when using the classical dependence to determine the probability of failure-free operation when the elements are connected in series. In addition, this method allows predicting the reliability of transmission units at the design stage.

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