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RESEARCH ON THE PARAMETERS AND CHARACTERISTICS OF ROAD EQUIPMENT FAILURES

Abstract. *The parameters and characteristics of failures of road equipment for road construction are investigated. Attention is paid to the main types of distribution of equipment operation time to failure on the basis of exponential, Weibull, gamma, normal and logarithmically normal. Thus, the logarithmic normal distribution is used when the development of the process leading to failure can be represented as the product of successive independent random variables (for example, crack growth). that the uptime and useful life of the technique depend on a large number of factors, some of which are beyond control and others are established with a certain degree of uncertainty. The systems of machine maintenance and the laws of distribution of operating time for failure and the duration of failure elimination are considered. The influence of parameters on ensuring the effective use of equipment in the formation of a construction project is determined.*

Keywords: *failure, parameters and characteristics, types of wear, distribution laws, maintenance, mathematical expectation.*

1. Introduction. Modern requirements of the construction industry for road equipment provide for the minimization of energy consumption with the implementation of high quality of the technological process. One of the directions for solving these problems is the trouble-free operation of prefabricated units and machine parts as a whole. At the same time, it is necessary to take into account the implementation of the technological process in relation to the environment, to identify the reasons for the gradual change in the technical characteristics of the machine as a result of its operation. Situation is complicated by the fact that the uptime, operating life and shelf life of the machine depend on a large number of factors, some of which are beyond control, while others are set with a certain degree of uncertainty. Therefore, the consideration of the machine maintenance system and the laws of the distribution of operating time per failure and the duration of elimination of failures is an urgent task.

2. Analysis of previous studies. The reliability of road equipment is the main factor in ensuring the minimization of energy costs with the implementation of high quality of the technological process. A number of works are devoted to the study of reliability. Thus, the work[1] highlights the issues of ensuring the reliability of machines during design, manufacture, operation and repair. An interrelated set of issues of friction and wear, causes of changes in the technical condition of machines and the physics of failures is considered. reliability theories. The work[4] reveals methods for improving the reliability and durability of parts and assemblies of light industry machines. The works[5,6] provide the justification of engineering solutions and the methodology of the system approach and scientific research, including data for possible use in the study of the reliability of systems. In the works[7,8] the main attention is paid to the mathematical apparatus for assessing the indicators of reliability of agricultural machinery, the data of probabilities and mathematical statistics are given. The paper[9] highlights the issues of ensuring the reliability of machines and the role of technical service in ensuring the highly efficient functioning of the technological process of livestock production. In the work [10] for the formation of optimal strategies for managing production stocks of an enterprise, the problems of building stochastic modeling in the management of production stocks are analyzed. The main parameters in this work are investigated precisely on the main theoretical provisions of the cited works for specific characteristics of possible failures of parts and assembly units of road machines and equipment, which will be the initial information for the development of a program and algorithms for the effective use of equipment in a certain technological process of road construction.

3. Purpose and objectives of the study. The purpose of the study is to study the parameters and characteristics of failures of road equipment for road construction. To achieve the goal, the following tasks are solved:

- assessment of the technical condition of machines and mechanisms, based on determining the degree of wear and tear of machines;
- research and determination of parameters and characteristics of failures of road equipment.

4. Presentation of the main material.

4.1. Assessment of the technical condition of machines and mechanisms, based on determining the degree of wear and tear of machines.

The initial stage in determining the efficiency of the machine operation is the analysis of the technical condition and the degree of use of the machines in the previous period. Assessment of the technical condition of machines and mechanisms is based on determining the degree of wear and tear of machines (Fig. 1). Depending on the degree of wear of individual parts of prefabricated units, machine assemblies, their possible failures are determined, the expediency of the cost of their repair in order to restore the functions of operability is assessed.

Using the method of expert assessments of the technical condition of machines and equipment, the coefficient of real physical wear is defined as the average value of wear of the most important parts, weighted by their share in the total or renewable cost of the machine The failure flow is understood as a sequence of failures that occur one after another during the operation of machines [1]. The failures of assembly units or parts are random variables, each of them can take only one possible value with a certain probability, that is, they are discrete quantities. Like any discrete quantity, the number of failures has its own numerical values, which are called the numerical characteristics of a random variable. These include mathematical expectation, which is approximately equal to the mean value of failures, variance, mean square deviation, coefficient of variation, and others.

4.2. Study and determination of parameters and characteristics of failures of road equipment.

The failure flow parameter $\omega(t)$ is the main indicator of the reliability of the object and is the ratio of the average number of failures of the restored object for its arbitrarily small operating time to the value of this operating time and is determined through the characteristic of the failure flow based on the equation:

$$\omega(t) = \frac{dH(t)}{dt}, \quad (1)$$

where $H(t)$ is a characteristic of the failure flow, which is a mathematical expectation of the number of failures $r(t)$ over time t: $H(t)=M(r(t))$ [1].

Then the failover flow parameter

$$\omega(t) = \lim_{\Delta t \to 0} \frac{M[r(t+\Delta t)] - M[r(t)]}{\Delta t}, \quad (2)$$

where Δt is a sufficiently small time interval.

In terms of its physical content, the failure flow parameter ω is the rate of occurrence of failures, i.e. it is determined by the number of failures per unit of time or operating time.

When operating machines after some initial operating time, the failure flow parameter is constant $\omega(t)=\omega=const$ [2].

The mathematical expectation of the number of failures gives much less information about failures than the law of their distribution. To determine the law of distribution of failures of machines, let's consider the probability of trouble-free operation – "the probability that within the operating time the failure of an object will not occur" [1] and represents an unconditional probability that the failure will not occur in the time interval from 0 to *t*, but will occur in the time interval from *t* to ∞:

$$P(t) = \int_t^{\infty} f(t)dt . \quad (3)$$

The probability of failure is determined by the formula: Q(t)=1-P(t), and the curve of the function is a mirror image of the fault-free probability curve.

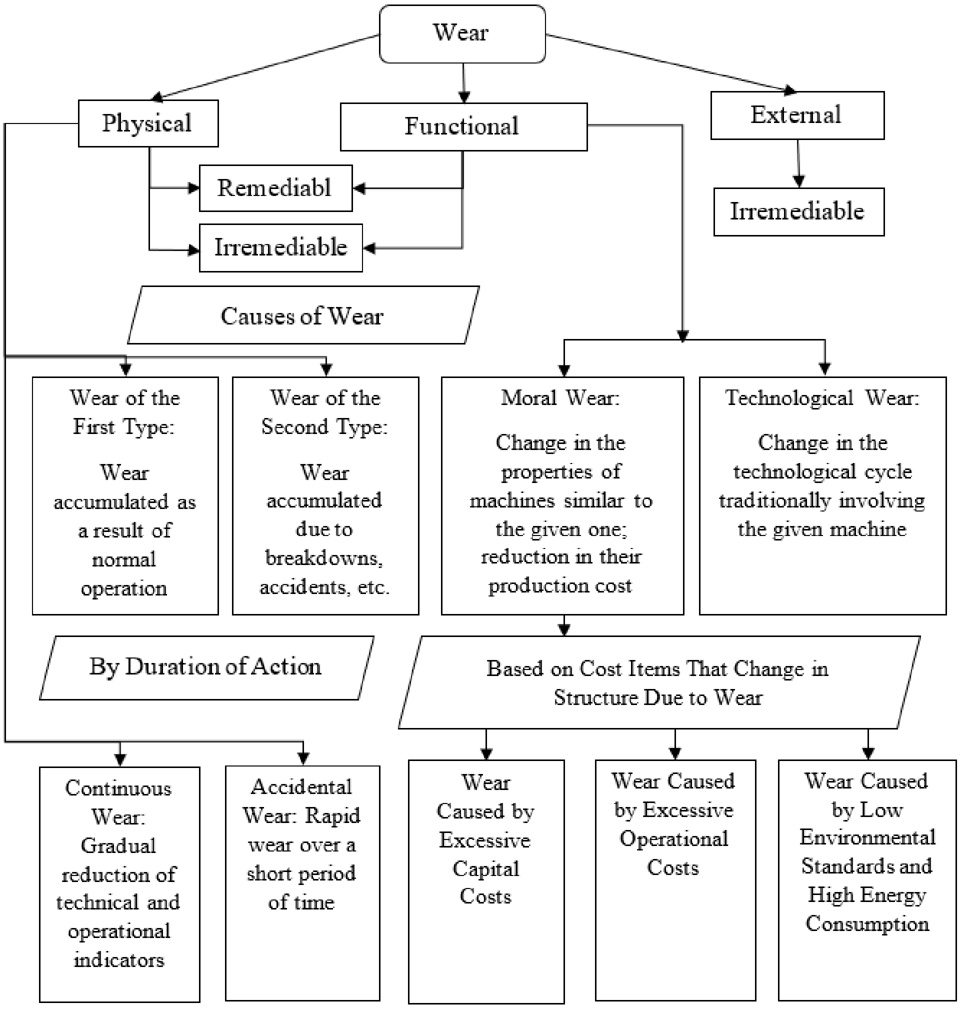

Fig. 1. Types of wear and tear

Random time intervals between events in the requirement stream can be subject to different distribution laws. The most acceptable distributions, as shown by a number of works on the theory of mass service [1,2], are the Poisson distribution; Exponential; Weibulla; gamma distribution; log-arithmic; normal;

The exponential time distribution between failures is asymptotic when fault flows overlap (combine) and when random rarefaction of the failure flow occurs.

The Weibull distribution is one of the three asymptotic distributions of extreme parameter values. It is used to justify the failure model. The gamma distribution is a convolution of exponential distributions, and it is used as a model of product failures with margin. The normal distribution is used when the runtime to failure of the product can be represented as the sum of a sufficiently large number of uniformly distributed terms. when the development of a process leading to failure can be represented as the product of successive independent random variables. The Poisson flow is characterized by the fact that the probability of receipt in the time period *t* is equal *to k* requirements,

$$P_k(t) = \frac{(\lambda t)^k}{k}\exp(-\lambda t), \quad (4)$$

where λ is the intensity of the failure flow.

As it is known [1,5], the simplest flow of requirements is characterized by the following properties: stationarity, ordinariness and absence of consequences. In this case, the flow is stationary within the operation of construction machines, is considered ordinary and has no consequence (failures of different machines occur independently of each other). If the failure flow of a fixed number of recoverable objects is ordinary and has no aftereffect, then the failure flow parameter and the failure rate coincide, i.e. $\omega(t)=\lambda(t)$..

It is generally accepted [1] that for the simplest flow with intensity λ, the interval t between neighboring events has the so-called exponential distribution with density $f(t)=\lambda e\text{-}\lambda t$.

To analytically determine the intensity of failures, the formula [1] is used:

$$\lambda(t) = f(t)/P(t), \quad (5)$$

where $f(t)=^{\lambda e\text{-}\lambda(t)}$ is the probability density function of the reliability indicator under the exponential distribution law; $P(t)=^{e\text{-}\lambda(t)}$ is the probability of trouble-free operation under the exponential law.

Substituting the values f(t) and P(t) into formula (5), we get λ=const, which characterizes the exponential law of probability distribution.

Time between failures is a mathematical expectation of an object's operating time between failures and shows what MTBF occurs on average per failure. Sometimes the term "average uptime" is used [2]:

$$t_{cp} = \int_0^\infty t f(t)dt = \int_0^\infty P(t)dt. \quad (6)$$

With the exponential probability distribution law, the statistical estimation of the average uptime is characterized by the average value of the failure intensity λ, i.e.

$$T_{cp} = \int_0^\infty t f(t)dt = \int_0^\infty t\lambda\, e^{-\lambda(t)} dt = \frac{1}{\lambda}. \quad (7)$$

But, due to the fact that the processes of wear and tear and destruction from fatigue are diverse due to the influence of various factors, a generalization of any law is unlikely for different details. Therefore, since, depending on the type of product and the nature of failures, the distribution of the resource can be described by different laws, for each specific case, the justification of the chosen distribution law is checked experimentally [5,6].

The probability of trouble-free operation of the machine over time (tp+t), according to the probability multiplication theorem, is:

$$P(t_p + t) = P(t_p) \cdot P(t; t_p), \quad (8)$$

where P(tp) is the probability of trouble-free operation of the machine during the time tp; P(t;tp) is the probability of failure-free

The operation of the machine during the time of the TABS, which is determined provided that during the TP time the machine did not fail.

Then, from the expression (8) we have:

$$P(t; t_p) = \frac{P(t_p + t)}{P(t_p)}. \quad (9)$$

In the case when the machine has worked flawlessly for some time *tp*, the indicator is the average uptime *To*(*tp*) characterizes the average technical resource of the machine that remains. Given that the average uptime

$$T_o = \int_0^{\infty} P(t)dt\,, \tag{10}$$

Get:

$$T_o(t_p) = \frac{1}{P(t_p)} \int_0^{\infty} P(t_p + t)dt\,. \tag{11}$$

Based on the basic law of reliability, given (11), we have:

$$P(t_p) = \exp\left(-\int_0^{t_p} \omega(t)dt \right), \tag{12}$$

$$P(t_p + t) = \exp\left(-\int_0^{t_p+t} \omega(t)dt \right). \tag{13}$$

Further, taking into account (9), we get:

$$P(t;t_p) = \exp\left(-\int_{t_p}^{t_p+t} \omega(t)dt \right). \tag{14}$$

The required frequency of regulatory operations is determined from the equation *P*(*t*;*tp*)=*Pd*, which, taking into account the expression (14), we will bring to the form:

$$\int_{t_p}^{t_p+t} \omega(t)dt = -\ln P_д\,. \tag{15}$$

Assuming that the parameter of the failure flow of the machine $\omega(t)$=const, i.e. does not change during the operating time, from the expression (15) we determine:

$$t = -\frac{1}{\omega(t)} \ln P_д\,. \tag{16}$$

If we assume that the parameter of the failure flow of machines during a certain period *t* can be approximated by a linear function of the form $\omega(t) = a + b(t)$, then substituting this function in (15) and integrating, we get a quadratic equation, the solution of which will be:

$$t = \frac{\left(a + bt_p\right) + \sqrt{\left(a + bt_p\right)^2 - 2b \ln P_д}}{b}\,.$$

The maximum resource of the machine or prefabricated unit will be provided that they are subject to a specified technical inspection. The optimal frequency of these operations can be determined based on the analysis of the service cost function.

Suppose that the machines have a constant failure rate. Then, to schedule the inspection operations, it is enough to determine the sequence of non-negative numbers tk (k=0;∞), where t0=0. At t_k=t k, the maintenance plan is periodic with a period *t*, i.e. the machines are to be serviced every *t* hours, provided that there have been no failures. If the machine fails between *k* and *k+1 maintenance, then the costs will be equal to:*

$$B = (k+1)B_{обс} + (t_{k+1} - t)B_{в}\,, \qquad (17)$$

where $в_{обс} = B_{пр}t_{обс}$ is the costs associated with the downtime of the machine for the serviced; $B_{в} = B_{пр}t_{р}$ – costs associated with the elimination of machine failures, here Spr is the cost of one hour of machine downtime; tbs, tp – respectively, the average time spent on maintenance operations and troubleshooting due to untimely performance of these operations.

Then the average total costs will be the value:

$$B_{c} = \sum_{k=0}^{\infty}\int_{t_k}^{t_{k+1}}\left[B_{обс}(k+1) + B_{в}(t_{k+1} - t)\right]dF(t)\,, \qquad (18)$$

where F(t) is a function of the machine uptime distribution.

Any schedule of maintenance operations that minimizes the function (18) will be optimal, from which their optimal frequency t is determined.

If the intensity of machine failures is not constant. but increases, then the frequency of maintenance of these machines should be reduced with an increase in operating time. Consider the case of carrying out such operations every *t* units of time or operating time. If the machine failed at the moment *τ*, *kt ≤ τ ≤ (k+1)t*, then the average total costs will be:

$$B_{c} = \sum_{k=0}^{\infty}\int_{kt}^{(k+1)t}\begin{Bmatrix} B_{обс}\left(k+1\right)+ \\ B_{в}\left[\left(k+1\right)t-\tau\right]\end{Bmatrix}dF(t) + B_{обс}\,. \qquad (19)$$

Assuming that the uptime of the machine has an exponential distribution law, i.e.

$$F(t) = 1 - \exp(-\omega\ t)\,, \qquad (20)$$

where $\omega = at^{m}$ is the failure flow parameter (here a, m are constants).

The expression (19) of average costs will take the form:

$$B_{c} = \frac{B_{обс}\exp\left(\omega\ t\right)}{1-\exp\left(-\omega\ t\right)} + \frac{B_{в}t}{1-\exp\left(-\omega\ t\right)} - \frac{B_{в}}{\omega} + B_{обс}\,. \qquad (21)$$

Differentiating (21) and equating the derivative to zero, we get an expression to determine the optimal period of maintenance operations, at which the total costs are minimized:

$$\exp\left(\omega\ t\right) - \omega\ t - \omega\frac{B_{обс}}{B_{в}} - 1 = 0\,. \qquad (22)$$

5. Discussion of results. The detected failures of assembly units or parts are random variables, each of them can take only one possible value with a certain probability, that is, they are discrete quantities. Like any discrete quantity, the number of failures has its own numerical values. It is determined that random time intervals between events in the flow of requirements can be subject to different distribution laws. From the analysis of various distribution laws, the Poisson distribution is investigated in the work. The maximum resource of the machine or prefabricated unit will be provided that they are subject to a specified technical inspection. The optimal frequency of these operations is determined on the basis of the analysis of the service cost function. Analytical dependencies have been obtained to determine the probability of trouble-free operation of the construction machine during the established time of the technological operation and the optimal frequency of technological inspection operations of construction machines based on the analysis of the service cost function has been determined. The disadvantages of the studies carried out include the lack of numerical values of the failure intensity, which is supposed to be determined in further studies on the basis of the already collected material of the workflow of the equipment of concrete mixers and concrete pavers.

Conclusions:

1. The probability density function of the reliability indicator of the operating parameters of machines according to the exponential law of their distribution has been investigated.

2. Obtained analytical dependencies to determine the probability of trouble-free operation of road machines during the set time of the technological operation.

3. The optimal frequency of technological inspection of road machines is determined on the basis of the analysis of the service cost function.

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