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ANALYSIS OF THE CHARACTERISTICS OF RELIABILITY INDICATORS OF MACHINES AND EQUIPMENT OPERATING IN EMERGENCY SITUATIONS AND EXTREME CONDITIONS

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ABSTRACT

The article analyzes the main characteristics of the reliability indicators of machines and equipment operated in emergency situations and extreme conditions. Methods for their evaluation are discussed using various methods of probability theory and mathematical statistics.

Keywords: machines; equipment; reliability; emergency; extreme conditions; evaluation; probability theory; mathematical statistics.

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During operation, many parts and assemblies of machines and equipment are subject to wear, breakage and destruction. The intensity of these processes significantly depends on the state of the working surfaces and the shape errors of the parts.

Machinery and equipment operated in emergency situations and extreme conditions operate in various environmental conditions. Their main components and parts are affected by moisture, heat, cold, light, sand dust, low and high pressure, radiation and other factors [1, 2].

In complex mechanized highly complex continuous production, when operating in severe extreme situations, in the fight against man-made and natural phenomena, for example, when extinguishing fires, when drilling and operating oil wells, etc., it is reliability should be assessed for the entire complex of machines and equipment required to perform the above processes. So, for extinguishing cascade fires or drilling and operating oil wells, the complex reliability of the entire system depends not only on the reliability of each of the units included in the circuit, but also on the reliability of control devices. At present, a modern mechanized fire extinguishing complex includes 25-35 machines and equipment, with a large number of transport devices, units, pumps, compressors, tools, electric motors, regulating, controlling and controlling devices.

Reliability indicators include: reliability indicators, durability indicators, maintainability indicators, maintenance indicators, standardized reliability indicators, etc. These indicators include: the probability of failure-free operation, the probability of failure-free operation within a specified time interval, the probability of failure, time to failure, established operating time, operating time, assigned operating time, persistence, specific manufacturing costs, normalized reliability indicator, etc. [3].

Machines and equipment operated in severe emergencies and extreme conditions are objects whose operation is related to ensuring safety.

To ensure the reliable operation of machines and assemblies, it is necessary to provide an approximate equal wear resistance of their critical parts. Without determining the wear resistance characteristics of critical parts of machines and equipment, it is difficult to establish the time of effective operation of individual machines, equipment, units, tools or complexes as a whole.

The wear resistance of parts is characterized not only by the material from which they are made, but also by the state of their working surfaces. The issue of regulating these indicators is especially relevant, based on the capabilities of individual processes and their combinations as a whole.

The research results show that it is very difficult to establish the degree of danger of certain defects under operating conditions, and there are very few systematic studies in this direction. At present, the solution of this problem is of exceptional interest, since the wear resistance of the surfaces of critical parts directly depends on it. This is essential for equipment operated in emergency situations and extreme conditions [4].

As you can see, the reliability and durability of the equipment in operation mainly depend on the accuracy and quality of its individual components and parts. Therefore, a comprehensive solution to the issue of machine reliability should be studied depending on the technological reliability of processes and their components in terms of accuracy, quality and wear resistance of individual parts [5].

The research results show that the parameters of accuracy, quality, wear resistance, reliability, durability and performance in many cases are characterized by non-identity of the obtained patterns. At the same time, the results of experimental studies often do not allow obtaining reliable information about the nature of the patterns obtained. This is especially evident when determining the quality, accuracy, wear resistance of the surfaces of parts of machines and

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equipment operating in severe emergency situations and extreme conditions.

An analysis of the works of scientists working in this field indicates that certain special issues have not been sufficiently studied. In the literature, there are often conflicting opinions about the influence of various design, operational and technological factors on the nature of friction, wear intensity, reliability and durability of machines and mechanisms in general.

The dependences obtained by the researchers are limited by the experimental conditions and cannot be fully extended to a number of specific types of machines and equipment operated in emergency situations and extreme conditions.

The results of numerous observations show that critical parts of machines and equipment operating in emergency situations and extreme conditions are mainly characterized by overload in operation, fatigue fracture, fracture from repeated static and single excess loads and wear, which leads to their failure.

Failures of machines and equipment, considered in the theory of reliability, are considered a random event and can be characterized using the laws of probability theory.

For random events, the following basic laws are valid: the law of combination, the law of displacement, the distribution law, the law of inversions.

Reliability parameters are often random discrete values.

The analysis shows that binomial and Poisson distributions are usually used for this purpose [6].

The binomial distribution characterizes the number of normal trials x out of the total number of trials n and is described by the Bernoulli formula

$$P(x)=\frac{n!}{x!(n-x)!}P^x(1-P)^{n-x}=C_n^xP^x(1-P)^{n-x},x=0,1,\ldots,n \quad (1)$$

or is written as

$$(x)=\sum_{i=0}^{x}P(i)=\sum_{i=0}^{x}\frac{i!}{i!(n-i)!}P^i(1-P)^{n-i}=\sum_{i=0}^{x}C_n^iP^i(1-P)^{n-i} \quad (2)$$

where P is the probability of one normal trial, $P(x)$ is the probability of normal results with a total number of trials n; C_n^x are binomial coefficients.

The characteristics of the binomial distribution is described as

$$M(x)=nP;\ D(x)=nP(1-P);V=\sqrt{\frac{1-P}{nP}}. \quad (3)$$

For objects that failed in a fixed time, the Binomial Law can also be applied.

The Poisson distribution is described by the expression

$$P(x)=\frac{\lambda x}{x!}\exp(-\lambda),\ x=0,1,2,... \quad (4)$$

The distribution function is written as the dependence

$$F(x)=\sum_{i=1}^{x}\frac{\lambda^i}{i!}\exp(-\lambda),\text{где},\ \lambda=nP. \quad (5)$$

The main characteristics of the Poisson distribution are characterized by dependencies:

$$M(x)=D(x)=\lambda,V=\frac{1}{\sqrt{\lambda}}. \quad (6)$$

Poisson distributions can be used in assessing the reliability of machines and equipment operating in emergency situations and extreme conditions.

In the study of reliability, the distribution of random variables can be analyzed using the Pascal distribution.

$$(x)=C_{R+x-1}^iP^R(1-P)^x,x=0,1,\ldots,R \quad (7)$$

or by dependency

$$F(x)=\sum_{i=0}^{x}C_{R+i-1}^{i}\ P^R(1-P)^i. \quad (8)$$

The Pascal distribution characterizes the number of «negative» results by the previous «positive» results in a design of independent Bernoulli trials. It is often used in determining the reliability of equipment with a known failure [6].

When determining the reliability of equipment operating in emergency situations and extreme conditions, the uniform distribution method can be used. In reliability theory, a uniform distribution can characterize the parameters of elements, systems, load, etc. In this case, these indicators take on different values in a known interval a, b [3]:

$$F(x)=\frac{x-a}{b-a},f(x)=\frac{1}{b-a},a\le x\le b. \quad (9)$$

To determine the operating time characteristics of machines and equipment operated in emergency situations and extreme conditions, before the occurrence of failure or failures at their constant intensity $\lambda=const$ and average operating time

$$t=\frac{1}{\lambda},$$

exponential distribution can be used.

The exponential distribution is characterized by an integral function and distribution density

$$F(x)=1-\exp(-\lambda x),f(x)=\lambda\exp(-\lambda x),x\ge 0, \quad (10)$$

где λ – distribution parameter, or failure rate.

At $\lambda x\le 0.1$ formula can be expanded into a series [3]

$$F(x)=1\left[1-\lambda x+\frac{\lambda x^2}{2!}-\frac{\lambda x^3}{3!}+\ldots\right]\approx\lambda x. \quad (11)$$

Formula (11) can be used in preliminary calculations.

The exponential distribution can be thought of as a variation of the Weibull distribution and the gamma distribution.

The Weibull distribution is often used to describe failures of machines and mechanisms with monotonic intensity [3]. The Weibull distribution has various forms and can be described as

$$F(x)=1-\exp\left[-\left(\frac{x}{a}\right)^b\right],f(x)=\frac{b}{a}\left(\frac{x}{a}\right)^{b-1}\exp\left[-\left(\frac{x}{a}\right)^b\right],x\ge 0. \quad (12)$$

$a>0$ и $b>0$ – scale and shape options.

A distinctive characteristic of the Weibull distribution is that with a change in the shape parameter b, the form of the distribution graph also changes. These properties of the Weibull distribution make it possible, by appropriate selection of parameters, to ensure the coincidence of experimental data with theoretical descriptions.

In the Weibull distribution, special cases of the exponential distribution (for $b=1$), the Rayleigh distribution (b = 2), as well as closeness to the normal

distribution (for $b \geq 3.5$) can be seen.

If the x_i values have an identical exponential distribution, then their sum has a gamma distribution. This makes it possible to use it to describe machines and mechanisms with redundancy of parts or assemblies with further substitution.

If the values $x_1, x_2, \ldots, x_n$ obey the gamma distribution with the same scale parameter a and with the shape parameters $b_1, b_2, \ldots, b_n$, then their sum equally characterizes the specified distribution.

For $b = 0$, the gamma distribution is identical to the exponential one, for large values of b it practically coincides with the normal one, for integer values of b, with the Erlang distribution [6].

In the calculations, another formula is also used:

$$F(x) = \frac{\lambda^{\alpha}}{\Gamma(\alpha)} \int_0^x x^{\alpha-1} \exp(-\lambda x) dx, \quad f(x) = \frac{\lambda^{\alpha}}{\Gamma(\alpha)} x^{\alpha-1} \exp(-\lambda x), \quad (13)$$

$$\alpha = b + 1, \lambda = \frac{1}{\alpha}.$$

When analyzing the reliability of machines and mechanisms, situations sometimes arise in which the parameters are a combination of more than two parameters with different distributions.

Then the integral function will have the form:

$$F(x) = P_1 F_1(x_1) + P_2 F_2(x_2) + \ldots + P_n F_n(x_n) = \sum_{i=1}^{n} P_i F_i(x_i). \quad (14)$$

$F_i(x_i)$ – integral functions of density distributions $f_i(x_i)$.

When assessing the reliability of machines and mechanisms, one of the main theorems is often used - the central limit theorem, according to which the distribution of $x = x_1, x_2, \ldots, x_n$ with any probability distribution tends to the normal law in the limit:

$$\lim_{n \to \infty} P\left\{ a < \frac{x - n\mu}{\sigma\sqrt{n}} < b \right\} = \Phi(b) - \Phi(a). \quad (10)$$

The central limit theorem in many cases is the basis for using the normal distribution in determining the reliability of machines and mechanisms. For example, when evaluating the time between failures as a result of fatigue changes, as well as when calculating reliability parameters using static modeling methods, etc.

According to [3], if the random variables x and y are related to each other by the relation $y = y(x)$ and the distribution functions $F_x(x)$ and $f_x(x)$ are known, then the distribution function will be written as

$$F_y(y) = F_x\left[x(y)\right], f_y(y) = f_x\left[x(y)\right] \cdot \left|\frac{dx}{dy}\right|. \quad (16)$$

For a linear function $y = ax + b$

$$f_y(y) = \frac{1}{|a|} f_x\left(\frac{y - b}{a}\right), M(y) = M(ax + b) = aM(x) + b, \quad D(y) = D(ax + b) = a^2 D(x). \quad (17)$$

Thus, using the methods of mathematical statistics and reliability theory, it is possible to determine the main characteristics of machines and equipment operated in emergency situations and extreme conditions.

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Анализ характеристик показателей надёжности машин и оборудований, эксплуатируемых в чрезвычайных ситуациях и экстремальных условиях

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Реферат

В статье анализируются основные характеристики показателей надежности машин и оборудований, эксплуатируемых в чрезвычайных ситуациях и экстремальных условиях. Обсуждаются методики их оценки с применением различных методов теории вероятностей и математической статистики.

Ключевые слова: машины; оборудование; надежность; аварийные ситуации; экстремальные условия; оценка; теория вероятностей; математическая статистика.

Fövqəladə hallar şəraitində və ekstremal vəziyyətlərdə istismar olunan maşın və avadanlıqların etibarlılıq göstəricilərinin xarakteristikalarının analizi

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Xülasə

Məqalədə fövqəladə hallar şəraitində və ekstremal vəziyyətlərdə istismar olunan maşın və avadanlıqların etibarlılıq göstəricilərinin əsas xüsusiyyətləri təhlil edilir. Onların qiymətləndirilməsi üsulları ehtimal nəzəriyyəsinin və riyazi statistikanın müxtəlif üsullarından istifadə etməklə müzakirə olunur.

Açar sözlər: maşınlar; avadanlıq; etibarlılıq; qəza halları; ekstremal şərait; qiymətləndirmə; ehtimal nəzəriyyəsi; riyazi statistika.