Classification of indicators of reliability of systems in heavy engineering

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Abstract. A feature of this work is the study of the design reliability assessment based on analytical data, with further classification of its indicators. Like any other properties of technical devices, reliability is assessed by a certain set of indicators. The paper provides an overview of domestic and foreign sources on this topic. The main tasks associated directly or indirectly with the problem of reliability are identified, the solution of which is necessary to create designs of technical devices with an optimal level of reliability indicators. It was also found that the reliability indicators, depending on the specific conditions of their use, can be classified according to various criteria. The results of the work show the most significant factors of reliability, which can be quantitatively determined directly using the method of expert assessments.

1. Introduction
Two opposite tendencies can be observed in the development of technology: a tendency to complicate technology, which results in the emergence of great difficulties in ensuring high reliability in its design and manufacture, and a tendency to increase requirements for the reliability of complex technical devices, which is accompanied by an increase in the costs of development, manufacture and operation. As an example, consider a heavy car performing special tasks [1;2].

These circumstances largely predetermined the situation when the reliability property is considered as one of the most important properties of technical devices, and the reliability indicators and their quantitative characteristics are the object of assignment, provision and evaluation.

In recent years, the problem of creating a reliable wheeled special transport has attracted more and more attention of specialists working in the design, production and operation of heavy equipment. To a large extent, this situation is due to the widespread use in various fields of technology of devices with higher technical characteristics, devices that are complex and highly automated technical systems. Failure of such devices, even for a short time, is usually accompanied by large economic or other types of damage. This is especially typical for aviation and space technology [3].

Reliability, as a property of technical devices, is a complex property. Reliability is often considered as a set of properties of reliability, maintainability, preservation and durability. In turn, reliability is one of the constituent parts of a more general and, as a rule, a complex property of technical devices - quality. When solving such issues as the choice of the composition of quality indicators and the establishment of their level, this provision should be taken into account [4].

2. Reliability assessment
The indicators used to assess one side or the other of reliability characterize the property of the structure. However, their quantitative values vary within some limits due to the action of variable factors of production and operational nature. At the same time, design solutions largely predetermine the nature
and intensity of the impact on the reliability characteristics of production and operational factors. As an example, we can consider rubber products, the term of their use and reliability of work directly depend on the environment of use, when operating in a more aggressive environment, the term of use is significantly reduced [5,6]. Obviously, feedback can be traced as well.

The properties of the structures of technical devices, expressed in their relationship with the factors acting during the manufacture and operation, are called the manufacturability of structures in the manufacture and operation. The use of these concepts in the practice of designing complex technical devices makes it possible to substantiate the adopted technical decisions taking into account the requirements of the economy, i.e. taking into account the costs of manufacturing and operating devices.

The creation of designs of technical devices that have an optimal level of reliability indicators in operation presupposes the solution of a number of problems related directly or indirectly to the problem of reliability. These tasks primarily include:

a) establishing the type of models that describe the process of changing the state of structural elements, technical devices and a complex of devices during their operation;
b) the choice of the composition of indicators and the establishment of their values corresponding to the design features, purpose and operating conditions of the technical device;
c) development and implementation in the process of design and manufacture of measures aimed at ensuring the established requirements for the reliability of devices;
d) establishment of a system of technical maintenance and repair of technical devices, carried out during their operation;
e) assessment of the achieved level of reliability characteristics of technical devices at the stages of development of design documentation, production of prototypes, interdepartmental and state tests, serial production and operation.

3. Failures of technical means

Failures, as events directly related to reliability, are usually classified according to the following criteria:

a) depending on the nature of the manifestation: sudden failures - failures resulting from an abrupt change in the parameters of the device; gradual failures - failures resulting from a gradual change in device parameters.

This division of failures is due to the reasons for their occurrence and the model of their description. Sudden failures are mainly due to design and calculation errors, manufacturing and operational errors. Gradual failures are the result of wear, material aging and misalignment.

b) depending on the causes of occurrence: structural failures - failures caused by errors in design or imperfection of design and calculation methods; technological (production) failures - failures resulting from a violation or imperfection of the applied technological processes; operational failures - failures arising as a result of violation of operating rules or the influence of factors not provided for in the design.

In the literature, you can find the classification of failures also on other grounds. Like any other properties of technical devices, their reliability can be assessed by a certain set of indicators. Reliability indicators are the tool that allows you to manage this property at all stages of the creation and operation of technical devices. Indicators used to assess reliability must meet a number of requirements, including:

a) they should be sensitive to changes in factors affecting reliability;
b) characterize both individual properties of reliability and complex properties;
c) make it possible to assess the influence of individual reliability factors.

Reliability indicators, depending on the specific conditions of their use, can be classified according to various criteria:

1) depending on the property being assessed:
   a) reliability indicators;
   b) indicators of maintainability;
   c) indicators of preservation;
   d) indicators of durability;
e) indicators for assessing several properties at the same time.

2) depending on the number of assessed properties:
   a) single indicators used to assess one property;
   b) complex indicators used to assess simultaneously two or more properties;

3) depending on the nature of the property being assessed:
   a) operational (temporal) indicators characterizing the time or probability of being in a certain state;
   b) economic indicators characterizing the absolute or relative (specific) costs of labor and funds to ensure and maintain reliability;

4) depending on the type of indicators:
   a) main indicators, i.e. indicators whose values are the object of assignment, provision and control;
   b) additional indicators, the values of which are not established in the terms of reference. These indicators characterize the secondary aspects of reliability or reliability factors. The presence of additional indicators makes it possible to obtain dependencies between characteristics and reliability factors [4].

The following are used as the numerical characteristics of reliability and reliability factors: mathematical expectation \( M[R] \), variance \( D(R) \); distribution law given as a probability density \( f(R) \) or a distribution function \( F(R) \) or their statistical estimates \( R^*, S^2(R), \sigma_{R^*}^2 f^*(R) \) and \( F^*(R) \). Note that the variance \( D(R) \) and \( S^2(R) \) characterize the dispersion of the values of the reliability characteristics, and the variance \( \sigma_{R^*}^2 \) characterizes the accuracy of determining the characteristic \( R^* \) from the results of observations of volume \( n \). For some laws of distribution of random variables between the quantities \( S^2(R) \) and \( \sigma_{R^*}^2 \) the following relation is observed:

\[
\sigma_{R^*}^2 = \frac{S^2(R)}{n}.
\]

It is known that the most complete numerical characteristic of a random variable is its distribution law. However, in a number of cases this characteristic is unknown, or for solving practical problems of reliability, it is enough to know the mathematical expectations and variances or their estimates of the considered reliability characteristic.

The values of the numerical characteristics of reliability indicators can be determined both as a result of using theoretical (analytical) dependencies, and as a result of mathematical processing of statistical data. In the latter case, as a rule, maximum likelihood estimates are used. The latter are known to be unbiased, wealthy and efficient. Along with point estimates for reliability characteristics \( R \) and \( D(R) \), interval estimates are often used: two-sided and one-sided.

Below, when considering reliability indicators, formulas will be given for their determination both using theoretical dependencies and statistical data.

Reliability indicators.

a) non-recoverable elements and devices.

The indicators of the reliability of non-recoverable elements and devices, hereinafter referred to as products, are:
- the probability of failure-free operation \( P(t) \);
- uptime distribution density or failure rate \( f(t) \);
- failure rate \( \lambda(t) \);
- mean time to first failure \( T_{cp} \).

Let us consider the dependencies for determining the indicated indicators, which are operational single indicators of reliability.

The probability of failure-free operation \( P(t) \) is the probability that under certain operating conditions of the product in a given time interval \( t \) or within a given operating time failures will not occur. By definition

\[
P(t) = \text{Bep}\{T > t\} = 1 - F(t),
\]
where \( F(t) \) is the product uptime distribution function.

The value of \( P(t) \) in the literature is sometimes called the reliability function.

The quantity \( q(t) = 1 - P(t) = F(t) \) is called the probability of failure.

To determine the value of \( P(t) \), dependencies are used:

a) with the known distribution law of uptime \( f(t) \)
\[
P(t) = 1 - \int_0^t f(t) \, dt,
\]
where \( f(t) \) is the probability density of the product operation time until the first failure.

In the source [3], it is proposed to call this value the failure rate and denote \( a(t) \);

b) according to statistics
\[
P^*(t) = \frac{N(t)}{N_0},
\]
where \( N_0 \) is the number of products at the beginning of tests (observations);
\( N(t) \) is the number of products that remained operational by the time \( t \).

Probability density of product operation time before the first failure \( f(t) \) or failure rate \( a(t) \).

By definition
\[
f(t) = \lim_{\Delta t \to 0} \frac{P(t < T < t + \Delta t)}{\Delta t},
\]

In the theory of reliability, the following basic laws of distribution of a random variable are applied:

1) exponential
\[
f(t) = \lambda e^{-\lambda t},
\]
where \( \lambda \) is the distribution parameter. The exponential distribution is used as a model for the occurrence of sudden failures;

2) truncated normal
\[
f(t) = \frac{1}{F(\frac{T_1}{\sigma})\sigma\sqrt{2\pi}} e^{-\frac{(t-T_1)^2}{2\sigma^2}},
\]
where \( T_1 \) and \( \sigma^2 \) are the parameters of the normal distribution. The need to use a truncated distribution is due to the fact that \( 0 \leq t \leq \infty \). Normal distribution is used as a model for the occurrence of failures.

3) Weibull
\[
f(t) = \lambda_0 k t^{k-1} e^{-\lambda_0 t^k},
\]
where \( \lambda_0 \) and \( k \) are distribution parameters. The parameter \( \lambda_0 \) characterizes the scale, and the parameter \( k \) characterizes the asymmetry and kurtosis of the distribution. For \( k = 1 \), the Weibull distribution turns into an exponential distribution. The Weibull distribution can be used as a model for the occurrence of failures under the action of a combination of factors that cause the occurrence of sudden and gradual failures.

According to statistical data, the value \( f(t) \) is determined by the formula:
\[
f^*(t) = a^*(t) = \frac{m(t)}{N_0 \Delta t},
\]
where \( m(t) \) is the number of failed products during the time \( \Delta t \).

Consequently, the failure rate \( a(t) \) is the ratio of the number of failed elements per unit time to the initial number of tested products, provided that the failed ones are not restored [7].
The traditional way of accounting for failures based on probabilistic and statistical modeling often turns out to be inadequate to the tasks being solved and can lead to incorrect results, since the functioning of complex organizational and technical systems in practice is characterized by an uncertainty of the “non-stochastic” type [8].

4. Conclusion
Considering the above, it is possible to point out the most significant factors of reliability.

1. Factors of a constructive nature: schematic and constructive solutions; the complexity of the structures; manufacturability of the device design in manufacture and operation; rational choice of component parts; the level of application in the design of the device of standardized, normalized and unified structural elements; correct accounting of existing loads and environmental influences; the appointment of rational tolerances in the manufacture of structural elements; correct selection of materials; ensuring traceability requirements.

2. Factors of production (technological) nature: rational construction of technological processes and modes of their flow; the quality of the materials and workpieces used; the quality of technological equipment and technological equipment; qualification of production personnel; perfection of quality control at the enterprise; the effectiveness of moral and material incentives for quality work.

3. Factors of an operational nature: the impact of the environment surrounding the device (climatic factors, biological factors, the chemical composition of the environment); perfection of the system of maintenance and repair; qualification of maintenance and repair personnel; perfection of technology and organization of maintenance and repair of devices; strict observance of operating rules.

A significant part of these factors can be quantified directly using the method of expert assessments.

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