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ASSESSMENT OF THE RELIABILITY OF ELECTROMECHANICAL SYSTEMS WITH INCOMPLETE SPECIFICATION OF INITIAL DATA

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Abstract
Modern complex electromechanical systems (hereinafter referred to as the system) are characterized by a more complex connection structure and increased requirements for the reliability of components. Moreover, advanced systems are quite unique and (or) small-batch, and their constituent elements are basically miniature or expensive, so the direct use of engineering methods based on the processing of statistical data in determining the reliability indicators of systems is not possible.

Introduction

The methods of combining various methods of physical reliability considered in the article predetermine the possibility of assessing the reliability indicators of systems, the structural complexity and incompleteness of information about which do not allow the use of analytical methods and methods of direct simulation modeling.

Taking into account the priority of the most important stage of system operation - application for their intended purpose, methods for assessing failure-free as a property reflecting the main content of reliability are considered. As applied to systems, reliability is understood as the ability to perform the intended functions in switching, amplifying, rectification and other modes, as well as in various design solutions and operating conditions.

At the stage of running-in of systems, when information on the functioning of components in real operating conditions is not enough to use graphs of failure rates (for example, in the absence of information on the functioning of an element newly introduced into the structure of a developed or modernized system), at the initial stage of solving such problems, it is advisable to use the coefficient method for calculating reliability, which has become the most popular and widely used in theory and practice reliability [1, 2].

The initial reference data are the known values of the failure rates of the elements introduced into the structure of the systems $s = \overline{1, m}$ for the ideal conditions of functioning of the object of study (normal: atmospheric pressure, humidity, temperature; absence of vibrations and shocks) – $\lambda_s^{(0)}$.

To obtain the values of failure rates corresponding to the real operating conditions of the elements under consideration (such conditions are denoted by *F*, and the resulting values of failure rates are denoted by $\lambda_s^{(F)}$), the values $\lambda_s^{(0)}$ are multiplied by the reference values of the correction factor $k_{\lambda_s^{(F)}}$, showing how many times the values of the failure rates of elements of a given type operating under the given conditions of application are greater than the failure rates of these elements operating under ideal conditions

$$\lambda_s^{(F)} = \lambda_s^{(0)} k_{\lambda_s^{(F)}}.$$

In order to perform a detailed analysis of the calculated values of failure rates corresponding to real operating conditions $\lambda_s^{(F)}$, calculations should be carried out both for the average and for the boundary values of the considered failure failure index of the studied elements over the entire operating time interval *T*.

Further, to calculate the remaining indicators of failure-free elements of this type, formalized dependencies of physical reliability in a direct formulation are used. The reliability indicators of the tested elements for the specified operating conditions are determined using the following modified expressions [1]:

– probability of failure-free operation

$$P_s^{(F)}(t) = e^{-\int_0^T \lambda_s^{(F)}(t)dt}; \tag{1}$$

– the probability of failure

$$Q_s^{(F)}(t) = 1 - e^{-\int_0^T \lambda_s^{(F)}(t)dt}; \tag{2}$$

– the density of the probability of failures

$$f_s^{(F)}(t) = \lambda_s^{(F)}(t) e^{-\int_0^T \lambda_s^{(F)}(t)dt}; \tag{3}$$

– mean time between failures

$$\bar{t}_s^{(F)} = \int_0^\infty P_s^{(F)}(t)dt. \tag{4}$$

It should be noted that when determining the mean time between failures of elements of this type, $\bar{t}_s^{(F)}$ possible values of time between time and time between 0 and , including much smaller and significantly exceeding the operating time value specified in the operational documentation,∞ are taken into account.

The specific type of expression (1) depends on the reasonable choice of the known random uptime distribution law, which establishes a relationship between the possible values of a random variable and their probability [3, 4].

If there is information on the values of failure rates of elements of this type in some conditions of system application (conventionally denote the conditions with F = 1) – $\lambda_s^{(1)}$ (for example, in stationary ground objects) and the absence of such information in other conditions of use of similar system elements (conditionally denote the conditions with F = 2) – $\lambda_s^{(2)}$ (e.g. on trailers), as well as the lack of information on the values of failure rates for ideal operating conditions of the elements $\lambda_s^{(0)}$, the solution can also be obtained on the basis of the coefficient method.

In order to recalculate the values of failure rates from the known conditions of application of system elements (F = 1) to others (F = 2), first of all, it is necessary to calculate the value $\lambda_s^{(0)}$ according to the formula

$$\lambda_s^{(0)} = \frac{\lambda_s^{(1)}}{k_{\lambda_s^{(1)}}},$$

where $k_{\lambda_s^{(1)}}$ are the reference values of the coefficient $k_{\lambda_s^{(F)}}$ corresponding to the known conditions for the use of system elements (F = 1).

Further, the obtained values $\lambda_{\text{of } 0}$ are multiplied by the reference values of the coefficient $k_{\lambda_s^{(2)}}$ corresponding to other conditions for the use of system elements (F = 2)

$$\lambda_s^{(2)} = \lambda_s^{(0)} k_{\lambda_s^{(2)}}.$$

In this case, the main indicators of the failure-free elements are also determined using expressions of type (1) for the previously declared methods.

The assessment of the failure-free systems as a whole is feasible by determining the type, nature of connections and relations between the set of elements $r = \overline{1, n}$, the failure-free indices of which for actual operating conditions are a priori known $P_r^{(F)}(t)$ and the set of elements newly introduced into the structure of systems, $s = \overline{1, m}$ the methods for calculating the failure-free indices of which for real operating conditions $P_s^{(F)}(t)$ are presented in the article.

Thus, in the classical implementation of reliability models, the final assessment of the reliability of systems is determined on the basis of dependencies of the following form [1–4]:

– with a sequential scheme of connecting elements

$$P_c^{(F)}(t)=\prod_{r,s}P_{r,s}^{(F)}(t),\ r=\overline{1,n},\ s=\overline{1,m},\ m\prec n;$$

– with a parallel scheme of connecting elements

$$P_c^{(F)}(t)=1-\prod_{r,s}\left[1-P_{r,s}^{(F)}(t)\right],\ r=\overline{1,n},\ s=\overline{1,m},\ m\prec n.$$

The features of the construction and functioning of modern and promising systems are: the complexity of the structure, the presence of a large number of elements, intersecting chains and feedbacks, the interconnection of elements of different physical nature. Therefore, almost everywhere there are problems of assessing the reliability of a mixed structure. In this case, according to the well-known rules (for example, [2, 3]), it is necessary to identify areas in the mixed structure with the same reliability models, determine the reliability of each of them, and then, depending on the nature of the enlarged model reduced to a series or parallel connection of elements, determine the reliability of the system under study.

Some systems (e.g., bridging elements) may have a structure that is not reducible to universal reliability models. In this case, the method for calculating the failure functions of the systems is satisfactory

$$V_c^{(F)}\left[P_c^{(F)}(t)\right]=P_{r\vee s}^{(F)}(t)V_{r\vee s}^{(F)}(t)+Q_{r\vee s}^{(F)}(t)\overline{V}_{r\vee s}^{(F)}(t),\ r=\overline{1,n}\vee s=\overline{1,m},\ m\prec n,$$

where $P_{r\vee s}^{(F)}(t)$ and $Q_{r\vee s}^{(F)}(t)$ are the probability of failure-free operation and the probability of failure, respectively, of the selected most reliable element $r=\overline{1,n}$ or $s=\overline{1,m}$ for the given operating conditions *F*, $V_{r\vee s}^{(F)}(t)$ and $\overline{V}_{r\vee s}^{(F)}(t)$ are the direct and inverse functions of the failure-free operation of the system, respectively, relative to the selected most reliable element $r=\overline{1,n}$ or $s=\overline{1,m}$ for the specified operating conditions *F*, determined by special methods [1].

The application of the presented approaches in engineering practice shows that the proposed resolution of reasonable and systematized interpretations does not present significant computational difficulties. Consequently, the considered methods of differentiated selection of physical reliability methods are an effective tool for calculating, evaluating and quantifying probabilistic indicators of system reliability of systems of various degrees of uncertainty.

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