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EVALUATION METHODOLOGY OF C-PERCENTILE TIME TO FAILURE OF ELECTRONIC COMPONENTS IN INFORMATION-MEASURING SYSTEMS BY SHORT-TERM TEST RESULTS

Elementwise evaluation of dependability measures is carried out during designing information – measuring systems. Climatic conditions essentially affect operability of resistors. The paper offers evaluation methodology of resistors' dependability measures, which is used at change of their operation conditions. Based on results of short-term reliability tests in the specified conditions, dependability measures of resistors are calculated by prediction of electric parameters values of resistors during their life.

Keywords: *short-term tests, temperature, prediction, resistor, probability.*

Designing and manufacture of radio-electronic components having high dependability measures is one of the major problems at development of the information – measuring systems working in various service environments. Such systems are complex technical objects consisting of assemblies, units containing many radio-electronic components. At a design stage of information – measuring system in the certain cases elementwise evaluation of its component dependability measures can be carried out with the purpose of the whole system dependability calculation.

Resistors are widely used as element base of various information – measuring systems that can be applied in conditions of moderate, cold and tropical climates. Climatic conditions can affect parameters of resistors essentially. For example, the increased temperature leads to degradation of materials of which the resistor is made. Deviations in properties of materials cause change of resistors' parameters and lead to increase in probability of defects and failures occurrences.

The developer of resistors determines operating temperature range in corresponding specifications. A number of dependability measures are specified for operating temperature range. In practice, it is accepted to estimate dependability of radio-electronic components according to the following measures: c-percentile time to failure (T_γ), failure rate (λ) and c-percentile storageability time ($T_{c\gamma}$). For one type of a resistor several values of dependability measures can be established depending on operating temperature and operation conditions, for example, the nominal conditions – at rated power of dispersion $P_{ном}$, the facilitated conditions – at capacity of dispersion equal to $0{,}5P_{ном}$.

In selection of a resistor type the developers of information – measuring systems in the greater degree are guided by values of resistors' characteristics established in specifications. In certain cases, restrictive lists with the established nomenclature of the products of electronic equipment allowed to application also are taken into account. Various features and requirements to characteristics of developed information – measuring system frequently lead to necessity of an issue consideration about an opportunity of electronic equipment application under operating conditions, distinguished from established in the as-built manufacturing documentation [1]. According to study [2], if it is necessary to apply products in modes and conditions expanding area of their application, not connected to deterioration of the product basic technical parameters, it is possible to do so only under the report sanction of the enterprise – manufacturer of a product or the organization, to which the duty on delivery of such a sanction report for application is assigned.

Functions to approve of sanction reports to application of electronic equipment products in modes and conditions, which have been not stipulated in specifications, are assigned to a number of enterprises under the listed products assigned to them.

If by results of researches the opportunity of resistors' application under operating conditions, required by the developer of information – measuring system is established, but not stipulated in specifications for evaluation of resistors' dependability measures it is required to carry out their reliability or storageability tests in demanded modes or conditions, or to use test results of similar products. According to the normative documentation requirements, reliability tests include tests for short-term and long-term reliability. To take advantage of the information about dependability measures of similar products is not always possible, for example, because of brought changes in design or in the list of product materials. Material and time expenditures, great volume of reliability tests lead to necessity of application of a probabilistic-physical method for dependability measures' evaluation based on results of short-term tests. The method is based on statistical prediction of dependability measures according to time dependence [3]. According to this method short-term reliability tests are performed first in modes and conditions required by the customer. Then dependability measures of resistors are calculated based on statistical data on electric parameters' change of products, number of failures occurred during tests.

For an evaluation of conformity of resistors to dependability requirements the evaluation methodology of c-percentile time to failure of electronic components, failure rate and c-percentile storageability time has been developed. The design procedure of dependability measures is based on definition of point and interval assessments of predicted sets of resistors' electric parameters values and the further calculation of values T_γ , λ and $T_{c\gamma}$ using results of short-term tests of resistors.

Sample of resistors in quantity n, which has past short-term reliability tests during time t is exposed to an evaluation. During tests, the value of suitability criteria (X_{ij}) of each resistor is measured. The absolute value of resistance R or the value of a relative deviation of its resistance is selected as suitability criterion:

$$\delta = \frac{R(t) - R_0}{R_0},$$

where R_0 and R(t) are values of resistances during the initial moment of time and at the moment of time t respectively.

According to the data received as a result of tests, the calculation of statistic values is carried out. The boundary of predicted sets and dependability measures depend on these statistic values. The following random variables used in the theory of dependability [4] as such measures are used:

1) Expectation:

$$m_j = \frac{1}{n}\sum_{i=1}^{n} X_{ij},$$

where $i = 1.. n$ are numbers of tested resistors,

j = 1... l are the moments of suitability criterion values' control.

2) Mean square deviation of a random variable:

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(X_{ij} - m_j\right)^2}.$$

3) Correlation factor:

$$r_{j,j+s} = \frac{\sum_{i=1}^{n}\left(X_{ij} - m_j\right)\left(X_{ij+s} - m_{j+s}\right)}{n\sigma_j\sigma_{j+s}},$$

where $s = 0... 1-j$.

The interval evaluations of expectation of mean square deviation is found in the framework of Gaussian model when the density of random variable X_{ij} distribution can be described as the normal law of distribution [5]. Boundaries of value X_{ij} deviation and therefore probability of no-failure operation of resistors depend on regression coefficient and conditional mean square deviation. Then c-percentile confidence estimate is defined for regression coefficient. The probability of non-failure operation of resistors further is calculated based on the determined interval estimates of expectation and mean square deviation of a random variable $X_{ij.}$

Thus, the evaluation methodology of c-percentile time to failure of resistors consists in performance of the following operations:

1. Short-term tests of resistors under specified conditions and modes

2. Calculation of expectation values, mean square deviations of a random variable and correlation factor based on the measured values of suitability criteria of resistors for each time section.

3. Calculation of regression coefficient [6]:

$$b_{j,j+s_i} = r_{j,j+s_i} \cdot \frac{\sigma_{j+s_i}}{\sigma_j},$$

where $j = 1... l\text{-}1$, $s_i = 1.. l\text{-}j$;

4. C-percentile confidence estimate c-percentile confidence estimate.

4.1. Definition of time sections t_j, t_{j+s1} (hereinafter referred to as T_1 and T_2), satisfying the following condition:

$$\begin{cases} b_{j,j+s_1} \le 1 \\ T_1 = \min\limits_{j+s_1}\left(T - t_{j+s_1}\right), \\ T_2 = \max\limits_{s_1}\left(t_{j+s_1} - t_j\right) \end{cases} \quad (1)$$

where T is accepted as equal to the value T_γ.

4.2. Estimation of upper ($\overline{b}$) and lower ($\underline{b}$) boundary of mean square deviation σ for two-dimensional distribution of suitability criterion parameter for time sections t_j, t_{j+s1} (hereinafter referred to as t_1 and t_2) [7]:

$$\overline{b} = b_0 + U_{n-2(\gamma)} \frac{\sqrt{1-r_{12}^2}}{\sqrt{n-2}} \frac{\sigma_2}{\sigma_1},$$

$$\underline{b} = b_0 - U_{n-2(\gamma)} \frac{\sqrt{1-r_{12}^2}}{\sqrt{n-2}} \frac{\sigma_2}{\sigma_1},$$

$$b_0 = r_{12} \frac{\sigma_2}{\sigma_1},$$

where σ_1, σ_2 are mean square deviation values of controllable suitability criterion parameter of a resistor in time sections t_1 and t_2;

r_{12} – the pair correlation coefficient between values of controllable parameter in 1 and 2 time sections;

$U_{n-2(\gamma)}$ – C-percentile Student's inverse distribution with n-2 degrees of freedom;

4.3. Definition of upper ($\overline{a}$) and lower ($\underline{a}$) boundary of expectation m for two-dimensional distribution of suitability criterion parameter for determined time sections t_1 and t_2 [7]:

$$\overline{a} = m_2 - \underline{b} m_1 + U_\gamma \frac{\sigma_0}{\sqrt{n}},$$

$$\underline{a} = m_2 - \overline{b} m_1 - U_\gamma \frac{\sigma_0}{\sqrt{n}},$$

$$\sigma_0 = \frac{\sqrt{n\left(1-r_{12}^2\right)}}{\sqrt{Z_{n-2(\gamma)}}} \sigma_2,$$

where m_1, m_2, are values of expectation for controllable suitability criterion parameter of a resistor in time sections t_1 and t_2;

U_γ – C-percentile inverse normal distribution;

$Z_{n-2(\gamma)}$ – C-percentile inverse distribution χ^2 2 with n-2 degrees of freedom;

4.4. Calculation of upper and lower boundary of expectation assessment $\overline{m}_T$, $\underline{m}_T$, for time section corresponding to T_γ [7]:

$$\overline{m}_T = \frac{1}{n}\sum_{i=1}^{n} \overline{\mu}_T^i;$$

$$\underline{m}_T = \frac{1}{n}\sum_{i=1}^{n} \underline{\mu}_T^i.$$

Values of upper $\overline{\mu}_T^i$ and lower $\underline{\mu}_T^i$ boundary of confidential interval are calculated accordingly under the following formulas [7]:

$$\overline{\mu}_T^i = \overline{a} \cdot \left(1 + \underline{b} + \ldots + \underline{b}^{k-1}\right) + \underline{b}^k X_{i2};$$

$$\underline{\mu}_T^i = \underline{a} \cdot \left(1 + \overline{b} + \ldots \overline{b}^{k-1}\right) + \overline{b}^k X_{i2};$$

where the factor $k = \left[\frac{T}{t_2 - t_1}\right] + 1$ is an integer.

5. Evaluation of resistors' compliance to dependability requirements.

5.1. Calculation of probability of non-failure operation during time equal to T_γ, under the formula [8]:

$$P(t) = P_П(T) \cdot P_B(T),$$

where $P_П(T)$ is the probability of non-failure operation of resistors concerning gradual failures;

$P_B(T)$ is the probability of that no sudden failure will occur in sample under condition that during tests there was not any sudden failure;

5.2. Definition of probability of non-failure operation on gradual and sudden failures [8]:

$$P_П(T) = \Theta\left(\frac{\overline{b} - \overline{m}_T}{\Sigma_T}\right) - \Theta\left(\frac{\underline{b} - \underline{m}_T}{\Sigma_T}\right),$$

$$P_B(T) = e^{-\overline{\lambda}_B \cdot n (T - t_n)},$$

$$\Sigma_T = \sqrt{\sigma_0^2 \cdot \left(1 + \overline{b}^2 + \ldots + \overline{b}^{2(k-1)}\right)},$$

where $\overline{\lambda}_B$ is the upper confidence boundary of failure rate on sudden failures,

Θ – Heaviside function.

If a priori information on sudden failures of products – analogues at their operation is absent, the value $\overline{\lambda}_B$ is accepted as equal to an average-group from dependability handbook.

5.3. Checkup of condition $P(t) \ge P(T)_3$, where $P(T)_3 \le 0{,}975$. If the condition is satisfied, resistors correspond to requirements of c-percentile time to failure.

Using the offered evaluation methodology of dependability measures the calculation of c-percentile time to failure (T_γ) of resistors such as Р2-67 has been performed at their use under conditions of increased temperature.

According to requirements of specifications OZhO.467.563TU the c-percentile time to failure of resistors R2-67 at electric loading $P = 0{,}5P_{ном}$ (light duty) and temperature from minus 60 °C up to 40 °C is equal to 40000 hours.

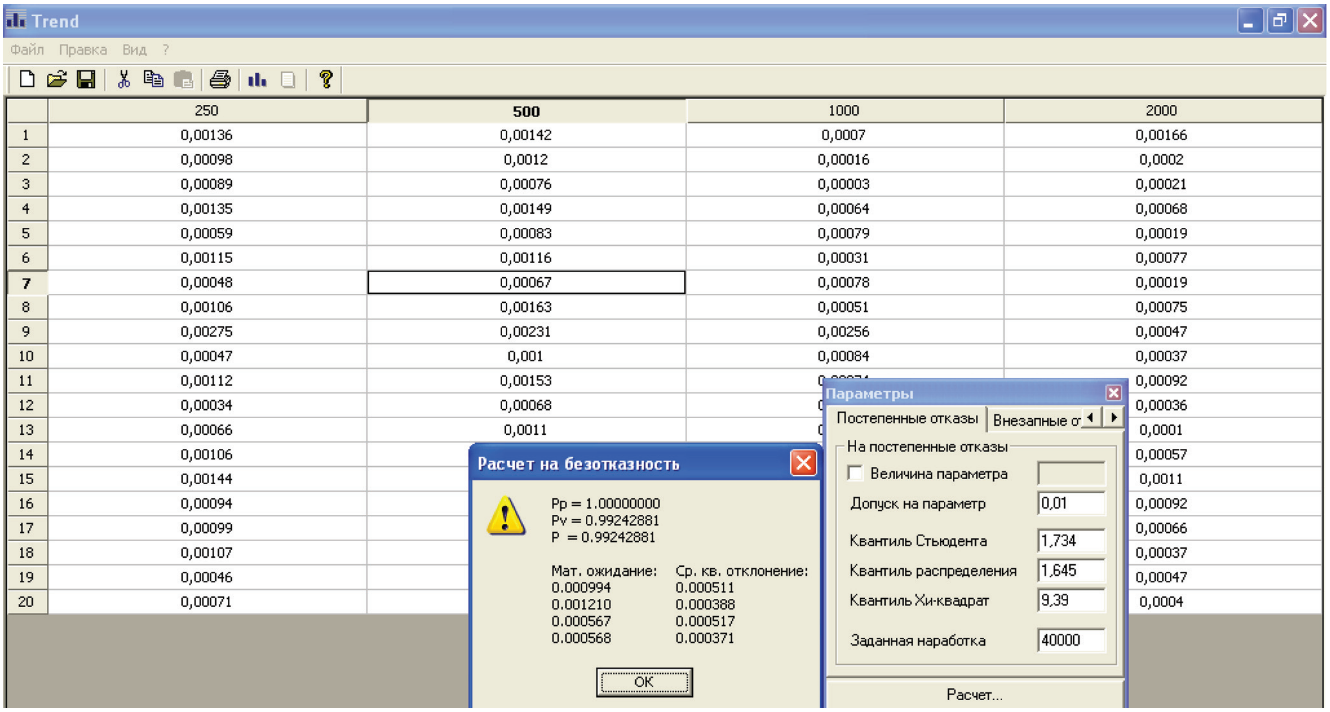

Fig. 1. Visual display of the program "Trend" for evaluation of reliability probability *P* of resistors with results of calculations

Within the framework of the given study, it was required to estimate the possibility of resistors application in structure of information – measuring system with the electric loading corresponding to the light duty. However, the ambient temperature while in service could change in a range from minus 55 °C up to 55°C, and at the same time, the minimal time to failure should be not less than 40000 hours.

For the solution of the stated task, tests for short-term reliability were performed within 2000 hours at ambient temperature equal to minus 55 ºC and DC voltage, corresponding to $0{,}5P_{ном}$.

For processing results of tests with the help of the above-described method, the program "Trend" which realizes the offered methodology has been developed using object-oriented language C++.

The program "Trend" provides input and data processing in the form of adjusted spreadsheet and panels for calculation of parameters. The entered data can be kept in a file, and subsequently are read out from it. The program realizes information type-out, executes function of data reception – transfer from clipboard. Visual display of the program with test data of resistors R2-67 and results of calculations is shown on figure 1.

Thus, by results of tests for short-term reliability probability of resistors R2-67 within 2000 hours, no failures have been fixed, and electric parameters have been within the limits of the established tolerance. With the help of the given technique the reliabilities probability of $P(t)$ = 0, 9924 is calculated. The condition $P = P(t) \geq P(T)_з$ where $P(T)_з \leq 0{,}975$ has been met, hence, resistors R2-67 can applied by the customer in the equipment with the electric loading corresponding to the light duty at change of ambient temperature while in service in a range from a minus 55°C up to 55°C. At the same time, the minimal time to failure makes up not less than 40000 hours.

The developed methodology allows performing evaluation of c-percentile time to failure of resistors at their development stage with the purpose of dependability requirements confirmation.

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