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Reliability of Electronic Devices at Early Stages of Life Cycle

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Introduction

In the paper, early stages of existence of electronic devices are considered: design stage and stage of early failures. At the design stage of electronic devices, various actions are carried out: choice of circuit and structural decisions; choice of parts of devices, components and elements; performance of programs on maintaining reliability [1, 2]. Among programs on maintenance of reliability, important role is attributed to evaluation works related to reliability of various variants of structure of electronic devices [3]. At evaluation of reliability of devices, help data manufacturers components and elements (further – components) are used [4].

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The stage of early failures is usually related to the beginning of technological running–in of electronic devices. At this stage, failures of both devices, parts of devices and components are revealed. In general, the reason of the given failures is industrial lacks. To organize works on revealing early failures in a rational way is possible having estimated reliability of electronic devices for the given stage [3, 5, 6].

In the article, the method of forecasting of reliability of components applied at a design stage of electronic devices is analyzed. Models of reliability of electronic devices for the stage of early failures are considered. Methods of evaluation of parameters of considered models and method of evaluation of conformity of models with statistical data on failures, are offered.

Forecasting of reliability of components of electronic devices

Works of calculation of reliability are carried out at various stages of life cycle of electronic devices. At early stages of life cycle this usually is the counting of indexes of reliability of devices. The given evaluations are based on the information by manufacturers on reliability of components. The information on reliability of components of electronic devices is specified in various sorts of directories. The important question is definition of failure rate of components during the moments of time further from time of publication of help data.

Let's consider a time interval from the moment of publication of help data for which the manufacturer specifies reduction of failure rate of components. Then, for the certain type of components, it can be written down:

$$\lambda(t) = \lambda_0 K_\lambda(t), \quad (1)$$

$$K_\lambda(t) = \exp(-At), \quad (2)$$

where t – the moment of time of a considered interval; $\lambda(t)$ – predicted value of failure rate of component of the device; λ_0 – help value of failure rate of component of the device; $K_\lambda(t)$ – failure rate reduction coefficient of component of the device.

Let's analyze a case when the manufacturer specifies certain values $K_\lambda(t_i)$, $\left(i = \overline{1, l}\right)$ for the moments of time t_i. It is easy to show that based on the method of the least squares, values of coefficient A in (2) can be determined from expression

$$A = -\left(\sum_{i=1}^{l} t_i \ln K_\lambda(t_i)\right) \Bigg/ \sum_{i=1}^{l} t_i^2 . \quad (3)$$

For example, the manufacturer specifies reduction of failure rate of the certain type of components within the first three years from the moment of publication of help data: $K_\lambda(1) = 0.9$; $K_\lambda(2) = 0.8$; $K_\lambda(2) = 0.7$. For coefficient A, according to (3), we shall receive $A = 0.116$. In Table 1, for a considered case, values of coefficient $K_\lambda(t)$ for various t (in years), determined on expression (2) are specified.

Table 1. Dependence $K_\lambda(t)$ for various t

t	1	2	3	4	5
$K_\lambda(t)$	0.89	0.79	0.71	0.63	0.56

Values $K_\lambda(t)$ in Table 1 for $t>3$ are fair in the event that law of reduction λ_0 is verified by the manufacturer of components.

Models of reliability of electronic devices at a stage of early failures

For a stage of early failures, it is first necessary to choose a kind of the dependence describing change of mean value of a failure rate (further – failure rate) of devices in the course time.

For the device the density of a distribution of time from the beginning of technological running–in to first failure, and between other consecutive failures can be presented as superposition of two exponential distributions with parameters λ_1 and λ_2 [6]. Parameter λ_1 characterizes failure rate of parts of the device and components due to industrial lacks. Parameter λ_2 characterizes failure rate without taking into account the mentioned lacks. Then dependence (regression) of failure rate of the device on time will be as follows

$$\Lambda(t)=\Lambda_1\exp(-\alpha_0 t)+\Lambda_0\,, \tag{4}$$

where Λ_1 – value of a failure rate, caused, basically, by defects of manufacture of the device, parts of the device and components; Λ_0 – the established value of failure rate; α_0 – coefficient describing speed of revealing of defects of manufacture during running–in. Between coefficient Λ_1, α_0, Λ_0 and failure rate λ_1, λ_2 there is following relation [3]:

$$\Lambda_1=b_1\lambda_1+b_2\lambda_2-\Lambda_0\,, \tag{5}$$

$$\Lambda_0=\lambda_1\lambda_2/(\lambda_1 b_2+\lambda_2 b_1), \tag{6}$$

$$\alpha_0=\lambda_1 b_2+\lambda_2 b_1\,, \tag{7}$$

where b_1, b_2 – coefficients depending on a parity between two kinds of failures of the device, described by failure rate λ_1 and λ_2, with $b_1+b_2=1$.

The following dependence (regression) of failure rate of the device on time can also be used:

$$\Lambda(t)=\begin{cases}\Lambda_*\exp(-\alpha_1 t), 0\le t\le t_t\,,\\ \Lambda_*\exp(-\alpha_1 t_t), t>t_t\,,\end{cases} \tag{8}$$

where t_t – duration of technological running–in of the device.

Evaluation of parameters of models of reliability of electronic devices based on statistical data on failures

The following issue to be solved is determining values of coefficients Λ_1, α_0, Λ_0 in regression (4) and coefficients Λ_*, α_1 in regression (8). As it may be seen from (4) and (8), considered regressions are nonlinear.

With the information on failures N_i of devices during the moments of time $t_i\left(i=\overline{1,n}\right)$ of carrying out of technological running–in, it is possible to receive statistical evaluations (at $t=t_i$) of average value $\hat{\Lambda}_i$ and a dispersion $\hat{D}_i$ of failure rate. With availability of data it is also possible to use data of exploitation of devices.

Let's consider intervals $\Delta\tau_i$: $\Delta\tau_1=t_1$; $\Delta\tau_2=t_2-t_1$; …, $\Delta\tau_n=t_n-t_{n-1}$. Considering their actual duration, we shall consider a flow of failure during $\Delta\tau_i$ as the Poisson flow. Then, for $\hat{\Lambda}_i$ and $\hat{D}_i$, it will be fair:

$$\hat{\Lambda}_i=r_i/(N_i\Delta\tau_i)\,, \tag{9}$$

$$\hat{D}_i=r_i/(N_i\Delta\tau_i)^2\,, \tag{10}$$

where r_i – quantity of the failures that have arisen during interval $\Delta\tau_i$.

The method of the least squares can be applied for definition of coefficients of regression (4) and (8) [6]. If random errors of supervision are independent and are subordinate to normal distribution, the given method provides evaluation of unknown coefficients with the least dispersion. Thus, the received estimations are efficient [7]. Otherwise, other methods leading to steady estimations can be applied [7, 8].

On the basis of method of the least squares, coefficients Λ_1, α_0, Λ_0 of regression (4) can be determined in view of following requirements:

$$\sum_{i=1}^{n}\frac{\left[\hat{\Lambda}_i-\Lambda(t_i;\Lambda_1,\alpha_0,\Lambda_0)\right]^2}{\hat{D}_i}\to\min_{\Lambda_1,\alpha_0,\Lambda_0}\,, \tag{11}$$

$$\Lambda(t_i;\Lambda_1,\alpha_0,\Lambda_0)=\Lambda_1\exp(-\alpha_0 t_i)+\Lambda_0\,. \tag{12}$$

To find Λ_1, α_0, Λ_0, according to (11), it is necessary to carry out differentiation of the left part (11) according to Λ_1, α_0, Λ_0 and to equate derivatives to zero:

$$\begin{cases}\sum\limits_{i=1}^{n}B_i\left(\dfrac{\partial\Lambda}{\partial\Lambda_1}\right)_i=0,\\ \sum\limits_{i=1}^{n}B_i\left(\dfrac{\partial\Lambda}{\partial\alpha_0}\right)_i=0,\\ \sum\limits_{i=1}^{n}B_i\left(\dfrac{\partial\Lambda}{\partial\Lambda_0}\right)_i=0,\end{cases} \tag{13}$$

$$B_i=\frac{\hat{\Lambda}_i-\Lambda(t_i;\Lambda_1,\alpha_0,\Lambda_0)}{\hat{D}_i}, \tag{14}$$

where $\left(\dfrac{\partial\Lambda}{\partial\Lambda_1}\right)_i=\Lambda'_{\Lambda_1}(t_i;\Lambda_1,\alpha_0,\Lambda_0)$ – value of partial derivative function Λ on parameter Λ_1 in a point t_i; the same $\left(\dfrac{\partial\Lambda}{\partial\alpha_0}\right)_i$, $\left(\dfrac{\partial\Lambda}{\partial\Lambda_0}\right)_i$.

Considering that regression (4) is nonlinear it is not possible to solve the system of the equations (13) in analytical way. In this view, we shall stop on numerical methods.

Let's use a method of search on a grid. Let's consider area of possible values α_0 with limits $\alpha_{0\min}$ and $\alpha_{0\max}$. Based on the demanded accuracy let's allocate q of values α_0 within the limits: α_{01}; α_{02}; ... ; α_{0l}; ... ; α_{0q}. Let's consider that $\alpha_{01} = \alpha_{0\min}$, $\alpha_{0q} = \alpha_{0\max}$, and value α_0 is known and is equal to $\alpha_{0j}\left(j = \overline{1,q}\right)$. Then, corresponding values Λ_{1j} and Λ_{0j} can be determined considering requirements of the method of the least squares, under formulas:

$$\Lambda_{1j} = \frac{\sum_{i=1}^{n} C_i \sum_{i=1}^{n} C_i E_i \hat{\Lambda}_i - \sum_{i=1}^{n} C_i \hat{\Lambda}_i \sum_{i=1}^{n} C_i E_i}{\sum_{i=1}^{n} C_i \sum_{i=1}^{n} C_i E_i^2 - \left(\sum_{i=1}^{n} C_i E_i \right)^2}, \quad (15)$$

$$\Lambda_{0j} = \left(\sum_{i=1}^{n} A_i \hat{\Lambda}_i - \Lambda_{1j} \sum_{i=1}^{n} A_i B_i \right) \Bigg/ \sum_{i=1}^{n} A_i, \quad (16)$$

$$C_i = r_i^{-1}, \quad (17)$$

$$E_i = \exp\left(-\alpha_{0j} t_i\right). \quad (18)$$

Values Λ_0, Λ_1 and α_0 can be considered as required values of coefficients at which S_l satisfies the following equation

$$S_l = \min\left\{S_1, S_2, ..., S_l, ..., S_q\right\}, \quad (19)$$

where

$$S_j = \sum_{i=1}^{n} C_i \left\{\hat{\Lambda}_i - \Lambda_{0j} - \Lambda_{1j} E_i\right\}^2, \left(j = \overline{1,q}\right). \quad (20)$$

For unbiased estimate of square deviation σ_0, it will be fair

$$\sigma_0 = \sqrt{\frac{\sum_{i=1}^{n} C_i \left\{\hat{\Lambda}_i - \Lambda_0 - \Lambda_1 \exp\left(-\alpha_0 t_i\right)\right\}^2}{n-3}}. \quad (21)$$

Values of coefficients Λ_* and α_1 in regression (8) shall also define based on the requirement of the method of the least squares:

$$\sum_{i=1}^{n} \frac{\left[\hat{\Lambda}_i - \Lambda\left(t_i; \Lambda_*, \alpha_1\right)\right]^2}{\hat{D}_i} \to \min_{\Lambda_*, \alpha_1}, \quad (22)$$

$$\Lambda\left(t_i; \Lambda_*, \alpha_1\right) = \Lambda_* \exp\left(-\alpha_1 t_i\right). \quad (23)$$

For finding Λ_* and α_1 according to (22) it is necessary to solve the following system of the equations:

$$\begin{cases} \sum_{i=1}^{n} F_i \left(\frac{\partial \Lambda}{\partial \Lambda_*} \right)_i = 0, \\ \sum_{i=1}^{n} F_i \left(\frac{\partial \Lambda}{\partial \alpha_1} \right)_i = 0, \end{cases} \quad (24)$$

$$F_i = \frac{\hat{\Lambda}_i - \Lambda\left(t_i; \Lambda_*, \alpha_1\right)}{\hat{D}_i}. \quad (25)$$

Regression (8) is also nonlinear. In this case, definition of values of coefficients Λ_* and α_1 is possible by using the logarithm or numerical methods. At transformation of regression (8) by using the logarithm, coefficients α_1 also Λ_* can be received in an analytical way:

$$\alpha_1 = \frac{n \sum_{i=1}^{n} t_i \ln \hat{\Lambda}_i - \sum_{i=1}^{n} \ln \hat{\Lambda}_i \sum_{i=1}^{n} t_i}{\left(\sum_{i=1}^{n} t_i \right)^2 - n \sum_{i=1}^{n} t_i^2}, \quad (26)$$

$$\Lambda_* = \exp\left\{ \left(\sum_{i=1}^{n} \ln \hat{\Lambda}_i + \alpha_1 \sum_{i=1}^{n} t_i \right) \Big/ n \right\}. \quad (27)$$

The unbiased estimation of square deviation σ_1 for regression (8) will be as follows

$$\sigma_1 = \sqrt{(n-2)^{-1} \sum_{i=1}^{n} C_i \left\{\hat{\Lambda}_i - \Lambda_* \exp\left(-\alpha_1 t_i\right)\right\}^2}. \quad (28)$$

As a numerical method for regression (8), it is also possible to use the above–considered method of search on a grid. Let's allocate q values in the field of possible values α_1. Let's consider value α_1 known and equal to $\alpha_{1j}\left(j = \overline{1,q}\right)$. Then, corresponding Λ_{*j} shall be defined as follows

$$\Lambda_{*j} = \frac{\sum_{i=1}^{n} C_i \hat{\Lambda}_i \exp\left(-\alpha_{1j} t_i\right)}{\sum_{i=1}^{n} C_i \left\{\exp\left(-\alpha_{1j} t_i\right)\right\}^2}. \quad (29)$$

Definition of consistency of models of reliability of electronic devices with statistical data on failures

Let's consider the issue of check of validity of judgments on a kind of regression $\Lambda(t)$. Let's consider a zero hypothesis that dependence of failure rate on time corresponds to (4).

Let's consider that $N_i = N_0$, $\Delta\tau_i = \Delta\tau\left(i = \overline{1,n}\right)$. Then, it is possible to conclude [9] that statistics ξ^2, subordinate χ^2 distribution with $\beta_0\left(\beta_0 = n-3\right)$ degrees of freedom, can be determined from expression

$$\xi^2 = \left(N_0 \Delta\tau \sigma_0\right)^2. \quad (30)$$

Value of statistics ξ^2, calculated by (30), can satisfy one of following conditions:

$$\chi^2_{1-\frac{\varepsilon}{2}}(\beta_0) < \xi^2 < \chi^2_{\frac{\varepsilon}{2}}(\beta_0), \qquad (31)$$

$$\xi^2 \le \chi^2_{1-\frac{\varepsilon}{2}}(\beta_0), \qquad (32)$$

$$\xi^2 \ge \chi^2_{\frac{\varepsilon}{2}}(\beta_0), \qquad (33)$$

where $\chi^2_{1-\frac{\varepsilon}{2}}(\beta_0)$ – $100\left(1-\frac{\varepsilon}{2}\right)$ percentage point of χ^2 distribution with β_0 degrees of freedom; $\chi^2_{\frac{\varepsilon}{2}}(\beta_0)$ – $100\frac{\varepsilon}{2}$ percentage point of χ^2 distribution with β_0 degrees of freedom; ε – significance level of criterion.

At performance of (31), follows that the stated hypothesis about regression of kind (4) has been approved as not contradicting to statistical data. At performance of (32) or (33), hypothesis about regression of kind (4) is rejected with significance level ε. Except for that, at performance of (32) it is possible to consider that the number of coefficients of regression $\Lambda(t)$ of kind (4) is overestimated. At performance of (33), it is possible to consider that the number of coefficients of considered regression is underestimated.

Check of conformity to available statistical data of regression of kind (8) is the same as above. In this case, statistics ξ_1^2 with $\beta_1(\beta_1 = n-2)$ degrees of freedom will be equal

$$\xi_1^2 = (N_0 \Delta\tau\sigma_1)^2. \qquad (34)$$

Conclusions

1. Early stages of existence of electronic devices are analyzed: design stage and stage of early failures.
2. At the design stage the important question is definition of failure rate of components during the moments of time further from time of publication of help data by the manufacturer.
3. The method of forecasting of reliability of components is offered. The method considers data by the manufacturer on change of failure rate of components during the moments of time after publication of help data.
4. The stage of early failures of electronic devices is considered. Two models of dependence of failure rate on time for the given stage are offered.
5. Methods of estimation of parameters of considered models and a method of estimation of conformity of models with statistical data on failures are offered.
6. Models of reliability of electronic devices are nonlinear, numerical method of finding the parameters of models is therefore considered. The method provides carrying out of computing experiment.

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Early stages of existence of electronic devices are considered: design stage and stage of early failures. At the design stage, works on evaluation of reliability of various variants of structure of electronic devices are carried out. At performance of the given works, help data by manufacturers of components are used. The important question is definition of failure rate of components during the moments of time further from time of publication of help data. The method of forecasting of reliability of components is offered. The method considers data by the manufacturer on change of failure rate of components during the moments of time after publication of help data. The stage of early failures of electronic devices is considered. Two models of dependence of failure rate on time for the given stage are analyzed. Methods of estimation of parameters of considered models and method of estimation of conformity of models with statistical data on failures are offered. Models of reliability of electronic devices are nonlinear, the numerical method of finding the parameters of models is therefore considered. The method provides carrying out of computing experiment. Bibl. 9 (in English; abstracts in English and Lithuanian).

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Nagrinėjami elektroninių įtaisų projektavimo ir ankstyvųjų gedimų etapai. Projektavimo etape atliekami elektroninių įtaisų negendamumo vertinimo darbai. Tam naudojami žinynų duomenys apie komponentų patikimumą. Atliekant šiuos darbus, svarbu žinoti komponentų, pagamintų vėlesniais negu žinynų publikavimo data laiko momentais, gedimų intensyvumą. Siūlomas komponentų negendamumo prognozavimo metodas. Metodas remiasi gamintojų duomenimis apie komponentų negendamumo pakitimus. Nagrinėjamas ankstyvųjų gedimų laikotarpis ir analizuojamos dvi įtaisų gedimų srautų priklausomybės nuo laiko. Siūlomas šių modelių parametrų vertinimo metodas ir sprendimų apie pasirinktų modelių panaudojimą pagrįstumo tikrinimo metodas. Atsižvelgiant į tai, kad negendamumo modeliai yra netiesinės funkcijos, siūlomas skaitinis modelių parametrų vertinimo metodas, pagrįstas skaičiavimo eksperimentu. Bibl. 9 (anglų kalba; santraukos anglų ir lietuvių k.).