CURRENT APPROACHES TO ANALYSIS OF THE PROJECT RELIABILITY OF ELECTRONIC DEVICES OF CYCLIC USE

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Reliability calculating methods (1)

№	Method	Distribution reliability requirements /goals	Qualitative analysis	Quantitative analysis	Recommendations
1	Predictingfailure rate	Applicable for sequential systems without redundancy	Can be used to analyze the maintenance strategy	The calculation of the failure rate and MTTF* for electronic components and equipment	Support
2	Fault tree analysis	Applicable if the behavior of the system depends on the time and sequence of events	An analysis of the combination of faults	Calculation of indicators of dependability and efficiency and of the relative contribution of the subsystems in the system	Applicable
3	Event Tree Analysis	Possible	Analysis of failures Sequence	The calculation of failure rates	Applicable
4	Analysis of structural reliability schemes	Applicable for systems which can distinguish independent blocks	Analysis of ways of working capacity	Calculation of performance and dependability of systems complex reliability indices	Applicable
5	A Markov analysis	Applicable	Analysis of failures Sequence	Calculation of reliability indices and of complex systems dependability indices	Applicable

Reliability calculating methods (2)

№	Method	Distribution reliability requirements /goals	Qualitative analysis	Quantitative analysis	Recommendations
6	Analysis of Petri nets	Applicable	Analysis of failures Sequence	Preparing the description of the system for a Markov analysis	Applicable
7	Mode and Effect Analysis (critical) of failure FME (C) A	Applicable for systems which have dominated the single failure	Analysis of the impact of failures	The calculation of failure rates (and their criticality) for the system	Applicable
8	The truth table (the analysis of the functional structure)	Not applicable	Possible	Calculation of reliability indices and of complex systems dependability indices	Support
9	Statistical methods for reliability	Possible	Analysis of the impact of faults	Determination of quantitative estimates of reliability indicators with the uncertainty	Support

The basic principles of the calculation model of reliability for electronic devices

Consider this issue on an example of calculation of reliability of the electronic module, which has a series connection of elements working in the "session" mode.

In this case, the element failure rate function, λ(t), is periodic (see. Fig.1).

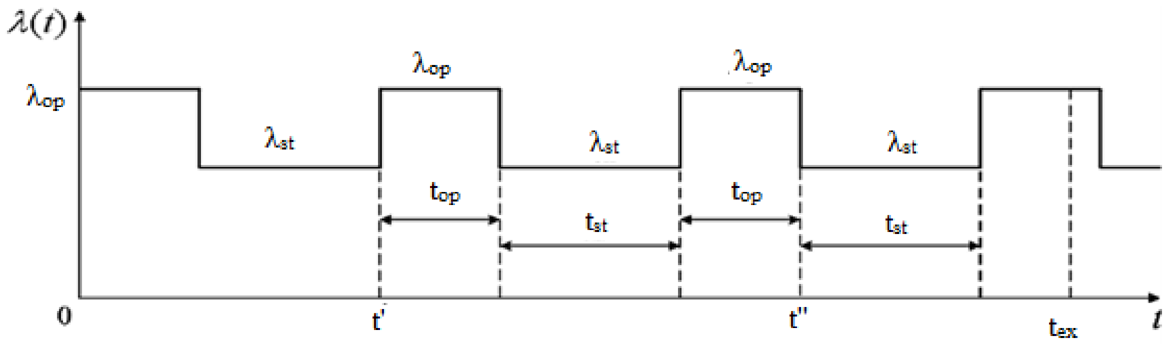

Figure1. Cyclogram of component operation

In accordance with the general equation for determining the probability of failure-free operation of the component:

$$\boldsymbol{P(t) = e^{-\int_0^t \lambda(\tau)d\tau}}, \quad (1)$$

where: $\boldsymbol{\lambda(\tau)} = \begin{cases} \boldsymbol{\lambda_{op}, for\ t' < t < t' + t_{op}} \\ \boldsymbol{\lambda_{st}, for\ t'' < t < t'' + t_{st}} \end{cases}$. $\mathbf{t=t_{ex}}$ **-** the set time of existence.

If the calculation is performed on integer work and storage plots, the ratio of the estimated probability of failure-free operation of the component is:

$$\boldsymbol{P(t) = e^{-(\lambda_{op} \cdot T_{op} + \lambda_{st} \cdot T_{st})}}, \qquad \textbf{(2)}$$

where: $\mathbf{T_{op}=m \cdot t_{op}}$ – cumulative operating time (for the time t_{ex}) for all *m* working areas; $\mathbf{T_{st}=m' \cdot t_{st}}$ – cumulative storage time (for the time t_{ex}) for all *m'* working areas; $\boldsymbol{m' = \begin{cases} m \\ m-1 \\ m+1 \end{cases}}$ – number of areas depending on whether the area (work or storage) starts and ends the time interval t_{ex}.

The reliability graph constructed by the equation (1) is continuous, but have breaks at the points of the t' and t'' in which the failure rate function has a jump.

In cases where calculation is to be made on a predetermined number *m* of work areas and storage areas obtain:

$$\boldsymbol{P\left[m\left(t_{op} + t_{st}\right)\right] = e^{-m(\lambda_{op} \cdot t_{op} + \lambda_{st} \cdot t_{st})}}, \qquad \textbf{(3)}$$

where: $\mathbf{t_{ex}=m(t_{op}+t_{st})}$.

The calculations then resorted to the determination of the average (per period of work and storage) component failure rate, which is obtained from the following equation:

$$\boldsymbol{\lambda_{av} = \frac{\lambda_{op} \cdot t_{op} + \lambda_{st} \cdot t_{st}}{t_{op} + t_{st}}}, \qquad \textbf{(4)}$$

where: $\boldsymbol{\lambda_{op} \cdot t_{op}}$ - the proportion of the influence of the failure rate in operation mode for the period;

$\boldsymbol{\lambda_{st} \cdot t_{st}}$ - the proportion of the influence of the failure rate in the storage mode for the period;

$\boldsymbol{t_{per} = t_{op} + t_{st}}$ – the period.

Probability of failure-free operating is calculated by the model 2.

As an example, consider the assembly of electronic device, which has a single unloaded reserve (see Fig.2) having the following inputs:

Assembly is working in sessions on the amount of in work mode for 32,000 hours and in the storage mode for 55600 hours. The two components are the same and have the following parameters:

The failure rate during work mode $\boldsymbol{(\lambda_{op})}$ $\mathbf{1.232992 \cdot 0^{-6}}$ 1/h.;

The failure rate in the storage mode $\boldsymbol{(\lambda_{st})}$ $\mathbf{2{,}194 \cdot 10^{-8}}$ 1/h.

2. The failure criterion is the following:

- In the work mode the main element 1 is working, a reserve element 2 is switched off; in case of failure the second element switches on;

- In storage mode, both elements are disconnected from the power supply and it is necessary to consider whether the first element will work after turning on or not. If not, a second element will turn on (both elements together are in loaded reserve with failure rate parameter for storage mode).

Consider a few ways to calculate:

Using a model for calculating the probability of failure-free operation for redundant groups from [2], [3] or the scientific literature, and the parameter of the failure rate is determined by the model (4), periods of work and storage are known. According to [2] - a method №4;

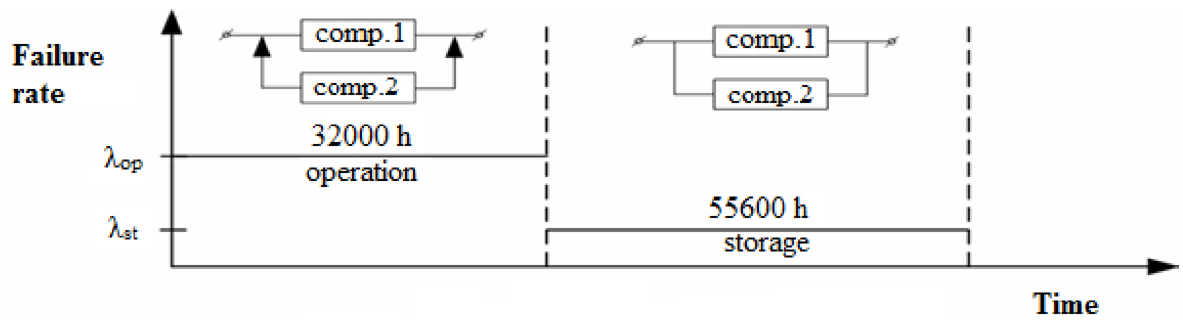

Figure 2. The block diagram of the reliability of the product

2. Construction of a model for calculating the probability of failure-free operation by a method of search of hypotheses based on the total probability formula [4] in accordance with the time schedule specified in [1], where the main parameters will be the failure rate in session mode and storage mode and time intervals. According to [2] - a method №5;

3. The method of decomposition of the time is used – a partition model for calculating the probability of failure-free operation in accordance with a predetermined schedule of operation for the work mode and storage mode. For each of the segments is selected model to calculate the probability of failure-free operation from a standard set or other sources provided that the probability of failure-free operation of a storage mode is determined basing on failure criterion at the time of switching. According to [2] - a methods №1 and 4;

4. Building a model for calculating the probability of failure-free operation using the Monte Carlo method, where the main parameters are the failure rate in the "session" mode, in work mode and in the mode of storage, storage and work periods. According to [2] – a method №9.

Now consider each method in more detail.

When using the first method, choose model for calculating the probability of failure-free operation, based on the criteria of failure for the entire service life of 87600 hours:

$$\boldsymbol{P_1(t) = \frac{\prod_{j=0}^{m}(n+j\alpha)}{\alpha^m m!}\sum_{i=0}^{m}(-1)^i \frac{C_m^i}{n+i\alpha} e^{-(n+i\alpha)\lambda_{av} t}}\ , \qquad \textbf{(5)}$$

where: n – the number of basic components (in this case 1) and m – redundant components (in this case 1); $\alpha = \frac{\lambda_{st}}{\lambda_{op}}$ - coefficient of proportionality; λ_{op}, λ_{st} - the failure rate of components in the work and storage modes.

The result of the calculation is following value of the probability of failure-free operation over the lifetime (87600 hours): 0.999180711554146.

The second method involves the output probabilities of all scenarios that lead to the operation at the end of the period of exploitation on the basis of the above criteria of a failure of the electronic assembly, of temporary work schedule (see. Fig. 2), the list of incompatible successful hypothesis [1]. As a result, get the following model:

$$\boldsymbol{P_2(t) = e^{-\lambda_{av} t_\gamma} + \int_0^{t_\gamma} \lambda_{av} \cdot e^{-\lambda_{av}\cdot t} \cdot e^{-\lambda_{st}\cdot t} \cdot e^{-\lambda_{av}(t_\gamma - t)} dt} \qquad \textbf{(6)}$$

As seen from the mathematical model (6), it takes into account all aspects of the assembly, including the time schedule, failure criteria and a transition of component 2 from storage mode to work mode dependent on status of the first component. Thus, this model will be considered as "Pareto standard" for evaluating the error.

As a result of the calculation get the following value of the probability of failure-free operation over the lifetime: 0.999157335573541.

The third method is analytical calculation by using method of temporal decomposition, it means to estimate separately the probability of failure-free operation of the electronic device for the time of work and time of storage, considering the event of failure at any stage of exploitation independent. In this case, the calculation is divided into three stages:

- The first phase is calculated probability of failure-free operation for the structural scheme of electronic device in work mode for a single period of work;

- The second phase describes the structure of the electronic device in storage mode and similarly the probability of failure-free operation on a single period of storage is estimated;

- At the final stage estimates the probability of failure-free operation for electronic device for the entire exploitation period, taking into account the amount of work and storage periods.

In general, the design equation for determining the probability of failure-free operation over the exploitation period is as follows:

$$\boldsymbol{P_{gen} = \prod_{i=1}^{m} P_{st}(\tau_{sti}) \cdot \prod_{j=1}^{n} P_{op}(\tau_{opj})}\ , \qquad \textbf{(7)}$$

where: P_{gen} – general probability of failure-free operation for system; P_{st} - function of the probability of failure-free operation of the system in storage mode;τ_{sti} - the i-th storage interval, h.; P_{op} - function of the probability of failure-free operation of the system in work mode;τ_{opj} - j-th interval of work, h.

Using equation (7) in practice quite inconvenient, especially when there is redundancy in the system, which implies a fairly complex function defining the probability of failure of the system in either storage mode or in work mode. In addition, the design phase is usually not know the exact schedule of the electronic device (in general, it may be the case), it is known only to the expected ratio of time of work and time of storage, in this case suggest that the duration of sessions is constant. Based on this and on the use of mathematical models with time-constant failure rates equation (7) is transformed to the following form:

$$\boldsymbol{P_{gen} = (P_{st}(\tau_{st}))^{n} \cdot (P_{op}(\tau_{op}))^{m}} \qquad \textbf{(8)}$$

Also, based on the use of the exponential model for failure of electronic devices, intervals of work and storage can be combined:

$$\boldsymbol{P_{gen} = (P_{st}(\sum \tau_{st})) \cdot (P_{op}(\sum \tau_{op})) = P_{st}(t_{st}) \cdot P_{op}(t_{op})} \qquad \textbf{(9)}$$

where: t_{st} - cumulative time of storage, h.;; t_{op} – cumulative work time, h.

Equation (9) is valid for a strictly exponential mathematical models of failures of investigated electronic devices. However, in practice (9) is used to estimate the probability of failure-free operation of redundant systems, which failure model no longer corresponds to an exponential form.

Consider the application of (9) at the example of the investigated electronic assembly. It is possible to determine that during storage the failure rates of the main and the reserve component groups are same as both chains are identical and are stored under identical conditions. Thus, during storage, the electronic assembly is a loaded reserve, which probability of failure-free operation is described by the following expression [2]:

$$\boldsymbol{P_{st} = 1 - (1 - e^{-\lambda_{st} t_{st}})^2} \qquad \textbf{(10)}$$

In mode of work the components of the redundant group are located in different conditions, main chain performs its functions and is under load, while the backup continues to be stored unloaded. In case of failure in the main chain, the backup chain will be loaded. In this case, the system works on the scheme of facilitated reserve, probability of failure-free operation of which is determined by the equation [2]:

$$\boldsymbol{P_{op} = e^{-\lambda_{op} t_{op}} (1 + (1 - e^{-\lambda_{st} t_{st}}) \cdot \frac{\lambda_{op}}{\lambda_{st}})} \qquad \textbf{(11)}$$

Thus, substituting (10) and (11) into (9) we can determine the overall probability of failure on the entire period of operation. The result of calculation is the following value: 0.99922699998305.

One of the sources of error in this method is that the failures in the storage mode and operation mode considered to be independent, that is only true to a simple linear structural reliability schemes where a failure of any component in any mode is the failure of all electronic devices. In (9, 10, 11) are considered two groups of two parallel elements as independent, that is, order to system is considered not failed enough that to the end of the period of work to keep working capacity of any one component of the two examined groups. This statement is incorrect, since the event of failures of system components in the first and second group are dependent.

Consider the specific of inaccuracy of the assumption of independence of groups of components on an example: the mathematical model (9) finds a workable system in which the first group declined 2 component, the second - 1, while it is physically the same components, and such a situation will lead to failure. That is, in such a calculation deliberately introduced an error, leading to an overestimation of the result, which is unacceptable in assessing of the reliability.

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