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A method of identifying the durability indicator of microcircuitry

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Abstract. *The Aim of this paper is to ensure the compliance of the requirements for the durability of long-life space technology with the fact that regulatory documents for microcircuitry do not contain durability indicators. Thus, in accordance with OST V 11 0998-99, the dependability requirements only contain indicators of reliability and storability. On the other hand, along with the requirements for reliability and storability, the dependability specifications for space technology feature requirements for durability in operation that are usually equal to the gamma-percentile life $T_{l.r}$ = 100 000 h and more if r = 99.9%. Therefore, for such long-life systems one must define durability indicators that are now absent in the technical conditions or other delivery documents. The definition of such indicators by means of durability testing is costly and time-consuming. Thus, an analytical method was proposed, according to which the lower estimate boundary for the gamma-percentile life $T_{l.r}$ of microcircuitry can be obtained by equalizing the probability of no-failure of the microcircuit over time $T_{l.r}$ to the probability of non-occurrence of life failures that put the microcircuit into the limit state, upon which its operation shall be terminated. In this case, in order to obtain $T_{l.r\ =\ 99.9\%}$ = 100 000 h, a non-redundant microcircuit or another product must have the failure rate of 10^{-8} 1/h. In the case of more complex microcircuits, it does not appear to be possible to obtain the required value of $T_{l.r=99.9\%}$ = 100 000 h. The paper suggests extending the use of the proposed method of durability indicator identification taking into consideration the fact that in the systems under consideration the failure of any one product is not allowed and, in this view, various ways of ensuring equipment redundancy are used. Hot standby is understood as a redundancy with one or several backup modules that operate similarly to the main module. Warm standby is understood as a redundancy with one or several modules that operate at a lower rate that the main module until they start functioning as the main module. The paper considers a number of redundancy architectures of a complex microcircuit that enable the specified high durability indicators. The formula was obtained for calculation of the durability indicator for more general cases, when the microcircuit is part of a module backed-up by another identical module. In this case, if the second module is in warm standby, a high durability indicator can be ensured for the microcircuit. If the second module is in hot standby, the specified durability indicator of the microcircuit is not ensured. The considered method of durability indicator identification can be used for other redundancy architectures of modules in a system.*

Keywords: *durability, gamma-percentile life, redundancy, hot standby, warm standby.*

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Introduction

In accordance with GOST 27.006-2015 [1], durability is a property of an item, which consists in its ability to perform the required functions in the specified modes and conditions of use, maintenance and repair until the limit state is reached, in which its further operation is unacceptable or impractical, or its recovery is impossible or impractical.

One of the durability indicators of electric components (EC) is the operating life, defined as the total operating time of EC from the beginning of its operation or its resumption after repair until the limit state is reached. The life during which the EC does not reach the limit state with probability г, expressed as a percentage, is called the gamma-percentile life $T_{l.г}$.

In technical specifications, the durability indicator of EC has the form of minimum operating time $T_{o.min}$, which according to OST 4.012.013-84 [2] equals to the corresponding gamma-percentile indicator $T_{l.г}$ if г = 99.9%

$T_{o.min} = T_{l.г}$ if г = 99.9%.

However, in accordance with OST V 11 0998-99 [3], the dependability requirements do not contain indicators of durability. Therefore, there is usually no data on durability in the specifications for newly developed microcircuitry. It should be noted that there is also no durability characteristics in the technical documentation for EC of foreign manufacture [4]. In many practical cases the $T_{l.г}$ estimation of EC must be obtained if the $T_{o.min}$ or $T_{l.г}$ are absent in the corresponding technical documentation or specifications.

Estimation of operating life $T_{l.г}$

The failures of EC used in modern radio electronic equipment usually form the simplest failure flow. For such EC, operation life failures that put EC into the limit state are more typical than degradation failures that are caused by the natural process of aging, wear, corrosion, and fatigue, provided that the operation process is stabilized (the causes of all structural, manufacturing, and operational failures have been eliminated).

EC life failure shall imply the EC failure during time $T_{l.г}$ from the start of operation, the probability $R_{l.f}(t = T_{l.г})$ of which does not exceed a given value (1–γ/100). Then, the time $T_{l.г}$ is defined by the formula

$$R_{l.f}\left(t = T_{l.\gamma}\right) = 1 - e^{-\lambda_o \cdot T_{l.\gamma}} \le \frac{\gamma}{100},$$

or, using the probability of no failure (PNF) of EC, by the formula

$$R_n\left(t = T_{l.\gamma}\right) = 1 - e^{-\lambda_o \cdot T_{l.\gamma}} \ge \frac{\gamma}{100}, \qquad (1)$$

where$R_n(t = T_{l.г})$ is the PNF of a non-redundant EC within time t;

λ_o is the operational failure rate (FR) for EC, defined in the handbook [5] or provided by the supplier/manufacturer;

γ is the probability of non-occurrence of life failure.

$T_{l.г}$. for a non-redundant EC derived from the formula (1) is

$$T_{l.\gamma} \ge \frac{-\ln \frac{\gamma}{100}}{\lambda_o}. \qquad (2)$$

Experience has shown, that even when using all possible ways to improve reliability, the FR of modern complex digital microcircuitry often exceeds $\lambda_o > 0.03 \cdot 10^{-6}$ 1/h, which, in accordance with formula (2), means the value of the durability index $T_{l.г} < 33333$ h if γ = 99.9%.

However, modern space systems often require the values of $T_{r.г} \ge 100000$ h. In order to ensure such high durability indicators when using modern complex microcircuitry in systems, various redundancy methods have to be considered.

Taking into account the microcircuitry redundancy options

Hot standby is understood as a redundancy with one or several backup modules that operate similarly to the main module. Warm standby is understood as a redundancy with one or several modules that operate at a lower rate than the main module until they start functioning as the main module. Thus, when warm standby is used as a redundancy for microcircuitry, PNF is defined by formula [6]

$$R_{red(w)}(t) = e^{-\lambda_o \cdot t}\left[1 + \frac{1}{\alpha}\left(1 - e^{-\alpha\lambda_o t}\right)\right], \qquad (3)$$

where λ_o is the FR of a microcircuit in operational mode;

$\alpha = \lambda_o/\lambda_s$ is the storage factor of a microcircuit in warm standby mode, where λ_s is the FR of a microcircuit in warm standby mode.

Then, in order to achieve a given value of $T_{l.г}$, the following relation should be satisfied

$$R_{red}\left(t = T_{l.\gamma}\right) \ge \frac{\gamma}{100}. \qquad (4)$$

Consider the following example:

$\lambda_o = 0.3 \cdot 10^{-6}$ 1/h;

α = 0.012;

$T_{l.г(req)} = 100000$ h;

γ = 99.9%.

Then, out the relation (3) at $t = T_{l.г(req)} = 100000$ h we obtain

$R_{red(w)}(t = 100000\text{ h}) = 0.9996 \ge 0.999$,

which corresponds to inequation (4).

When hot standby is used as a redundancy for microcircuitry, PNF is defined by the formula

$$R_{red(n)}(t) = 1 - \left(1 - e^{-\lambda_o \cdot t}\right)^2. \qquad (5)$$

Using the example in question, from this formula we obtain

$R_{red(h)}(t = 100000\text{ h}) = 0.9991 \ge 0.999$,

which also corresponds to inequation (4).

Table 1. Calculated values of the PNF of a redundant integrated circuit

$T_{l.r}$, h	100000	110000	120000	130000	140000	150000	160000
$R_{red(w)}(T_{l.r})$	0.9996	0.9995	0.9994	0.9993	0.9991	0.9990	0.9989
$R_{red(h)}(T_{l.r})$	0.9991	0.99895	0.9988	0.9985	0.9983	0.9981	0.9978

Thus, in this example, a redundant microcircuit will ensure the required value of $T_{l.r(req)}$ = 100000 h at γ = 99.9%.

The explicit value of $T_{l.r}$ can be obtained by inserting increasing values of t in increments of $+0.1T_{l.r(req)}$ into formulas (3) and (5) as long as inequation (4) is satisfied. Table 1 shows the obtained values of the PNF of a microcircuit at the given values of $T_{l.r.}$

Thus, in this case, the integrated circuit enables the required durability indicator:

– when warm standby is used: $T_{l.r}$ = 150000 h at г = 99.9%,

– when hot standby is used: $T_{l.r}$ = 100000 h at г = 99.9%.

Taking into account the module redundancy options

In practice, individual integrated circuits are part of modules that are made redundant within a system. Let us assume that a microcircuit, along with other EC, is part of module M_A that is backed-up by module M_B in warm standby. Let us find the PNF of such microcircuit.

An integrated circuit operates without failures during time t in two cases:

1) Module M_A has operated without failure for time t, i.e. a microcircuit in it did not fail

$$R_1(t) = e^{-\lambda_{o(M\_A)} \cdot t}, \tag{6}$$

where $\lambda_{o(M\_A)}$ is the FR of module M_A in operational mode.

2) The following sequence of events took place:

- module M_A failed at the moment τ ($0 < \tau \le t$) (microcircuit or other EC has failed);

- module M_B did not fail until moment τ;

- at moment τ module M_A turned off and module M_B started to operate as the main module;

- within the remaining time interval $(t-\tau)$ the microcircuit did not fail.

The PNF for this case is the following [7]

$$R_2(t) = \int_0^t a_{M\_A}(\tau) \cdot R_{M\_B}(\tau) \cdot R_{MC}(t-\tau)\,dt, \tag{7}$$

where $a_{M\_A}(\tau)$ is the probability distribution function of module M_A failure time, or, which is the same, failure rate of module M_A within time τ, which equals $a_{M\_A}(\tau) = \lambda_{o(M\_A)} \cdot e^{-\lambda_{o(M\_A)} \cdot \tau}$;

$R_{M\_B}(\tau)$ is the PNF of module M_B within time τ;

$R_{MC}(t-\tau)$ is the PNF of microcircuit within time $(t-\tau)$.

Combining formulas (6) and (7) and substituting the values of the variables into formula (7), we obtain

$$R_{red(w)}(t) = e^{-\lambda_{o(M\_A)} \cdot t} + \int_0^t \lambda_{o(M\_A)} \cdot e^{-\lambda_{o(M\_A)} \cdot \tau} \cdot e^{-\lambda_{o(M\_B)} \cdot \tau} \cdot e^{-\lambda_{o(MC)} \cdot (t-\tau)} dt =$$
$$= e^{-\lambda_{o(M\_A)} \cdot t} + \frac{\lambda_{o(M\_A)}}{\lambda_{o(M\_A)} + \lambda_{x(M\_B)} - \lambda_{o(MC)}} \cdot e^{-\lambda_{o(MC)} \cdot t} \cdot \left(1 - e^{-\left(\lambda_{o(M\_A)} + \lambda_{x(M\_Б)} - \lambda_{o(MC)}\right)t}\right). \tag{8}$$

Here $\lambda_{o(M\_A)}$ is the FR of module M_A in operational mode;

$\lambda_{s(M\_B)}$ is the FR of module M_B in warm standby mode when off;

$\lambda_{o(MC)}$ is the FR of microcircuit in operational mode.

Substituting the obtained value of $R_{red(w)}(t)$ at $t = T_{l.r}$ from formula (8) into inequation (4), we obtain the condition for the microcircuit to achieve a durability index equal to $T_{l.r}$.

Let us illustrate the case considered with a real-life example [8], in which the following data were used:

$\lambda_{o(M\_A)} = 0.4522 \cdot 10^{-6}$ 1/h;

$\lambda_{s(M\_B)} = 0.016 \cdot 10^{-6}$ 1/h;

$\lambda_{o(MC)} = 30.340 \cdot 10^{-9}$ 1/h;

$T_{l.r}$ = 100000 h;

γ = 99.9 %.

Substituting these data into formula (8), we obtain

$$R_{red(w)}(T_{l.\gamma}) = e^{-0,4522 \cdot 10^{-6} \cdot 10^5} + \frac{0,4522 \cdot 10^{-6}}{0,4522 \cdot 10^{-6} + 0,016 \cdot 10^{-6} - 30,340 \cdot 10^{-9}} \cdot e^{-30,340 \cdot 10^{-9} \cdot 10^5} \times$$
$$\times \cdot \left(1 - e^{-\left(0,4522 \cdot 10^{-6} + 0,016 \cdot 10^{-6} - 30,340 \cdot 10^{-9}\right)10^5}\right) = 0,999897.$$

In this case

$R_{MC(life)}(T_{l.r}) = 0.999897 \ge 0.999$,

i.e. the microcircuit enables the specified durability indicator $T_{l.r}$ = 100 000 h at γ = 99.9%.

When hot standby is used for modules M_A and M_B, the corresponding formula for the PNF of the microcircuit takes the form

$$R_{red(n)}(t) = e^{-\lambda_{o(M\_A)} \cdot t} + \frac{\lambda_{o(M\_A)}}{2 \cdot \lambda_{o(M\_A)} - \lambda_{o(MC)}} \cdot e^{-\lambda_{o(MC)} \cdot t} \cdot \left(1 - e^{-\left(2 \cdot \lambda_{o(M\_A)} - \lambda_{o(MC)}\right) \cdot t}\right). \tag{9}$$

Then, substituting the example data into formula (9), we obtain

$$R_{red(n)}(T_{l.\gamma}) = e^{-0,4522 \cdot 10^{-6} \cdot 10^5} + \frac{0,4522 \cdot 10^{-6}}{2 \cdot 0,4522 \cdot 10^{-6} - 30,340 \cdot 10^{-9}} \cdot e^{-30,340 \cdot 10^{-9} \cdot 10^5} \times \cdot \left(1 - e^{-\left(2 \cdot 0,4522 \cdot 10^{-6} - 30,340 \cdot 10^{-9}\right) \cdot 10^5}\right) = 0,998956.$$

In this case, inequation (4) in not satisfied, i.e. the microcircuit does not ensure the specified durability indicator $T_{l.r}$ = 100 000 h.

The considered method of durability indicator identification can be used for other redundancy architectures of modules in a system [9].

Conclusion

If the durability indicators (for example, the gamma-percentile life $T_{l.r}$) are not specified in the technical specifications or other documents for the delivery of microcircuitry or other EC, the probability that the microcircuit will not reach the limit state, upon which its further operation is unacceptable, over time $T_{l.r}$ can be equalized to the PNF of the microcircuit over time $t = T_{l.r}$.

A non-redundant microcircuit will have a given gamma-percentile life $T_{l.r}$ defined by relation (2). If the FR of the microcircuit does not satisfy relation (2), then in order to achieve a given durability indicator, various redundancy options can be used.

A redundant microcircuit will ensure the given indicator $T_{l.r}$ if the PNF of the microcircuit satisfies relation (4).

Formulas were obtained for estimating the PNF of a microcircuit, when the microcircuit is part of a backed-up module.

The proposed method can be used to evaluate a given durability indicator of a microcircuit or other EC if the initial data on durability is absent.

References

[1] GOST 27.002-2015. Dependability in technics. Terms and definitions. Moscow: Standartinform; 2016 [in Russian].

[2] OST 4.012.013-84. Electronic equipment. Definition of durability indicators [in Russian].

[3] OST V 11 0998-99. Integrated circuits. General technical conditions [in Russian].

[4] Netes VA. New international standard for dependability. Dependability 2016;3:54-58.

[5] Dependability of Electronic Products Handbook. Moscow; 22-nd Central Research, Design and Test Institute of the Ministry of Defense of Russia; 2006 [in Russian].

[6] Zayko YuG, Smirnov MB. Otsenka nadezhnosti sistem so smeshannym rezervirovaniem [Dependability assessment of systems with combined redundancy]. Dependability 2004;4(11):40-45 [in Russian].

[7] Polovko AM. Osnovy teorii nadiozhnosty [Fundamentals of the dependability theory]. Moscow: Nauka; 1964 [in Russian].

[8] Borisov YuI. O vybore arkhitektury otkazoustoychivykh vychislitelnykh kompleksov dlya kosmicheskikh apparatov [On the selection of the architecture of fail-safe computer systems for spacecraft]. Dependability 2004;2(9):46-51 [in Russian].

[9] Zayko YuG, Iskandarova LN, Trakhtomirov AV. Simulation model to calculate the indices of reliability of redundant radio electronic systems. Dependability 2016;16(3):8-17.

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