Original article
DOI: 10.21683/1729-2646-2017-17-2-24-30

Processing of dependability testing data

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Abstract. Aim. *The development of the electronics industry is associated with a fast growth of the products functionality, which in turn causes increasing structural complexity of the radioelectronic systems (RES) with simultaneously more pressing dependability requirements. The currently used methods have several shortcomings, the most important of which is that they allow accurately evaluating reliability indicators only in individual cases. This type of estimation can be used for verification of compliance with specifications, but it does not enable RES dependability analysis after the manufacture of the pilot batch of equipment. That is why the task of identification of dependability indicators of manufactured radioelectronic systems is of relevance.* **Methods.** *The paper examines the a posteriori analysis of RES dependability analysis that is performed after the manufacture of the pilot batch of equipment in order to identify its dependability characteristics. Such tests are necessary because at the design stage the design engineer does not possess complete a priori information that would allow identifying the dependability indicators in advance and with a sufficient accuracy. An important source of dependability information is the system for collection of data on product operational performance. There are two primary types of dependability tests. One of them is the determinative test intended for evaluation of dependability indicators. It is typical for mass-produced products. Another type of test is the control test designed to verify the compliance of a system's dependability indicator with the specifications. This paper is dedicated to the second type of tests.* **Results.** *The question must be answered whether the product (manufactured RES) dependability characteristics comply with the requirements of the manufacturing specifications. This task is solved with the mathematical tools of the statistical theory of hypotheses. Two hypotheses are under consideration: hypothesis H_0, mean time to failure $t^*=T_0$ as per the specifications (good product); hypothesis H_1, mean time to failure $t^*=T_1<T_0$, alternative (bad product). The hypothesis verification procedure has a disadvantage that consist in the fact that the quality of the solution is identified after the test. Such procedure of hypothesis verification is not optimal. The paper examines the sequential procedure of hypothesis verification (Wald test) that involves decision-making after each failure and interruption of the test if a decision with specified quality is possible. An algorithm is shown for compliance verification of the resulting sample distribution law with the exponential rule or other distribution law over criterion χ^2.* **Conclusions.** *It was shown that the test procedure [n, B, r] ensures the quality of decision identical to that of the procedure [n, V, r] provided the testing time t is identical. Under the sequential procedure, if the number of failures r and testing time are not known from the beginning, a combined method is used (mixed procedure), when additionally the failure threshold limit r_0 is defined and the decision rule is complemented with the condition: if $r < r_0$, the sequential procedure is used; if $r = r_0$, normal procedure is used. An algorithm is shown for compliance verification of the resulting sample $w_1(y_i)$ distribution law with the exponential rule or other distribution law over criterion χ^2. The paper may be of interest to radioelectronic systems design engineers.*

Keywords:*radioelectronic system, test procedures, no-failure operation time, test duration, Neyman-Pearson rule, Wald procedure, χ^2 criterion.*

For citation:Filippov BI, Trush TB.Processing of dependability testing data. Dependability 2017;2: 24-30. DOI: 10.21683/1729-2646-2017-17-2-24-30

Introduction

As it is known, the development of the electronics industry is associated with a fast growth of the products functionality, which in turn causes increasing structural complexity of the radioelectronic systems (RES) with simultaneously more pressing dependability requirements. The currently used methods have several shortcomings, the most important of which is that they allow accurately evaluating reliability indicators only in individual cases [1-4]. This type of estimation can be used for verification of compliance with specifications, but it does not enable RES dependability analysis after the manufacture of the pilot batch of equipment.

Therefore, the task of identification of dependability indicators of manufactured RES is of relevance.

Problems and solutions

1. Problems of a posteriori analysis

A posteriori dependability analysis is performed after the manufacture of the pilot batch of equipment in order to identify its dependability characteristics. For that purpose RES is submitted to statistical testing using one of the procedures described below [5]:

a) procedure [n, B, r] implies that the test involves n RES to r failures without replacement of failed systems;

b) procedure [n, V, r] implies that the test involves n RES to r failures with replacement of failed systems (renewal);

c) procedure [n, B, T] implies that the test involves n RES within given time T (test duration) without replacement of failed systems;

d) procedure [n, V, T] implies that the test involves n RES within given time T with replacement of failed systems (renewal);

e) mixed procedures: [n, B, r/T] or [n, V, r/T] imply specified test duration and number of failures; the tests are stopped when either r or T reach the specified value; if the test duration to last failure $t_r \leq T$, then the results are processed using procedures a) or b), if $t_r > T$, then the results are processed using procedures c) or d);

f) procedure [n, B, n], tests are conducted to failure of all n RES that participate in the test; this procedure is used rarely, primarily in cases when it is required to identify statistical characteristics of failure sequences of individual RES elements.

Each testing procedure has its advantages and disadvantages, some of which will be shown below.

Test results processing aims to solve one of two tasks:

First task. Identification of dependability indicators of manufactured RES;

Second task. Identification of the degree of compliance of dependability indicators of manufactured RES with the specifications.

The first task is considered in [6].

2. Identification of the compliance of dependability indicators with the specifications (Second task)

The verification of RES dependability characteristics compliance with specifications is the second task of dependability testing. The question must be answered whether the product (manufactured RES) dependability characteristics comply with the requirements of the manufacturing specifications. This task is solved with the mathematical tools of the statistical theory of hypotheses [5].

Definition of goals of the research

1. As the result of tests as per procedure [n, V, r] with replacement of (renewal) of failed systems the sample of failure time points (t_1, …, t_r) was obtained that was used for identification of the sample of times between failures (y_1, …, y_r).

2. Two hypotheses are under consideration:

- hypothesis H_0: mean time to failure $t^*=T_0$ as per the specifications (good product);
- hypothesis H_1: $t^*=T_1<T_0$, alternative (bad product).

3. As it is known, the distribution density of times between failures matches the exponential rule (otherwise, the experimental data is verified for compliance with the adopted theoretical model).

4. The decision regarding the correctness of a hypothesis is taken based on the Neyman-Pearson rule, for which under a specified probability of errors of first kind the probability value of the errors of second kind is the lowest.

Based in the test results, the question must be answered as to which of the hypotheses is correct.

Description of the method to solve the research task

1. The sample is a point in an$r$-dimensional space Y, Figure 1.

Before starting the tests, the sample space must be divided into two spaces in accordance with the adopted decision rule.

$$\text{if}\,(y_1,\dots,y_r)\in y_r^{(H_0)} \xrightarrow{\gamma_0} H_0,$$

$$\text{if}\,(y_1,\dots,y_r)\in y_r^{(H_1)} \xrightarrow{\gamma_1} H_1, \qquad (1)$$

whereγ_0 is the decision in favour of the hypothesis H_0, while γ_1 is that in favour of the hypothesis H_1.

Wrong decision are also possible:

- error of first kind: γ_0/H_1, buyer's risk,
- error of second kind: γ_1/H_0, manufacturer's risk.

Accordingly, the correct decisions are as follows: γ_0/H_0 and γ_1/H_1.

2. According to the Neyman-Pearson rule:

- buyer's risk $\alpha=P\{\gamma_0/H_1\}$ (probability of error of first kind is specified by the buyer);
- manufacturer's risk $\beta= P\{\gamma_1/H_0\}$ (probability of error of second kind is minimized by the manufacturer).

Decision quality indicator: $(1-\beta) = P\{\gamma_1/H_1\}$, probability of correct decision that the product is bad.

3. Let us calculate the likelihood ratio

$$L(y_1, y_2, \dots, y_r) = \frac{w_r(y_1, \dots, y_r / H_0)}{w_r(y_1, \dots, y_r / H_1)}.$$

That enables the transformation of the decision rule in the r-dimensional space (1) into the decision rule in the one-dimensional space, when the likelihood ratio is compared to a certain threshold

decision γ_0: H_0, if $L(y_1, \dots, y_r) \geq C$,

decision γ_1: H_1, if $L(y_1, \dots, y_r) \leq C$.

4. Let us identify the threshold C for the Neyman-Pearson rule.

Threshold C is identified through the specified value α as follows.

$$\alpha = P\{\gamma_0/H_1\} = P\{L(y_1, \dots, y_r) \geq C/H_1\} \quad (2)$$

Let us rewrite the rule (2) as

$\ln L(y_1, \dots, y_r) \geq \ln C$, then the decision is γ_0, otherwise γ_1. (3)

Then

$$\ln L(y_1, \dots, y_r) \geq \ln \prod_{i=1}^{r} \frac{w_1(y_i/H_0)}{w_1(y_i/H_1)} = \sum_{i=1}^{r} \ln \left(\frac{w_1(y_i/H_0)}{w_1(y_i/H_1)} \right),$$

if y_i are independent, then

$$w_r(y_1, \dots, y_r / H_0) = \prod_{i=1}^{r} w_1(y_i/H_0)$$

Provided failed systems are replaced (procedure [n, V, r])

$$w_1(y_i / H_0) = \frac{n}{T_0} e^{-\frac{n}{T_0} y_i},$$

where $\lambda_0 = \dfrac{1}{T_0}$ is the allowed failure rate of good products,

$$w_1(y_i / H_1) = \frac{n}{T_1} e^{-\frac{n}{T_1} y_i},$$

where $\lambda_1 = \dfrac{1}{T_1} > \lambda_0$ is the failure rate of the products that do not comply with the specifications.

Then

$$\frac{w_1(y_i/H_0)}{w_1(y_i/H_1)} = \frac{T_1}{T_0} e^{-ny_i\left(\frac{1}{T_0} - \frac{1}{T_1}\right)}$$

and the likelihood ratio becomes as follows

$$\ln L(y_1, \dots, y_r) = \sum_{i=1}^{r} \left\{ n \frac{T_1}{T_0} - ny_i \left(\frac{1}{T_0} - \frac{1}{T_1} \right) \right\} =$$

$$= r \ln \frac{T_1}{T_0} + n \left[\frac{1}{T_1} - \frac{1}{T_0} \right] \sum_{i=1}^{r} y_i = r \ln \frac{T_1}{T_0} + \left(\frac{1}{T_1} - \frac{1}{T_0} \right) t_\Sigma. \quad (4)$$

The decision rule (3) subject to (4) becomes as follows

$t_\Sigma \geq K$, then the decision is γ_0, otherwise γ_1,

where the threshold $K = f(C) = \dfrac{C - r \ln \frac{T_1}{T_0}}{\frac{1}{T_1} - \frac{1}{T_0}}.$ (5)

5. Threshold K can be identified with the help of the χ^2 distribution tables. For that purpose let us rewrite (2) as follows

$$P\{t_\Sigma \geq K/H_1\} = \alpha \quad (6)$$

and transform the variable t_Σ in such a way that the new variable had normalized distribution by χ^2.

It is known, that $t_\Sigma = n \sum_{i=1}^{r} y_i$ is the sum of the exponentially distributed random values y_i. Therefore, $t\Sigma$ has an unnormalized distribution by χ^2. In order to normalize it, is in [6], a new variable $\tau = \left(\dfrac{2t_\Sigma}{t^*} \right)$ must be introduced.

Then, provided that the hypothesis H_1 corresponds with the mean time to failure $t^* = T_1$, the probability (6) is as follows

$$P\left\{ \frac{2t_\Sigma}{t^*} \geq \frac{2K}{T_1} \right\} = \alpha \text{ or } P\left\{ \tau \geq \frac{2K}{T_1} \right\} = \alpha,$$

where τ has a $\chi^2(2r)$ distribution with $2r$ degrees of freedom.

In this distribution (Figure 2) $\dfrac{2K}{T_1} = \chi^2_\alpha(2r)$, which corresponds with the α% distribution point $\chi^2(2r)$.

Therefore, the threshold (5) equals to

$$K = \frac{T_1}{2} [\chi^2_\alpha(2r)]. \quad (7)$$

6. For the threshold of the decision (7), let us find the manufacturer's risk β, of which the value for the Neyman-Pearson rule will be minimal.

According to the Neyman-Pearson rule and equation (6)

$$\beta = P\{\gamma_1/H_0\} \text{ или } \beta = P\{t_\Sigma < K/H_0\}. \quad (8)$$

Let us proceed to the normalized distribution by $\chi^2(2r)$

$$\beta = P\left\{\frac{2t_\Sigma}{T_0} < \frac{2K}{T_0}\right\}, \text{ or } \beta = P\left\{\tau < \frac{2K}{T_0}\right\},$$

where $\frac{2K}{T_0} = \chi^2_{(1-\beta)}(2r)$, which corresponds with the $(1-\beta)$% distribution point $\chi^2(2r)$, Figure 2.

Given that T_0 and K are known, we can identify $(1-\beta)$, the decision quality indicator.

It should be noted that

$$\chi^2_{(1-\beta)}(2r) = \frac{T_1}{T_0}\chi^2_\alpha(2r),$$

$$\frac{\chi^2_{(1-\beta)}(2r)}{\chi^2_\alpha(2r)} = \frac{T_1}{T_0}, \quad (9)$$

i.e., α% and (1– β)% points of $\chi^2(2r)$ distribution differ as many times as much the mean time to failure T_1 obtained as the result of the tests is worse than the specified T_0.

Thus, we need to know four parameters: $\frac{T_1}{T_0}, \alpha, \beta, r$ (or T_1, T_0, r, α). Normally, tree out of these parameters are specified at the beginning of the tests, while the fourth one is identified.

In conclusion it should be noted that if the test procedure [n, B, r] is used the decision quality will be identical as under the procedure [n, V, r], if the same total testing time t_Σ is ensured.

Application interpretation and demonstration of final research results

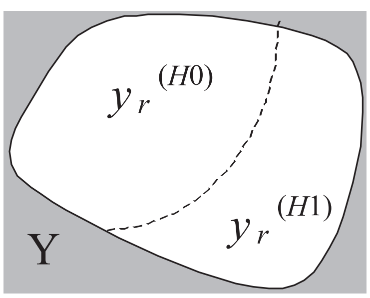

Figure 1. Sample space *Y*

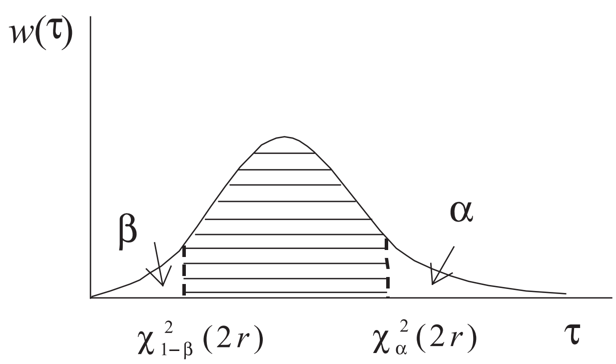

Figure 2. α% and (1– β)% of distribution point $\chi^2(2r)$

Example. Verification of hypothesis of mean time of no-failure

Table 1 shows a sample of the no-failure times obtained as the result of radiotechnical systems dependability testing using plan [1, V, 50], i.e. one RES (n = 1) is examined with replacement of failed systems (renewal), where the number of failures is (r = 50). Let us consider that renewal after failure happens so quickly that the time of renewal can be ignored.

Table 1. Sample of no-failure times for RES testing per plan [1, V, 50]

i	1	2	3	4	5	6	7	8	9	10
y_i, h	118	1.5	85	45	169	243	145	49	39	138
i	11	12	13	14	15	16	17	18	19	20
y_i, h	17	267	107	115	331	17	70	20.5	5	102
i	21	22	23	24	25	26	27	28	29	30
y_i, h	117	115	112	65	306	93	50	96	71	280
i	31	32	33	34	35	36	37	38	39	40
y_i, h	7	9.5	53	4	28	257	364	123	159	116
i	41	42	43	44	45	46	47	48	49	50
y_i, h	52	18.5	2	34	35	14	48	1	2.5	43

Let the value of mean time of no-failure be specified as T_0 = 100 h. Using the test data, the hypothesis if T_{mn} = 100 h must be verified. Let us set the manufacturer's risk as α = 0.05. The Neyman-Pearson optimal verification procedure for the above hypothesis, where the number of failures is 50 (r = 50), consists in comparing the total system operation time over the testing time with the threshold:

$$K = \frac{T_0}{2}\chi^2_{1-\alpha}(2r) = 50\chi^2_{0,95}(100) = 3896,5 \text{ h}.$$

Using the data from Table 1 let us find the total system operation time during the tests:

$$t_\Sigma = \sum_{i=1}^{50} y_i = 4759,5 \text{ h}.$$

As the total operation time t_Σ = 4759,5 h, i.e. above the threshold K = 3896,6 h, the decision should be taken of the compliance with the specifications. Assuming T_1 = 75 h, the buyer's risk β can be identified. According to (8.1)

$$\chi^2_{(1-\beta)}(100) = \frac{75 \cdot \chi^2_{0,05}(100)}{100} = 93,265.$$

In the table of percentage points distribution we find:
1 – β = 0,67,
out of which we calculate the buyer's risk β = 0,33.

Estimation and hypothesis verification under a small number of failures

Let us show the potential reduction of the quality of estimation of the mean time of no-failure and hypothesis verification regarding this dependability indicator, if the system dependability tests stopped after the 10th failure. Out of the Table 1 we find that the total operation time by the time of the 10th failure is $t_\Sigma = \sum_{i=1}^{10} y_i = 1032,5$ h. The testing time is reduced by $\frac{4759,5}{1032,5} \approx 4,6$ times compared with the testing to the 50th failure. In this case, the maximum likelihood estimation of the mean time of no-failure equals to

$$T_{mn} = \frac{1032,5}{10} = 103,25\ h.$$

From the tables of percentage points of χ^2 distribution we find for the confidence coefficient γ = 0,96.

For tests to the 50th failure under the confidence coefficient γ = 0,96 we deduce

$$\chi^2_{0,5-0,48}(100) = 131,\ \chi^2_{0,5+0,48}(100) = 73.$$

The lower confidence contour equals to

$$\frac{2t_\Sigma}{\chi^2_{0,02}(100)} = \frac{9519}{131} \approx 73\text{ h.}$$

The upper confidence contour equals to

$$\frac{2t_\Sigma}{\chi^2_{0,98}(100)} = \frac{9519}{73} \approx 130\text{ h.}$$

Thus, the confidence interval for the mean time of no-failure is defined by the equality

$$73 \le T_{mn} \le 130\text{ h.}$$

The length of the confidence interval is 57 h.

From the tables of percentage points of χ^2 distribution we find for the confidence coefficient γ = 0,96

$$\chi^2_{0,5-0,48}(20) = 35,02,\ \chi^2_{0,5+0,48}(20) = 9,24.$$

The lower confidence contour equals to

$$\frac{2t_\Sigma}{\chi^2_{0,02}(20)} = \frac{9519}{35,02} \approx 272\text{ h.}$$

The upper confidence contour equals to

$$\frac{2t_\Sigma}{\chi^2_{0,98}(20)} = \frac{9519}{9,24} \approx 1030\text{ h.}$$

Thus, the confidence interval for the mean time of no-failure is defined by the equality

$$272 \le T_{mn} \le 1030\text{ h.}$$

The length of the confidence interval is 758 h, i.e. almost 14 times longer compared to the tests to the 50th failure under the same confidence coefficient.

Let us now consider the verification of the hypothesis of T_{mn} = 100 h for the sample r = 10. In this case under α = 0,05 the threshold value equals to

$$K = \frac{T_0}{2}\chi^2_{1-\alpha}(2r) = 50\chi^2_{0,95}(20) = 50 \cdot 10,85 = 542,5\text{ h.}$$

As $t_\Sigma = \sum_{i=1}^{10} y_i = 1032,5$ h, i.e. above the threshold K = 542,5 h, the hypothesis is accepted (product complies with the specifications). Assuming T_1 = 75 h, we find the buyer's risk:

$$\chi^2_{(\beta)}(20) = \frac{100}{75} \cdot 10,85 = 14,5,\ \beta = 0,8.$$

Thus, the value of the buyer's risk is absolutely acceptable.

Let us increase the manufacturer's risk to α = 0,3. In this case the threshold value will be equal to

$$K = \frac{T_0}{2}\chi^2_{1-\alpha}(2r) = 50\chi^2_{0,7}(20) = 50 \cdot 16,27 = 813,5\text{ h.}$$

The decision of the correctness of the hypothesis is still in force. We find the buyer's risk

$$\chi^2_{(\beta)}(20) = \frac{100}{75} \cdot 16,27 = 21,7,\ \beta = 0,35.$$

We confirm that under sample size r = 10 the probabilistic characteristics of the made decision cannot satisfy neither the buyer, nor the manufacturer and therefore the tests must continue.

3. Sequential hypothesis verification procedure

The hypothesis verification procedure considered in section 2 has a disadvantage that consists in the fact that the quality of the solution is identified after the tests (we test first, then we evaluate the result quality). Such procedure of hypothesis verification is not optimal and therefore inefficient.

At the same time there is a sequential procedure of hypothesis verification (Wald test) that involves attempts of decision-making after each failure and interruption of the test if a decision with specified quality is possible. α, β are specified, and using the sequential procedure the statistic $y_1, y_2, \ldots, y_r$ is attempted to be found, that minimizes the average number of failures: $m\{r/H_0\}$ or $m\{r/H_1\}$ required for decision-making.

An accurate solution is difficult to find. In practice, an approximative decision rule is used, when the likelihood ratio is compared to two thresholds:

if $t_\Sigma \le K_1$, the solution is γ_1:H_1 (product does not comply with the specifications);

if $K_0 < t_\Sigma < K_1$, the solution is γ_k (tests continue); (10)

if $t_\Sigma \ge K_0$, the decision is γ_0:H_0 (product complies with the specifications).

The shortcoming of the sequential procedure is that the number of failures r and test duration are not known in advance. For that reason a combined method (mixed procedure) is sometimes used, when additionally the failure threshold limit r_0 is defined and the decision rule (10) is complemented with the condition:

if $r<r_0$, the sequential procedure is used;

if $r=r_0$, normal procedure is used, e.g. the one considered in section 2.

4. Estimation of distribution law

As mentioned above, before identifying the dependability characteristics based on test results we must verify the compliance of the distribution law of the resulting sample $w_1(y_i)$ with the exponential distribution law (e.g. $w_1(y_i) = n\lambda e^{-n\lambda y_i}$ or another). That can be done using criterion χ^2.

Verification algorithm

1. Test procedure selection.
2. Testing, obtaining of sample $(t_1, t_2, \dots t_y)$, $(y_1, y_2, \dots y_i)$.
3. Test duration is divided into k equal intervals.
4. Identification of the number a failures in each interval m_i.
5. Point estimation $\hat{\lambda} = \dfrac{r-1}{t_\Sigma}$. (11)

Let us assume that the distribution law y_i is exponential.

We calculate the theoretical probability of the number of failures in each interval.

$$P_i = 1 - e^{-n\hat{\lambda}\frac{t_\Sigma}{k}} \quad (12)$$

and estimation of the probability of failures in each interval.

$$\hat{P}_i = \frac{m_i}{r}. \quad (13)$$

Calculation results are tabulated.

We deduce

$$\chi^2 = \sum_{i=1}^{k} \frac{\left(\hat{P}_i - P_i\right)^2}{P_i} \le \chi^2_\alpha\left(k-1-\theta\right), \quad (14)$$

where $\chi^2_\alpha(k-1-\theta)$ is the allowable deviation, $\alpha<<1$, θ is the number of the evaluated parameters of the distribution law.

If the inequation (14) is true, the resultant experimental results do not contradict the expected theoretical distribution law.

Example

Table 2 shows a sample of the no-failure times obtained as the result of radiotechnical systems dependability testing using plan [1, V, 112], i.e. one RES (n = 1) is examined with replacement of failed systems (renewal), where the number of failures is (r = 112). Let us assume that renewal after failure happens so quickly that the time of renewal can be ignored.

Using the data from Table 2 let us find the total system operation time during the tests:

$$t_\Sigma = \sum_{i=1}^{112} y_i = 11363 \text{ h}.$$

Let all the test be divided into k equal intervals (k = 8).

Let us find the point estimate using the formula (11):

$$\hat{\lambda} = \frac{r-1}{t_\Sigma} = \frac{112-1}{11363} = 0{,}0098 \text{ 1/h}.$$

Let us calculate the theoretical probability of the number of failures in each interval using the formula (12) and the evaluation of failure probability using the formula (13) and tabulate the results (Table 3).

The values of the theoretical probability P_i are equal or close to 1, because the value of the right part of the formula (12) tends to 0; e.g., if k = 1: $e^{-n\hat{\lambda}\frac{t_\Sigma}{k}} = 4{,}35\cdot10^{-49} \to 0$.

Table 2. Sample of no-failure times for RES testing per plan [1, V, 112]

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
y_i, h	120	1.5	82	45	169	243	145	49	39	138	11	267	108	121	331	17
i	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
y_i, h	70	20.5	5	102	117	115	112	65	306	93	50	96	71	280	7	9.5
i	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
y_i, h	53	4	28	255	366	123	159	116	52	18.5	2	34	35	14	48	1
i	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
y_i, h	2.5	43	249	99	104	103	122	32	337	18	19	205	60	8.5	154	388
i	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
y_i, h	10	4.5	9	74	24	177	44.5	10.5	292	150	21	126	189	16	38	92
i	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
y_i, h	57	31	7	97	108	111	113	70	298	98	69	100	75	275	11	9
i	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
y_i, h	7	49	260	88	101	105	117	28	327	15	19	211	67	4.5	143	357

Table 3. Results of dependability calculation

Time Interval	m_i(number of failures within the interval)	$\hat{P}_i$ (evaluation of failure probability)	P_i (theoretical probability)
1	37	0.3304	1
2	10	0.0893	1
3	15	0.1339	1
4	7	0.0625	1
5	2	0.0179	1
6	4	0.0357	0.999999991
7	3	0.0268	0.999999877
8	2	0.0179	0.999999099

Then, using the formula (14) let us deduce

$$\chi^2 = 6.71,$$

and with the table of percentage points of χ^2 distribution we will find for $k-1-\theta=k-1-1=6$ degrees of freedom and $\alpha = 0.05$ significance level the threshold value

$$\chi^2_{0,05}(6) = 12,592.$$

Thus,

$$\chi^2 \le \chi^2_{0,05},$$

therefore, according to the goodness-of-fit test χ^2 the exponentiality hypothesis does not contradict the system dependability test results.

Conclusions

1. The test procedure [n, B, r] ensures the quality of decision identical to that of the procedure [n, V, r] provided the testing time t_Σ is identical.

2. Under the sequential procedure, if the number of failures r and testing time are not known from the beginning, a combined method is used (mixed procedure), when additionally the failure threshold limit r_0 is defined and the decision rule is complemented with the condition:

- if $r<r_0$, the sequential procedure is used;
- if $r=r_0$, normal procedure is used, e.g. the one considered in section 2.

3. An algorithm is shown for compliance verification of the resulting sample $w_1(y_i)$ distribution law with the exponential rule or other distribution law over criterion χ^2.

4. The paper may be of interest to radioelectronic systems design engineers.

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Received on 20.12.2016