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Predicting the reliability of radio-electronic devices by the monitoring of production defectiveness

Abstract. *The concept of predicting the reliability of radio-electronic devices at the stage of its production based on defectiveness monitoring during the performance of technological and controlling procedures was laid. The results of theoretical and experimental investigations of the processes of manufacturing defection and experimental-statistical and theoretical-statistical methods of predicting the reliability of equipment on this basis were given.*

Streszczenie. *Przedstawiono koncepcję przewidywania niezawodności urządzeń radioelektronicznych. Diagnoza niezawodności może być wykonywana na etapie produkcji w oparciu o śledzenie usterek podczas procesów produkcyjnych i kontrolnych. Podano wyniki teoretycznych i doświadczalnych badań procesów powstawania uszkodzeń z wykorzystaniem metod statystycznych przewidywania niezawodności urządzeń.* ***(Prognozowanie niezawodności urządzeń radio-elektronicznych przez monitorowanie uszkodzeń w procesie produkcyjnym)***

Keywords: reliability, predicting, monitoring, manufacturing defects.
Słowa kluczowe: niezawodność, prognozowanie, monitorowanie, defekty produkcyjne.

1. Introduction

The statistic analysis of functioning of multi-purpose radio-electronic devices (RED) confirms the tendency of monotonous increase of its reliability at almost constant refuses ratio due to the reasons of defects, admitted during designing, production and exploitation.

The part of refuses, caused by production defects, reaches the half of total refuses quantity, detected during its exploitation. Therefore, the reduction of its quantity is the real reserve of reliability increasing of current equipment type. The solution of this problem can be reached through the way of complex optimization and controlling of production processes using the results of defectiveness monitoring. As the result, we receive the determination and providing of allowable defectiveness level during every stage of technological process at the conditions of the given level of RED reliability providing with minimum or allowed total revenues.

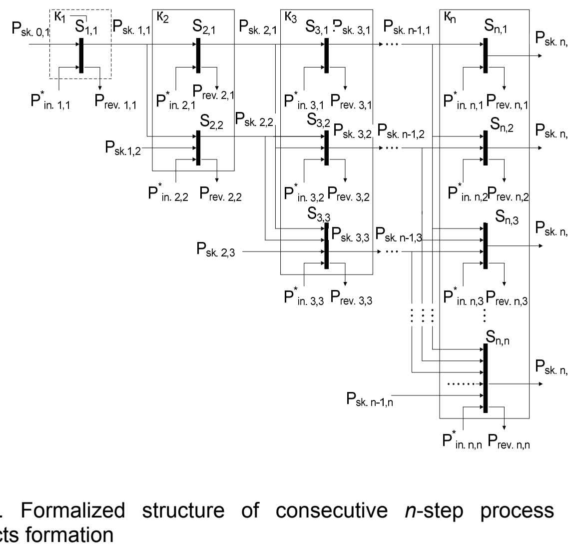

Fig.1. Formalized structure of consecutive *n*-step process of defects formation

2. Formalization and models of defectiveness forming in the production of RED

The realization of such approach to the solution of the problem of RED reliability increasing on a production stage is based on the known principles of modeling and optimization of technological systems. Herewith, the processes of forming the specified apparatus properties are described by models in the form of serial, parallel and combined structures of technological and control procedures with appropriate straight and reverse connections. In most cases the structure on Fig.1 is the base.

Technological processes of RED manufacturing, in their essence, are hierarchical systems for ensuring quality and reliability of such devices. Depending on the accepted level of abstraction, they can be considered as a set of jointly functioning elements, i.e. of local subsystems each of which is characterized by their own series of features and, in particular, variety of defect parameters. Conducted researches have shown that indexes of additive and multiplicative defectiveness, whose nature is essentially different, can be integral parameters of quality of products. The additive defectiveness of products is defined by the sum of indexes of the elements defectiveness, i.e. by the sum of indexes of separate subsystems. Multiplicative defectiveness is a consequence of the phenomenon of emergentness which emerges as a result of interaction between elements of system that can lead to emergence of new, sometimes unexpected, features. Currently, this phenomenon is not studied enough; although it is proved that multiplicative component of general defection can reach and exceed the level of additive defection [1].

The generalized diagram of the defectiveness formation at *k*-th step of technological process by system S_k within the technological subsystem S_{TOk} and controlling subsystem S_{COk} is presented in the Fig.2.

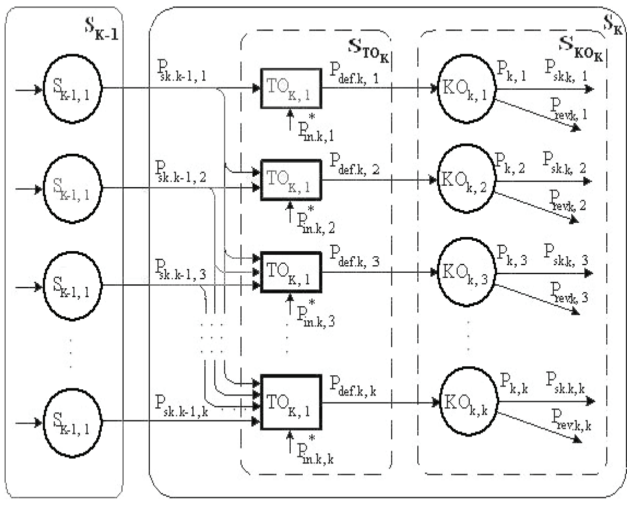

Fig.2. Scheme of defects formation on the *k*-th step of the process by system S_k

The k-th step of technological process ($k=\overline{1,n}$) is characterized by the following input, intermediate, and output indexes:

$P_{sk.\ k-1,\ i}$ – probability of defects transferring from k-1-th step of the technological process to k-th step by the i-th parameter;

$P^{*}_{in.\ k,\ i}$ – probability of the defects introduction during the implementation of technological procedure at the k-th step by the i-th parameter;

$P_{def.\ k,\ i}$ – probability of presence of defects after the implementation of technological procedure at the k-th step by the i-th parameter;

$P_{rev.\ k,\ i}$ – probability of the defect revealing during the implementation of checking procedure at the k-th step by the i-th parameter;

$P_{sk.\ k,\ i}$ – probability of the defect skipping during the implementation of checking procedure at the k-th step;

Forming the defectiveness, skipped at the stage of its control, for each product parameter during the full technological process is described by dependencies:

by the first parameter:

$P_{sk.1,1}=\Psi_{1.1}(P_{sk.0,1},\ P^{*}_{in.1,1},\ P_{11})$

$P_{sk.2,2}=\Psi_{2,1}(P_{sk.1,1},\ P^{*}_{in.2,1},\ P_{2,1})$

. . . .

$P_{sk.n,1}=\Psi_{n,1}(P_{sk.n-1,1},\ P^{*}_{in.n,1},\ P_{n,1})$

by the second parameter:

$P_{sk.2,2}=\Psi_{2,2}[P_{sk.1,2},\ P_{in.2,2}(P^{*}_{in.2,2},\ P_{sk.1,1},\ P_{sk.1,2}),\ P_{2,2}]$

$P_{sk.3,2}=\Psi_{3,2}[P_{sk.2,2},\ P_{in.3,2}(P^{*}_{in.3,2},\ P_{sk.2,1},\ P_{sk.2,2}),\ P_{3,2}]$

. . . .

$P_{sk.n,2}=\Psi_{n,2}[P_{sk.n-1,2},\ P_{in.n,2}(P^{*}_{in.n,2},\ P_{sk.n-1,1},\ P_{sk.n-1,2}),\ P_{n,2}]$

. . . .

by the *(n-1)*-th parameter:

$P_{sk.n-1,n-1}=\Psi_{n-1,n-1}[P_{sk.n-2,n-1},\ P_{in.n-1,n-1}(P^{*}_{in.n-1,n-1},\ P_{sk.n-2,1},\ P_{sk.2,2},\ \ldots,\ P_{sk.n-2,n-2},\ P_{sk.n-2,n-1}),\ P_{n-1,n-1}]$

by the *n*-th parameter:

$P_{sk.n,n}=\Psi_{n,n}[P_{sk.n-1,n},\ P_{in.n,n}(P^{*}_{in.n,n},\ P_{sk.n-1,1},\ P_{sk.n-1,2},\ \ldots,\ \ldots,\ P_{sk.n-1,n-1},\ P_{sk.n-1,n}),\ P_{n,n}]$.

Where $P_{in.n,i}=(P^{*}_{in.n,i},\ P_{sk.n-1,1},\ P_{sk.n-1,2},\ P_{sk.n-1,3},\ \ldots)$ – the possibility of defects introduction with regard the subsystem emergentness S_{TOk} [1,2,3].

One option of the mathematical model of input probability of defects during the forming of *i*-th index is:

$$P_{in.n,i} = 1-(1-P^{*}_{in.n,i})\times \exp\{-K_a\ P^{*}_{in.n,i}(1-P^{*}_{in.n,i})\ P_{sk.n-1,i}\},$$

where K_a – the adaptive coefficient.

Mathematical models of defects missed the last step of the process are represented by a system of recurrent equations:

$P_{sk.n,1}=\langle\ [P_{sk.n-2,1}+(1-P_{sk.n-2,1})P_{in.n-1,1}](1-P_{n-1,1})+\{1-[P_{sk.n-2,1}+(1-P_{sk.n-2,1})P_{in.n-1,1}]\cdot(1-P_{n-1,1})\}\ P_{in.n,1}\ \rangle\ (1-P_{n,1});$

$P_{sk.n,2}=\langle\ [P_{sk.n-2,2}+(1-P_{sk.n-2,2})P_{in.n-1,2}](1-P_{n-1,2})+\{1-[P_{sk.n-2,2}+(1-P_{sk.n-2,2})P_{in.n-1,2}]\cdot(1-P_{n-1,2})\}\ P_{in.n,2}\ \rangle\ (1-P_{n,2});$

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$P_{sk.n,n}=[P_{sk.n-1,n}+(1-P_{sk.n-1,n})P_{in.n,n}](1-P_{n,n});$

These models of defectiveness of multistep technological processes of the recurection reasons are cumbersome analytical dependencies, making them of little use for evaluating the quality of production at different stages. Thus the matrix representation is more convenient for practical use:

$$\left\|P_{sk}\right\| = \left(\left\|P_{sk.k-1,i}\right\| + \left\|1-P_{sk.k-1,i}\right\|\cdot\left\|P_{in\ k,i}\right\|\right)\cdot\left\|1-P_{k,i}\right\|,$$

Each step of the process is characterized by the corresponding value of probability of skipped defects:

$P_{sk.1} = P_{sk.1,1}$

$P_{sk.2} = [P_{sk.2,1},\ P_{sk.2,2}]^{T}$

$P_{sk.3} = [P_{sk.3,1},\ P_{sk.3,2},\ P_{sk.3,3}]^{T}$

....

$P_{sk.n} = [P_{sk.n,1},\ P_{sk.n,2},\ \ldots,\ P_{sk.n,n}]^{T}$

Column matrix elements are partial values of skipping probabilities of manufacturing defects by the appropriate parameters at each step.

3. Methods of reliability predicting by the level of manufacturing defects

In general, the relationship between defectiveness of product and its reliability is described by the dependence:

$$I_{Rk}=F_k(P_{sk.k})$$

where I_{Rk} - product reliability index at *k*-step of technological process.

It should be noted that for today there are no commonly recognized and suitable for practical use methods of analytical quantity estimation of the relationship between I_{Rk} and $P_{sk.k.}$ It complicates predicting the reliability of products taking into account real possibilities of manufacturers of RED, which are mainly determined by the quality of received materials, intermediate products and components, precision of manufacturing equipment, the perfection of the instrument and equipment and other resources. In these conditions the relationship between the equipment reliability indexes and its defectiveness may be established by experimental-statistical method through carrying out active or passive experiments on registration of this relationship in a normal working mode of manufacturer without making deliberate disturbances that lead to deviation of parameters of technological processes from a priori established norms. Experimental studies have confirmed the reality of such an approach to estimation of the reliability of products based on consideration of flow manufacturing defects at different stages of technological processes. Example of experimentally set dependence of probability of refuse of printed circuit boards, made using combined additive method, from probability of skipping defects is shown in Fig. 3:

Quite clear connection between the specified parameters indicates the possibility of prediction using such method of reliability of these products, taking into account information about level of their defectiveness.

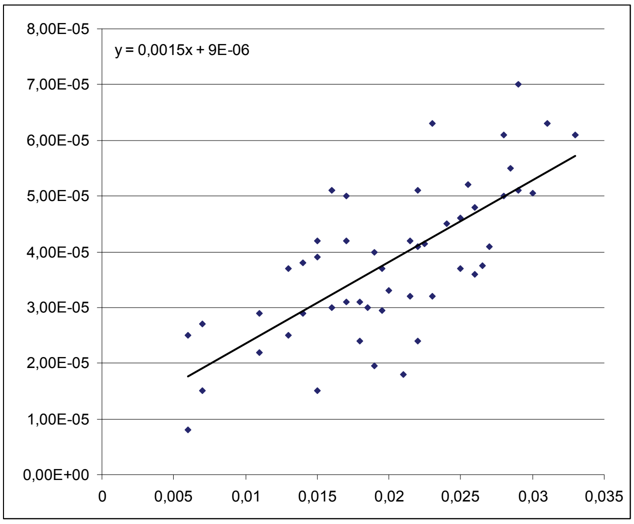

Fig.3. Dependence of probability of printed circuit boards refusing to probability of manufacturing defects skipping

Analytical-statistical method for determining the dependence of reliability indexes on the level of products defectiveness is based on the condition of equality to one by the sum of probabilities of two opposing events: the refuse *q* and infallible work P_i:

$$q + P_i = 1.$$

Here $q(t)=P_{sk}[1-P_o(t_r)]$ – probability of product refuse, in which $P_o(t_r)$ – probability that during maintenance a defect will not lead to product failure within a resource t_r, experimentally determined by a statistical method;

$P_i(t) = e^{-\int_0^{t_p} \lambda(t)dt}$ - probability of refuse-free work of product as a function of refuse intensity $\lambda(t_r)$ (option of exponential time distribution operating time to failure is considered).

Therefore:

$$\lambda(t) = \arg\left\{ P_{sk}[1 - P_0(t_r)] + e^{-\int_0^{t_p} \lambda(t)dt} = 1 \right\}$$

4. Conclusions

The study showed a significant difference of dependence of the reliability of various products from the indexes of their production defectiveness. The difference between these dependencies is due to the influence of set of objectively existing factors, such as construction, schematics and technological features of products, the difference of components base, technological equipment, tools, testing stands, etc. It is determined that the greatest impact on reliability of equipment is characterized by defects that arise during the maintenance of technological processes of structure- and morphogenesis, defects in components, printed circuit boards, printed functional nodes and blocks. The smallest are chemical and galvanic coatings, ceramics, ferrites. But the complexity and limitations of research and almost complete lack of publications in this field does not allow making any generalization, and therefore the results of experiments can be used for specific manufacturers and specific facilities for the construction of adequate mathematical models.

Similarly the dependences of the reliability indexes of products to the level of manufacture defectiveness under other laws of distribution of time working out to failure is determined.

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