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Research into emergence of radio electronic devices quality forming systems

Abstract. *The results of the formalization of radio electronic apparatus quality providing processes and experimental studies of technological systems emergence are given.*

Streszczenie. *W pracy przedstawiono formalne określenie jakości elektronicznej aparatury radiowej z uwzględnieniem teorii matematycznej i praktycznych eksperymentów. (**Formalne określenie jakości elektronicznej aparatury radiowej z uwzględnieniem teorii matematycznej**)*

Keywords: quality of radio electronic devices, emergence of technological systems, defectiveness.
Slowa kluczowe: jakość urządzeń elektronicznych, projektowanie procesów technologicznych, awaryjność.

Introduction

Technological processes of manufacturing radio electronic devices in their essence are hierarchical systems which ensure their quality and reliability. Depending on the accepted level of abstraction they can be considered as a set of commonly functioning elements –local subsystems, with each being characterized by its own series of features as well as its own indices of defectiveness. The research has shown that indices of additive and multiplicative defectiveness the nature of which is essentially different can be interpreted as integral indices of the product quality [1].

The additive product defectiveness is defined by the sum of indices of the elements defectiveness, i.e. the sum of indices of the separate subsystems. The multiplicative defectiveness results from the emergence caused by interaction between the system elements leading to the appearance of new and sometimes unexpected features. This phenomenon has not thoroughly studied yet though the multicomponent of general defectiveness proved to be able to reach and exceed the level of additive defectiveness.

The research done enabled these processes to be formalized, and the mathematical models of additive and multiplicative defectiveness of radio electronic apparatus to be obtained. The results of the experimental research are presented.

Formalization of quality process

The process of forming specified properties of a device, i.e. the process of forming quality, is a complex of elements characterized by proper indices. In the paper this complex will be considered as a system, S:

(1) $$S=[S_1, S_2, ..., S_n]$$

where S_i, $i=\overline{1, n}$ is the i-th step subsystems of the apparatus production technological process, and n is the total number of the steps.

The quality indices of the subsystems, S_i, are the following sets

(2) $$\{q_{S1}\}, \{q_{S2}\}, ..., \{q_{Sn}\}$$

The system, S, is characterized by the additive and multiplicative integral quality indices $Q^{(A)}{}_S$ and $Q^{(M)}{}_S$. The additive index of system quality is determined by the sum of independent indices of the subsystems, and the multiplicative index is the result of their interaction leading to the appearance of specific system features, in scientific literature known as the emergence properties, often different from those of separate subsystems [2, 3].

In general, these indices are dependences described by the following equations:

(3) $$Q^{(A)}{}_S = \{q_{S1}\} +\{q_{S2}\}+...+\{q_{Sn}\}$$

(4) $$Q^{(M)}{}_S=\Psi_S (\{q_{S1}\},\{q_{S2}\},...,\{q_{Sn}\})$$

Modern production of radio electronic devices is characterized by a great variety of properties of the separate subsystems, S_i, and their quality indices q_{Si}. This variety makes it difficult and sometimes even impossible to create generalized mathematical models which would cover all the stages of the technological processes. This is the case of poorly-grounded simplifications, and assumptions that have a negative influence on the model adequacy. Under these conditions, the development of the models becomes possible provided the common universal quality index known as a probabilistic index of defectiveness used for all the subsystems S_1, S_2, ..., [1].

The generalized diagram of forming the defectiveness is presented in Fig.1.

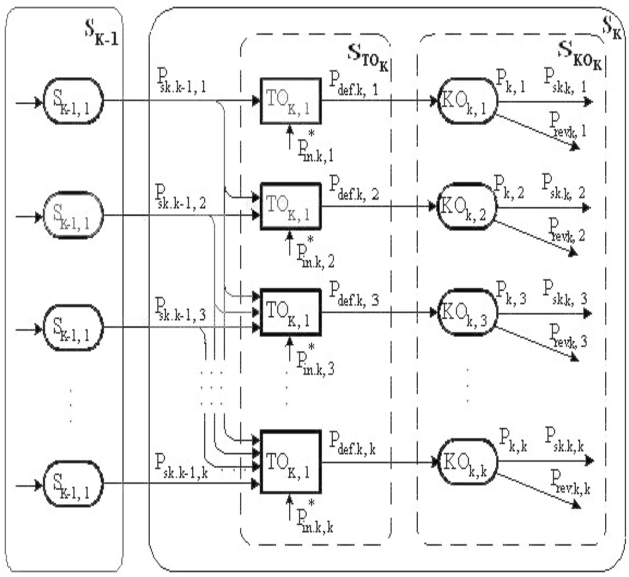

Fig.1 Diagram of forming defectiveness at k-th step of the technological process by system, S_k

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

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

$P^{*}_{in.\,k}$ – probability of occurring defects when implementing the technological procedure at *k*-th step;

$P_{def.\,k}$ – probability of present defects after completing the technological procedure at k-th step;

$P_{rev.\,k}$ – probability of detecting defects in the process of testing at *k*-th step;

$P_{sk.\,k}$ – probability of missing defects in the process of testing at *k*-th step;

The product defectiveness at the output of *k*-th technological subsystem S_{TOk} is quantitatively estimated by the set of probabilities $P^{(A)}_{def.k,i}$ and $P^{(A)}_{def.k,i}$, where $i=\overline{1,k}$:

$$
(5)\quad
\begin{aligned}
P^{(A+M)}_{def.k,1} &= P^{(A)}_{def.k,1} \oplus P^{(M)}_{def.k,1}\\
P^{(A+M)}_{def.k,2} &= P^{(A)}_{def.k,2} \oplus P^{(M)}_{def.k,2}\\
&\dots\dots\dots\dots\dots\\
P^{(A+M)}_{def.k,k} &= P^{(A)}_{def.k,k} \oplus P^{(M)}_{def.k,k},
\end{aligned}
$$

where $\oplus$ is the symbol of the probabilistic summation.

The components of probabilities $P^{(A+M)}_{def.k,i}$ are defined by the following dependences:

$$
(6)\quad
\begin{aligned}
P^{(A)}_{def.k,1} &= P_{sk.k-1,1} \oplus P^{*}_{in.k,1}\\
P^{(A)}_{def.k,2} &= P_{sk.k-1,2} \oplus P^{*}_{in.k,2}\\
&\dots\dots\dots\dots\dots\\
P^{(A)}_{def.k,k} &= P_{sk.k-1,k} \oplus P^{*}_{in.k,k}
\end{aligned}
$$

$$
(7)\quad
\begin{aligned}
P^{(M)}_{def.k,1} &= \Psi_1(P^{*}_{in.k,1}, P_{sk.k-1,1})\\
P^{(M)}_{def.k,2} &= \Psi_2(P^{*}_{in.k,2}, P_{sk.k-1,1}, P_{sk.k-1,2})\\
&\dots\dots\dots\dots\dots\dots\dots\dots\\
P^{(M)}_{def.k,k} &= \Psi_k(P^{*}_{in.k.k}, P_{sk.k-1,1}, P_{sk.k-1,2}, \dots P_{sk.k-1,k}),
\end{aligned}
$$

i.e. $P^{(M)}_{def.k,i} = \Psi P^{(M)}_{in.k,i},\ i=\overline{1,k}$.

Thus the components of general defectiveness in terms of their physical and mathematical essence are divided into two groups. The first one includes independent components, in total being described by the probabilistic sum, i.e. by the additive sum. The second one contains dependent components which are characterized by the system multiplicative effects of some elements of the system on the others. These objectively existing, and being familiar to technologies phenomena of emergence occurring in the process of radio electronic devices production have not been sufficiently studied and not formalized (for the most part) by now. The applied system tasks of the mathematical modeling of the defectiveness when producing radio electronic devices are really difficult and incorrectly formulated tasks. There are some different approaches to their solution: optimal performance of a multifactor technological experiment by using an appropriate result processing methodology, and regularization of poorly-grounded decisions. The comparison of these approaches has revealed their advantages and disadvantages. Since functions (7) are complex nonlinear multi-parameter and often undefined dependences, the known approaches are not widely used. Therefore the methods of the defectiveness modeling which are based on the experimental-statistic material are still effective. The empiric functions describing such dependences must provide the following conditions:

$$
(8)\quad
\begin{aligned}
&P_{in.k.} = P^{*}_{in.k,k}, \quad \text{when } P_{sk.k-1,l} = 0,\ i=\overline{1,k-1};\\
&P_{in.k,k}=0 \quad \text{when } P^{*}_{in.k,k} = 0,\ \forall P_{sk.k-1} = [0,1];\\
&\lim_{P^{*}_{in.k.k} \to 1} P_{in.k,k} = 1,\ \forall\ P_{sk.k\text{-}1,i} = [0,1];
\end{aligned}
$$

One of the variants of the dependence can be satisfactorily described by empiric function (9):

$$
(9)\quad P_{in.k,k} = 1-(1-P^{*}_{in.k,k})\exp[-K_a \cdot P^{*}_{in.k,k} \cdot (1-P^{*}_{in.k,k})P_{sk.k-1,i}],
$$

where K_a is the adaptive coefficient defined by expression:

$$
K_a = \frac{\ln\left[\dfrac{1-P^{*}_{in.k,k}}{1-P_{in.k,k}}\right]}{P^{*}_{in.k,k}\left(1-P^{*}_{in.k,k}\right)P_{sk.k-1,k}}.
$$

For the subsystem S_{TOk} the adaptive coefficient, K_a, is the function of the set of influence coefficients, $K_{inf,i}$, $i=\overline{1,k-1}$; defections of the previous steps on the process of forming of k-th index of quality:

$$K_a=\varphi(K_{in,1}, K_{in,2}, \dots, K_{in,k-1})$$

Experiment

The emergence of the technological systems which essentially influences the processes of forming quality and reliability of radio electronic devices will be illustrated by soldered connections taking place when producing printed circuits. ПОС-61 solder (in Ukraine) (LSn 60) is an alloy the main components of which are tin and lead with the melting temperature of 232^{0}C and 327^{0}C respectively. This system with 61,9% Sn and 38,1% Pb forms an eutectic alloy with the melting temperature of 183^{0}C - Fig.2.

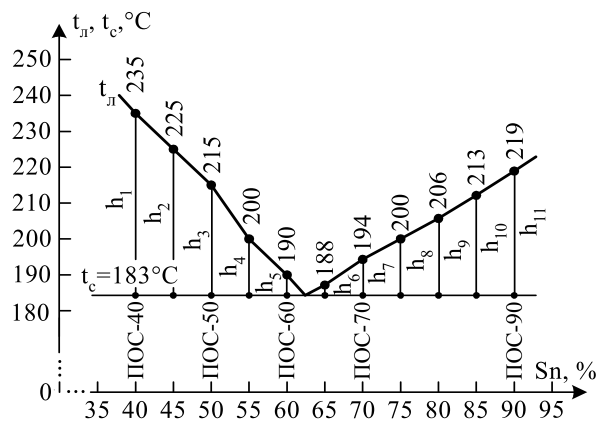

Fig.2 State of Sn-Pb system
Solidification temperature range:
h_1=52,0; h_2=42,0; h_3=32,0; h_4=17,0; h_5=7,0; h_e=0;
h_6=5,0; h_7=11,0; h_8=17,0; h_9=23,0; h_{10}=30; h_{11}=036,0 ^{0}C.

In terms of reliability of soldered connection, this alloy is not optimal. At the exact value of the specified solder components ratio, the solder is characterized by a zero value solidification temperature range. The rapid solidification at its eutectic point 183°C, exposed to the process of mechanical factors, including vibrations, always existing in a mass production of printed circuits, leads to the so-called cold solders, which are characterized by a significant level of the defectiveness. Defects that arise when moving the contact output of the element, or moving the solder during solidification appear in the form of surface and internal cracks, damaging the contact properties of the joints and reduce their mechanical strength.

Growth of the defection of the soldered connections in printed circuits with the use of tin-leaden solders also takes place as a result of destroying of correlation of the components in Sn-Pb system. Under the conditions of mass production of radio electronic apparatus by using group methods of soldering there is permanent oxidization of the solder at the temperature of fusion, which considerably exceeds an eutectic temperature and makes 240-270°C. Thus the intensity of oxidization of tin is considerably higher, than lead which results in the permanent diminishing of its percent content in the solder. As a result the temperature characteristics of solder change and, consequently the defection of the soldered connections grows. The result of the research into this phenomenon is shown in Fig.3.

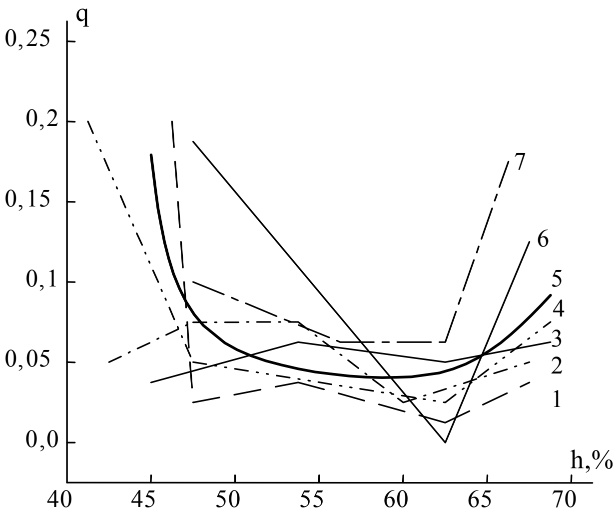

Fig.3 Dependence of defect soldered joints of seven types PCB on change of the solder composition.\

It is experimentally proved that for the wave soldering of printed circuits pays the best are tin-leaden solders with tin content of 60-64% [4].

It is proven that defection also depends on the temperature of a solder during soldering, deviation of which from nominal for the real correlation of the components improves the system emergence and results in the growth of defection - Fig.4. The research has shown that the total multiplicative deficiency can reach and exceed the level of the additive defection for hundreds percents.

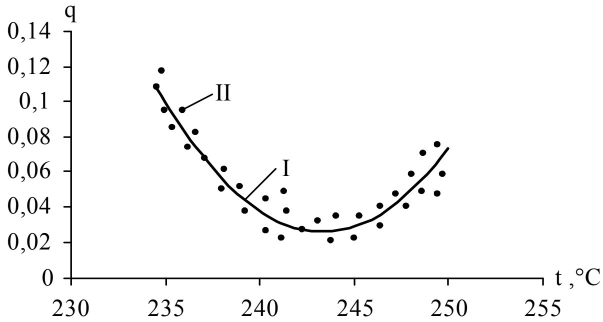

Fig.4 Dependence of defect soldered joints on the solder temperature (I - average dependence, II – experimental results)

In modern production of radio equipment, the emergence phenomenon appears in many technological processes. The processes of causing chemical and galvanic layers, epitaxial, diffusion, production of ceramic, ferrite, quartz and other parts are particularly relevant to them. Their defects frequently have the hidden nature; therefore they become the source of significant part of total apparatus refuses.

Summary

Refuses of apparatus in the process of exploitation are predefined by production defects appearing with the proper probability at all stages of a technological process. The production defects have the additive and multiplicative nature. The research has shown that the level of the multiplicative defection can reach and considerably exceed the level of the additive defectiveness. The origin of the multiplicative defectiveness is conditioned by the system effect of the technological processes in which the components with certain properties are involved. Their interaction generates new properties, which can be revealed as the multiplicative production defects. The offered formalization of these processes is the theoretical basis of their mathematical modeling and optimization according to the criteria of faultlessness of products.

REFERENCES

[1] Yuriy Bobalo, Myroslav Kiselychnyk, Leonid Nedostyp. Analysis of quality of radio electronic devises in multistage production system// Przeqlad Elektrotechniniczny (Electrical Review). - 2010/ - R.86. - NR1. - P.124-126

[2] Радченко С.Г. Математическое моделирование технологических процессов в машиностроении. ЗАО "Укрспецмонтажпроект", Киев, 1998. - 274с.

[3] Борщ В.И., Донец В.А., Коваль В.В., Лейбзон А.Я., Лесовой Н.П. Оптимизация структур больших систем. Киев, Наукова думка, 2000 - 191 с.

[4] Ханке Х.-И., Фабиан Х. Технология производства радиоэлектронной аппаратуры. Пер. з нем. - М.: Энергия, 1980.

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