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Optimization of processes designed for ensuring the quality and reliability of electronics using cumulative models of defectiveness and total production expenses

Abstract. *The paper offers an approach to solving the problem of ensuring the quality and reliability of electronics using a comprehensive optimization of manufacturing processes by means of the criteria of minimization of defectiveness and total expenses with application of end-to-end mathematical models.*

Streszczenie. *W artykule opisano sposób rozwiązania problem zapewnienia jakości I niezawodności elektroniki. Wykorzystano optymalizację procesu wytwarzania z kryterium minimalizacji defektów bazując na modelu matematycznym.* ***Optymalizacja procesu projektowania zapewniająca jakość i niezawodność układów elektronicznych***

Keywords: quality, reliability, defectiveness, optimization of manufacturing processes.
Słowa kluczowe: jakość, niezawodność, optymalizacja procesu produkcji

Introduction

The manufacturing of electronics comprises multi-stage technological processes of complex structure designed for ensuring the given characteristics of the devices with necessary levels of their quality and reliability as well as acceptable total expenses for the quality and reliability. A promising approach to solving this problem is the implementation of techniques for their systematic administration. In such case the quality (in broad sense) as an administration object is assessed by two sets of factors – total defectiveness of the devices in the course of technological operations and total expenses due to their manufacturing and operation. Those processes may be numerically assessed using their integral effectiveness as a sum of functional and economic components. A necessary effectiveness may be reached by their integral optimization applying corresponding criteria. In accordance with intended purpose of the products, with their manufacturing and operation specifications, a set of tasks of extremal type arises; the difference between the tasks consists in the set of variational parameters and response functions [1].

The models of defects' occurrence processes that serve as a parameter of quality and operational effectiveness of a technological process are created in the form of matrices dependencies with recurrent elements, i.e. partial components of total defectiveness that emerge due to omitted defects at the final step of a full n-step technological process:

$$P_{pr.n} = \left[P_{pr.n,1},\ P_{pr.n,2},\ \ldots,\ P_{pr.n,n} \right]^T \tag{1}$$

The probability model of the total defectiveness $P_{pr.n.sum}$ if we assume the additive character of the events leading to occurence of partial components is written as follows:

$$P_{pr.n.sum} = P_{pr.n,1} \oplus P_{pr.n,2} \oplus \ldots \oplus P_{pr.n,n} \tag{2}$$

where $\oplus$ is the sign of additivity of accumulable events.

The model of total production expenses $C_{v.sum}$ designed for ensuring the quality during the manufacturing and operation processes is an additive function of expenses connected with technological operations C_v, with performing of monitoring procedures C_{kon}, with recognizing and removal of acceptable defects C_k as well as expenses due to scheduled work for guarantee maintenance connected to failures in the course of operation C_e:

$$\begin{aligned} C_{v.sum} &= C_v\left(C_{v.k,i}, K_{v.k,i}\right) + C_{kon}\left(C_{kon,k,i}, æ_{k,i}\right) + \\ &+ C_k\left(C_{k,k,i}, P_{vya.k,i}\right) + C_e\left(C_{e,i}, P_{vya.e,i}\right), \end{aligned} \tag{3}$$

where $k = \overline{1,n},\ \ i = \overline{1,k}$ are the number of a technological process step and the number of the product's parameter shaped at the k-th step; $C_{v.k,i}$ are the expenses due to shaping the i-th parameter; $K_{v.k,i}$ is the coefficient of expenses variations; $C_{kon,k,i}$ are the expenses due to quality monitoring of the i-th parameter; $æ_{k.i}$ is the factor of monitoring intensity of the i-th parameter; $C_{k,k,i}$ are the expenses connected with rejection of the product in accordance with its i-th parameter; $C_{e,i}$ are the expenses in the course of operation; $P_{vya.k,i}$ is the probability of detection of the i-th parameter flaw; $P_{vya.e,i}$ is the probability of detection of the product failure in the course of its operation.

The variants of detailed models of manufacturing defects and forming of total production expenses for ensuring the products' quality in the course of their manufacturing and operation are given in [2, 3, 4].

Processes of forming and simulation of electronics' defectiveness

Modern manufacturing of electronic devices is mostly based on typical and original technological processes which are characterized by complexity and specificity. Systems ensuring their quality and reliability are marked by their structural size, many contours of internal and external control, diversity of tasks to be operationally solved with taking into account the systematic control of the whole ergodic manufacturing system, which is connected with a human being as its element. The overall aim of all these processes is providing the products at each manufacturing stage with required properties that, in total, determine their cumulative quality. Key figures of these properties are of different physical nature that practically complicates their comparison and thus the development of thorough mathematical cumulative models suitable for solving real multiatlernative optimization problems. Under these conditions, a comprehensive optimization of electronics' manufacturing according to the criteria of quality, reliability and total expenses can be carried out by simulation and optimization of processes for ensuring the appropriate criteria during the entire production cycle using a single universal criterion of quality. This criterion is the level of defectiveness in manufactured items - parts, components, blocks, and other structural and technological components as well as products in general after completion of technological and control procedures. Absence of physical meaning in the mathematical models is partly compensated by their flexibility and versatility.

The dynamics of forming of initial, intermediate and final factors of quality and reliability in the course of the entire technological process is depicted by a sequence of transformations whose operators may be of explicit and implicit nature.

The processes of forming of quality factors are structures that are featured by actively-forming, passively-forming and non-forming transformations of quality characteristics of materials, intermediate products, articles, and other components into factors of quality and reliability of end-stage products.

The formalized scheme of the process of reliability factor forming on the *k*-th step of a technological process is depicted in Fig. 1.

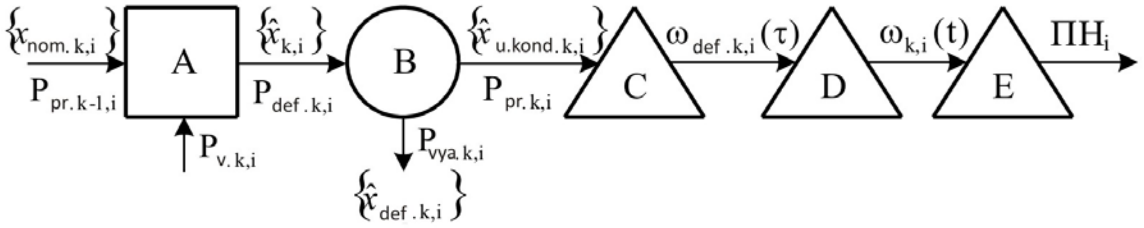

Fig.1. Forming of reliability factor on the *k*-th step

In this figure:

A – an actively-forming transformation of the set of quality factors $\{x_{nom.k,i}\}$ into the set of their random values $\{\hat{x}_{k,i}\}$ in the course of performance of the technological operation on the k-th step while shaping i-th parameter;

B – a passively-forming transformation of the set $\{\hat{x}_{k,i}\}$ into the set of quality factors for evidently defective products $\{\hat{x}_{u.kond.k,i}\}$ and the set quality factors of conditionally-flawless products $\{\hat{x}_{u.kond.k,i}\}$, what is performed in the course of monitoring;

C – the transformation of defectiveness of conditionally-flawless products in the parameter of defects' flow $\omega_{def.k,i}(\tau)$,D – the transformation of the parameter of defects' flow $\omega_{def.k,i}(\tau)$ into the parameter of failures' flow $\omega_{k,i}(t)$;

E – the transformation of the parameter of failures' flow $\omega_{k,i}(t)$ into the reliability factor ΠH_i;

ΠH_i – i-th reliability factor of a product;

$P_{pr.\ k\text{-}1,i}$ – the probability of omitting defects of the i-th parameter on the k-th step of the technological process;

$P_{def.k.i}$ – the probability of presence of a defect after performance of k-th step of the technological process;

$P_{vya.k.i}$ – the probability of detection of defective products after performance of monitoring;

$P_{pr.k.i}$ – the probability of omitting defective products in the set of conditionally-flawless products.

The transformation by A operators of the set of nominal values of quality factors into the set of their random values reflects the real situation of emerging defectiveness on the all stages of technological process.

There are three typical structure variants of processes ensuring quality that can be represented by charts of serial, parallel, and combined connection of sub-systems.

Depending on the number of quality factors of products, each step combines a corresponding number of forming and monitoring sub-systems. On the k-th step the sub-system $S_{k,k}$ shapes and monitors k-th parameter. Concurrently, sub-systems $S_{k,k\text{-}1}$, $S_{k,k\text{-}2}$, …, $S_{k,1}$ can compress or dilute defects' flows correspondingly to parameters shaped on previous steps. The probability of introducing defects on the k-th step of a technological process is considered as a certain sum of their partial introductions with probabilities $P_{v.k,1}$, $P_{v.k,2}$, …, $P_{v.k,k\text{-}1}$.

The boundaries of significance field for partial introductions of defects in the structural field of *k*-th parameter's shaping may depend not only on the *k*-th parameter, but also on the set of k, k-1, k-2, …, 1 parameters, i.e. comprise parameters shaped on previous steps.

The mathematical model of products' defectiveness, manufactured in the course of a *n*-step parallel process, is represented by a set of probabilities of defects' omitting on the last step of *m* subsystems comprising this structure:

(4)

$$\text{Đ}^{(1)}_{pr.n,1} = \langle[\text{Đ}^{(1)}_{pr.n-2,1} + (1-\text{Đ}^{(1)}_{pr.n-2,1})\text{Đ}^{(1)}_{v.n-1,1}](1-\text{Đ}^{(1)}_{n-1,1}) + \{1-$$

$$-[\text{Đ}^{(1)}_{pr.n-2,1} + (1-\text{Đ}^{(1)}_{pr.n-2,1})\text{Đ}^{(1)}_{v.n-1,1}](1-\text{Đ}^{(1)}_{n-1,1})\}\text{Đ}^{(1)}_{v.n,1}\rangle(1-\text{Đ}^{(1)}_{n,1});$$

$$\text{Đ}^{(1)}_{pr.n,2} = \langle[\text{Đ}^{(1)}_{pr.n-2,2} + (1-\text{Đ}^{(1)}_{pr.n-2,2})\text{Đ}^{(1)}_{v.n-1,2}](1-\text{Đ}^{(1)}_{n-1,2}) + \{1-$$

$$-[\text{Đ}^{(1)}_{pr.n-2,2} + (1-\text{Đ}^{(1)}_{pr.n-2,2})\text{Đ}^{(1)}_{v.n-1,1}](1-\text{Đ}^{(1)}_{n-1,2})\}\text{Đ}^{(1)}_{v.n,2}\rangle(1-\text{Đ}^{(1)}_{n,2});$$

. . . .

$$\text{Đ}^{(1)}_{pr.n,n} = \{\text{Đ}^{(1)}_{pr.n-1,n} + (1-\text{Đ}^{(1)}_{pr.n-1,n})\text{Đ}^{(1)}_{v.n,n}\}(1-\text{Đ}^{(1)}_{n,n});$$

$$P^{(2)}_{pr.n,1} = \langle[P^{(2)}_{pr.n-2,1} + (1-P^{(2)}_{pr.n-2,1})P^{(2)}_{v.n-1,1}](1-P^{(2)}_{n-1,1}) + \{1-$$

$$-[P^{(2)}_{pr.n-2,1} + (1-P^{(2)}_{pr.n-2,1})P^{(2)}_{v.n-1,1}](1-P^{(2)}_{n-1,1})\}P^{(2)}_{v.n,1}\rangle(1-P^{(2)}_{n,1});$$

$$P^{(2)}_{pr.n,2} = \langle[P^{(2)}_{pr.n-2,2} + (1-P^{(2)}_{pr.n-2,2})P^{(2)}_{v.n-1,2}](1-P^{(2)}_{n-1,2}) + \{1-$$

$$-[P^{(2)}_{pr.n-2,2} + (1-P^{(2)}_{pr.n-2,2})P^{(2)}_{v.n-1,2}](1-P^{(2)}_{n-1,2})\}P^{(2)}_{v.n,2}\rangle(1-P^{(2)}_{n,2});$$

. . . .

$$P^{(2)}_{pr.n,n} = \{P^{(2)}_{pr.n-1,n} + (1-P^{(2)}_{pr.n-1,n})P^{(2)}_{v.n,n}\}(1-P^{(2)}_{n,n});$$

. . . .

. . . .

. . . .

$$\text{Đ}^{(m)}_{pr.n,1} = \langle[\text{Đ}^{(m)}_{pr.n-2,1} + (1-\text{Đ}^{(m)}_{pr.n-2,1})\text{Đ}^{(m)}_{v.n-1,1}](1-\text{Đ}^{(m)}_{n-1,1}) + \{1-$$

$$-[\text{Đ}^{(m)}_{pr.n-2,1} + (1-\text{Đ}^{(m)}_{pr.n-2,1})\text{Đ}^{(m)}_{v.n-1,1}](1-\text{Đ}^{(m)}_{n-1,1})\}\text{Đ}^{(m)}_{v.n,1}\rangle(1-\text{Đ}^{(m)}_{n,1});$$

$$\text{Đ}^{(m)}_{pr.n,2} = \langle[\text{Đ}^{(m)}_{pr.n-2,2} + (1-\text{Đ}^{(m)}_{pr.n-2,2})\text{Đ}^{(m)}_{v.n-1,2}](1-\text{Đ}^{(m)}_{n-1,2}) + \{1-$$

$$-[\text{Đ}^{(m)}_{pr.n-2,2} + (1-\text{Đ}^{(m)}_{pr.n-2,2})\text{Đ}^{(m)}_{v.n-1,1}](1-\text{Đ}^{(m)}_{n-1,2})\}\text{Đ}^{(m)}_{v.n,2}\rangle(1-\text{Đ}^{(m)}_{n,2});$$

. . . .

$$P^{(m)}_{pr.n,n} = \{P^{(m)}_{pr.n-1,n} + (1-P^{(m)}_{pr.n-1,n})P^{(m)}_{v.n,n}\}(1-P^{(m)}_{n,n}).$$

The chart of a combined serial-parallel structure describing an assembling procedure is depicted in Fig.2.

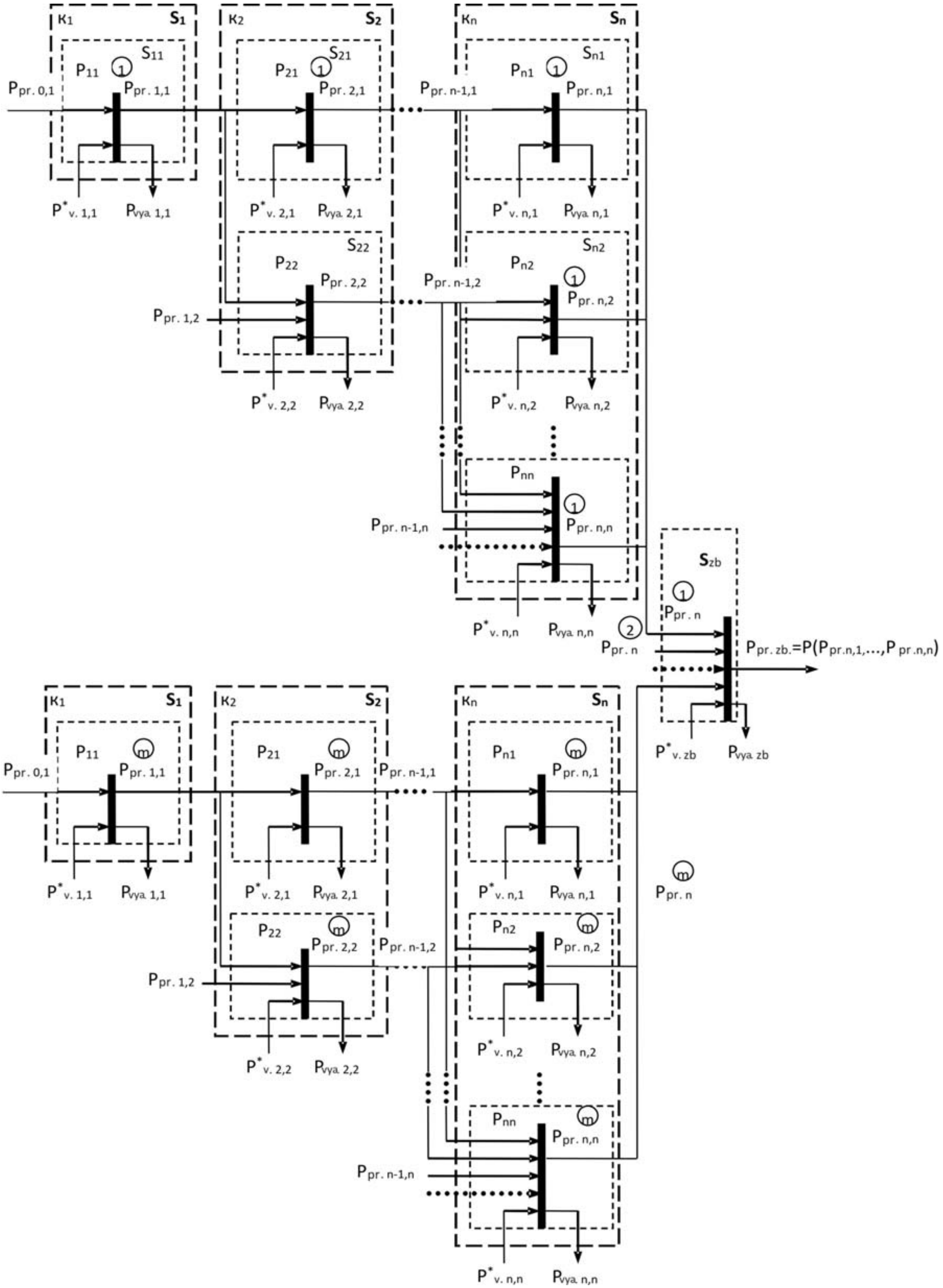

Fig. 2. The assembling procedure as a chart of a combined serial-parallel structure.

For thorough optimization to the said criteria we utilize statistical data in the form of cumulative functions. Matrix representation of the models allows us to significantly minimize their structure what is important for complicated multi-stage technological processes [1].

Main results and conclusion

The problem of constantly growing demands for quality and reliability of electronic devices intended for various use determines the necessity of a consistent approach to its solution. Improvements in the effectiveness of manufacturing processes can be achieved by their comprehensive optimization to technical and economic criteria using thorough cumulative models of production defects' flows and cumulative models of total expenses. The proposed criteria differ from known ones by their uniform dimension at all stages of the process. This makes it possible to realize the vision of their thorough simulation and comprehensive optimization.

The developed concept for evaluating the reliability of products in terms of their defects is based on established dependences of failures' flows of end products on defects' flows at all stages of manufacturing and operation of electronic devices.

The advantage of the proposed approach to thorough probabilistic simulation of processes designed for ensuring product quality and of expenses due to their implementation consists in the fact that it has no restrictions on the structural complexity and physical peculiarities of some technological procedures accounting for these processes. The offered mathematical apparatus using universal quality criteria such as probabilities of introducing, detection, omitting of defects allows us to simulate and carry out the optimal process control for a wide range of technical objects, to perform the procedure of decomposition and synthesis of these systems, to solve problems of their comprehensive optimization [1].

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