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SENSITIVITY ANALYSIS OF PROCESS EXPENSE INDICES TO THE PARAMETERS OF MANUFACTURING OPERATIONS

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Abstract: The article presents the dependencies of total manufacturing and maintenance costs on process characteristics, obtained using OPTAN software-methodical complex.

Key words: electronics processes, process optimization, OPTAN software-methodical complex.

1. Introduction

One of the most important scientific and technical problems is to ensure the quality and reliability of radio-electronic apparatus (REA).

During the operational issues of maintenance of quality and reliability of REA, especially in the case of complex manufacturing processes, a developer makes his decision largely on the basis of empirical or heuristic methods, and these decisions can be significantly far from optimal ones.

Recently, to find rational options on the stage of the technological preparation of a manufacturing process and of the manufacturing itself, the tools of automated design have found their wide application.

Developed by a group of authors, an automated system for simulation, investigation, and optimization of manufacturing and technology processes named OPTAN enables a technologist to consciously make decisions regarding control strategies, to assess the risks and expenses caused by the taken decisions on the stages of manufacturing and operation, to assess quickly the impact of interrelations between numerous manufacturing operation parameters of different physical nature on the expenses of processing and warranty maintenance. OPTAN provides recommendations for optimal selection of multistage manufacturing processes of radio-electronic apparatus. Theoretical principles underlying the design, were published in many scientific papers [1, 2], and the peculiarities of algorithmic and software implementation were discussed in [3, 4].

However, the impact of some parameters on the result of optimization has not been investigated in full.

The purpose of this paper is to analyze the possibilities of practical application of recommendations obtained by the OPTAN complex on the stages of process design or upgrading.

2. Mathematical modeling of economic costs due to securing the REA quality

The functional dependence of total manufacturing (including control procedures) and maintenance costs is extremely cumbersome, since it takes into account the impact of numerous parameters of various manufacturing operations of different physical nature. As a result of the authors' previous theoretical investigations of a compact mathematical model of total costs due to securing the products quality was developed using scalar product of matrices. This model has the form (1).

$$C_{\Sigma} = \left(C_{\hat{A}}, K_{\hat{A}}\right) + (B, æ, C_{KOH}) + (C_K, P_{BЯ.E}) + \\ + (C_E, P_{\hat{A}ß.\mathring{A}}), \qquad (1)$$

where $\left(C_{\hat{A}}, K_{\hat{A}}\right), \ldots, (C_E, P_{\hat{A}ß.\mathring{A}})$ are scalar products of corresponding matrices obtained by the rule (2):

$$(A_1, A_2, \ldots A_m) = \sum_{\hat{e}=1}^{n} \sum_{³=1}^{n} \alpha_{\hat{e},³}^{(1)} \alpha_{\hat{e},³}^{(2)} \ldots \alpha_{\hat{e},³}^{(m)}, \qquad (2)$$

where $(A_1, A_2, \ldots A_m)$ is the scalar product of the matrices; here the denotation of the matrices in the form

$$A_j = \left\| \alpha_{k,i}^{(j)} \right\|, \quad i = \overline{1,n}, \quad k = \overline{1,n}, \quad j = \overline{1,m} \qquad (3)$$

is used to determine the total costs C_{Σ} in the case when the control depth $æ$ serves as an optimization parameter.

The physical meaning of the matrices in (1) is described below.

$$C_B = diag\left\| C_{B.1,1}, C_{B.2,2}, \ldots, C_{B.n,n} \right\| \text{ -}$$

costs due to securing the quality of each parameter of the product at all process stages, i.e. for each manufacturing operation (from 1 to n);

$$K_B = diag\left\| K_{B.1,1}, K_{B.2,2}, \ldots, K_{B.n,n} \right\| \text{ -}$$

coefficients of costs variation for each manufacturing operation;

$$B = diag\left\| b_{1,1}, b_{2,2}, \ldots, b_{m,n} \right\| \text{ -}$$

the matrix of Boolean values which identify the presence ("1") or absence ("0") of control procedures for corresponding manufacturing operations.

$$æ = diag\left\| æ_{1,1}, æ_{2,2}, \ldots, æ_{n,n} \right\| \text{ –}$$

the matrix of control depth indices. In the version $æ$ is the only vector optimization parameter.

$$C_{KOH} = diag\left\|C_{KOH.1,1}, C_{KOH.2,2}, \ldots, C_{KOH.n,n}\right\| -$$

the matrix of costs due to performance of control procedures.

$$C_K = diag\left\|C_{K.1,1}, C_{K.2,2}, \ldots, C_{K.n,n}\right\| -$$

the matrix of costs due to detecting and fixing occurred defects;

$$C_E = diag\left\|C_{E.1,1}, C_{E.2,2}, \ldots, C_{E.n,n}\right\| -$$

the matrix of costs due to planned warranty maintenance as well as costs due to failures of REA in the course of their operation that are caused by production defects;

$P_{ВЯ.E}$ – the matrix of probabilities of the product failure identification in the course of its operation. The values of its elements depend on the probability of presence of a defect characterized by k-th parameter, on the probability of this defect identification (this is a conditional probability) and on the probability of the defect omission at the k-th process stage as a result of insufficient control; $P_{ВЯ}$ – the matrix of probabilities of the defect identification at the k-th process stage.

The formation of the matrix $P_{\hat{A}ß}$ is the most difficult stage of the formalization of the manufacturing process description.

The values of the matrix elements are conditional probabilities of detecting a defect if it has been introduced into the product with the probability $P_{B.K}$.

Due to imperfect manufacturing technology and quality control technology the events of introducing defects may happen at every process stage as well as the events of defects omission at the next stage. This is determined by a selected control option, by the appropriate skills of supervising personnel, and by the accuracy and reliability of measuring tools.

Those events are assessed by:

$$P_{в.к} = P\{(x_к < X^{Д}_{н.к}) \cup (x_к > X^{Д}_{в.к})\} -$$

the probability of introducing a defect in the product at the k-th process stage, $k = \overline{1,n}$, where n is the number of stages; $X^{Д}_{н.к}$, $X^{Д}_{в.к}$ are the lower and upper tolerance limits; P_K is the probability of appropriate quality control after accomplishing k-th process stage; $P_{ВЯ.K}$ is the probability of detecting a defect at the k-th process stage; this is the conditional probability of the defect identification if it has been introduced into the product with the probability $P_{B.K}$.

Dependence of the matrix $P_{ВЯ}$ elements on the above parameters is recurrent and is described by equations (4).

$$P_{ДЕФ.K} = P_{ПР.K-1} + (1 - P_{ПР.K-1}) \cdot P_{B.K};$$

$$P_{ВЯ.K} = P_{ДЕФ.K} - P_K;$$

$$P_{ПР.K} = P_{ДЕФ.K}(1 - P_K). \quad (4)$$

The results presented in this paper show the application of this model to optimization of a particular manufacturing process.

3. Input data and an example of optimization of a complex manufacturing process

The discussed version of OPTAN complex provides a technologist with recommendations for selecting the optimal depth control for each manufacturing operation (MO). The input data describing the manufacturing process are 12n process parameters related to different probabilities and costs (n – the number of manufacturing operations).

The indices of the probabilistic process are presented in the form of three upper-triangular matrices, and five vectors. Among them:

- the matrix of probabilities $P_{\hat{A}}$ of defect introduction; its diagonal elements are the probabilities of defect introduction while performing corresponding manufacturing operations;
- the matrix of probabilities P of appropriate quality control; its diagonal elements are probabilities of correct defect identification as a result of quality control of relevant manufacturing operations;
- the vector of probabilities of the defect presence in the materials, components, semi-finished products and so on at the stage of initial control (initial defectiveness P_{def_0}).

Process expense indices are presented in the form of two upper-triangular matrices, and three vectors. Among them:

- the vector of relative average costs due to control organization and performance;
- the matrix of control expenses; its diagonal elements are the relative costs due to control organization and performance with respect to a corresponding product's parameter at each process stage;
- the vector of relative average operating expenses re-associated with the necessity to eliminate defects detected during the maintenance for each product's parameter.

Actual values of these indices are different for different processes, and even for similar processes that reflect the peculiarities of process organization in different enterprises, using slightly different process and control equipment, higher/lower qualified personnel and even the general approach to manufacturing.

While testing OPTAN complex the authors obtained relevant statistics regarding the process of manufacturing a printed circuit board with plated holes in it; the material of the board is foil reinforced fluoroplastic (ФАФ-1). This process comprises nine manufacturing operations, from making blanks up to the application of a protective mask.

In Fig. 1 the process optimization results obtained by applying the OPTAN complex are shown. The optimized parameter is the depth control vector (i.e. 9 values of depth control for the manufacturing operations) and the total cost incurred at all process and operation stages serves as optimization criterion. Three mathematical optimization techniques, namely step-by-step optimization, golden section search, and Hooke-Jeeves pattern search, have been used. For comparison, Fig. 1 shows the values of "full control" (red columns), when the relative control depth is equal to figure of one.

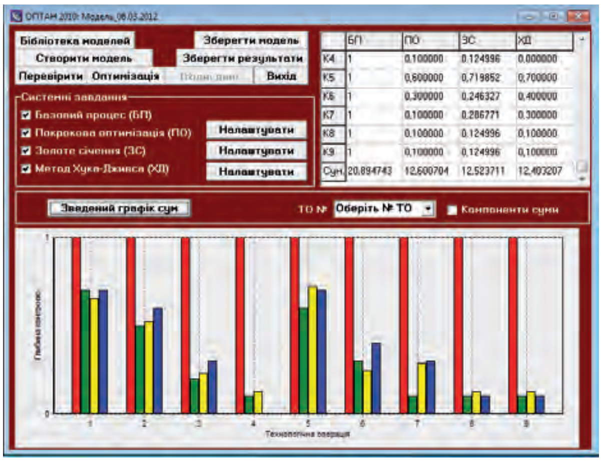

Fig. 1. Optimization results for the nine-stages process.

Similar results have been obtained for a range of various processes. However, one can point out the following features that they have in common:

- optimal values of depth control determined using different mathematical methods only slightly differ from each other;
- optimal values of depth control considerably differ from the values of "full control";
- for some manufacturing operations (in the presented example TO4, TO8, and TO9) control is not necessary.

The obtained optimized values are the result of correct and tested mathematical procedures, but their practical application depends on many other factors.

4. Dependencies of expense indices of multi-stage processes on manufacturing operations parameters

Due to different physical nature of manufacturing operations the change of separate parameters requires the performance of some technical and organizational arrangements of varying complexity. During the practical implementation of optimization results of such a multi-parametric system it is necessary to make decisions concerning appropriate changes in separate parameters and concerning possible risks in case of deviations of the parameters from the optimal ones.

To facilitate the decision making OPTAN provides a technologist with dependencies of total costs incurred at all manufacturing and operation stages of a product on the variable control depth. An example of such dependency is shown in Fig. 2. It is mentioned in the previous section that the values of the probabilistic and expense indices are specific for each manufacturing operation but to discover major regularities and trends in this example we have assigned their identical values for all manufacturing process operations.

In our example, the following values of the parameters have been chosen: the probability of introducing defects at each MO P_B =0.05, the probability of the presence of defects in materials and components at the stage of initial control P_{def_0} =0.06, the cost of control =0.6, the cost of the elimination of the defects during an operation phase = 30. For better visualization, the dependencies for only MO are shown in Fig. 2.

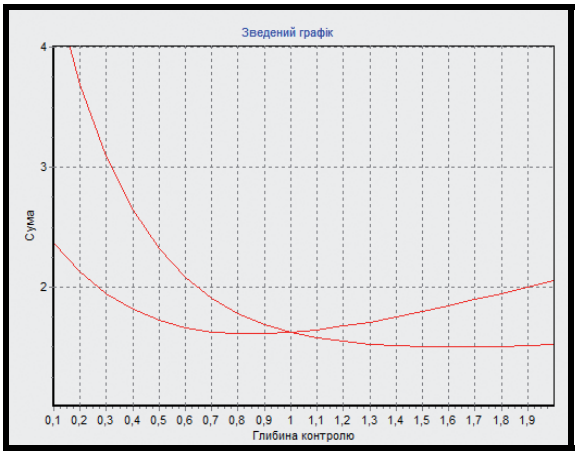

Fig. 2. The dependency of total costs on control depth: P_B *=0,05;* P_{def_0} *=0,06;control expensse = 0,6; operation expenses=30.*

It can be concluded from the example in Fig. 2 that the optimal depth control for the first MOT is of 1.7, and for the second – of 0.9. Reducing the depth control for the first MO at 1.0 only slightly affects the level of costs but further reducing does considerably. What concerns the second MO, a technologist may choose, without a significant risk, a value of control depth ranging from 0.4 to 1.3.

Further studies are concerned with the analysis of influence of changes in separate process parameters on the optimization results. The appropriate examples are shown in Fig. 3–6.

Let us discuss the possibility and consequences of reducing the probability of defects' introducing during manufacturing operations to the level of P_B=0.01 (compared to P_B = 0.05 in the basic example). This reduction of P_B can be achieved, for example, by replacement of existing technological equipment with a more perfect one.

The simulation results are shown in Fig. 3.

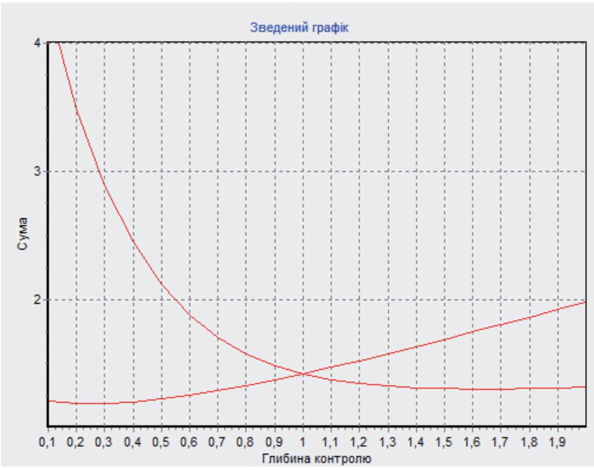

Fig. 3. The dependency of total costs on control depth for P_B =0,01.

The comparison of Fig. 2 and Fig. 3 shows that no changes in the dependency for the first MO can be noticed; what concerns the second MO, its control depth can be reduced to the level of 0.2 ... 0.3, and the total costs in this case will be reduced by 50%.

Fig. 4 shows us the case of increased control expenses to the level of 1.6 compared to 0.6 in the basis example (Fig. 2). Total costs in this case are rising, but the recommendations with respect to the optimal choice of control depth are virtually unaffected.

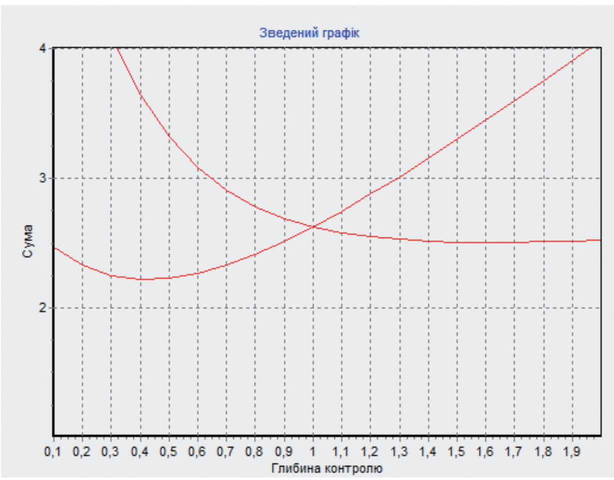

Fig. 4. The dependency of total costs on control depth for control expenses = 1,6.

It means that for the discussed process there is no reason for improve its checkout and diagnostic facilities.

The next computational experiment concerns the increase of defectiveness of input materials (up to 0.6 in comparison with 0.06 in the basis example). Such a case may be caused by the state of the market – either a lack of high-quality components, or the appearance of new cheap ones without sufficient quality warranty.

The simulation results for this case are shown in Fig. 5.

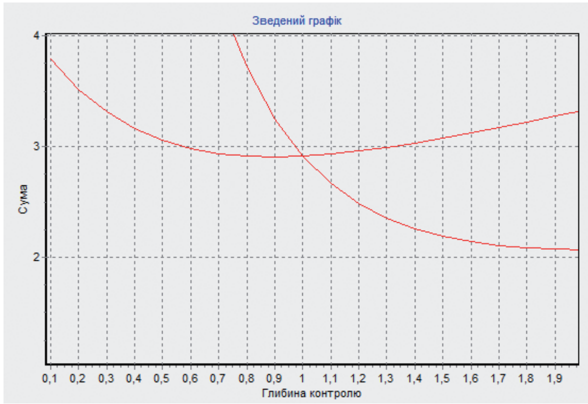

Fig. 5. The dependency of total costs on control depth for P_{def_0} =0,6.

It can be seen from the comparison with the basic example (Fig. 2) that for the first MO the requirements to depth control become more stringent, because the reduction of depth control leads to the sharp increase in total costs. At the same time, the control operations for the second MO can be the same as previously but reduction of control depth is unacceptable.

The last computational experiment concerns the case of a significant reduction in the cost of defect elimination during the product's operation phase. It is possible, for example, when there is a redundant amount of typical elements for replacement.

The simulation results for this case are shown in Fig. 6.

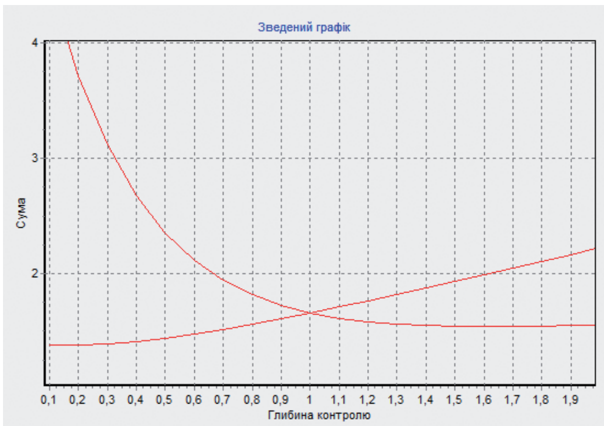

Fig. 6. The dependency of total costs on control depth for operation expenses = 10.

The obtained dependencies show that in this particular case the control is practically unnecessary for the second MO but it is crucial to adhere to the recommendations given for the first MO.

The results of our analysis have been obtained for the parameters' values selected solely for demonstration reasons. In fact, our team has obtained similar results for real complex multi-stage processes, including processes for manufacturing printed circuit boards and liquid-crystal indicators.

5. Conclusions

The presented results of sensitivity analysis of process expense indices to manufacturing operations parameters show additional features of the OPTAN software-methodical complex that can be used for practical implementation of the output data of process optimization. While developing or updating a manufacturing process, a technologist, using these results, is provided with the possibility to realistically estimate the risks and costs caused by deviation of the parameters from their optimal values and to determine the most demanding process stages, as well as to quickly assess the impact of interrelations between numerous manufacturing operations parameters of different physical nature on the expenses of processing and warranty maintenance.

Furthermore, the revealed important trends regarding changes in expense indices caused by changes in process parameters' values confirm the adequacy of the proposed mathematical model and its software implementation through the OPTAN complex.

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АНАЛІЗ ЧУТЛИВОСТІ ВИТРАТНИХ ПОКАЗНИКІВ ТЕХНОЛОГІЧНИХ ПРОЦЕСІВ ДО ПАРАМЕТРІВ ТЕХНОЛОГІЧНИХ ОПЕРАЦІЙ

Леонід Недоступ, Юрій Бобало, Андрій Бондарєв, Мирослав Кіселичник, Олег Надобко

Представлено залежності сумарних витрат на виробництво та експлуатацію виробів від характеристик технологічного процесу, отримані з використанням програмно-методичного комплексу ОПТАН.

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