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Algorithmization and optimization of processes for integrated electronics engineering

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Abstract. This paper discusses the challenges of taking a technological solution based on certain requirements, with the existence of several alternative options (alternatives) with regard to the technical requirements in the manufacture of integrated circuits, as listed in the following. The algorithm of the choice of process equipment during the production of integrated electronics is developed. The functional block diagram of an adaptive system with an adjustable model is given. The structure of the information schema implementation of the adjustment model of technological production of integrated electronics is given. The developed model of the technological process of production of integrated electronics is presented. The stages of optimization of production of integrated electronics are given. The algorithm of control of technological process of production of integrated electronics is developed.

1. Introduction

Engineering of a new series or type of chips gives an expert a number of uncertainties [1-3]. For example, it is necessary to evaluate the possibility to engineer this series or party of products while considering the specifications of the existing equipment and to evaluate the expected yield percentage.

In fact, a process solution needs to be made, based on certain requirements with several versions (alternatives), considering the specifications.

A process plant selection algorithm of engineering with several alternatives, considering the uncertainties that an expert has, at evaluation of criteria quality, is proposed for engineering application in the parameters of units on the basis of optimization methods. The algorithm allows for the selection of an alternative, which brings us nearest to the "ideal value" (i.e. "an ideal point") in the case of uncertainty [4, 5].

2. Algorithm for the selection of the process plant at integrated electronics engineering

Let us assume some number of alternatives n for selection of a processing method or selection of specific equipment (plant), out of which a decision-maker (an engineer) shall select, considering the influencing criteria (quality criteria of the products under the specifications) in an amount of m :



$$\begin{aligned}
A_1 &= \{a_{11}, a_{12} \dots a_{1n}\} \\
A_2 &= \{a_{21}, a_{22} \dots a_{2n}\} \\
&\dots \\
A_m &= \{a_{m1}, a_{m2} \dots a_{mn}\}
\end{aligned}$$

Let us introduce the concept of an ideal alternative:

$$A_{id} = \{a_{id1}, a_{id2} \dots a_{idn}\},$$

such that any value of a_{idi} is better than the a_{ji} , $i=1 \dots n, j=1 \dots m$ for any i and j . Thus, it is necessary to determine such an A_j , which would be most closely approximate to A_{id} . However, we must also consider the importance of each criterion (in the quality criteria of engineered products). With this purpose, let us introduce an importance option for each criterion U_i . Let us set the probability distribution function as p_j [6, 7]. Let us consider the effect of evaluation of the relative importance of each j criterion, by expressing it through the probability distribution:

$$p_{ji} = \frac{F_{E_j}(a_{ji})}{\sum_{k=1}^m F_{E_j}(a_{ji})},$$

where E_j is a fuzzy set, p_{ij} – membership degree evaluation, F_{E_j} – function of preferability on each criterion. To estimate the uncertainty Δ , let us use the Shannon measure for the uncertainty [1, 8]:

$$\Delta = -K \sum_{j=1}^m p_j \log_2 p_j$$

where K is a norming quantity to bring the uncertainty to the range from 0 to 100% (0 to 1). The overall uncertainty will be:

$$\Delta_{\hat{a} \hat{u}} = -K \sum_{j=1}^m \sum_{i=1}^n p_{ji} \log_2 p_{ji}.$$

The uncertainty of a certain quality criterion at chipping will be:

$$C = \frac{\omega_j \Delta}{\Delta_{all}}$$

where ω_j – is a factor of quality importance, given by an expert.

As a result, the actual deviation $\sigma[A_j]$ of the alternative A_j from A_{id} shall be determined.

The mean square deviation may be written as:

$$\sigma[A_j] = \sqrt{\sum_{j=1}^m C [1 - F_{E_j}(a_{ji})]}.$$

Having determined the deviation for all $j=1 \dots m$, the alternative (the best engineering version) with the minimum deviation from A_{id} should be selected. This selection algorithm is shown in Figure 1.

In step 1, the process (processing procedure) is selected. Then, the list of equipment and the operation modes available are loaded from the database. Then, the expert is provided with all preset alternatives of A_j .

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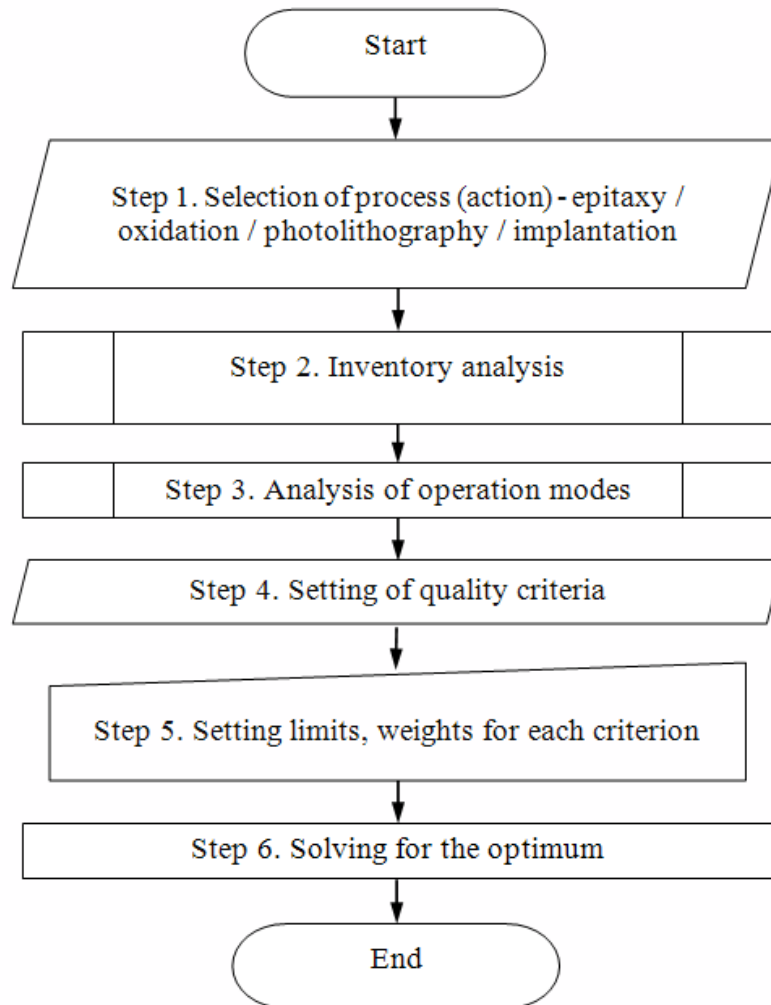


Figure 1. Algorithm for the selection of process plant via integrated electronics engineering

Then an ideal selection is made. The next step includes the entering of $F_{E_j}(a_{ji})$, which characterizes a preference of alternative i as of j quality parameter and weight coefficients for all $i=1..n$ and $j=1..m$.

The deviations are calculated as described above and the expert is provided with the computed solution.

This algorithm is used in the unit for the selections of equipment and operation mode of the engineering optimization system for the chips, allowing for (if required) adjustment of the road sheet, to determine the most appropriate process plant for this series of chips, considering the specifications. That is, there is a feedback of the algorithm and the process for the selection of an operation mode and applied plant composition.

The past experience of the algorithm provides for three options:

1. The products cannot be engineered further to the specifications, using this equipment; either specifications need to be adjusted, or the equipment needs to be upgraded.
2. There is the only one implementation option.
3. There are several implementation options. In this case, the best solution is to be found according to the above algorithm for the selection of the best alternative.

Thus, the above algorithm allows for making a rational selection of operation modes and the composition of the process plant for engineering of a new series of products, considering the requirements, as well as for determining the manufacturability at the process engineering stage.

3. The forming of an adaptive system

Given the fact that in the period of production of chips, for the accounting of uncontrolled variables, the existing process model or operations thereof need to be adjusted to solve this problem. Further, for the results of the above analysis, it is proposed to use the adaptive systems with adjustable models.

The adaptive system, shown in Figure 2, can be operated in two modes - information gathering and control. At information gathering, values $y(t)$, $u(t)$ are recorded to the database for k time intervals (at a lack of process information). The proposed control algorithm is as follows:

Processing of the controlled object information and entry of the current process settings to the database.

Adjustment of the existing (adjustable) model parameters, considering the new data about the current process state (if required). If the system parameters are stable, the model is not adjusted.

Determining the best values of a controlling action as of the adjusted model. Implementation of the controlling action so that the system behavior meets the specified criterion.

The information diagram of this system is shown in Figure 3.

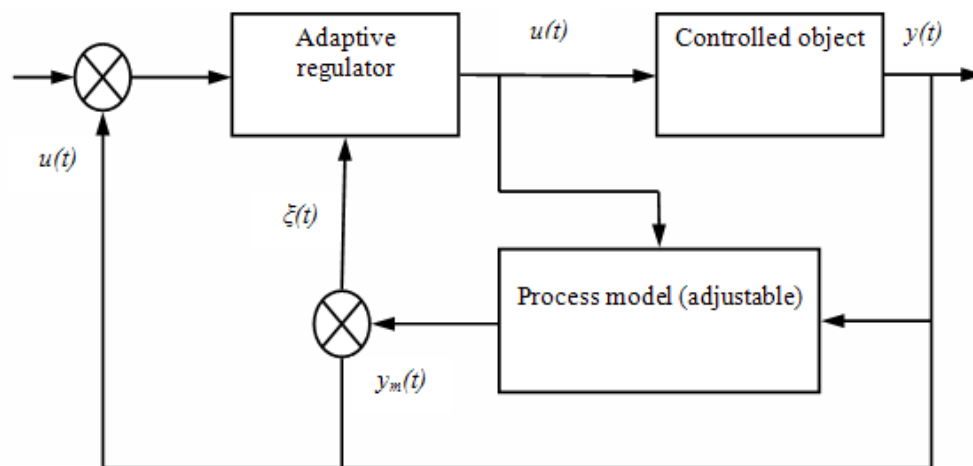


Figure 2. Functional diagram of the adaptive system with adjustable model

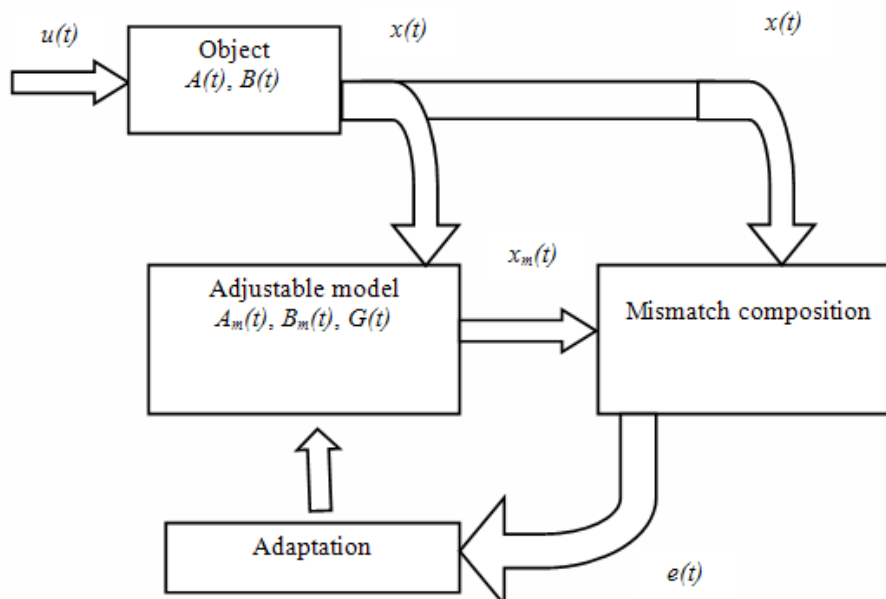


Figure 3. The information diagram for adjustment of the process model for integrated electronics engineering

4. The algorithm of optimization the system

As described above, the non-ideality and aging of processing plants and effects of random or uncontrolled parameters for integrated electronics engineering can cause alteration of input and output variables for each operation and the process in general in time, so the process optimization should consider the effect of uncontrolled parameters.

The process model is shown in Figure 4. In general, the process optimization steps are shown in Figure 5.

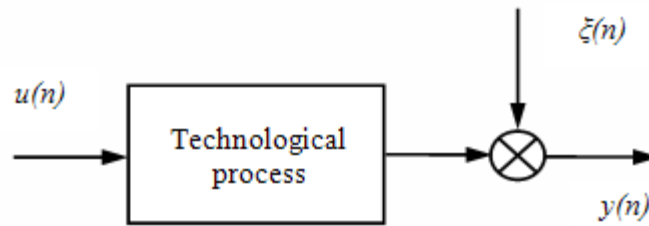


Figure 4. Process model for integrated electronics engineering

Let us develop an algorithm for the calculation of adaptation coefficients.

Let us put the object model with adaptation, which is well-known from literature [9]:

$$B \cdot u(t) = \sum_{m=0}^M K_n \cdot \frac{d^m y}{dt^n} + \sum_{m=0}^M H_n \cdot \frac{d^m y}{dt^n} \quad (1)$$

where K_n is the object characterizing matrix and H_n is the correction unit matrix (parameter adjustment) [9].

In this case, the number of object parameters and adjustment parameters is the same, equal to m , which does not always happen in practice.

The process control task is to find proper coefficients for minimal deviation of the actual state of the process.

The adjustment model [9] can be similarly written as:

$$B \cdot u(t) = \sum_{m=0}^M A_n \cdot \frac{d^m y}{dt^n} \quad (2)$$

where A_n is the adjustable model matrix.

Expressions (1) and (2) show that the ideal adaptation with a zero error requires:

$$\begin{aligned} K_m + H_m &= A_m \\ H_m &= H_m(t) \end{aligned} \quad (3)$$

If no restrictions are imposed on H_m , and if (3) is fulfilled, then the coefficients in the two previous expressions will be identical.

Considering (2):

$$\frac{dH_m}{dt} = \frac{\partial J(\xi)}{\partial A_m} \quad (4)$$

Using the expression (2), we get:

$$\frac{dH_m}{dt} = \sum_{m=0}^M \left(-C \cdot \frac{d\xi(t)}{dt} \cdot \frac{du_m(t)}{dt} \right) \quad (5)$$

Now, let us develop a control algorithm for the process of integrated electronics engineering.

In general, (5) is a system of nonlinear equations. The search for solutions for this system may take a long time and is often impossible [10-12].

Since control and output variables have a limited range of possible values, one can use polynomial approximations, such as the linear (for n parameters ($n=1,2,\dots$)):

$$Y_{out} = \sum_{i=1}^n k_i X_i + \sum_{i=1}^n k_i X_i Y_i + \tilde{n}_0$$

where k_i , c_0 are some coefficients. To find the best solution, the extremum of the optimization function F needs to be found.

In practice and in [14], the authors indicate the need to bring the equations to a linear form [14, 15] for process control tasks, for faster calculations at solution finding.

To validate the mathematical model, we propose to calculate the deviation of the estimated value from the actual one and to compare it with a permitted deviation value Δ :

$$|F_{fact_i} - F_{calc_i}| \geq \Delta$$

The actual value is calculated by substituting the current values Y_{mex} in the objective function with the values measured at the process outcome.

We propose to find the estimated value by substitution of values of the Y_{1i} and Y_{2i} output variables, calculated by a mathematical model.

At this, if the difference modulus does not exceed a permissible value, it is considered that the mathematical model adequately describes the real process and can be used for process control. In other cases, the mathematical model requires clarification.

The values of control and output variables for the i -th moment are denoted by U_{1i} , U_{2i} , U_{1i} , U_{2i} .

We propose to organize the interaction with the control system as follows.

Data transmission to the control system starts at time $t=t_0=0$.

Some time (from the time $t=t_0$ to $t=t_i$, $i=1,2,\dots,n$) after the start of the process is required to gather information about the current state of the system: hardware settings, given chipping algorithms and others.

At time $t=t_i$ the control algorithm starts.

Switching of the control system (that is, the process control) is started at time t_i , that is, at the moment the process plant is switched on.

The management process enters the transmitted data to the control system and records them to the history files of the process after a certain period of time.

At the optimization of the process, the transmission of now-used-data to the control system should be limited: it is necessary to use the data for the last period of time - Δt , as the previously recorded data is outdated (Fig.5).

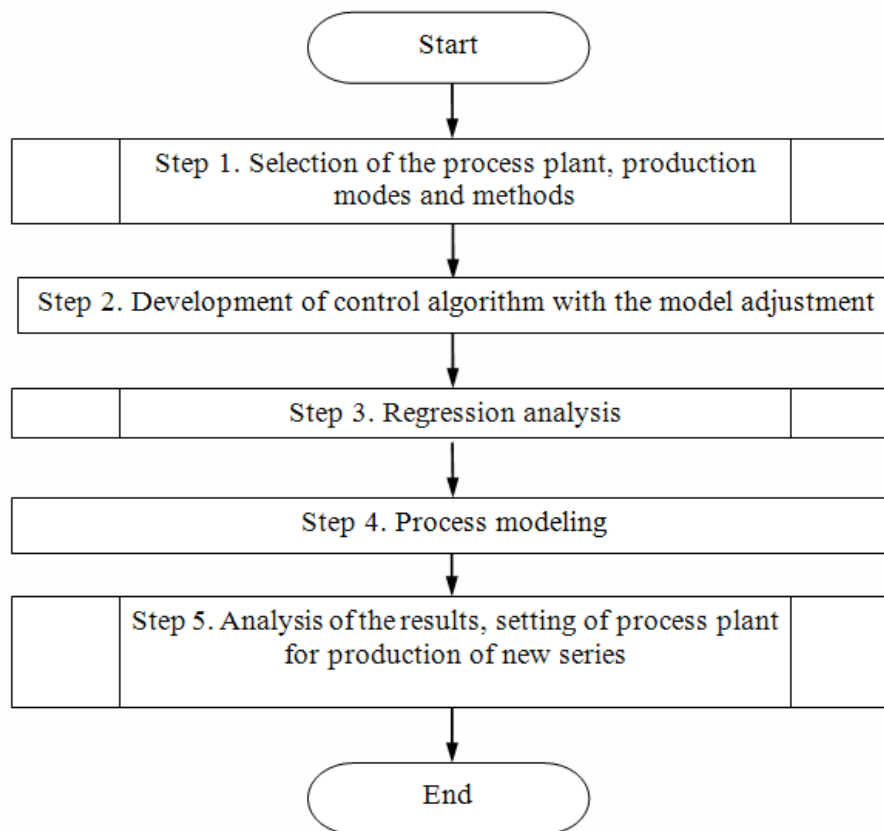


Figure 5. Steps to optimize the integrated electronics engineering

The moment of time $t=0$ is the time of the first measurement of process parameters.

The value for Δt is selected considering the time of each process step.

Thus, an automated process control system receives and transmits data, necessary for adaptation to the actual state of the process. To determine the influence of the control systems on the actual state of the process for the production of the subsequent series of products, there are used regression analysis and data, which are transmitted to the automated process control system.

The developed algorithm is shown in Figure 6.

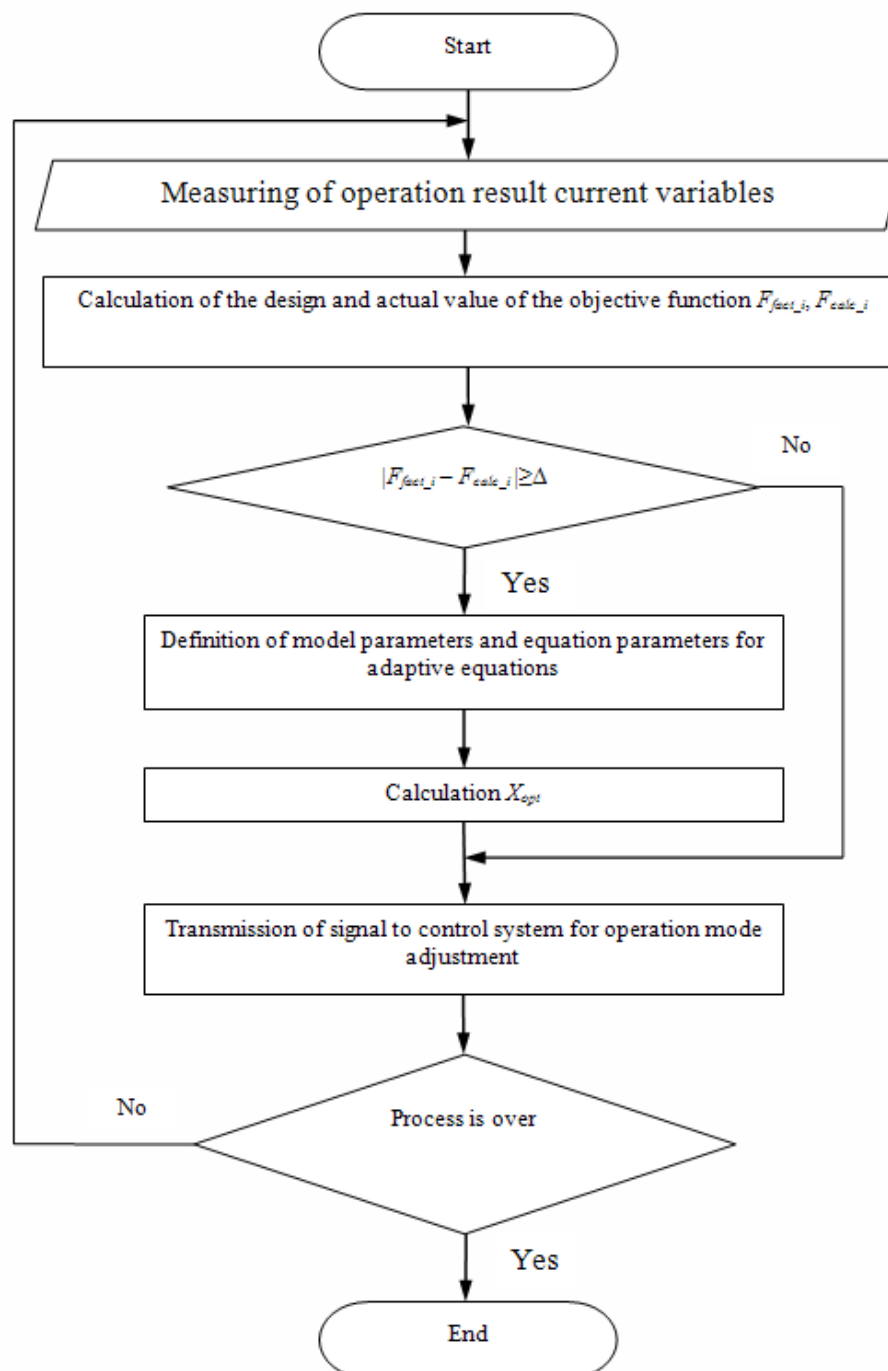


Figure 6. Control algorithm for the process of integrated electronics engineering

5. Conclusion

The paper presents developed algorithms to manage the production process in the manufacturing of integrated circuits. Within it, the algorithm of the choice of technological equipment, a model of the production process, and the algorithm of the control of the technological process of production are developed, and recommendations for the optimization of the production of integrated electronics are given.

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