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CONTROL OF MULTINOMIUM PRODUCTION TECHNOLOGY PROCESSES

Mykola STARODUBTSEV, Gennadiy MAKARENKO

Department of Computer-Integrated Technologies, Automation and Robotics, Kharkiv National University of Radio Electronics, Kharkiv

ABSTRACT
The problem of operational control of a manufacturing process under uncertainty is formulated as a problem of trajectory control. A model of phase-trajectory control of the process is developed, designed to select and adjust technological modes depending on the current state of the controlled technological object (TO) under a priori insufficiency and/or fuzziness of information.
Keywords: phase-trajectory control, technological process, multi-nomenclature production, fuzzy information.

1. INTRODUCTION

Currently, there is a growing trend towards the transition to small-scale, multi-number production. The manufacture of products in small batches with a wide range of sizes and properties leads to an increase in the frequency of changing settings (parameters of technological operations, equipment operating modes), and increased requirements for the flexibility of the settings model. At the same time, the model has to be developed on the basis of a limited amount of noisy experimental data and very vague a priori information about the statistical characteristics of the added disturbances. In many cases, these difficulties are exacerbated by the presence of drift in the TO characteristics.

Automated TP control systems, most of which are based on the use of statistical models, are ineffective during the development of new products. Statistical models are by their nature very sensitive to changes in the experimental conditions, and their adequacy can only be guaranteed under the conditions under which they were built.

As a result, the technologist is usually deprived of ACSTP support and spends considerable time selecting modes for manufacturing pilot batches and collecting statistical data at the most critical moment - the moment of mastering new processes. Thus, the task of developing models for adaptive TP control in small-scale, multi-item production is an urgent one.

2. PRESENTATION OF THE MAIN MATERIAL

To reduce the time required to develop and introduce new products, it is necessary to create a decision-making model at the design stage, which will be adjusted and supplemented during the TP debugging process and concentrate the experience of manufacturing a particular product. The model should contain and clarify the requirements for the basic TP, provide the calculation of process control during the manufacture of the product, and work in conditions of a limited amount of noisy experimental data. The proposed approach allows taking into account these requirements for the decision-making model.

In the conditions of small-scale, multi-nomenclature production, the sources of uncertainty that complicate the choice of a particular control option are the following factors: insufficient amount of available information that does not allow the use of statistical methods for developing the technology; inability to accurately determine the phase coordinates (for example, with group processing methods common in instrumentation, the determination of the average value of a parameter for the entire batch of products is only of an estimation nature); inability to absolutely accurately implement the selected control on the

We will consider the technological process as a multi-stage system with a sequential transition from one state to another along a certain trajectory. In this regard, the development of algorithms for optimal process control should be considered as a single procedure for end-to-end design [1].

The task of developing a TP control model is formulated as follows: for the initial states of the object of manufacture, which are determined during the control operation, and the states measured during the intermediate control, it is necessary to select the control u_i $(i=0, \dots N-1)$, i.e. TP modes, so that the output characteristics of the product differ minimally from the target ones.

The model development begins with an assessment of the possibility of using the modes of the basic technology for the device being manufactured. The choice of the basic technology means that the sequence of controlled operations is set and the restrictions on the control variables are determined. The choice of an analog, i.e., a device that is closest to the designed one in terms of its characteristics and implemented on this basic technology, determines the initial state constraints that can be revised in the future. It should be noted that this problem only formally coincides with the traditional optimal control problem. The difference is that in the traditional control problem, the values of the initial phase coordinates are known to within the measurement error, while in the synthesis problem, the initial values of the phase coordinates are not known in advance, since the values of the output parameters can randomly take values from the permissible range. This, in turn, leads to an error in the choice of control.

The problem belongs to the class of multi-step problems, where information about the process and its control are carried out at discrete points in time. In modern control theory [2], this problem is usually solved by dynamic programming in two stages: building an optimal trajectory; synthesis of a control that implements the trajectory.

The possibility of separating the stages assumes that the disturbances affecting the process are small.

Given that in practice, manufacturers always strive to expand tolerances on the initial parameters of materials, the assumption of small perturbations becomes unjustified, and the construction of a single optimal trajectory is impractical.

The presence of a single trajectory, i.e., the use of fixed modes, requires tighter tolerances on the initial materials, which supplier plants are often unable to meet. Despite the constant improvement of the properties of the starting materials, the improvement of methods and means of controlling their parameters, the production of new equipment products usually has heterogeneous characteristics of objects, especially in TP groups.

Under these conditions, the technologist is forced to either increase rejects due to workpieces that do not fall within the zone of an acceptable fixed mode or to proceed to mode correction. In general, mode correction allows to expand the tolerance for the parameters of the starting materials, since by selecting modes and correcting them, it is possible to bring the process, which deviated from the calculated trajectory in previous operations, within the target interval.

In this regard, at the stage of TP development, it is advisable to set the extreme problem as a phase-trajectory control problem [3, 4]. And only after the developer is convinced that the production of devices with the required properties is possible for a wide range of initial states and operating modes, it is possible to set the task of process optimization in terms of production cycle time, cost, etc. using standard and heuristic optimization methods to solve it.

The description of a multistage decision-making problem is based on the fuzzy mapping $f: X \times U \to X$, where X is the space of states, U is the space of strategies (control sequences that transfer an object from an initial state to a final state).

Any state, including the initial and final states, is represented by a convex fuzzy subset. Thus, the basic TP is determined by a sequential transition from one fuzzy state to another

$$X_0 \to X_1 \to X_2 \to \cdots \to X_N. \quad (1)$$

The state X_k is determined by the vector of controlled parameters $\{x_j\}_{j=1}^{L_k}$ at the k-th stage of TP.

The control model at the k-th stage of TP is built based on the method of forming a maintenance control model. According to this method, the set of experimental data by design parameters is divided into n_k fuzzy clusters corresponding to n_k possible TP modes at the k-th stage.

The fuzzification procedure works even when the amount of experimental data is less than the number of clusters. However, in the case of extremely limited data on design parameters and the availability of data from controls, the following approach can be applied.

Using the TP model in the state space [5,6], we form fuzzy relations in the space $X \times U \times X$, which is a formalized representation of management strategies and is characterized by fuzzy relationship matrices R_k,, such as

$$X_{k+1} = R_k \circ X_k, \quad (2)$$

where $\circ$ – maximal product operation.

Such a representation is adaptive to changes in design parameters, the structure of the controlled object, and changes in TP modes. For n_k possible TP modes at the k-th stage, we build the set $\{R_{k,i}\}_{i=1}^{n_k}, k = 0, \dots, N-1$,for which the following is performed:

$$X_{k+1,i} = R_{k,i} \circ X_k. \quad (3)$$

By "backtracking" the obtained solution, starting from X_N, we determine the sets $\{X_{k,i}\}_{i=1}^{n_k}$ of admissible states of the system at each stage:

$$X_{k,i} = R_{k,i}^{-1} \circ X_{k+1}, \quad (4)$$

where $R_{k,i}^{-1}$ – is the inverse of $R_{k,i}$.

Let μ_x – AF fuzzy state ФП нечіткого стану $X_{k,i}$. Technological restrictions on design parameters are also set by the relevant AF of μ_c. Then an acceptable solution of $D_{k,i}$ at the k-th stage can be defined as follows:

$$\mu_D = \mu_X * \mu_C, \quad (5)$$

where * – is a binary operation, the specific type of which is determined based on the TP features.

An admissible solution $D_{\{k,i\}}$ ensures that the required values of the output parameters are obtained by redistributing the design and technological stocks. Thus, instead of a single trajectory, we get a set of admissible trajectories

$$\{D_{0,i}|R_{0,i}\}_{i=1}^{n_0} \to \{D_{1,i}|R_{1,i}\}_{i=1}^{n_1} \to \cdots \to \{D_{k,i}|R_{k,i}\}_{i=1}^{n_k} \to \cdots \to X_N. \quad (6)$$

Suppose that at the k-th stage TP, the real state of the system is determined by a fuzzy set Y_k with the corresponding AF μ_Y. The control algorithm consists in determining the closest possible trajectory to the state Y_k and developing the corresponding control influence.

The relative distance between two fuzzy sets can be taken as a measure of proximity, for example, the Hamming distance (linear) [7,8]:

$$\delta(Y_k, D_{k,i}) = \frac{1}{L_k}\sum_{j=1}^{L_k}|\mu_Y(x_j) - \mu_D(x_j)|, \quad (7)$$

or Euclidean distance (quadratic):

$$e(Y_k, D_{k,i}) = \frac{1}{L_k}\sqrt{\sum_{j=1}^{L_k}\left(\mu_Y(x_j) - \mu_D(x_j)\right)^2}, \quad (8)$$

$$0 \le \delta, e \le 1.$$

We define an acceptable solution $D_{k,i}^*$ from the condition $\min d(Y_k, D_{k,i})$, $i = 1, .., n_k$, where δ or e can be taken as the relative distance d between μ_Y and μ_D. As an optimal control, we choose the control defined by the fuzzy relation $R_{k,i}^*$, corresponding to $D_{k,i}^*$.

The proposed model for building a family of trajectories allows us to control TP in real time. If the base trajectory is known, and for some reason (external disturbances) the state of the system turned out to be different from the expected one, a new trajectory is selected that will bring our system to the goal or its vicinity. The control algorithm is reduced to a step-by-step correction of TP modes by minimizing the difference between the current state and the acceptable solution at this stage.

A feature of the proposed model of phase-trajectory control of TP is the fundamental possibility of designing control strategies for several potentially possible groups of products at once, which makes it possible to identify common process stages for all groups in conditions of multi-nomenclature production. The use of the model makes it possible to reduce the number of controls developed, as well as to decide on the feasibility of adjusting the modes of certain operations.

3. CONCLUSIONS

The task of operational control of TP production under conditions of uncertainty is formulated as a task of trajectory control. A model of phase-trajectory control of TP has been developed, designed to select and adjust technological modes depending on the current state of the controlled TP.

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