УДК 621.396.6 **doi: 10.26906/SUNZ.2023.4.067**

Dmytro Vlasenkov[1], Rauf Allakhveranov[2], Mykola Starodubcev[2]

[1] Kryvyi Rih Professional College of National Aviation University, Kryvyi Rih, Ukraine
[2] Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

OPERATIONAL CONTROL OF PRODUCTION PROCESSES UNDER CONDITIONS OF UNCERTAINTY

Abstract. the task of developing models for adaptive technological processes control in small-scale, multi-item production is relevant. The task of operational control of technological processes production under conditions of uncertainty is formulated as a task of trajectory control. The model of phase-trajectory control of technological processes of manufacturing new equipment products has been developed, which allows adjusting the modes of technological processes depending on the current state of the technological object. Using the control model allows you to expand the tolerances to the parameters of the starting materials and optimally assign technological modes of manufacturing of products. A model of phase-trajectory control has been developed, which is adaptive to changes in operating conditions and process characteristics and works in a priori insufficiency and/or fuzzy information.

Keywords: control model, phase-trajectory control, technological process, technological modes, technological object, uncertainty of conditions.

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 ME characteristics.

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

As a result, the process engineer is usually deprived of ACSTP support and spends considerable time selecting modes for manufacturing pilot batches and collecting statistical data at the most critical time - the moment of mastering new processes. Existing ACSTP options are mostly only able to maintain the level achieved by the technologist.

Thus, the task of developing models for adaptive TP control in small-scale, multi-item production is relevant.

Presentation of the main material

In order to reduce the time required for the development and introduction of 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 context 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 technology development;
- inability to accurately determine the phase coordinates (for example, with group processing methods common in instrumentation, the determination of the average value of the parameter for the entire batch of products is only of an estimation nature);
- the impossibility of absolutely accurate implementation of the selected control on shop equipment.

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 manufacturing object, which are determined at the control operation, and the states measured at the intermediate control, it is necessary to select the control $u_i(i=0,...N-1)$, i.e. TP modes, so that the output characteristics of the product minimally differ from the target ones.

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:

- construction of an optimal trajectory;
- synthesis of the control that realizes the trajectory.

The possibility of separating the stages is based on the assumption 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 move 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 the sequential transition from one fuzzy state to another

$$X_0 \to X_1 \to X_2 \to \cdots \to X_N.$$

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

The control model at the k-th stage of TP is built on the basis of 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 control data, the following approach can be applied.

Using the TP model in the state space [5–8], we form fuzzy relations in the $X \times U \times X$ space, which is a formalized representation of control strategies and is characterized by fuzzy relationship matrices R_k, such that

$$X_{k+1} = R_k \circ X_k,$$

where ∘ – the operation of the maximum product.

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 a set of $\{R_{k,i}\}_{i=1}^{n_k}$, $k = 0, \dots, N-1$, for which the:

$$X_{k+1,i} = R_{k,i} \circ X_k.$$

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:

$$X_{k,i} = R_{k,i}^{-1} \circ X_{k+1}.$$

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

Let μ_x – physical indicator of a $X_{k,i}$ fuzzy state. Technological restrictions on design parameters are also set by the corresponding μ_c PI. Then a permissible solution $D_{k,i}$ at the k-th stage can be defined as follows:

$$\mu_D = \mu_X * \mu_C,$$

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

A permissible 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

$$\{D_{0,i} | R_{0,i}\}_{i=1}^{n_0} \to \{D_{1,i} | R_{1,i}\}_{i=1}^{n_1} \to \cdots$$

$$\to \{D_{k,i} | R_{k,i}\}_{i=1}^{n_k} \to \cdots \to X_N.$$

Suppose that at the k-th stage of TP, the real state of the system is determined by a fuzzy set Y_k with the corresponding PI 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, for example, the Hamming distance (linear), can be used as a measure of proximity [9–12]:

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

or Euclidean distance (quadratic):

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

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

We define a permissible 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.

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 designed to select and adjust technological modes depending on the current state of the controlled equipment has been developed.

REFERENCES

1. Невлюдов І.Ш. Комп’ютерно-інтегровані технології виробництва технічних засобів автоматизації. Частина 1: Підручник. Харків: ФОП Панов А.М., 2021. 604 с.
2. Ладанюк А.П., Луцька Н.М., Кишенько В.Д. Методи сучасної теорії управління. Київ: Ліра-К, 2018. 368 с.
3. Бодянский Е.В., Кучеренко Е.И., Михалев А.И., Филатов В.А., Гасик М.М., Куцин В.С. Интеллектуальное управление технологическими процессами: монография. Днепропетровск: Национальная металлургическая академия Украины, 2013. 213 с.
4. Павленко П. М. Автоматизовані системи технологічної підготовки розширених виробництв. Методи побудови та управління: Монографія. К.: Книжкове вид-во НАУ, 2005. 280 с.
5. Герасимов О.І. Фізика складних нерівноважних систем та процесів: монографія. Одеса : Одеський державний екологічний університет, 2022. 187 с.
6. Дубовой В.М., Квєтний Р.Н., Михальов О.І., Усов А.В. Моделювання та оптимізація систем : підручник Вінниця : ПП «ТД«Едельвейс», 2017. 804 с.
7. Datsenko, S. and Kuchuk, H. (2023), “Biometric authentication utilizing convolutional neural networks”, *Advanced Information Systems*, Vol. 7, no. 2, pp. 87–91, doi: https://doi.org/10.20998/2522-9052.2023.2.12
8. Poroshenko, A. and Kovalenko, A. (2023), “Optimization of a basic network in audio analytics systems”, *Advanced Information Systems*, Vol. 7, no. 1, pp. 23–28, doi: https://doi.org/10.20998/2522-9052.2023.1.04
9. Petrovska, I. and Kuchuk, H. (2023), “Adaptive resource allocation method for data processing and security in cloud environment”, *Advanced Information Systems*, Vol. *7*, No. 3, pp. 67–73, doi: https://doi.org/10.20998/2522-9052.2023.3.10
10. Dun, B., Zakovorotnyi, O. and Kuchuk, N. (2023), “Generating currency exchange rate data based on Quant-Gan model”, *Advanced Information Systems*, Vol. 7, no. 2, pp. 68–74, doi: https://doi.org/10.20998/2522-9052.2023.2.10
11. Желдак Т.А., Коряшкіна Л.С., Ус С.А. Нечіткі множини в системах управління та прийняття рішень: за редакцією С.А. Ус ; М-во освіти і науки України, Нац. техн. ун-т «Дніпровська політехніка». Дніпро : НТУ «ДП», 2020. 387 с.
12. Раскін Л. Г., Сіра О. В., Кожевніков Г. К. Методи аналізу систем і прийняття рішень в умовах невизначеності: підручник. Харків : Факт, 2023. 256 с.

Received (Надійшла) 04.09.2023
Accepted for publication (Прийнята до друку) 29.11.2023

Оперативне управління технологічними процесами виробництва в умовах невизначеності

Д. П. Власенков, Р. Ю. Аллахверанов, М. Г. Стародубцев

Анотація. Актуальною є задача розробки моделей адаптивного керування технологічним процесом у дрібносерійному багатономенклатурному виробництві. Задача оперативного керування виробництвом технологічного процесу в умовах невизначеності сформульована як задача траєкторного керування. Розроблено модель фазово-траєкторного управління технологічного процесу виробництва виробів нової техніки, що дозволяє коригувати режими ТР залежно від поточного стану технологічного об'єкта. Використання моделі управління дозволяє розширити допуски на параметри вихідних матеріалів і оптимальним чином призначити технологічні режими виготовлення виробів. Розроблена модель фазово-траєкторного управління, адаптивна до зміни умов функціонування та характеристик процесу і працює при апріорній недостатності та/або нечіткості інформації.

Ключові слова: модель управління, фазово-траєкторне управління, технологічний процес, технологічні режими, технологічний об’єкт, невизначеність умов.