Adaptive hybrid climate control in the manufacture of microelectronics

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Abstract. The article discusses the procedure for hybrid control of microclimate parameters in a clean room intended for the production of electronics, using a combination of technologies for recurrent estimation and fuzzy regulation. On the basis of the developed procedure, a smooth assessment of the current values of the controlled parameters and compensation control adequate to disturbing influences are provided. The developed technology is designed to provide an increase in the quality indicators of overcoming transient processes, and, consequently, to improve the efficiency of controlling the climate dynamic system during the implementation of the production process for manufacturing electronics with increased requirements for its operational characteristics. Modern information systems are characterized by the rapid development of the capabilities of the used hardware. At the same time, in order to achieve maximum results, the use of artificial intelligence technologies is inevitable, the most effective implementation of which requires adequate consideration of all available information about the controlled production process. In the formulation under consideration, the complexity of the problem is determined by the need to meet mutually conflicting requirements while ensuring specified values of climatic parameters. The specificity of the control problem is determined by the fact that a change (restoration) of the values of one controlled parameter should not lead to a loss of the set values of other climatic parameters. To achieve the described target effect, it is proposed to supplement the procedure of recurrent climate monitoring with a fuzzy logic mechanism when changing values of climatic parameters.

1. Introduction

Obtaining reliable information about the processes taking place in controlled dynamic systems, its prompt and adequate analysis are the basis of management intellectualization. Therefore, the improvement of technical characteristics in the manufacture of microelectronics to a predominant degree will be determined by the quality control of the production process (PP). The task of ensuring the continuity and sustainability of climate control in the production room can be solved using advanced intelligent control technologies [1].
2. The modernization of automatic control systems of microclimate parameters in the production of microelectronics

Reliability, quality and the percentage of suitable microelectronics products depend on the compliance of a clean production room (CPR) with the requirements of the current standard [3]. Premises for the production of microelectronics are a sealed circuit (architecture "room in room"), equipped with its own independent climate dynamic system (CDS). One of the options for equipping the CPR and the technology for providing related processes of air preparation are presented in figure 1. The main task of CPR is to provide the required stability of microclimate parameters. From its decision depends on a reduction in risk and yield.

![Diagram showing the modernization of automatic control systems of microclimate parameters in the production of microelectronics]

In the conditions of modern continuously increasing requirements for the effectiveness of software, the manufacture of on-board electronics is characterized by a complex of qualities that are difficult to implement in the framework of the classical theory of automatic control systems (ACS). Such objects are structurally underdetermined and endowed with such properties as incomplete mathematical construction and ergodic non-stationary parameters, as well as the incompleteness of the formal description of the object [2]. The management of such objects is a non-trivial, but applicationally typical task, since the construction of a traditional control system requires a formal description of the control object, as well as clarification of the control criteria formed on the basis of the mathematical apparatus that operates with quantitative categories.

In practice, such objects are controlled by an operator (technologist), using professional experience, he makes decisions that do not have a strict mathematical description. Therefore, the construction of models of procedures close to the arguments of a specialist, and their subsequent use in self-propelled
guns, is one of the most important areas of modernization of CDS. The introduction of intelligent self-propelled guns allows you to improve the quality of PP manufacturing microelectronics while reducing energy and resource costs and provides higher stability and adaptation to disturbing influences in comparison with traditional self-propelled guns. A promising area in modern technology of cognitive control is fuzzy regulation, which is currently actively used for the synthesis of fuzzy, hybrid controllers that require less time resources, but a more detailed linguistic description of decision rules and behavior of executive devices.

When controlling processes that do not have an exact mathematical description, fuzzy systems, compared to traditional ones, have higher indicators by such criteria as speed, stability, noise immunity, and accuracy due to a more adequate description of the real environment in which they operate.

To obtain refined, continuously updated estimates of the current state of a certain dynamic system according to the results of a time series of inaccurate measurements associated with the observation equation with estimated parameters, it is advisable to use the technology of recurrent estimation [4].

In figure 2 presents an illustration of a hybrid climate control procedure based on the integration of a recurrent filter and a fuzzy controller, characterizing the interconnections and mutual influence of parameters determined by the rule base of formalized knowledge.

![Figure 2. Hybrid CDS control based on a combination of recurrent filtering and fuzzy regulation.](image)

3. Adaptive control of a climate dynamic system using fuzzy logic and recurrent estimation under perturbation conditions
The main operations of the proposed hybrid control procedure are detailed monitoring of the process of finding the controlled parameters in the specified tolerances and their prompt restoration to the required values in case one or several parameters go beyond certain boundary values, as well as the principle of openness to external additions. Using the described procedure allows you to achieve higher quality indicators of the functioning of the CDS in the conditions of the occurrence of unpredictable disturbances, as well as to control the microclimate in the PP using resource-saving procedures. To implement resource-saving technologies in PP, one should take into account the characteristics and type of CPR used in the manufacture of materials, structural features of the production room, building, architecture of the surrounding buildings and the state of the environment, etc. On the other hand, it is
important to provide for the possibility for self-propelled guns to use a flexible management strategy, which allows for a limited amount of time to bring the CDS to its normal mode of operation. In other words, it is necessary to determine how effective it is for ACS CDS to use optimization procedures aimed at implementing energy-saving directive technologies through the use of a hybrid control technique.

The authors attempted to create an ACS model with an intuitively “friendly” structure, accessible for external additions and capable of implementing the features of an intellectual system of the cybernetic level: the introduction of provocative testing algorithms, preventive procedures, models using a remote (remote) monitoring device, and identification of processes when disturbed environment signs of critical state, etc.

Given the specifics of control, when parrying the perturbations of one of the parameters should not lead to critical changes in the characteristics of other parameters of the CDS, it is proposed to carry out cognitive control. It involves assessing, in a near-real time scale, the current values of the monitored parameters, their heuristic prediction, as a result of which you can calculate the value by the value of which you need to make a correction and get the proper control action.

With the manifestation of a noticeable change in disturbing influences, we consider such a measure of parrying their consequences as correcting the norm of an adjustable parameter by dynamically controlling the kernels of membership functions (MF) during the operation of a fuzzy controller.

In this case, the following values of the MF cores of the variable Temperature mode $T$ were subjected to variations:

- for the term SN, the values are changed from 20°C to 21°C;
- for term Z the values are changed from 21°C to 22.5°C;
- for the term SP, the values are changed from 22°C to 24°C.

The values of the MF cores of the variable Moisture Mode $M$ have changed as follows:

- for the term SN, the values are changed from 71% to 63.5%;
- for term Z the values are changed from 73% to 65.5%;
- for the term SP, the values are changed from 75% to 67.5%.

The parameters of the MF terms of the variable $D_u$ dust concentration mode have been changed as follows:

- for term Z the values are changed from 1300 particles / kg * m$^3$ to 650 particles / kg * m$^3$;
- for the term SP, the values are changed from 1350 particles / kg * m$^3$ to 700 particles / kg * m$^3$;
- for term P the values are changed from 1400 particles / kg * m$^3$ to 750 particles / kg * m$^3$.

The result of working out the control system parameters of the control process with directive displacement of the MF cores is shown in figure 3 (temperature), 4 (humidity) and 5 (dust content).
Figure 3. Temperature dynamics during correction of MF nuclei.

Figure 4. Moisture dynamics in the correction of MF nuclei.

From the analysis of the graphs it can be seen that, despite the introduction of time settings by directive shifting the MF cores by a certain amount, the control system ensures a smooth transition to new standard values with the retention of process control quality indicators in acceptable values, adapting to new conditions.
Figure 5. Dynamics of dust concentration in the correction of MF nuclei.

Thus, self-propelled guns CDS provides bringing parameters PP in accordance with the given rules in the presence of a disturbing effect. The process is accompanied by smooth stabilization of parameters relative to the changing set point and external disturbances without overshoot and within the limits of the permissible “play” of control.

In figure 6 is a graph illustrating the law of change in air temperature in the CPR depending on the outside temperature when the proposed ACS CDS after the operating mode of the CPR at night time is operational.

Figure 6. The reaction of the CDS to the settings for the outdoor temperature and set for the CPR.
As a result of the research of self-propelled guns based on hybrid control using recursive filtering with fuzzy logic, it can be concluded that the developed software and algorithmic solutions allow us to provide the specified characteristics of transients, adaptively changing the impact on the actuators.

So, when lowering the temperature of the outdoor air in accordance with the developed settings, the ACS CDS ensures that the air temperature is maintained in the CPR, bringing the temperature regime into the range of values corresponding to the requirements specified in the fuzzy controller's rule base.

4. Conclusion
The proposed combination of technologies for recurrent estimation and adaptive compensation of the uncertainty of state and observation models based on fuzzy rules for the formation of control action will allow efficient use of the CDS resource, excluding both losses of continuity and stability of the control process, and excessive volatility of the estimated parameters [4].

References
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