The formation of control actions in the automatic climate control system in the production of electronics based on the inclusion of a fuzzy controller in the recurrence algorithm

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Abstract. To meet the ever-growing requirements for the production of electronic components, production facilities should be improved along the way to achieve the required level of internal climatic parameters of the environment: temperature, humidity, and the degree of air purification from dust. Of particular difficulty is the need to simultaneously control the specified vector of parameters. Promising climate dynamic systems should be focused on intelligent technologies for the formation of control actions. The lack of the possibility of an exact mathematical description of control processes adequate to the nature of disturbing influences motivates researchers to search for mechanisms to parry the noted disturbances. The article proposes to use the fuzzy regulation apparatus for these purposes, which allows one to take into account information presented in verbal form. A model of a climatic dynamic system and the results of modeling based on it are presented.

1. Introduction

The development trends of the electronic industry associated with the increased dependence of product quality on the cleanliness of indoor air as a technological environment is an objective reality of high-tech industrial complexes. This led to a transition to an increase in the nomenclature and characteristics of the environment that are subject to monitoring and regulation. Recently, the application of innovative management methods in industry has noticeably intensified. The introduction of intelligent control systems can improve the quality of production processes while reducing resource and energy costs and provides higher resistance to the influence of disturbing factors. The modern industry of clean production room (CPR) allows in the process of multiple filtration to minimize the penetration of particles hazardous to the production of microelectronics into the CPR. At the same time, operating experience of CPR and analysis of the reasons for the decrease in yield indicate other factors in the production environment. Indeed, the microclimate of the CPR is formed by the air conditioning system during the exchange processes of air flows. Moreover, the enlargement of inevitable nanoparticles occurs with a change in temperature and relative humidity. Therefore, countering the causes of the formation of unacceptably large particles, preventing the implementation of mechanisms of agglomeration of nanoparticles and developing solutions to eliminate or minimize
their negative impact is of both scientific and practical interest in the design of CPR for the manufacture of on-board microelectronics.

2. Control actions in the automatic climate control system
Premises for the production of electronic equipment are a sealed circuit (construction «room in a room»), equipped with its own independent climate dynamic system (CDS).

Since the production process of microelectronics is accompanied by disturbing microclimatic parameters, for each sensitive operation of the microclimate of the technological cycle operation (responsible for dimensional accuracy and stability during the installation of photo templates, exposure, development, drilling, pressing of microelectronic components), norms of deviation of current values from the boundary parameters are set microclimate of the air.

For example, in technological operations associated with heat treatment, irregularities (erosion) can form on the surfaces of the elements, leading to a deterioration in the parameters of the finished product.

The boundary values of the parameter “Humidity” in the CPR are established in GOST R ISO 14644-1-2002 “Cleanrooms and associated controlled environments” [1], since the level of static charge increases with minimal humidity. It should be noted that when the humidity of the air is below the sanitary norm, a drop in the working capacity of personnel is observed. At low humidity, less than 30%, the staff feels discomfort, while when exceeding the permissible humidity value, more than 65%, comfortable conditions are created for the growth of bacteria and mold, which is also unacceptable in precision instrumentation.

GOST R ISO 14644-1-2002 sets the permissible values for maintaining the temperature of the air: ± 0.1; ± 0.2; ± 0.3; ± 0.5; ± 1.0; ± 5.0. The accuracy interval for the “Temperature” parameter is set depending on the specific operation of the technological cycle, however, the parameter values must be in the range of 20 - 24°C.

**Figure 1.** Terms of engineering support for modern production of radio electronics.
Allowed values for the parameter “Humidity” are set within the following limits: ± 5%, ± 10%, ± 15%.

As for the “Temperature” parameter, accuracy values for regulating the relative humidity of the air of the NWP are selected depending on the technological operations but should not exceed 65%.

All operations of the technological cycle of the production of microelectronics must meet more stringent requirements for the stability of microclimatic parameters and "fall" into the narrow range specified for a particular operation. Changes in the size of photomasks, blanks of printed circuit boards will lead to the appearance of marriage and the lack of accuracy of combining elements of multilayer structures. The engineering support conditions for modern production are listed in figure 1.

In the production of microelectronics, it is often difficult to isolate clean zones. The specifics of its production (dimensions and volumes of production) dictates primarily the requirements for CPR - the main production environment [1].

The international standard ISO 14644 “Cleanrooms and associated controlled environments” and the interstate standard GOST R ISO 14644 [1] contain comprehensive information on ensuring air purity and the degree of concentration of suspended particles in the CPR.

The composition of the air in the process room is controlled by adding fresh air to the indoor environment when using the ventilation system. The process of obtaining the required temperature occurs by supplying the prepared air to the calculated value from an industrial air conditioner.

Humidity control is carried out by changing the amount of steam supplied by the humidification system to the channel of an industrial air conditioner from a steam generator. The degree of air pollution is controlled by appropriate filters, and their status is monitored by optical sensors.

The production facilities in which microelectronic products are manufactured have stringent requirements for microclimatic parameters. Issues of confirmation of CPR compliance during operations with increased sensitivity to changes in climatic parameters were reflected in [3].

The high-efficiency filters installed in the CPR are designed not only to purify the air, but also to create air flows, so that they maintain the dust content of the air at the required level.

3. Climate control system based on the inclusion of a fuzzy controller in the recurrence algorithm

The process of ventilation of the CPR is as follows: a unidirectional laminar air flow passes through the room and the perforated floor, after which the exhaust air is taken in through vertical ducts and processed in the mixing chamber with the outside air, that is, cleaning through filters and air preparation, then the air enters the room [4]. Air preparation consists of cleaning, cooling or heating operations, as well as moisture saturation with steam or ultrasonic humidifiers. It is also necessary to maintain excess pressure in the CPR in order to avoid contaminants from surrounding areas, to protect the laminar flow from accidental dust impurities, to prevent mixing of air in neighboring rooms, and also to maintain temperature and humidity parameters within specified limits. Overpressure is maintained in the CPR compared with the adjacent lock and adjacent rooms in the building, in which there is no tight circuit and corridor at the entrance to the CPR zone.

The microclimate parameter of the CPR “Outdoor dust concentration” reflects how efficiently the supply and exhaust ventilation and air conditioning system ensures its compliance with the specified limits according to the requirements for PP. Here, attention should be paid to the influence of the process of regulation of this parameter on the remaining elements of the state vector of CDS.

When managing complex processes that do not have an exact mathematical description, fuzzy systems, in comparison with traditional ones, have better stability, speed and accuracy of operation due to a more adequate description of the real medium. However, for the effective application of fuzzy control technology, it is important to correctly formalize the physical model of the control process. Here, the advantage of an intelligent automatic control system (ACS) is due to the fact that it works not only with quantitative data, like traditional self-propelled guns, but also with knowledge based on qualitative information. This makes it possible to fairly objectively describe the environment and
organize adequate behavior of the control system under the conditions of the perturbed state vector of the CDS.

Since human knowledge and experience are mainly verbal in nature, the most promising are self-propelled guns that use linguistic variables and the apparatus of fuzzy sets to represent knowledge about the properties and principles of controlling an object. The principle of operation of a system with fuzzy logic is illustrated in figure 3.

An approach is proposed that focuses on adaptive fuzzy regulation of control actions in nonlinear dynamic systems. For its implementation, a fuzzy controller should be included in the ACS circuit, countering the inaccuracy of the mathematical description of the process being evaluated and implementing the procedure for generating a control action based on the fuzzy regulation mechanism. When using the procedures of empirical synthesis of membership functions, the adaptive value of the robust control action that holds the state vector of the system at specified boundaries is determined.

Figure 2. The principle of operation of the controller with fuzzy logic.

Figure 3 presents graphs of the behavior of CPR air temperature in the process of climate control in the presence of disturbing factors, which are impossible to parry in the framework of traditional self-propelled guns (the dashed and solid curves do not coincide). An analysis of the graphs presented in figure 4 indicates the possibility of forming control actions that provide the necessary stability of the system during climate control.

Figure 3. Temperature control in a traditional self-propelled guns (diverging process).
Figure 4. Temperature control with a fuzzy controller.

It should be noted that it is especially difficult to take into account the heterogeneity of the estimated parameters, adequately describe the behavior fields of the measured parameters, adapt the membership functions to climate dynamics, and also select the size of the sliding window of the analyzed observations when determining the levels of trust in linguistic rules.

In industries such as avionics, microelectronics, instrumentation, the creation of special zones with controlled climatic parameters is required. In control systems included in CPR of industrial enterprises that meet certain quality standards, optimal decision-making processes often proceed in conditions of uncertainty and are based on the examination and monitoring of external and internal disturbing factors.

In conditions of unpredictable disturbances, after obtaining estimates of the current state vector and determining the degree of their compliance with the norm, it is necessary to make the transition to the formation of control actions for executive bodies that ensure the maintenance (restoration) of the required values of climatic parameters synthesized using fuzzy regulators.

For example, if it was a question of fixing the temperature, then the problem could be solved by turning on the heating elements to the maximum mode. In the situation under consideration, stringent requirements are imposed not only on the range of possible values of the actual temperature, but also on keeping the remaining parameters within given narrow boundaries.

Therefore, ACS CDS should embody the principles of construction, providing a high degree of resistance to disturbances, optimizing the operation of actuators (climatic equipment) that keep all controlled parameters in a given interval.

ACS should be freely integrated in a centralized system of regulation and control of engineering, technological and information processes, for example, in a dispatch system. At the same time, self-propelled guns must ensure the reliability of the CDS and protect its individual nodes from premature failures and errors when internal and external disturbances occur.

In this case, the self-propelled guns, evaluating the information, according to the microclimate, from the sensors installed in the CPR synthesizes sequential control actions, thereby developing a certain algorithm for achieving the goal. In this case, the ACS response algorithm to disturbances and the control strategy (necessary microclimate parameters) can be adjusted depending on the nature and intensity of external influences.

4. Conclusion

Thus, there is an obvious trend towards the use of intelligent climate control systems, incorporating an apparatus for adapting to external factors and a database, the use of which is designed to provide a precise assessment of the current state vector of microclimate parameters of CPR, predicting its dynamics, and this regulating effect on executive mechanisms of self-propelled guns CDS, a posteriori identification of the microclimate state of CPR. The proposed solution makes the control system of CDS adaptive, which makes it possible to build fault-tolerant dynamic systems for controlling the
quality of the technological process in the production of radio electronics with the required level of risk indicators. The reliable operation of this chain is designed to guarantee the stability of the production process control in the manufacture of electronics to external factors.

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