Methodology for ensuring sustainable automatic control of the manufacturing process of manufacturing electronics using the fuzzy logic apparatus

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Abstract. The production equipment on which the electronics products are manufactured has stringent requirements for controlling the conformity of physical characteristics, such as thickness, depth, width, and others, to standard values. It is necessary to formalize the task of evaluating the current state vector of product characteristics to ensure real adequacy in the generation of control action and the implementation of a process control strategy close to optimal. The article discusses the process control process for manufacturing electronics by introducing means of inter-machine intellectual interaction and a self-learning multi-parameter fuzzy classifier. Based on the developed procedure, a real assessment of the current state of the controlled characteristics of the object and adequate control of disturbing influences will be provided. The formulated technology is designed to provide an improvement in the quality of transients and to preventively eliminate the risk of defective products, and, consequently, to positively affect the effectiveness of the manufacturing process of electronics manufacturing.

1. Introduction

In the context of organizing digital production at industrial enterprises, ensuring the implementation of an apparatus for tracking the product life cycle using big data, it is necessary to create and maintain a relationship between the automated regulation systems implemented in the organization.

One of the connecting tasks of creating a continuous production process is its adaptability, consistency and sustainability of the use of information systems in production. Considering the multidimensionality of the vector of the monitored parameters, their heterogeneity and the complexity of the mathematical description of both the state variables themselves and their interconnections, such indicators as the stability and reliability of the functioning of dynamic control systems are vulnerable when special requirements are made for electronics production.

2. Methodology for ensuring the quality of the process of automatic installation of electronics in terms of the use of inter-machine intellectual interaction

The manufacturing process of electronics consists of seven steps, shown in figure 1. The operations performed by a person are presented as a “control action” (CA).
Ensuring the quality of automatic installation of electronics is to reduce the share of defective products in the production process by introducing means of inter-machine intellectual interaction (MII).

The results of the analysis of statistical information accumulated during the operation of the production line indicate that the most frequent occurrence of products of inadequate quality occurs at steps S3 and S7. The following operations can be used as elements of product quality assessment at the stages of “solder paste inspection” and “automatic optical inspection”:

- coating the site with solder paste;
- filling the volume of the stencil;
- compliance with the shape of the hole;
- the presence of jumpers [4].

In order to ensure the product-specific quality criteria for a specific product, operations CA1-CA6 can be replaced by software products (computer programs and databases) for various equipment using fuzzy logic elements, discrete linear and mixed integer programming methods. Implementation of technological innovations in the enterprise in the form of automatic control systems, MII systems and the management of large data arrays is carried out by replacing sequential interoperational connections at the stages: “solder paste inspection” and “automatic optical inspection” with enlarged operators of stages 3 (M2M) and 7 (M2M SPI-OAI) [5-7].

The operator M2M SPI-OAI-AXI is an autonomous monitoring software and hardware complex that performs the function of monitoring the stability of software and instant response in case of product quality that does not meet the specified criteria. The introduction of MII means in PP manufacturing electronics is shown in figure 2.
Figure 2. TP stages using a self-learning MII system.

The direction of modernization of production M2M, M2M SPI-OAI and M2M SPI-OAI-AXI are elements of digital production (DP) that can optimize the manufacturing process of electronics by reducing the time of the production cycle, the number of production personnel, as well as minimize technical risks and the number of defective products.

3. Adaptive sustainable automatic control technique for the manufacturing process of manufacturing electronics based on fuzzy regulation

A mechanism is needed that would allow an adaptive way to generate a control action that ensures the convergence of the generated and given values while maintaining continuity, stability of control and non-violation of the set limits. Therefore, to create a mathematical model of the behavior of the described dynamic system, it is proposed to use a fuzzy logic apparatus, which allows synthesizing stable algorithms for its functioning in the conditions of the observation model under determination.

Fuzzy logic represents an innovative approach to the development of dynamic control systems, guarantees the ability to solve problems in which data and disturbances are unpredictable, not stationary and difficult to determine, and therefore not amenable to an exact mathematical description. The authors developed a model for managing technological operations of automatic assembly of printed circuit boards based on a multi-parameter fuzzy classifier with training in a computer simulation environment MatLab, which contains tools for designing Fuzzy Logic Toolbox fuzzy logic systems. In the process of using the Fuzzy Logic Toolbox, the production process (PP) was reproduced, which is a simulation Simulink model that allows you to control the execution of all previously defined algorithms, change the source code, providing line flexibility and intellectualization of equipment.

Figure 3. Three-channel control system TP.
The adaptive Simulink model is a three-channel control system SPI, SPI-AOI and SPI-AOI-AXI (figure 3) whose inputs are equipped with sensors that receive information (depth, length, width, etc.) according to the types of possible defects. Based on the accumulated data and developed proposals on introducing SPI, SPI-AOI and SPI-AOI-AXI inter-machine interaction elements into the production line, an expert system based on fuzzy logic was created, which is represented by functions for fuzzy clustering with learning, as well as rule bases of four types of clustering depending on the types of marriage occurring in the PP.

One of the most important tasks of introducing technological innovations is to ensure the organizational and technological reliability of software, as well as assess the level of stability of the software control system. The main idea is to ensure the sustainability of the process of maintaining the state parameters of a dynamic system in emergency situations. The solution to the synthesis problem of the control system is designed to ensure stability and accuracy of the quality control of the functioning of the dynamic system with strict restrictions on the parameters of the state of the technological process, minimizing the time of transient processes, and reducing the risks of manufacturing low-quality products.

The simulation model of the automatic control system (ACS) is illustrated in figure 2. The designations in figure 4 e - input (input, o - output), S1, S2 and S3 управления control units and logical integrators of SPI, SPI-AOI and SPI- systems AOI-AXI, respectively (System 1, 2, and 3).

![Software and hardware complex for production process control](image)

Figure 4. The structural diagram of the ACS PP.

The stability of the ACS is ensured by maintaining the system parameters at small and tending to 0 error values. If this condition is met, the transition process fades over time, and the system goes into a stable position. In this case, the transient is:

\[
 a_n o^{(n)}(t) + a_{n-1} o^{(n-1)}(t) + \cdots + a_1 o'(t) + a_0 o(t) = b_m e^{(m)}(t) + b_{m-1} e^{(m-1)}(t) + \cdots + b_1 e'(t) + b_0 e(t)
\]  

(1)
Thus, after the end of the transition process, the value of stability is determined at the output. In a stable position, all derivatives are equal to 0, and the transient equation has the form:

\[ a_0 y_{уст} = b_0 e_0, \]  

(2)

Where

\[ y_{установ} = \frac{b_0 e_0}{a_0} \]  

(3)

The steady-state error value is calculated:

\[ y_s = e_0 - y_{уст} = (1 - \frac{b_0}{a_0})e_0 \]  

(4)

The transfer function of the open system is calculated:

\[ S_{open\ system} = \frac{k_1}{1+sT_1} * \frac{k_2}{1+sT_2} * \frac{k_3}{1+sT_3} = \frac{K}{(1+sT_1)(1+sT_2)(1+sT_3)} \]  

(5)

where the gain of the entire system (K) is calculated

\[ K = k_1 * k_2 * k_3 \]  

(6)

The equation of steady state is calculated:

\[ (K + 1) * y_{steady} = Kx_0, \]  

(7)

where

\[ o_{steady} = K(e_0/(1 + K)) \]  

(8)

In a static state, the system is represented by:

\[ o_s = \frac{e_0}{1+K}, S = 1/(1 + K) \]  

(9)

The characteristic equation of the whole system is:

\[ T_1T_2T_3 * s^3 + (T_1T_2 + T_1T_3 + T_2T_3) * s^2 + (T_1 + T_2 + T_3) * s + (1 + K) = 0 \]  

(10)

Since all the coefficients of the third-order characteristic equation are positive, according to the Hurwitz stability criterion, the system will be stable if the inequality holds:

\[ (T_1T_2 + T_1T_3 + T_2T_3)(T_1 + T_2 + T_3) - (T_1 + T_2 + T_3) * (1 + K) > 0 \]  

(11)

from which the gain is determined:

\[ K < \frac{(T_1T_2 + T_1T_3 + T_2T_3)(T_1 + T_2 + T_3)}{T_1T_2T_3} - 1 \]  

(12)

To achieve stable and correct operation of the system, the gain of the system must be less than the limiting coefficient of the system \( K < K_{препелный} \)

\[ K_{limit} < \frac{(T_1T_2 + T_1T_3 + T_2T_3)(T_1 + T_2 + T_3)}{T_1T_2T_3} - 1 \]  

(13)

In the particular case, when the time intervals for the transition from one system to another are equal to each other, then the limiting coefficient of the system is - 8, i.e., \( K < 8 \). To determine the stability of the proposed model for controlling technological operations of automatic mounting of printed circuit boards and to obtain a small error of the system, we determine the maximum allowable static state coefficient. Suppose that the coefficient is equal to 0.97 (the minimum allowable percentage of yield), then \( K > 97 \). According to the conditions, \( K < K_{limit} \), this means that the system was able to get out of the state of stability. The resolution of such a conflict of the system is possible by changing the time intervals of transients, by introducing additional links in the system.
The stability of the automatic control system for PP is achieved by introducing a multi-parameter fuzzy classifier with training, which allows predicting disturbances, eliminating both loss of control continuity and stability, and excessive volatility of the estimated parameters.

4. Conclusion

Thus, there is an obvious trend towards the use of intelligent PP control systems, which include an adaptation apparatus and a knowledge base, the use of which is designed to provide a precise assessment of the current state vector of the technological cycle, predicting its dynamics, and this regulating effect on ATS actuators is adequate. The reliable operation of this chain is designed to guarantee the stability of the control of PP in the manufacture of electronics to the effects of various disturbing factors.

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