Intelligent control system for continuous technological process of alkylation

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Abstract. Relevance of intelligent control for complex dynamic objects and processes are shown in this paper. The model of a virtual analyzer based on a neural network is proposed. Comparative analysis of mathematical models implemented in MathLab software showed that the most effective from the point of view of the reproducibility of the result is the model with seven neurons in the hidden layer, the training of which was performed using the method of scaled coupled gradients. Comparison of the data from the laboratory analysis and the theoretical model are showed that the root-mean-square error does not exceed 3.5, and the calculated value of the correlation coefficient corresponds to a "strong" connection between the values.

1. Introduction
According to the classical theory of automatic control, the design of automatic control systems is a completely formalized operation sequence. At the initial stage, a mathematical description of the technological object or process and the control device is made using the fundamental laws of the applied field of research. Then, the performance criteria of control (response time, overshoot, phase and amplitude margins, etc.) are refined. At the final stage, the design of the automatic control system is carried out, namely synthesis of the structure and parameters of the control device to ensure the required values of performance criteria of control. The nature of the arising subtasks and the ways of dealing with that kind of problem depends on the results obtained in the previous stages. By the methods of the theory of automatic control, the last two stages of designing the automatic control system are realized, namely the analysis of the object of control and the synthesis of the control mode that maintain an acceptable or optimal operation mode. Analytical calculations are carried out proceeding from the fact that the control system is written in exact terms of the formal model and adequately reflects the actual state and processes of interaction with the external environment. In practice, to hack out the mathematical model, it is required to simplify and linearize the differential equations. As a result, the synthesized ACS is only «workable in theory». Thus, the model of the control system (technological object and control device) is the critical moment, on the basis of which the quality and operability of the real ACS depends.

Models of control systems are created and modified as the quality requirements of the ACS become more stringent and the process and control objects become more complex. Each kind of model generates new control criteria and methods of synthesis of ACS. At the moment, the critical parameters of automatic control systems are high levels of autonomy and adaptability, reliability and quality of functioning in the conditions of uncertainty of external disturbing influences, as well as high requirements for high-speed, precision and other technical characteristics of the control object.

The application of classical methods of the theory of automatic control, developed in the second
half of the twentieth century by Ya. Z. Tsypkin [1], A. A. Krasovskii [2], E. P. Popov [3], S. V. Emel'yanov [4], and others. in the modern formulation of the problem of designing an ACS, it does not always allow to achieve the required functionality and qualitative parameters. The technology of PID-regulation laws allows to provide limited characteristics of accuracy, speed and invariance to external perturbations.

According to the analysis of the modern tendencies in the development of systems for automatic control of complex technological objects established that artificial intelligence methods and technologies should be used to increase the levels adaptability and autonomy of such systems.

2. **Formulation of the problem**

The modern intellectual information technologies include technologies of expert systems, fuzzy logic, neural network structures, associative memory, etc. [4–7]. Technologies of neural network structures are built on the basis of operating characteristics of biological prototypes. Intellectual system is a homogeneous structure, consisting of a set of interrelated dynamic elements with a given transfer function. The body of knowledge, laid in the learning process, is determined by the adjustment of the weight coefficients of interelement connections. The most important advantage of the technology under consideration is the rapid response time achieved by calculation process paralleling during their hardware implementation.

The architectural characteristic of intelligent control systems (Figure 1) is connected with the usage of special mechanisms for storage and processing of knowledge to perform the required functions in incomplete (or uncertain) conditions with the random nature of environmental perturbations [5].

The changing control purpose, operating characteristics of the technological object, environmental parameters, etc. relate to uncontrolled (random) perturbations. The structure of the system is included specialized tools for a generalization of the accumulated experience, and as a result, the replenishment of knowledge if necessary. Thus, the control object is a complex construction of a number of functionally-subordinate subsystems.

![Figure 1. Generalized structure of intellectual management system](image)

3. **Results of experiments**

A promising trend in the development of automatic control systems is the usage of virtual analyzers [8], which can be implemented both by means of classical methods of statistics and intelligent technologies, in particular neural networks. As an example, the control loop for the temperature of the end of boiling of stable alkylation gasoline will be discussed. The parameter should not exceed 205°C to provide the quality of the product (butane-butylene fraction with a high octane number of 96). The laboratory data are used for verification the adequacy of mathematical models of virtual analyzers. According to the normative documentation the reproducibility of the laboratory analysis is not more than 3.5 °C.

Various models of neural networks differing in the number of neurons in the hidden layer, as well as the learning algorithm are synthesized by the MathLab software (Table 1). A comparative analysis of the results was carried out using statistical indicators, namely the standard deviation (RMS) and the correlation coefficient (CC) and is presented in Table 1.
Table 1. Neural network simulation results.

| №  | Learning Algorithm                        | Number of neurons in the hidden layer | Entire segment | Training segment | Final segment |
|----|------------------------------------------|----------------------------------------|----------------|------------------|---------------|
|    |                                          |                                        | RMS            | CC               | RMS           | CC            |
| 1  | Levenberg-Markar method                  | 5                                      | 4.11           | 0.66             | 4.4           | 0.59          | 3.79          | 0.72          |
| 2  | The Baess regularization method           | 3                                      | 3.75           | 0.73             | 4.14          | 0.64          | 3.32          | 0.79          |
| 3  | Quasi-Newtonian method                    | 1                                      | 4.17           | 0.66             | 4.55          | 0.54          | 3.74          | 0.74          |
| 4  | Method of elastic back propagation        | 2                                      | 3.77           | 0.72             | 3.84          | 0.71          | 3.68          | 0.75          |
| 5  | Method of scaled coupled gradients        | 7                                      | 3.45           | 0.77             | 3.61          | 0.74          | 3.29          | 0.79          |
| 6  | Method of coupled Powell-Bil gradients    | 7                                      | 3.97           | 0.71             | 4.27          | 0.62          | 3.61          | 0.79          |
| 7  | Method of coupled Polak-Ribira gradients  | 8                                      | 3.59           | 0.75             | 3.94          | 0.68          | 3.2           | 0.81          |
| 8  | One-step secant method                    | 4                                      | 3.73           | 0.73             | 3.7           | 0.73          | 3.74          | 0.75          |

Since the root-mean-square deviation for model No. 5 satisfies the reproducibility requirements for the process under consideration, the optimal model from the list in Table 1 is recognized as the model with seven neurons in the hidden layer and the learning algorithm “The method of scaled coupled gradients” (Fig. 2).

![Figure 2](image_url)

**Figure 2.** Model No. 5 of the virtual quality analyzer with 7 neurons in the hidden layer.

As a result of the comparison of the laboratory analysis data for the training, final and entire segments with the calculated values of the virtual analyzer, it was established that the theoretical curve has a “good” repeatability, the RMSE does not exceed 3.7. The value of the correlation coefficient R of the model output and the data of the laboratory analysis is declarative of a strong relationship between the factors.
Conclusion

Thus, the results of the literature review, experimental and applied research prove the effectiveness of the usage of intelligent technologies for the control of complex technological objects, in particular, the installation of sulfuric acid alkylation. The synthesized mathematical model of a virtual analyzer for a temperature-control loop of the end boiling of stable alkylation gasoline, proved the applicability and adequacy of neural network technologies for control a continuous technological process.

References

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